Program and Abstracts of the 10th International Congress of Vertebrate Morphology
Fira Palace Hotel, Barcelona, Spain
8–12 July 2013
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Welcome to ICVM-10 – Barcelona 2013!

The International Congress of Vertebrate Morphology (ICVM) has emerged as the premier conference for scientists researching the morphology of vertebrate animals at all levels of organization. The Congresses are held typically every three years with the broad goal of providing an opportunity for interaction, integration, and interfacing. Through a mixture of symposia, workshops, and open platform and poster sessions, everyone from senior scholars to students share ideas in an informal and genial setting. The 2013 ICVM in Barcelona, Spain, marks not only the tenth Congress but also the 30-year anniversary of the first ICVM, held in Gießen, Germany, in 1983. It’s appropriate for the International Congress of Vertebrate Morphology to be held in the city of Barcelona and in Spain in that there is a rich tradition here of diverse morphological research, much of which is showcased at ICVM-10.

Indeed, ICVM-10 reflects the growth and vitality of morphology, fully embracing the 21st-century’s themes of both technological advancement and disciplinary integration. Classical morphological approaches such as dissection, histological sectioning, and morphometrics are alive and well at ICVM-10 and have been invigorated by the widespread use of 3D imaging technologies. At the same time, studies of the genetic and molecular control of gross morphological form and its development have become important parts of morphological analyses. At the other end of the scale, the broad evolution and ecological deployment of morphologies through deep time have provided a rich perspective, requiring further integration with the disciplines of paleontology, geology, and systematics. EvoDevo has matured into a robust scientific discipline melding all levels of morphological scale from molecules and proteins to populations of organisms and drawing important relationships between ontogeny and phylogeny. Functional morphology at ICVM-10 has also broken new ground with the incorporation of new engineering approaches, 3D modeling, and simulations that shed new light on how vertebrates move and feed. This ICVM also is introspective, looking at the role that this truly ancient science of morphology (the study of form) plays in the context of modern science.

We thank the hard work of the Executive Committee of the International Society of Vertebrate Morphology (ISVM), which is the organization that hosts the Congresses. In particular, we thank Marvalee Wake, the chair of the Scientific Program Committee and Past-President of the ISVM, for her tireless work with her committee on assembling the program. We also are grateful to our sponsors who have provided support for various Congress activities: The U. S. National Science Foundation, Loligo Systems, Visualization Sciences Group, The Company of Biologists, the Journal of Morphology, The Palaeontological Association, and Royal Society Publishing. We single out here Wiley Publishing, the Anatomical Record, and the American Association of Anatomists for their generous support of symposia and for their willingness to publish the ICVM Program and Abstracts.

Lawrence Witmer, President

Adam Summers, Secretary
Administration of the
International Society of Vertebrate Morphology

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Michael Thompson, Australia
Adam Summers (ISVM Secretary), USA (ex officio)
Lawrence Witmer (ISVM President), USA (ex officio)
### Previous Locations of the International Congress of Vertebrate Morphology

<table>
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<tr>
<th>ICVM</th>
<th>Year</th>
<th>Location</th>
<th>Participants</th>
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<tbody>
<tr>
<td>ICVM-1</td>
<td>1983</td>
<td>Gießen, Germany (~300 participants)</td>
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<tr>
<td>ICVM-2</td>
<td>1986</td>
<td>Vienna, Austria (~350 participants)</td>
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<td>1989</td>
<td>Antwerp, Belgium (~430 participants)</td>
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<td>1994</td>
<td>Chicago, Illinois, USA (~450 participants)</td>
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<td>ICVM-5</td>
<td>1997</td>
<td>Bristol, UK (~450 participants)</td>
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<td>ICVM-6</td>
<td>2001</td>
<td>Jena, Germany (~700 participants)</td>
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<td>ICVM-7</td>
<td>2004</td>
<td>Boca Raton, Florida, USA (~470 participants)</td>
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<td>ICVM-8</td>
<td>2007</td>
<td>Paris, France (~600 participants)</td>
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<td>ICVM-9</td>
<td>2010</td>
<td>Punta del Este, Uruguay (~315 participants)</td>
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<tr>
<td>ICVM-10</td>
<td>2013</td>
<td>Barcelona, Spain (~450 participants)</td>
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<td>ICVM-11</td>
<td>2016</td>
<td>Washington, DC, USA</td>
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**ICVM-11 Washington, DC 2016**

Crystal Gateway Marriott  
Crystal City, Virginia  
12–16 July 2016

**Save the Date!**
Note from The Anatomical Record

The Anatomical Record (AR) – a flagship journal of the American Association of Anatomists – is proud to host the program and abstracts for the 10th International Congress of Vertebrate Morphology (ICVM 2013) in Barcelona, Spain this month. Hosting is done on the Wiley Online Library for AR web page. The full URL address is at the end of this welcome message. Please copy and paste the URL to explore the science that will be presented and discussed at the ICVM 2013 meeting.


We anticipate discovering more fantastic state-of-the-art science at the ICVM 2013 meeting in Barcelona! And we look forward to receiving your manuscripts for consideration for publication in AR, and to continuing the tradition of advancing the best science in vertebrate morphology in our journal.

Kurt H. Albertine, Ph.D.  Jeffrey T. Laitman, Ph.D.
Editor-in-Chief, The Anatomical Record  Associate Editor, The Anatomical Record
Past-President, American Association of Anatomists

http://onlinelibrary.wiley.com/store/10.1002/%28ISSN%291932-8494/asset/homepages/ICVM_2013.pdf?v=1&s=8e8d03ff9d6f37a123328c338aa097c3b97af10f&isAguDoi=false
EDITORIAL FOCUS

The Anatomical Record is positioned to be the premier publication venue for hypothesis-driven research that uses **biomolecular imaging and image analysis** approaches to integrate morphology with other scientific disciplines:

- cell & molecular biology
- neuroscience
- physiology
- paleontology
- biochemistry
- pathology

In addition to its focus on full length papers, the journal includes Reviews, Commentaries, and Letters-to-the-Editor.

AR FOR AUTHORS

**AR articles receive over 5,000 citations per year:** AR has a Cited Half Life of 10 years. You can use our Citation Tracking tool to monitor citations of your own research.

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American Association of Anatomists
(please be sure to include your CV, using format LASTNAME_FIRSTNAME_ YEAR_CV, when you submit your application.)

STEP 2: Choose a Member Type

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  ☐ Fellow    ☐ Medical Resident
☐ Student................................ $ 30
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☐ Undergraduate Student ...... $ 25
☐ HAPS Affiliate (E-membership)..... $ 30

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(calender years)

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☐ Developmental Dynamics E-only

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American Association of Anatomists
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STEP 5: Please create your member profile, checking all that apply:

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☐ Research

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☐ AAI    ☐ ASNS
☐ ABRF    ☐ ASPET
☐ ACT    ☐ Biophysical Society
☐ APEpS    ☐ Endocrine Society
☐ APS    ☐ HAPS
☐ ASBMB    ☐ Histochem Society
☐ ASBMR    ☐ Protein Society
☐ ASCB    ☐ SDB
☐ ASCI    ☐ SIN

Topical Interests & Research Areas:

☐ Applied Anatomy
☐ Aging & Disease
☐ Bioengineering
☐ Biomechanics
☐ Bones, Cartilage & Teeth
☐ Comparative Anatomy
☐ Cancer, Metastasis & Tumor Biology
☐ Cell Cycle/Cell Death
☐ Cell & Molecular Biology
☐ Cell/Organ Culture
☐ Central Peripheral & Auto. Nerv. System
☐ Confocal Microscopy, µCT & Ultrasound
☐ Clinical Anatomy
☐ Developmental Biology
☐ Dynamic Imaging
☐ Evolutionary Anatomy
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☐ Educ.: Curriculum
☐ Educ.: Exam Design/Admin
☐ Educ.: Mentoring
☐ Educ.: Research
☐ Educ.: Teaching Methods/Innovations
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☐ Functional Anatomy
☐ Gross Anatomy
☐ Gene Expression
☐ Genomics
☐ Growth Factors/Receptors
☐ Homeostasis
☐ Immunology
☐ Integrative Neuroscience
☐ Induction, Specification & Patterning
☐ Mathematical Modeling
☐ Muscle Biology
☐ Morphology
☐ Migration/Pathfinding
☐ Nanotechnology
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☐ Pathology/Human Disease
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☐ Transgenic Animals/Other Models
☐ Terminology
☐ Urinary System
☐ Veterinary Anatomy

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<td>VERDI</td>
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<td>SYMPOSIUM 2 Hominid Bipedalism</td>
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<td>Tues July 9th</td>
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<td>09.30 - 11.30</td>
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<td>SYMPOSIUM 5 Evolution of Locomotion</td>
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**Program & Abstracts of the 10th International Congress of Vertebrate Morphology, Barcelona 2013**

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<td>SYMPOSIUM 9 Interdisciplinary Approaches to Vertebrate Locomotion</td>
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<td>SYMPOSIUM 10 Dynamic Simulations in Paleobiology</td>
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<td>SYMPOSIUM 15 Axial Systems &amp; their Actuation</td>
<td>SYMPOSIUM 13 Substrate, Morphology, &amp; Biomechanics</td>
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<td>CONTRIBUTED 22 Reproductive Biology</td>
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ICVM 2013

FINAL PROGRAM

10th International Congress of Vertebrate Morphology

July, 8th-12th, 2013
Fira Palace Hotel

Barcelona, Spain
Welcome to ICVM-10!

The 10th International Congress of Vertebrate Morphology celebrates the diversity of scientific studies of vertebrate morphology, and we welcome you to Barcelona for what promises to be a stimulating and exciting Congress. Over the course of these five days in July, there will be more than 400 presentations by scientists from more than 30 countries, presenting their discoveries on vertebrate form, function, and evolution spanning all levels of organization, from molecules and cells to evolving communities. With five world-class plenary speakers, 19 diverse symposia and workshops, and hundreds of contributed talks and posters, coupled with the warmth and collegiality that makes ICVMs so special, we’re all sure to have an unforgettable experience…made all the more memorable by the beauty and history of Barcelona!

Lawrence Witmer, President

Adam Summers, Secretary
COMMITTEES

International Society of Vertebrate Morphology (ISVM) Executive Committee

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Lawrence Witmer (USA)

President-elect:
Ann Huysseune (Belgium)

Past President:
Marvalee Wake (USA)

Secretary:
Adam Summers (USA)

Treasurer:
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Dominique Adriaens (Belgium)
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David Carrier (USA)
Philip Donoghue (UK)
Shigeru Kuratani (Japan)
Anthony Herrel (France)
Emily Rayfield (UK)
Elizabeth Dumont (USA)
Michael Richardson (The Netherlands)
Alexander Haas (Germany)

Scientific Program Committee

Philip Donoghue (UK)
Anthony Herrel (France)
Ann Huysseune (Belgium)
Diego Rasskin-Gutman (Spain)
Michael Richardson (The Netherlands)
Matthias Starck (Germany)
Michael Thompson (Australia)
Marvalee Wake, Chair (USA)
Lawrence Witmer (ex officio)
Adam Summers (ex officio)

Nominating Committee

Peter Aerts (Belgium)
Susan Herring (USA)
Nadja Schilling (Germany)
LIST OF SPONSORS/SUPPORTERS

We are grateful for the support of a number of funding agencies and companies for ICVM 2013.

The Anatomical Record will publish the abstracts in an open access format. Symposium support has been provided by The Company of Biologists, the American Association of Anatomists, the Anatomical Record, The Palaeontological Society and Loligo Systems.

The National Science Foundation, USA, directly sponsored individual symposia as well as travel awards.

The Royal Society Publishing, UK, the Visualization Sciences Group, and the Journal of Morphology have generously underwritten our social events.

Please see the inside back cover of the programme brochure, and on line, for the logos of our sponsors.
GENERAL INFORMATION

DATES AND VENUE
Monday, July 8 through Friday, July 12, 2013
Fira Palace Hotel
Avinguda Rius i Taulet, 1
08004 Barcelona, Spain
Telephone: 34 934 26 22 23; website www.fira-palace.com

TECHNICAL SECRETARIAT
Grupo Pacifico
Marià Cubí, 4 Pral – 08006 Barcelona
Te. (34) 932.388.777 Fax (34) 932 387 488
icvm2013@pacifico-meetings.com

TECHNICAL SECRETARIAT DESK AND SPEAKERS ROOM
The Technical Secretariat and Speakers Room will be open at the Venue as follows:
• Monday, July 8: From 09:00 to 18:00
• Tuesday, July 9, and following days will be open from 08:00 to 18:00

ON-SITE REGISTRATION

<table>
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<tr>
<td>Regular Fee</td>
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<tr>
<td>Student Fee</td>
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<td>Accompanying person</td>
<td>30€</td>
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(*) Student certificate will be required.
VAT Included.

The regular and student registration fees include:
• Access to the Opening Ceremony, the Welcome Reception, and the Evening Social
• Access to all sessions
• Meeting printed documents
• Certificate of attendance
• Coffee breaks

The accompanying guests fee includes:
• Access to the Opening Ceremony, the Welcome Reception, the Evening Social, and one scientific session.

CANCELLATION POLICY
Registered participants unable to attend the Congress may ask for refunds.
All cancellations must be addressed by writing to the General Secretariat:
icvm2013@pacifico-meetings.com

• A cancellation fee of 25,00€ will be withheld if the refund is requested in writing before June 1st, 2013, and 50% of registration fees if before June 30th, 2013.
• No refunds will be accepted if requested after July 1st, 2013.
• All refunds will be finalized after the Congress.
TECHNICAL INFORMATION

POSTER AND ORAL PRESENTATIONS

Oral Presentations:
• Symposium Talks are 30 minutes long (25 minutes for presentation plus 5 minutes for questions and comments). Contributed Talks are 20 minutes long (15 minutes for presentation plus 5 minutes for questions and comments) and Lightning Talks are 5 minutes long.
• Rooms and times are listed in the program.
• The meeting room is equipped with an LCD Projector and computer for presentations.
• There will be a speakers’ “ready room” for checking talks.
• Please contact the technician in the “Speakers Room” a minimum of 2 hours before your session begins (preferably 24 hrs before) to have your presentation loaded for the computer in the presentation room.

Posters:
• The posters will be in the Rubi and Zafir rooms.
• Posters will be on display July 9-11th, including during coffee breaks and after the business meeting.
• Set up: Poster area Monday, July 8th, from 13:00.
• Dismantling: Sunday July 12th, by 12:00.
• The size of the poster board is 2m x 0.90m and all are numbered with the presentation poster code.
• Note: Please, when hanging the posters no thumbtacks will be allowed. We ask you to please use the double-sided tape provided.
• Presenters of even-numbered posters should be present at their posters on Tuesday afternoon at 16:30 (beginning of the afternoon coffee break) until 17:50.
• Presenters of odd-numbered posters should be present at their posters on Wednesday afternoon at 16:30 (beginning of the afternoon coffee break) until 17:50.
• All poster presenters should be present at their posters during the Thursday evening social from 19:30 to ~20:30.

SOCIAL EVENTS

Welcome Reception
• Monday, July 8th: 18:45—, Foyer, Fira Palace Hotel
  Free for registered participants
  Sponsored by the Visualization Sciences Group

Evening Social, in Honor of the Reinhard-Rieger Awardee and All Poster Presenters
• Thursday, July 11th, 19:30—, Rubi and Zafir rooms.
  Free for all registered participants
  Sponsored by the Royal Society Publishing and the Journal of Morphology
BADGES AND SECURITY
It is essential that you wear your personal badge at all times while in the Congress venue and during the social events, as it is the official entrance pass to scientific sessions and other Congress activities.

OFFICIAL LANGUAGE
The official language of the Congress is English. Simultaneous translation will not be provided.

MEDICAL ASSISTANCE AND INSURANCE
Participants are advised to make their own arrangements regarding travel insurance and medical assistance during the Congress. Neither the ISVM nor the Congress Secretariat are able to accept any responsibility whatsoever for damage or injury to persons or their belongings during the Congress.
## PROGRAM AT A GLANCE

### MONDAY JULY 8TH

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
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<tbody>
<tr>
<td>11.00 - 13.00</td>
<td>WELCOME; PLENARY I Hutchinson</td>
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<tr>
<td>13.00 - 14.30</td>
<td>MIDDAY BREAK</td>
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<td>14.30 - 16.30</td>
<td>SYMPOSIUM 1 EvoDevo SYMPOSIUM 2 Hominid Bipedalism SYMPOSIUM 3 3D-ilemmas Workshop CONTRIBUTED 1 Respiration CONTRIBUTED 2 Tooth EvoDevo CONTRIBUTED 3 Sensory Biology</td>
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<td>16.30 - 17.00</td>
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<td>17.00 - 18.00</td>
<td>SYMPOSIUM 1 EvoDevo SYMPOSIUM 2 Hominid Bipedalism SYMPOSIUM 3 3D-ilemmas Workshop</td>
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### TUESDAY JULY 9TH

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<tr>
<td>08.30 - 09.30</td>
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<td>09.30 - 11.30</td>
<td>CONTRIBUTED 6 Geometric Morphometrics SYMPOSIUM 5 Evolution of Locomotion SYMPOSIUM 6A Quantifying Development SYMPOSIUM 7 Reptilian Skeletal Biology CONTRIBUTED 4 General Morphology CONTRIBUTED 5 Ontogeny</td>
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<td>12.00 - 13.00</td>
<td>CONTRIBUTED 6 Geometric Morphometrics SYMPOSIUM 5 Evolution of Locomotion SYMPOSIUM 6A Quantifying Development SYMPOSIUM 7 Reptilian Skeletal Biology CONTRIBUTED 4 General Morphology CONTRIBUTED 5 Ontogeny</td>
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<td>14.30 - 16.30</td>
<td>SYMPOSIUM 4 Limb Development SYMPOSIUM 5 Evolution of Locomotion SYMPOSIUM 6B VSG Amira Workshop SYMPOSIUM 7 Reptilian Skeletal Biology CONTRIBUTED 7 Tooth EvoDevo CONTRIBUTED 8 Flight: bats, birds</td>
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<td>COFFEE BREAK</td>
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<td>17.00 - 18.00</td>
<td>SYMPOSIUM 4 Limb Development SYMPOSIUM 5 Evolution of Locomotion SYMPOSIUM 6B VSG Amira Workshop SYMPOSIUM 7 Reptilian Skeletal Biology</td>
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## Wednesday July 10th

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<td>08.30 - 09.30</td>
<td><strong>PLENARY III</strong>&lt;br&gt;Blackburn</td>
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<td>09.30 - 11.30</td>
<td><strong>CONTRIBUTED 11</strong>&lt;br&gt;Sensory biology&lt;br&gt;<strong>SYMPOSIUM 9</strong>&lt;br&gt;Interdisciplinary Approaches to Vertebrate Locomotion&lt;br&gt;<strong>SYMPOSIUM 10</strong>&lt;br&gt;Dynamic Simulations in Paleobiology&lt;br&gt;<strong>SYMPOSIUM 12</strong>&lt;br&gt;Paleohistology&lt;br&gt;<strong>CONTRIBUTED 9</strong>&lt;br&gt;Integration; Shape&lt;br&gt;<strong>CONTRIBUTED 10</strong>&lt;br&gt;Feeding</td>
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<td>12.00 - 13.00</td>
<td><strong>CONTRIBUTED 11</strong>&lt;br&gt;Sensory biology&lt;br&gt;<strong>SYMPOSIUM 9</strong>&lt;br&gt;Interdisciplinary Approaches to Vertebrate Locomotion&lt;br&gt;<strong>SYMPOSIUM 10</strong>&lt;br&gt;Dynamic Simulations in Paleobiology&lt;br&gt;<strong>SYMPOSIUM 12</strong>&lt;br&gt;Paleohistology&lt;br&gt;<strong>CONTRIBUTED 9</strong>&lt;br&gt;Integration; Shape&lt;br&gt;<strong>CONTRIBUTED 10</strong>&lt;br&gt;Feeding</td>
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<td>14.30 - 16.30</td>
<td><strong>SYMPOSIUM 8</strong>&lt;br&gt;Morphology: the Great Integration&lt;br&gt;<strong>SYMPOSIUM 9</strong>&lt;br&gt;Interdisciplinary Approaches to Vertebrate Locomotion&lt;br&gt;<strong>SYMPOSIUM 11</strong>&lt;br&gt;Muscle Extracellular Matrix&lt;br&gt;<strong>SYMPOSIUM 12</strong>&lt;br&gt;Paleohistology&lt;br&gt;<strong>CONTRIBUTED 12</strong>&lt;br&gt;Skeletal Evodevo&lt;br&gt;<strong>CONTRIBUTED 13</strong>&lt;br&gt;Feeding</td>
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<td><strong>SYMPOSIUM 8</strong>&lt;br&gt;Morphology: the Great Integration&lt;br&gt;<strong>SYMPOSIUM 11</strong>&lt;br&gt;Muscle Extracellular Matrix&lt;br&gt;<strong>SYMPOSIUM 12</strong>&lt;br&gt;Paleohistology</td>
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<td>Contributed 20 Paleontology</td>
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<td>Contributed 23 Paleontology</td>
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<td>Contributed 24 Cranial EvoDevo</td>
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<td>Contributed 23 Paleontology</td>
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### DETAILED DAILY PROGRAM

#### MONDAY, JULY 8th

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<tr>
<td>08:30-11:00</td>
<td>Registration</td>
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<tr>
<td>11:00-13:00</td>
<td><strong>VERDI ROOM</strong>&lt;br&gt;Opening Ceremony and First Plenary Lecture&lt;br&gt;President Larry Witmer - Welcome&lt;br&gt;Secretary Adam Summers - Logistics&lt;br&gt;Adria Casinos - Barcelona, Its Universities, and its Science</td>
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<td><strong>Plenary Lecture I: John Hutchinson</strong>&lt;br&gt;Professor, Department of Evolutionary Biomechanics Royal Veterinary College London, UK&lt;br&gt;“The evolutionary biomechanics of giant land animals” (Abstract PT-001)</td>
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<td>14:30-16:30</td>
<td><strong>VERDI ROOM</strong>&lt;br&gt;Symposium 1: EvoDevo and Vertebrate Morphology: Old Wine, New Bottles (and also new wine)&lt;br&gt;Organizers: Diego Rasskin-Gutman, University of Valencia&lt;br&gt;Gerd Müller, University of Vienna</td>
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<td><strong>S-001 AN ORGANISMAL PERSPECTIVE IN EVODEVO; A LEGACY OF PERE ALBERCH</strong>&lt;br&gt;Wake, David&lt;br&gt;University of California, Berkeley, United States</td>
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<td><strong>S-002 EVODEVO AND MORPHOLOGICAL NOVELTY: THE VERTEBRATE LIMB</strong>&lt;br&gt;Müller, Gerd B.&lt;br&gt;University of Vienna, Vienna, Austria</td>
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<td><strong>S-003 HOW NATURAL SELECTION SEES MORPHOLOGY? A MODEL BRINGING DEVELOPMENT INTO THE PICTURE</strong>&lt;br&gt;Marín-Riera, Miquel; Salazar-Ciudad, Isaac&lt;br&gt;Universitat Autònoma de Barcelona, Bellaterra, Spain</td>
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<td><strong>S-004 THE GENERATION OF VARIATION AND DEVELOPMENTAL CONSTRAINTS IN THE VERTEBRATE SKULL</strong>&lt;br&gt;Hallgrímsson, Benedikt (1); Young, Nathan (2); Pavlicev, Mihaela (3); Mitteroecker, Philipp (3); Gonzalez, Paula (4); Martinez-Abadias, Neus (5); Jamniczy, Heather (1); Marcucio, Ralph (2)</td>
</tr>
</tbody>
</table>

(1) Dept. of Cell Biology & Anatomy, University of Calgary, Canada; (2) Orthopedic Trauma Institute, University of California San Francisco, United States; (3) Dept. of Theoretical Biology, University of Vienna, Austria; (4) Dept. of Anthropology, University of La Plata, Argentina; (5) Systems Biology, Center for Regulatory Genomics, Spain
14:30-16:30  ROSSINI 1 ROOM
Symposium 2: The Anatomical, Biomechanical and Energetic Basis of Hominid Bipedalism
Organizers: David Carrier, University of Utah
Kristiaan D’Aout, University of Antwerp

S-007  BIPEDAL WALKING IN NON-HUMAN PRIMATES
Aerts, Peter (1); Berillon, Gilles (2); D’aout, Kristiaan (1)
(1) University of Antwerp, FunMorph-lab, University of Antwerp, Belgium;
(2) Centre National de la Recherche Scientifique, Paris, France

S-008  EVOLUTION OF THE LUMBAR PERIVERTEBRAL MUSCLES IN APES - IMPLICATIONS FROM FIBER TYPE COMPOSITION
Schilling, Nadja
Friedrich-Schiller-University, Institut of Systematic Zoology and Evolutionary Biology, Germany

S-009  DIFFERENCES IN THE MECHANICS OF CHIMPANZEE AND HUMAN BIPEDAL WALKING
Umberger, Brian R. (1); O’neill, Matthew C. (2); Demes, Brigitte (2); Lee, Leng-Feng (1); Thompson, Nathan E. (2); Larson, Susan G. (2)
(1) University of Massachusetts, Amherst, United States; (2) Stony Brook University, Stony Brook, United States

S-010  PLANTAR PRESSURE DISTRIBUTION DURING WALKING AND RUNNING IN HABITUALLY UNSHOD HUMANS
Wunderlich, Roshna E. (1); Hatala, Kevin G. (2); Dingwall, Heather (3); Richmond, Brian R. (4)
(1) Department of Biology, James Madison University, Harrisonburg, United States; (2) Hominid Paleobiology Doctoral Program, The George Washington University, Washington, United States; (3) Center for the Advanced Study of Hominid Paleobiology, Department of Anthropology, The George Washington University, Washington, United States; (4) Human Origins Program, National Museum of Natural History, Smithsonian Institution, Washington, United States
The past two decades have seen an explosion in the utilization of voxel data (3D digital volumes from high-resolution X-ray CT, synchrotron, MRI, etc.) in scientific research. Ever-improving acquisition technologies combined with increasing computational power and innovative applications ensure that these data will continue to proliferate. While the science is keeping up, the infrastructure for that science is not. Voxel volumes for individual specimens may now range into the tens of gigabytes, far exceeding the supplemental data limits of journals – even e-journals. Yet, giving scientific peers the opportunity to critically assess the voxel data upon which papers are based is no less critical to sound scientific practice than giving them access to the gene sequences underlying molecular phylogenetic hypotheses via GenBank.

How do we make a ‘GenBank’ for voxel data? How do we assure that these data do not retire with the researchers who collected them, or become unreadable and ultimately obsolete? How do we repurpose these data to maximize the initial investment by funding agencies in voxel technology and acquisition? And how do institutions that house the specimens from which voxel data are acquired protect their intellectual property interests in this age of rapid prototyping?

In this workshop, we will discuss these issues in an informal, round-table format. The workshop participants represent a cross-section of those with a major stake in the resolution of these 3D-ilemmas: researchers, collection (physical and digital) managers, and journal editors. All interested ICVM attendees are invited to join us. A list of relevant background material can be found at www.ctlab.geo.utexas.edu/ICVM10.pdf.

Workshop Participants/Discussants:
Paul Barrett (The Natural History Museum)
Betsy Dumont (University of Massachusetts Amherst)
Larry Frank (University of California San Diego, Digital Fish Library & Center for Scientific Computation in Imaging)
Peter Giere (Museum für Naturkunde, Humboldt University Berlin)
Alexander Haas (Biozentrum Grindel und Zoologisches Museum, Hamburg)
Christopher Norris (Yale Peabody Museum of Natural History)
David Polly (Indiana University)
Irina Ruf (University of Bonn)
Lawrence Witmer (Ohio University & OUµCT Facility)
Alexander Ziegler (Harvard University)
VIVALDI 1 ROOM
Contributed 1: Respiration
Chairs: Sabine Moritz
Jonathan Codd

C-001 THE INFLUENCE OF STERNAL MORPHOLOGY ON THE BREATHING MECHANICS OF BIRDS
Tickle, Peter; Codd, Jonathan
University of Manchester, Manchester, United Kingdom

C-002 PULMONARY MORPHOLOGY IN THE LEPIDOSAURIA AND ITS IMPLICATIONS FOR THE AMNIOTE BAUPLAN
Lambertz, Markus; Perry, Steven F.
Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn, Germany

C-003 EVOLUTION AND FUNCTIONAL MORPHOLOGY OF THE BRANCHIOSTEGAL APPARATUS IN ACTINOPTERYGIAN FISHES
Farina, Stacy (1); Ferry, Lara (2); Bemis, William (1)
(1) Cornell University, Ithaca, NY, United States; (2) Arizona State University, Tempe, Arizona, United States

C-004 LUNG LOSS: MOLECULAR AND MORPHOLOGICAL CONSEQUENCES
Lewis, Zachary (1); Kerney, Ryan (2); Dorantes, Jorge (1); Hanken, James (1)
(1) Dept. of Organismic and Evolutionary Biology and Museum of Comparative Zoology, Harvard University, Cambridge, MA, United States; (2) Dept. of Biology, Gettysburg College, Gettysburg, PA, United States

C-005 RIB KINEMATICS AND INTERCOSTAL MUSCLE FUNCTION DURING LUNG VENTILATION IN AMERICAN ALLIGATORS
Moritz, Sabine; Brainerd, Elizabeth
Functional Morphology & Biomechanics Laboratory, Brown University, Providence, United States

C-006 THE EVOLUTIONARY DERIVATION OF THE DIAPHRAGM FROM A SHOULDER MUSCLE: A NEW HYPOTHESIS
Hirasawa, Tatsuya; Kuratani, Shigeru
RIKEN Center for Developmental Biology, Kobe, Japan

VIVALDI 2 ROOM
Contributed 2: Tooth EvoDevo
Chairs: Gareth Fraser
Elodie Renvoisé

C-007 DEVELOPMENT AND REGENERATION OF THE LIFELONG ‘CONVEYOR BELT’ DENTITION IN SHARKS
Rasch, Liam; Fraser, Gareth
University of Sheffield, Sheffield, United Kingdom
C-008 HETEROCHRONY AND DENTAL ONTOGENETIC DIVERSITY IN METATHERIAN MAMMALS: CIRCUMVENTION OF CONSTRAINTS IN SOUTH AMERICAN EXTINCT PREDATORS (SPARASSODONTA)
Forasiepi, Analia (1); Sanchez-Villagra, Marcelo (2)
(1) Ianiglia, CCT Mendoza, CONICET, Mendoza, Argentina; (2) Paläontologisches Institut und Museum der Universität Zürich, Zürich, Switzerland

C-009 WHEN PRIMATES BARE THEIR TEETH: MOLAR PROPORTIONS IN THE LIGHT OF DEVELOPMENT, A NEW KEY TO EVOLUTION
Sébastien, Couette (1); Avana, Andriamboavonjy (2); Nicolas, Navarro (1); Gaëlle, Labonne (1); Sophie, Montuire (1)
(1) Ecole Pratique des Hautes Etudes & UMR CNRS “Biogéosciences”, Dijon, France; (2) Ecole Pratique des Hautes Etudes, Dijon, France

C-010 ORIGIN OF MECHANICAL CONSTRAINTS DURING CUSP PATTERN DEVELOPMENT OF VOLE MOLARS
Renvoisé, Elodie (1); Kavanagh, Kathryn (2); Kallonen, Aki (3); Jernvall, Jukka (1)
(1) Institute of Biotechnology, University of Helsinki, Finland; (2) Biology Department, University of Massachusetts Dartmouth, United States; (3) Department of Physics, University of Helsinki, Finland

C-011 HOW IS TOOTH REPLACEMENT REGULATED IN NON-AMNIOTES? FUNCTIONAL STUDIES ON THE ROLE OF WNT SIGNALING
Huysseune, Ann (1); Vandenplas, Sam (1); Dam Thi Minh, Tho (1); Vleminckx, Kris (2); Willems, Maxime (3)
(1) Evolutionary Developmental Biology Research Group, Ghent University, Belgium; (2) Department of Biomedical Molecular Biology, Ghent University, Belgium; (3) Department of Pharmaceutics, Ghent University, Belgium

C-012 TESTING THE INHIBITORY CASCADE MODEL IN MESozoIC AND CENOzoIC MAMMALIAFORMS
Halliday, Thomas (1); Goswami, Anjali (2)
(1) University College London, London, United Kingdom; (2) Dept of Genetics, Evolution and Environment, University College London, London, United Kingdom

14:30-16:30 DIAMANT ROOM
Contributed 3: Sensory Biology
Chairs: Mary Silcox
John Abramyan

C-013 UNDERSTANDING EARLY BRAIN EVOLUTION IN PRIMATES
Silcox, Mary (1); Lopez Torres, Sergi (1); Bloch, Jonathan (2); Boyer, Doug (3)
(1) University of Toronto, Toronto, Canada; (2) University of Florida, Florida Museum of Natural History, Gainesville, United States; (3) Duke University, Durham, United States
C-014 FUNCTIONAL MORPHOLOGY OF BIOSONAR BEAM FORMATION IN THE BOTTLENOSE DOLPHIN USING FINITE ELEMENT MODELING
Cranford, Ted (1); Trijoulet, Vanessa (2); Krysl, Petr (3)
(1) San Diego State University, San Diego, United States; (2) University of Strathclyde, Glasgow, United Kingdom; (3) University of California, San Diego, United States

C-016 MORPHOLGY OF A PUTATIVE VOMERONASAL ORGAN IN THE SOUTH AMERICAN LUNGFISH LEPIDOSIREN PARADOXA
Wittmer, Carolin; Nowack, Christine
University of Kassel, Kassel, Germany

C-017 PRESENCE AND DISTRIBUTION OF G PROTEIN ALPHA SUBUNITS IN THE THREE OLFACTORY ORGANS OF THE TOAD BOMBINA ORIENTALIS
Jordan, Sabrina; Nowack, Christine
University of Kassel, Kassel, Germany

16:30-17:00 Coffee Break

17:00-18:00 VERDI ROOM
Symposium 1: EvoDevo and Vertebrate Morphology: Old Wine, New Bottles (and also new wine)
Organizers: Diego Rasskin-Gutman, University of Valencia
Gerd Müller, University of Vienna

S-005 HOW TO MEASURE HETEROCHRONY? MODERN MORPHOMETRICS IN EVODEVO
Mitteroecker, Philipp
University of Vienna, Vienna, Austria

S-006 EVODEVO, MODULARITY, AND DEVELOPMENTAL CONSTRAINTS: THE TETRAPOD SKULL
Rasskin-Gutman, Diego; Esteve-Altava, Borja
University of Valencia, Valencia, Spain
17:00-18:00  ROSSINI 1 ROOM
Symposium 2: The Anatomical Biomechanical and Energetic Basis of Hominid Bipedalism

S-011 EVOLUTIONARY CONSEQUENCES OF THE REPRODUCTION LOCOMOTION NEXUS ON HUMAN SEXUAL DIMORPHISM
Wall-Scheffler, Cara (1); Myers, Marcie (2); Steudel, Karen (3)
(1) Seattle Pacific University, Seattle, United States; (2) St Catherine University, St Paul, United States; (3) University of Wisconsin, Madison, United States

S-012 HUNTER-GATHERER ENERGETICS AND LOCOMOTION
Pontzer, Herman (1); Raichlen, David (2); Wood, Brian (3); Mabulla, Audax (4); Marlowe, Frank (5)
(1) Hunter College, City University of New York, United States; (2) University of Arizona, School of Anthropology, United States; (3) Yale University, Dept. of Anthropology, United States; (4) University of Dar es Salaam, Department of Archaeology, United Republic Of Tanzania; (5) Cambridge University, Department of Anthropology, United Kingdom

17:00-18:00  ROSSINI 2 ROOM
Organizers: Timothy Rowe, Jessica Maisano, Richard Ketcham
Matthew Colbert, University of Texas
Brian Metscher, University of Vienna

Resume workshop

18:00  Welcome Social
TUESDAY, JULY 9TH

08:30-09:30
VERDI ROOM
Plenary Lecture II: Colleen Farmer
Professor, Department of Biology University of Utah, USA
“Recognizing a one-way street: The role of aerodynamic valves and unidirectional airflow in the evolution of archosaurs” (Abstract PT-002)

09:30-11:30
VERDI ROOM
Contributed 6: Geometric Morphometrics
Chairs: Jesús Merugan-Lobón
Eloy Gálvez-Lóbez

C-036 DOES SHAPE CO-VARIATION BETWEEN THE SKULL AND THE MANDIBLE HAVE FUNCTIONAL CONSEQUENCES? A 3D APPROACH FOR A 3D PROBLEM
Cornette, Raphaël (1); Baylac, Michel (1); Souter, Thibaud (1); Herrel, Anthony (2)
(1) UMR CNRS/MNHN 7205 Origine Structure et Evolution de la Biodiversité, Paris, France; (2) UMR CNRS/MNHN 7179 mécanismes adaptatifs: des organismes aux communautés, Paris, France

C-037 FAMILY TIES OR YOU ARE WHAT YOU EAT – EFFECTS OF SIZE, DIET, AND TAXON ON THE RODENT MANDIBLE
Schunke, Anja C.; Tautz, Diethard
Max-Planck-Institute for Evolutionary Biology, Ploen, Germany

C-038 GEOMETRIC MORPHOMETRIC ANALYSIS OF ANTLER DEVELOPMENT IN IBERIAN RED DEER (CERVUS ELAPHUS HISPANICUS)
Martínez-Salmerón, Débora (1); Gálvez-López, Eloy (1); Azorit, Concepción (2); O’higgins, Paul (3); Casinos, Adrià (1)
(1) Dept. of Animal Biology, University of Barcelona, Barcelona, Spain; (2) Dept. of Animal Biology, Plant Biology and Ecology, University of Jaén, Las Lagunillas, Jaén, Spain; (3) Center for Anatomical & Human Research Sciences, Hull York Medical School, University of York, Heslington, York, United Kingdom

C-039 ALLOMETRY, PHYLOGENY AND FUNCTION IN THE EVOLUTION OF CANIVORAN LIMBS: AN APPROACH BASED ON 3D GEOMETRIC MORPHOMETRICS
Martin-Serra, Alberto; Figueirido, Borja; Serrano, Francisco Jose; Palmqvist, Paul
Universidad de Málaga, Málaga, Spain

C-040 LOCOMOTOR ADAPTATIONS IN SCAPULAR SHAPE IN CARNIVORANS
Gálvez-López, Eloy
Dept. of Animal Biology, University of Barcelona, Barcelona, Spain

C-041 INFLUENCE OF LOCOMOTOR STYLE ON THE SHAPE OF THE FORELIMB IN MUSTELOID CARNIVORANS
Fabre, Anne-Claire (1); Cornette, Raphael (2); Goswami, Anjali (3); Peigné, Stéphane (4)
(1) CNRS/MNHN/UCL, Paris and London, France and United Kingdom; (2) MNHN, Paris, France; (3) UCL, London, United Kingdom; (4) CNRS/MNHN, Paris, France
09:30-11:30  
ROSSINI 1 ROOM  
Symposium 5: Evolution of Locomotion: Reciprocal Illumination From a Diversity of Approaches  
Organizers: Timothy Higham, University of California, Riverside  
        Theodore Garland, University of California, Riverside  

S-020  SELECTION EXPERIMENTS AS AN APPROACH TO STUDY THE EVOLUTION OF VERTEBRATE LOCOMOTION  
Garland, Theodore  
University of California, Riverside, United States  

S-021  WHAT SHOULD WE EXPECT FROM STUDIES OF SELECTION ON LOCOMOTION IN THE WILD?  
Husak, Jerry  
Univ of St. Thomas, St. Paul, United States  

S-022  DIVERGENCE AND NOVELTY IN LOCOMOTOR EVOLUTION: INSIGHTS FROM STUDIES OF WATERFALL-CLIMBING GOBIID FISHES  
Blob, Richard (1); Kawano, Sandy (1); Moody, Kristine (1); Cullen, Joshua (1);  
Maie, Takashi (1); Burchfield, Holly (2); Placek, Margaret (1); Schoentuss, Heiko (3)  
(1) Clemson University, Clemson, United States; (2) University of Georgia, Athens, United States; (3) St. Cloud State University, St. Cloud, United States  

S-023  HOW TRANSITIONS IN MODE OF LOCOMOTION HAVE SHAPED MACROEVOLUTIONARY PATTERNS IN VERTEBRATES  
Mahler, D. Luke  
University of California Davis, Davis, United States  

09:30-11:30  
ROSSINI 2 ROOM  
Symposium 6 A: Quantifying Evolutionary Development Using non-model Organisms: Integrating Metrical Frameworks, Gene Expression, and Morphology  
Organizers: Laura Wilson, University of New South Wales, Australia  
        Ingmar Werneburg, Eberhard-Karls University, Germany  

S-030  HETEROCHRONY ANALYSIS: FROM EVENT PAIRING TO CONTINUOUS ANALYSIS  
Laurin, Michel  
CNRS, Paris, France  

S-031  ANALYZING DEVELOPMENTAL SEQUENCES WITH PARSIMOV  
Ziermann, Janine M.  
Howard University, Washington DC, United States  

S-032  EVOLUTION OF NECK VERTEBRAL SHAPE AND NECK RETRACTION AT THE TRANSITION TO MODERN TURTLES: A GEOMETRIC MORPHOMETRIC APPROACH  
Werneburg, Ingmar (1); Wilson, Laura A. B. (2); Joyce, Walter G. (1)  
(1) Geowissenschaften, Eberhard Karls Universität, Tübingen, Germany;  
(2) University of New South Wales, Kensington, Australia, Germany
TUESDAY, JULY 9TH

S-033 QUANTIFYING EMBRYONIC SKELETAL DEVELOPMENT IN MAMMALS: EVOLUTION, VARIATION, AND CONSTRAINTS
Koyabu, Daisuke
Palaeontological Institute and Museum, University of Zurich, Zurich, Switzerland

09:30-11:30
VIVALDI 1 ROOM
Symposium 7: Reptile Skeletal Biology: Investigations Into Tissue Morphology, Development, and Evolution
Organizers: Casey Holliday, University of Missouri
Matthew Vickaryous, University of Guelph

S-036 SKELETAL REGENERATION FOLLOWING TAIL LOSS IN LIZARDS
Vickaryous, Matt; Coates, Helen; Delorme, Steph
University of Guelph, Guelph, Canada

S-037 SQUAMATE VERTEBRAL HISTOLOGY AND MICROANATOMY - DEVELOPMENT AND EVOLUTION
Houssaye, Alexandra
Steinmann Institut für Geologie, Paläontologie und Mineralogie, Universität Bonn, Bonn, Germany

S-038 COMPARATIVE SKULL MECHANICS OF THE LIZARDS TUPINAMBIS MERIANAE AND VARANUS ORNATUS
Gröning, Flora (1); Jones, Marc (2); Curtis, Neil (1); O’higgins, Paul (3); Evans, Susan (2); Fagan, Michael (1)
(1) University of Hull, Hull, United Kingdom; (2) University College London, London, United Kingdom; (3) University of York, York, United Kingdom

S-039 A COMPARISON OF TURTLE AND CHICKEN ONTOGENY REVEALS THE BASIS FOR DIVERGENT HARD PALATE MORPHOLOGY
Richman, Joy; Abramyan, John; Leung, Kelvin
Life Sciences Centre, University of British Columbia, Canada

09:30-11:30
VIVALDI 2 ROOM
Contributed 4: General Morphology
Chairs: Brian Metscher
Lorenzo Alibardi

C-018 THE DIGITAL BUZZARD – USING CONTRAST-ENHANCED CT SCANNING TO ELUCIDATE HARD- AND SOFT-TISSUE ANATOMY
Lautenschlager, Stephan; Bright, Jen A.; Rayfield, Emily J.
School of Earth Sciences, University of Bristol, Bristol, United Kingdom

C-019 CRANIAL SHAPE AND GROWTH IN THE DWARF SNAKE GENUS EIRENIS (SQUAMATA, SERPENTES) AS REVEALED BY X-RAY MICRO-COMPUTED TOMOGRAPHY
Mahlow, Kristin; Müller, Johannes
Museum für Naturkunde, Berlin, Germany
C-020 Refinements to Using Lugol’s Iodine as a Contrast Agent in X-ray µCT Imaging of Post-Embryonic Vertebrate Soft Tissues
Gignac, Paul; Kley, Nathan
Stony Brook University, Stony Brook, United States

C-021 Parallel Evolution of “Unique” Derived Characters in Amphibiania (Reptilia, Squamata)
Müller, Johannes; Hipsley, Christy
Museum für Naturkunde, Berlin, Germany

C-022 Mechanical Transgressive Segregation and the Rapid Origin of Trophic Novelty
Hulsey, Darrin (1); Holzman, Roï (2)
(1) University of Tennessee, Knoxville, United States; (2) Tel Aviv University and the Inter-University Institute for Marine Sciences, Eilat, Israel

C-023 Virtual Basal Actinopterygii: 3D Fish Models for Evo-Devo
Metscher, Brian
University of Vienna, Vienna, Austria

09:30-11:30 DIAMANT ROOM
Contributed 5: Ontogeny
Chairs: Kathryn Kavanagh
Anthony Herrel

C-028 New Insights on the Development of the Extant Coelacanth, Latimeria Chalumnae, Based on X-ray Synchrotron Microtomography
Dutel, Hugo (1); Clément, Gaël (1); Herrel, Anthony (1); Tafforeau, Paul (2); Paterson, Angus (3); Bills, Roger (3); Janvier, Philippe (1); Herbin, Marc (1)
(1) Muséum national d’Histoire naturelle, Paris, France; (2) European Synchrotron Radiation Facility, Grenoble, France; (3) South African Institute for Aquatic Biodiversity, Grahamstown, South Africa

C-029 Primitive Braincase Architecture of Crown Gnathostomes: Unexpected Data from the Early Devonian of Siberia
Brazeau, Martin (1); Giles, Sam (2); Friedman, Matt (2)
(1) Naturalis Biodiversity Center, Leiden, Netherlands; (2) University of Oxford, Oxford, United Kingdom

C-030 It’s in Their Face: Quantifying Ontogenetic and Static Allometry in Human Male Faces
Windhager, Sonja (1); Mitteroecker, Philipp (2); Schaefer, Katrin (3)
(1) Konrad Lorenz Institute for Evolution and Cognition Research, Altenberg, Austria; (2) Department of Theoretical Biology, University of Vienna, Vienna, Austria; (3) Department of Anthropology, University of Vienna, Vienna, Austria
TUESDAY, JULY 9TH

C-031 A DEVELOPMENTAL PERSPECTIVE ON STAGES IN THE EVOLUTION OF PHALANGES
Kavanagh, Kathryn; Leary, Brian; Winslow, Benjamin
University of Massachusetts Dartmouth, North Dartmouth, United States

C-032 HETEROCHRONY AND POSTNATAL GROWTH IN MAMMALS AN EXAMINATION OF GROWTH PLATES IN LIMBS
Geiger, Madeleine (1); Forasiepi, Analía M. (2); Koyabu, Daisuke (1); Sánchez-Villagra, Marcelo R. (1)
(1) Paläontologisches Institut und Museum der Universität Zürich, Zürich, Switzerland; (2) Conicet, Ianigla, CCT-Mendoza, Mendoza, Argentina

C-027 DIVERSITY AND CONSTRAINT IN THE EMBRYONIC ORIGIN OF THE VERTEBRATE SKULL
Hanken, James; Piekarski, Nadine
Harvard University, Cambridge, United States

11:30-12:00 Coffee Break

12:00-13:00 VERDI ROOM
Contributed 6: Geometric Morphometrics
Chairs: Jesús Merugan-Lobón
Eloy Galvez-Lóbez

C-042 MORPHOLOGICAL, DIETARY AND PHYLOGENETIC CONVERGENCE IN THE CRANIA OF DIURNAL BIRDS OF PREY
Bright, Jen (1); Cobb, Samuel (2); Marugán-Lobón, Jesús (3); Rayfield, Emily (1)
(1) University of Bristol, Bristol, United Kingdom; (2) Hull York Medical School, York, United Kingdom; (3) Universidad Autónoma de Madrid, Madrid, Spain

C-043 UNDERSTANDING FUNCTIONAL CONSEQUENCES OF VARIATION IN SKULL SHAPE; CROCS, KOOKABURRAS, AND GOANNAS
Walmsley, Christopher; Quayle, Michelle; McCurry, Matthew; Mchenry, Colin
Monash University, Melbourne, Australia

C-044 EVOLUTIONARY ORGANIZATION AND VARIATION OF THE SKULL IN BIRDS: SAMENESS WITH CRANIOFACIAL VARIATION IN TETRAPODS
Marugán-Lobón, Jesús; Buscalionii, Ángela D.
Universidad Autónoma de Madrid, Madrid, Spain
12:00-13:00  **ROSSINI 1 ROOM**  
**Symposium 5: Evolution of Locomotion: Reciprocal Illumination From a Diversity of Approaches**  
Organizers: Timothy Higham, University of California, Riverside  
Theodore Garland, University of California, Riverside  

S-019 **LOCOMOTOR ONTOGENY AND THE EVOLUTION OF AVIAN FLIGHT**  
Heers, Ashley  
*University of Montana, Missoula, United States*  

S-024 **MAKING WAVES: SELF-PROPELLED ROBOTS TEST HYPOTHESES ABOUT THE FUNCTIONAL AND EVOLUTIONARY MECHANISMS OF SWIMMING**  
Long, John (1); Lauder, George (2)  
(1) *Vassar College, Poughkeepsie, United States*; (2) *Harvard University, Cambridge, United States*  

12:00-13:00  **ROSSINI 2 ROOM**  
**Symposium 6A: Quantifying Evolutionary Development Using non-model Organisms: Integrating Metrical Frameworks, Gene Expression, and Morphology**  
Organizers: Laura Wilson, University of New South Wales, Australia  
Ingmar Werneburg, Eberhard-Karls University, Germany  

S-034 **MAMMALIAN SKELETAL CONSTRAINTS AND THEIR MOLECULAR DETERMINANTS**  
Sears, Karen  
*University of Illinois, Urbana, United States*  

S-035 **PHYSICAL AND BIOLOGICAL MECHANISMS GENERATING COMPLEXITY AND DIVERSITY OF SKIN APPENDAGES IN AMNIOTES**  
Milinkovitch, Michel; Tzika, Athanasia  
*University of Geneva, Geneva, Switzerland*  

12:00-13:00  **VIVALDI 1 ROOM**  
**Symposium 7: Reptile Skeletal Biology: Investigations Into Tissue Morphology, Development, and Evolution**  
Organizers: Casey Holliday, University of Missouri  
Matthew Vickaryous, University of Guelph  

S-040 **HOW DID ENAMEL MATRIX PROTEINS EVOLVE IN REPTILE TEETH AND ARE THEY PRESENT IN OSTEODERMS?**  
Sire, Jean-Yves (1); Gasse, Barbara (1); Silvent, Jérémie (1); Delgado, Sidney (1); Belheouane, Meriem (1); De Buffrénil, Vivian (2)  
(1) *Université Pierre et Marie Curie, Paris, France*; (2) *Muséum national d’Histoire naturelle, Paris, France*
S-041 DEVELOPMENTAL PLAN OF THE AMNIOTE SHOULDER GIRDLE AND ITS EVOLUTIONARY DIVERSITY
Nagashima, Hiroshi (1); Hirasawa, Tatsuya (2); Sugahara, Fumiaki (2); Takechi, Masaki (3); Sato, Noboru (1); Kuratani, Shigeru (2)
(1) Niigata University Graduate School of Medical and Dental Sciences, Niigata, Japan; (2) RIKEN Center for Developmental Biology, Kobe, Japan; (3) Iwate Medical University, Yahaba-cho, Japan

12:00-13:00 VIVALDI 2 ROOM
Contributed 4: General Morphology
Chairs: Brian Metscher
Lorenzo Alibardi

C-024 TISSUE TRADE-OFFS: MIND OVER MATTER
Muchlinski, Magdalena; Vollrath, Heidi
University of Kentucky, Lexington, United States

C-025 ADAPTATION AND PLASTICITY OF MYOFIBRILLAR MITOCHONDRIA IN DOMESTIC DOGS
Starck, J. Matthias (1); Gerth, Nadine (2); Jakob, Kathrin (1); Lehni, Christina (1); Vitger, Anne (3)
(1) Department of Biology, University of Munich (LMU), Germany; (2) Department of Biology, University of Munich (LMU), Germany; (3) Faculty of Health Sciences, University of Copenhagen, Denmark

C-026 ANALYSIS OF THE PROCESS OF CORNIFICATION IN LEPIDOSAURIAN EPIDERMIS
Alibardi, Lorenzo
University of Bologna, Bologna, Italy

12:00-13:00 DIAMANT ROOM
Contributed 5: Ontogeny
Chairs: Kathryn Kavanagh
Anthony Herrel

C-033 A MICROMORPHOLOGICAL-EXPERIMENTAL APPROACH TO BACULUM FUNCTION IN BATS
Herdina, Anna Nele (1); Jahelková, Helena (2); Kelly, Diane A. (3); Pulaski, Dan (6); Brennan, Patricia L.R. (4); Orr, Teri J. (6); Dumont, Elizabeth R. (4); Horáček, Ivan (2); Metscher, Brian D. (1)
(1) Department of Theoretical Biology, University of Vienna, Vienna, Austria; (2) Department of Zoology, Charles University, Prague, Czech Republic; (3) Organismic and Evolutionary Biology Program, University of Massachusetts, Amherst, United States; (4) Organismic and Evolutionary Biology Program, University of Massachusetts and Department of Biology, University of Massachusetts, Amherst, United States
C-034 EVOLUTION OF THE MAXILLARY NERVE AND THE VERTEBRATE CRANIOFACIAL DEVELOPMENT
Higashiyama, Hiroki (1); Kuratani, Shigeru (2)
(1) Kobe University; Lab. for Evolutionary Morphology, Riken CDB; JSPS Research Fellow, Kobe, Japan; (2) Lab. for Evolutionary Morphology, Riken CDB, Kobe, Japan

C-035. REGULATION OF JAW SIZE DURING DEVELOPMENT AND EVOLUTION
Schneider, Richard; Fish, Jennifer; Yu, Jane; Ealba, Erin
University of California San Francisco, San Francisco, United States

13:00-14:30 Midday Break

14:30-16:30 VERDI ROOM
Symposium 4: Vertebrate Limb Development
Organizers: Michael Richardson, Leiden University
Karen Sears, University of Illinois

S-013 FROM FIN FOLDS TO FISH WITH FINGERS: A NEW EMPIRICS OF FIN AND LIMB EVOLUTION
Brazeau, Martin (1); Coates, Michael (2)
(1) Naturalis Biodiversity Center, Leiden, Netherlands; (2) University of Chicago, Chicago, United States

S-014 PATTERNING THE LIMB
Wolpert, Lewis
University College London, London, United Kingdom

S-015 THE ROLE OF EARLY DEVELOPMENTAL CHANGES IN LIMB EVOLUTION
Sears, Karen
University of Illinois, Urbana, United States

S-016 LIMB MORPHOGENESIS AND TERATOLOGY
Vargesson, Neil
University of Aberdeen, Aberdeen, United Kingdom

14:30-16:30 ROSSINI 1 ROOM
Symposium 5: Evolution of Locomotion: Reciprocal Illumination From a Diversity of Approaches
Organizers: Timothy Higham, University of California, Riverside
Theodore Garland, University of California, Riverside

S-025 PHENOTYPIC DIVERGENCE IN LACERTID LIZARDS: A COMPARISON OF EVOLUTIONARY RATES BETWEEN CLADES
Vanhooydonck, Bieke (1); Huyghe, Katleen (1); Alfaro, Michael (2); Herrel, Anthony (3)
(1) University of Antwerp, Antwerp, Belgium; (2) University of California, Los Angeles, United States; (3) MNHN, Paris, France
USE IT OR LOSE IT: THE EVOLUTION OF LOCOMOTION ASSOCIATED WITH THE GAIN AND LOSS OF ADHESIVE CAPACITY IN GECKOS
Higham, Timothy (1); Birn-Jeffery, Aleksandra (1); Russell, Anthony (2)
(1) University of California, Riverside, United States; (2) University of Calgary, Calgary, Canada

MORPHOLOGICAL INTEGRATION AND EVOLVABILITY IN THE VERTEBRATE LOCOMOTOR SKELETON
Rolian, Campbell
University of Calgary, Calgary, Canada

14:30-16:30 ROSSINI 2 ROOM
Symposium 6B: Digital Morphology: 3D Visualization and Analysis with Amira/Avizo
Organizers: Robert Brandt, VSG
Alejandra Sánchez-Eróstegui, VSG

The workshop will present the visualization and analysis capabilities of the Amira software system. Avizo, VSG’s sister product to Amira, is fundamentally similar, but the examples in the workshop will be using Amira. After a short introduction into the user interface, the workshop will go through example cases which, among others, will cover the following topics: Quantification and analysis of images with many similar objects (Multi-component analysis), trabecular bone segmentation using morphological operators and arithmetic, and creation of animations and movie clips. The workshop will be interactive, and there will be opportunities for questions and discussion throughout. Although attendees are free to just observe the workshop, participants are encouraged to bring their laptops to join in. Organizers will be bringing Amira installers and temporary license keys on USB drives so that participants can load the software to follow along. There will be some parts of the workshop that will be demonstrated by the presenters. No prior experience with 3D visualization software is required, and the workshop will seek to keep both novices and experts engaged. The number of workshop participants is limited only by the physical constraints of the room.

Introduction of company and products by Alejandra, the VSG account manager

Brief introduction into the software, user interface, basic visualization

First Session: Multi-Component Analysis: How to quantify similar objects in a 3D data set

Second Session: Trabecular Bone Segmentation: How to utilize morphological operators in image segmentation
14:30-16:30  VIVALDI 1 ROOM  
Symposium 7: Reptile Skeletal Biology: Investigations Into Tissue Morphology, Development, and Evolution  
Organizers: Casey Holliday, University of Missouri  
Matthew Vickaryous, University of Guelph

S-042 MORPHOLOGY AND FUNCTION OF THE REPTILE MANDIBULAR SYMPHYSIS  
Holliday, Casey (1); Hieronymus, Tobin (2); Nesbitt, Sterling (3); Vickaryous, Matthew (4)  
(1) University of Missouri, Columbia, United States; (2) Northeastern Ohio Medical University, Kent, United States; (3) Field Museum of Natural History, Chicago, United States; (4) University of Guelph, Guelph, Canada

S-043 DEVELOPMENT AND EVOLUTION OF MESOPODIALIZATION IN THE ICHTHYOSAURIAN LIMB SKELETON  
Maxwell, Erin (1); Scheyer, Torsten M. (2); Fowler, Donald (2)  
(1) Universität Zürich, Paläontologisches Institut und Museum, Switzerland; (2) McGill University, Department of Biology, Canada

S-044 FRONTIERS IN THE EVOLUTION AND DEVELOPMENT OF THE REPTILIAN SKULL  
Bhullar, Bhart-Anjan (1); Marugan-Lobon, Jesus (2); Racimo, Fernando (3); Bever, Gabe (4); Rowe, Timothy (5); Norell, Mark (6); Abzhanov, Arhat (1)  
(1) Harvard University, Cambridge, United States; (2) University of Madrid, Madrid, Spain; (3) University of California, Berkeley, United States; (4) New York College of Osteopathic Medicine, Old Westbury, United States; (5) The University of Texas at Austin, Austin, United States; (6) American Museum of Natural History, New York, United States

S-045 CONSERVATION OF PRIMAXIAL REGIONALIZATION IN THE EVOLUTION OF THE SNAKE BODY FORM INDICATES HOMOPLASY IN HOX GENE FUNCTION  
Head, Jason (1); Polly, P. David (2)  
(1) University of Nebraska-Lincoln, Lincoln, United States; (2) Indiana University, Bloomington, United States

14:30-16:30  VIVALDI 2 ROOM  
Contributed 7: Tooth EvoDevo  
Chairs: Alistair Evans  
Moya M. Smith

C-045 SYNCHROTRON 3D IMAGING OF Earliest Tooth Formation IN MOUSE  
Raj, Muhammad (1); Prusinkiewicz, Martin (1); Cooper, David M. L. (1); Belev, George (2); Webb, M. Adam (2); Boughner, Julia C. (1)  
(1) University of Saskatchewan, Saskatoon, Canada; (2) Canadian Light Source Synchrotron, Saskatoon, Canada
C-046 THE NATURAL HISTORY OF TOOTH REPLACEMENT IN ADULT GECKOS
Richman, Joy; Whitlock, John; Wong, Andrew
Life Sciences Institute, University of British Columbia, Canada

C-047 DEVELOPING INNOVATION THROUGH REGENERATION: EVOLUTION AND DEVELOPMENT OF NOVEL DENTITIONS IN TETRAODONTIFORMES
Shono, Takanori (1); Riley, Alex (1); Britz, Ralf (2); Johanson, Zerina (3); Smith, Moya (4); Fraser*, Gareth (1)
(1) Department of Animal and Plant Sciences, University of Sheffield, Sheffield, United Kingdom; (2) Zoology Department, Natural History Museum London, London, United Kingdom; (3) Palaeontology Department, Natural History Museum London, London, United Kingdom; (4) Dental Institute, King’s College London, London, United Kingdom

C-048 SELF-ORGANIZATION VERSUS FUNCTION IN EXPLAINING SKELETAL STRUCTURES IN VERTEBRATES: TEETH AS AN EXAMPLE
De Renzi, Miquel
Institut Cavanilles, Universitat de València, Paterna, Spain

C-049 THE FOURTH MOLAR CONUNDRUM: THE INHIBITORY CASCADE IN MARSUPIALS
Evans, Alistair; Proctor, Karlena; Vitacca, Jesse; Islam, Md Roysul
Monash University, Melbourne, Australia

C-050 THE GREAT SYNOPSIS: USING A MULTIPROXY APPROACH ON DIFFERENT SCALES TO INFER FEEDING BIOMECHANICS AND MORPHOLOGICAL CONSTRAINTS OF MAMMAL TEETH
Kaiser, Thomas; Winkler, Daniela E.; Gailer, Juan Pablo; Landwehr, Christina; Schulz, Ellen
University of Hamburg, Biocenter Grindel and Zoological Museum, Hamburg, Germany

14:30-16:30
DIAMANT ROOM
Contributed 8: Flight: Bats and Birds
Chairs: Sharon Swartz
Jonathan R. Codd

C-051 CAN BAT WING MUSCLES OPERATE AS FORCE CONTROLLERS?
Konow, Nicolai; Von Busse, Rhea; J. Robersts, Thomas; M. Swartz, Sharon
Brown University, Providence, United States

C-052 INTEGRATING AERODYNAMICS AND ENERGETICS TO UNDERSTAND HOW BATS CHANGE FLIGHT DYNAMICS WITH SPEED
Swartz, Sharon (1); Von Busse, Rhea (1); Waldman, Rye (1); Konow, Nicolai (1); Voigt, Christian (2); Breuer, Kenneth (1)
(1) Brown University, Providence, United States; (2) Leibniz Institute for Zoo and Wildlife Research, Berlin, Germany
C-053 SEASONAL DIFFERENCES IN THE ENERGETICS AND BIOMECHANICS OF LOCOMOTION IN A HIGH ARCTIC BIRD
Lees, John (1); Codd, Jonathan (1); Stokkan, Karl-Arne (2); Folkow, Lars (2)
(1) University of Manchester, Manchester, United Kingdom; (2) University of Tromso, Tromso, Norway

16:30-17:00 Coffee Break

17:00-18:00 VERDI ROOM
Symposium 4: Vertebrate Limb Development
Organizers: Michael Richardson, Leiden University
Karen Sears, University of Illinois

S-017 DIGIT LOSS AND THE STEPWISE DISAPPEARANCE OF ANCESTRAL DEVELOPMENTAL PATHWAYS
Richardson, M.K. (1); De Bakker, M.A.G. (1); Fowler, D.A. (1); Den Oude, K. (1); Dondorp, E.M. (1); Garrido Navas, Mª. C. (1); Horbanczuk, J.O. (2); Sire, J.-Y (3); Szczerbiska, D. (4)
(1) Dept. Integrative Zoology, Institute of Biology, Leiden University, Leiden, Netherlands; (2) Institute of Genetics and Animal Breeding, Poland; (3) Evolution & Développement du squelette, UMR 7138, Paris, France; (4) Department of Poultry and Ornamental Bird Breeding, Western Pomeranian University of Technology, Szczecin, Poland

S-018 THE MOLE LIMB
Bickelmann, Constanze
Museum für Naturkunde - Leibniz-Institut für Evolutions- und Biodiversitätforrschung, Berlin, Germany

17:00-18:00 ROSSINI 1 ROOM
Symposium 5: Evolution of Locomotion: Reciprocal Illumination From a Diversity of Approaches
Organizers: Timothy Higham, University of California, Riverside
Theodore Garland, University of California, Riverside

S-028 INTEGRATION OF METHODS TO RECONSTRUCT THE LOCOMOTOR EVOLUTION OF ARCHOSAURS
Hutchinson, John; Allen, Vivian
Royal Veterinary College, London, United Kingdom

S-029 SWING PHASE MECHANICS AS A DETERMINANT OF LOCOMOTOR BEHAVIOR IN MAMMALS
Schmitt, Daniel (1); Lemelin, Pierre (2); Miller, Charlotte (1)
(1) Evolutionary Anthropology, Duke University, Durham, NC, United States; (2) Division of Anatomy, University of Alberta, Edmonton, Canada
17:00-18:00 ROSSINI 2 ROOM
Symposium 6B: Digital Morphology: 3D Visualization and Analysis with Amira/Avizo
Organizers: Robert Brandt, VSG
Alejandra Sánchez-Eróstegui, VSG

Third session: Creating Animations and Movies, and Q&A

17:00-18:00 VIVALDI 1 ROOM
Symposium 7: Reptile Skeletal Biology: Investigations Into Tissue Morphology, Development, and Evolution
Organizers: Casey Holliday, University of Missouri
Matthew Vickaryous, University of Guelph

S-046 IN VIVO CRANIAL BONE STRAINS DURING FEEDING IN THE LIZARDS TUPINAMBIS AND UROMASTYX
Porro, Laura (1); Ross, Callum (2); Herrel, Anthony (3); Evans, Susan (4); Fagan, Michael (5); O’Higgins, Paul (6)
(1) University of Bristol, Bristol, United Kingdom; (2) University of Chicago, Chicago, United States; (3) CNRS/Muséum National d’Histoire Naturelle, Paris, France; (4) University College London, London, United Kingdom; (5) University of Hull, Hull, United Kingdom; (6) University of York, York, United Kingdom

S-047 ARCHOSAUROMORPH BONE HISTOLOGY REVEALS EARLY EVOLUTION OF ELEVATED GROWTH AND METABOLIC RATES
Werning, Sarah (1); Irmis, Randall (2); Nesbitt, Sterling (3); Smith, Nathan (4); Turner, Alan (5); Padian, Kevin (1)
(1) University of California, Berkeley, CA, United States; (2) Natural History Museum of Utah & University of Utah, Salt Lake City, UT, United States; (3) The Field Museum, Chicago, IL, United States; (4) Howard University, Washington, DC, United States; (5) Stony Brook University, Stony Brook, NY, United States
WEDNESDAY, JULY 10TH

08:30-09:30  VERDI ROOM
Plenary Lecture III: Daniel Blackburn
Professor and Chair, Department of Biology, Trinity College, Hartford, CT, USA
“Functional morphology and evolution of placentas in reptiles”
(Abstract PT-003)

09:30-11:30  VERDI ROOM
Contributed 11: Sensory Biology
Chairs: Johannes Müller
Cathrin Schwarz

C-071  EVOLUTION OF THE MIDDLE EAR CAVITY: A NOVEL MECHANISM FOR A NEW EAR
Tucker, Abigail; Thompson, Hannah
King’s College London, London, United Kingdom

C-072  ENDOCRANIAL RECONSTRUCTIONS OF EXTINCT TURTLES USING μ-CT SCANS: NEW INSIGHTS INTO BRAIN AND INNER EAR ANATOMY
Paulina Carabajal, Ariana (1); Sterli, Juliana (2); Müller, Johannes (3); Joyce, Walter Gordon (4); Werneburg, Ingmar (4)
(1) CONICET-Museo Carmen Funes, Plaza Huincul, Argentina; (2) CONICET-Museo Paleontológico Egidio Feruglio, Trelew, Argentina; (3) Museum für Naturkunde - Leibniz-Institut für Evolutions- und Biodiversitätsforschung an der Humboldt-Universität zu Berlin, Berlin, Germany; (4) Fachbereich Geowissenschaften, Universität Tübingen, Tübingen, Germany

C-073  FUNCTIONAL MORPHOLOGICAL ADAPTATIONS OF THE INNER EAR IN SCIUROMORPHS (RODENTIA, MAMMALIA)
Schwarz, Cathrin (1); Ruf, Irina (2)
(1) Department of Palaeontology, University of Vienna, Geozentrum, UZA II, Austria; (2) Steinmann-Institut für Geologie, Mineralogie und Paläontologie, Rheinische Friedrich-Wilhelms-Universität Bonn, Bonn, Germany

C-074  LAONASTES AENIGMAMUS – MIDDLE AND INNER EAR MORPHOLOGY OF A NEW HYSTRICOMORPH RODENT
Tröscher, Adrian (1); Maier, Wolfgang (2); Böhme, Madelaine (1)
(1) Terrestrische Paläoklimatologie, Universität Tübingen, Germany; (2) Fachbereich Biologie, Universität Tübingen, Germany

C-075  TRENDS IN MIDDLE EAR AND BRAINCASE ANATOMY IN DINOSAURIA
Sobral, Gabriela; Müller, Johannes
Museum für Naturkunde, Berlin, Germany
ROSSINI 1 ROOM
Symposium 9: Interdisciplinary and Novel Approaches to Vertebrate Locomotion
Organizers: David Ellerby, Wellesley College, Shannon Gerry, Fairfield University
Christopher Sanford, Hofstra University
Graham Askew, University of Leeds

S-054 LINKING MORPHOLOGY TO SWIMMING PERFORMANCE IN BLUEGILL
Gerry, Shannon (1); Ellerby, David (2)
(1) Fairfield University, Fairfield, CT, United States; (2) Wellesley College, Wellesley, United States

S-055 TRACKING MUSCLE ENERGY USE DURING LOCOMOTION
Ellerby, David (1); Gerry, Shannon (2)
(1) Wellesley College, Wellesley, United States; (2) Fairfield University, Fairfield, United States

S-056 NEW APPROACHES TO THE STUDY OF HYDRODYNAMICS IN ANIMALS: V3V OR VOLUMETRIC PIV
Sanford, Christopher
Hofstra University, Hempstead, United States

S-057 WHY MIGHT FISHES BE DIFFERENTLY SHAPED
Feilich, Kara; Lauder, George
Harvard University, Cambridge, MA, United States

ROSSINI 2 ROOM
Symposium 10: Next Steps: Dynamic Simulations in Paleobiology
Organizers: Eric Snively, Ohio University
Heinrich Mallison, Museum fur Naturkunde, Berlin

S-063 CONSTRAINTS AND OPPORTUNITIES IN COMPUTATIONAL MODELING OF EXTINCT VERTEBRATES: A CASE STUDY USING PLESIOSAURS
Henderson, Donald
Museum, Drumheller, Canada

S-064 HOW WE CAN USE STRUCTURAL ANALYSIS AND FORCE-DRIVEN SYNTHESIS OF SKULL FORM TO PREDICT DYNAMIC LOADING IN EXTINCT AND EXTANT VERTEBRATES
Witzel, Ulrich
University of Bochum, Bochum, Germany

S-065 PLEUROKINETIC OR MANDIBULAR LONG-AXIS ROTATION? TESTING CHEWING HYPOTHESES IN HADROSAUR DINOSAURS USING MULTI-BODY DYNAMICS ANALYSIS
Curtis, Neil (1); Holliday, Casey (2); Tirabasso, Alex (3); Rybczynski, Natalia (4)
(1) University of Hull, Hull, United Kingdom; (2) University of Missouri, Missouri, United States; (3) Canadian Museum of Nature Collection Services, Quebec, Canada; (4) Canadian Museum of Nature Palaeobiology, Ottawa, Canada
S-066 THE INFLUENCE OF OSTRICH HIP MORPHOLOGY ON WALKING AND RUNNING ECONOMY: A TEST CASE FOR USING DETAILED MUSCULOSKELETAL MODELS AND COMPUTER SIMULATIONS TO LINK FORM AND FUNCTION
Rankin, Jeffery W. (1); Rubenson, Jonas (2); Hutchinson, John R. (1)
(1) Structure & Motion Laboratory, The Royal Veterinary College, University of London, United Kingdom; (2) School of Sport Science, Exercise & Health, The University of Western Australia, Crawley, Australia

09:30-11:30 VIVALDI 1 ROOM
Symposium 12: New Advances in Paleohistological Studies
Organizers: Alexandra Houssaye, University of Bonn
Dorota Konietzko-Meier, University of Opole, Poland

S-076 FOSSIL BONE HISTOLOGY “CORRECTED FOR” OSTEOGENESIS AND CUTTING PLANES: WHAT IS FIBROLAMELLAR BONE ANYWAY?
Prondvai, Edina (1); Stein, Koen (2)
(1) MTA-ELTE Lendület, Dinosaur Research Group, Budapest, Hungary; (2) Steinmann Institut fuer Geologie, Mineralogie und Palaeontologie, Bonn, Germany

S-077 BONE HISTOLOGY OF MARINE TURTLE SHELLS THROUGH TIME
Scheyer, Torsten M.
Universität Zürich, Zürich, Switzerland

S-078 BONE MICROANATOMY OF TURTLE LIMB BONES: ADVANCES IN PALEOBIOLOGY OF TESTUDINATES
Nakajima, Yasuhisa (1); Hirayama, Ren (2); Endo, Hideki (3)
(1) Steinmann Institute for Geology, Mineralogy and Palaeontology, University of Bonn, Bonn, Germany; (2) School of International Liberal Studies, Waseda University, Tokyo, Japan; (3) The University Museum, The University of Tokyo, Tokyo, Japan

S-079 WHY ARE SAUROPOD DINOSAURS SO DIFFICULT TO AGE? INSIGHT FROM LOCAL BONE APPOSITION RATES
Sander, Martin (1); Griebeler, Eva Maria (2); Klein, Nicole (1); Wings, Oliver (3)
(1) University of Bonn, Bonn, Germany; (2) University of Mainz, Mainz, Germany; (3) Niedersaechsisches Landesmuseum Hannover, Hannover, Germany

09:30-11:30 VIVALDI 2 ROOM
Contributed 9: Integration, Shape Mobility
Chairs: Christian Klingenberg
Diego Rasskin-Gutman

C-054 CRANIOMETRIC IMPACT OF SEASONALITY IN CERVIDS
Heckeberg, Nicola S. (1); Roessner, Gertrud E. (2); Asher, Robert J. (3); Wörheide, Gert (4)
(1) LMU Munich, Munich, Germany; (2) Bavarian State Collections of Palaeontology and Geology, Munich, Germany; (3) Museum of Zoology, Cambridge, United Kingdom; (4) LMU Munich, Bavarian State Collections of Palaeontology and Geology, Munich, Germany
C-055 FACTORS INFLUENCING MORPHOLOGY AND PATTERNS OF INTEGRATION ON THE SKULL OF SOAY SHEEP
Damasceno, Elis; Klingenberg, Christian
University of Manchester, Manchester, United Kingdom

C-056 IT’S NOT EASY BEING GREEN: PERFORMANCE AND FLUCTUATING SELECTION IN AN URBAN POPULATION OF GREEN ANOLE (ANOLIS CAROLINENSIS) LIZARDS
Lailvaux, Simon
University of New Orleans, New Orleans, United States

C-057 INTEGRATION AND MODULARITY OF SHAPE: EXPLORATORY ANALYSES IN AN EVOLUTIONARY CONTEXT
Klingenberg, Christian Peter
University of Manchester, Faculty of Life Sciences, Manchester, United Kingdom

C-058 USING NETWORK MODELS TO TACKLE MORPHOLOGICAL INTEGRATION AND MODULARITY IN THE HUMAN SKULL
Esteve-Altava, Borja; Rasskin-Gutman, Diego
University of Valencia, Valencia, Spain

C-059 FUNCTIONAL APPROACH TO THE EVOLUTION OF THE HUMAN HIP JOINT
Bonneau, Noémie (1); Baylac, Michel (1); Tardieu, Christine (1); Gagey, Olivier (2)
(1) Muséum National d’Histoire Naturelle, Paris, France; (2) University Paris Sud X, Orsay, France

09:30-11:30 DIAMANT ROOM
Contributed 10: Feeding
Chairs: Lawrence Witmer
Elizabeth Brainerd

C-063 MULTIBODY DYNAMICS OF FEEDING IN THE THEROPOD DINOSAUR ALLOSAURUS AND DOMESTIC PIGS: PALEONTOLOGICAL SIMULATION AND EXTANT VALIDATION
Snively, Eric (1); Kumbhar, Yatin (1); Cotton, John (1); Ridgely, Ryan (2); Witmer, Lawrence (2)
(1) Department of Mechanical Engineering, Ohio University, Athens, United States; (2) Department of Biomedical Sciences, Ohio University, Athens, United States

C-064 DEVELOPING A MULTIBODY DYNAMICS MODEL OF THE MOUSE MASTICATORY SYSTEM
Chabokdast, Anna (1); Fagan, Michael J. (1); Cobb, Sam N. (2)
(1) School of Engineering, University of Hull, Centre for Anatomical and Human Sciences, Hull York Medical School, University of Hull, United Kingdom; (2) Centre for Anatomical and Human Sciences, Hull York Medical School, University of Hull, Hull, United Kingdom
C-065 MULTIBODY DYNAMICS MODELLING OF A RABBIT SKULL
Watson, Peter (1); Gröning, Flora (1); Fitton, Laura (2); Herrel, Anthony (3); Fagan, Michael (1)
(1) Department of Engineering, University of Hull, Hull, United Kingdom; (2) Centre for Anatomical and Human Sciences, Hull York Medical School, University of York, York, United Kingdom; (3) Département d’Ecologie et de Gestion de la, Muséum National d’Histoire Naturelle, Paris, France

C-066 FINITE ELEMENT ANALYSIS OF BITING MECHANISM IN THE EXTANT COELACANTH, LATIMERIA CHALUMNAE
Dutel, Hugo (1); Clément, Gaël (1); Herrel, Anthony (1); Dumont, Elizabeth R. (2); Pulaski, Dan (2); Grosse, Ian R. (2); Fagan, Michael J. (3); Goussard, Florent (1); Janvier, Philippe (1); Herbin, Marc (1)
(1) Muséum national d’Histoire naturelle, Paris, France; (2) University of Massachusetts Amherst, Amherst, United States; (3) University of Hull, Kingston upon Hull, United Kingdom

C-067 MODELING THE FUNCTIONAL TRADE-OFFS OF DUROPHAGOUS TEETH
Crofts, Stephanie (1); Summers, Adam (2)
(1) University of Washington, Seattle, WA, United States; (2) University of Washington, Friday Harbor Labs, Friday Harbor, WA, United States

C-062 IS THE LEPTOCEPHALUS LARVA CAPABLE OF BITING? ANALYZING THE MORPHOLOGICAL LIMITATIONS OF THE FEEDING APPARATUS IN THE EUROPEAN EEL
Bouilliart, Mathias (1); Tomkiewicz, Jonna (2); Lauesen, Peter (3); Adriaens, Dominique (1)
(1) Ghent University, Ghent, Belgium; (2) Technical University of Denmark, Charlottenlund, Denmark; (3) Billund Aquaculture, Billund, Denmark

11:30-12:00 Coffee Break

12:00-13:00 VERDI ROOM
Contributed 11: Sensory Biology
Chairs: Johannes Müller
Cathrin Schwarz

C-076 GOOD VIBRATIONS: FUNCTIONAL MORPHOLOGY IN THE ODONTOCETE TYMPANOPERIOTIC COMPLEX
Ary, William (1); Cranford, Ted (1); Krysl, Petr (2); Berta, Annalisa (1)
(1) San Diego State University, San Diego, United States; (2) University of California, San Diego, United States

C-077 TRIGEMINAL NERVE MORPHOLOGY IN ALLIGATOR MISSISSIPPIENSIS AND ITS SIGNIFICANCE FOR CROCODYLIFORM FACIAL SENSATION
George, Ian; Holliday, Casey
University of Missouri, Columbia, United States
12:00-13:00  
**ROSSINI 1 ROOM**  
**Symposium 9: Interdisciplinary and Novel Approaches to Vertebrate Locomotion**  
Organizers: David Ellerby, Wellesley College; Shannon Gerry, Fairfield University; Christopher Sanford, Hofstra University; Graham Askew, University of Leeds  

**S-058 VARIATION IN VERTEBRAL NUMBER: CAUSES AND CONSEQUENCES**  
Ward, Andrea; Ackerly, Kerri  
Adelphi University, Garden City, NY, United States  

**S-059 DIABOLICAL DISPLACEMENT: THE ROLE OF STRUCTURAL COMPLIANCE IN LIZARD LOCOMOTION AND LOCOMOTOR ECOLOGY**  
Gilman, Casey (1); King, Dan (1); Bartlett, Michael (1); Imburgia, Michael (1); Crosby, Alfred (1); Federle, Walter (2); Irshick, Duncan (1)  
(1) University of Massachusetts Amherst, Amherst, United States; (2) University of Cambridge, Cambridge, United Kingdom  

12:00-13:00  
**ROSSINI 2 ROOM**  
**Symposium 10: Next Steps: Dynamic Simulations in Paleobiology**  
Organizers: Eric Snively, Ohio University; Heinrich Mallison, Museum für Naturkunde, Berlin  

**S-068 INTEGRATING CAD AND CAE MODELLING METHODS FOR VERTEBRATE PALÄONTOLOGY**  
Mallison, Heinrich  
Museum für Naturkunde Berlin, Berlin, Germany  

12:00-13:00  
**VIVALDI 1 ROOM**  
**Symposium 12: New Advances in Paleohistological Studies**  
Organizers: Alexandra Houssaye, University of Bonn; Dorota Konietzko-Meier, University of Opole, Poland  

**S-080 SLOW GROWING ENANTIORNITHES AMONG FAST GROWING PYGOSTYLLIA (AVES)**  
Cubo, Jorge (1); Buscalioni, Angela D. (2); Bourdon, Estelle (3); De Ricqlès, Armand (1)  
(1) UPMC, Université Paris 06, Paris, France; (2) Universidad Autonoma de Madrid, Madrid, Spain; (3) The Natural History Museum, London, United Kingdom  

**S-081 BODY SIZE AND PHYLOGENETIC SIGNALS IN MAMMALIAN BONE MICROSTRUCTURE AND THE DISTRIBUTION OF MAMMALIAN BONE GROWTH PATTERNS**  
Werning, Sarah  
University of California, Berkeley, CA, United States
12:00-13:00  **VIVALDI 2 ROOM**  
**Contributed 9: Integration, Shape Mobility**  
Chairs: Christian Klingenberg  
Diego Rasskin-Gutman 

**C-060** THE BONY LABYRINTH OF EXTANT HOMINIDS AND ITS BEARING ON PHYLOGENETIC RELATIONS AND LOCOMOTION OF FOSSIL HOMININS  
Stoessel, Alexander; Gunz, Philipp; David, Romain; Spoor, Fred  
Max Planck Institute for Evolutionary Anthropology, Department of Human Evolution, Leipzig, Germany 

**C-061** FOREARM ROTATIONAL EFFICIENCY IN HOMINIDS  
Ibáñez-Gimeno, Pere (1); Galtés, Ignasi (2); Malgosa, Assumpció (1); Manyosa, Joan (3); Jordana#, Xavier (4)  
(1) Unitat d’Antropologia Biológica, Departament de Biologia Animal, Biologia Vegetal i Ecologia, Univeristat Autònoma de Barcelona, Bellaterra, Spain; (2) Unitat de Medicina Legal i Forense, Departament de Psiquiatria i de Medicina Legal, Universitat Autònoma de Barcelona, Bellaterra, Spain; (3) Unitat de Biofísica, Departament de Bioquímica i de Biologia Molecular, and Centre d’Estudis en Biofísica, Universitat Autònoma de Barcelona, Bellaterra, Spain; (4) Grup de Recerca en Paleobiologia, Institut Català de Paleontologia Miquel Crusafont (ICP), Universitat Autònoma de Barcelona, Bellaterra, Spain 

12:00-13:00  **DIAMANT ROOM**  
**Contributed 10: Feeding**  
Chairs: Lawrence Witmer  
Elizabeth Brainerd 

**C-068** FEEDING PERFORMANCE OF KING MACKEREL, *Scomberomorus cavalla*  
Ferguson, Amber; Motta, Philip  
University of South Florida, Tampa, United States 

**C-069** THEORETICAL CALCULATIONS OF BITE FORCE IN BILLFISHES  
Habegger, Laura (1); Motta, Philip (1); Huber, Daniel (2)  
(1) University of South Florida, Tampa, United States; (2) University of Tampa, Tampa, United States 

**C-070** BITE FORCE, CHEWING KINEMATICS, AND THE IMPORTANCE OF WORK IN THE PHARYNGEAL JAW OF CYPRINID FISHES  
Gidmark, Nicholas; Tarrant, James; Konow, Nicolai; Brainerd, Elizabeth  
Brown University, Providence, RI, United States 

13:00-14:30  **Midday Break**
**WEDNESDAY, JULY 10TH**

**14:30-16:30  VERDI ROOM**

**Symposium 8: Morphology: The Great Integration. Contemporary Relevance of an Old Field**

Organizers: Jeanette Wyneken, Florida Atlantic University  
J. Matthias Starck, University of Munich (LMU)

**S-048 THE PUBLIC HUNGERS FOR STORIES ABOUT MORPHOLOGICAL RESEARCH**

Hutchinson, John R  
*The Royal Veterinary College, London, United Kingdom*

**S-049 MOLECULES OR MORPHOLOGY? DEVELOPMENTAL BIOLOGY NEEDS BOTH**

Richardson, Michael  
*Institute of Biology Leiden (IBL), Leiden University, Leiden, Netherlands*

**S-050 OBSERVATIONS ON OBSERVATION: VISUALIZING STRUCTURE AND MOTION**

Brainerd, Elizabeth  
*Brown University, Providence, United States*

**S-051 MORPHOMETRY OF THE BOID LUNG AND ITS IMPLEMENTATION FOR THE UNDERSTANDING OF DISEASE DEVELOPMENT**

Starck, J. Matthias (1); Pees, Michael (2)  
(1) Department of Biology, University of Munich, Germany; (2) Veterinary Medicine, Clinic for Birds and Reptiles, University of Leipzig, Germany

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**14:30-16:30  ROSSINI 1 ROOM**

**Symposium 9: Interdisciplinary and Novel Approaches to Vertebrate Locomotion**

Organizers: David Ellerby, Wellesley College, Shannon Gerry, Fairfield University  
Christopher Sanford, Hofstra University  
Graham Askew, University of Leeds

**S-060 TOWARDS AN INTEGRATIVE UNDERSTANDING OF THE MECHANICS AND ENERGETICS OF BIRD FLIGHT**

Askew, Graham  
*University of Leeds, Leeds, United Kingdom*

**S-061 THREE-DIMENSIONAL MOTION CAPTURE IN THE FIELD: A CASE STUDY OF HOVERING AND GROUP BEHAVIOR IN CLIFF SWALLOWS**

Jackson, Brandon E.; Deluga, Nick; Hedrick, Tyson L.  
*University of North Carolina, Chapel Hill, United States*

**S-062 COMPARATIVE BIOMECHANICS AND PATHOLOGY OF MAMMALIAN FEET: AN INTEGRATIVE 3D ANALYSIS**

Panagiotopoulou, Olga (1); Rankin, Jeffrey W. (2); Hutchinson, John R. (2)  
(1) University of Queensland, Brisbane, Australia; (2) The Royal Veterinary College, Hatfield, United Kingdom
14:30-16:30  **ROSSINI 2 ROOM**

**Symposium 11: Functional Morphology of Muscle Extracellular Matrix**
Organizers: Nicole Danos, University of California, Irvine  
Manny Azizi, University of California, Irvine

**S-069 FUNCTIONAL MORPHOLOGY OF INTRAMUSCULAR CONNECTIVE TISSUE: REVIEW**
Danos, Nicole; Azizi, Emanuel  
*University of California Irvine, Irvine, United States*

**S-070 BIOLOGICAL AND MECHANICAL STUDIES BETWEEN THE MUSCLE CYTOSKELETON AND THE EXTRACELLULAR MATRIX**
Tuttle, Lori; Lieber, R.  
*University of California, San Diego, San Diego, United States*

**S-071 MUSCLE FIBER-EXTRACELLULAR MATRIX MECHANICAL INTERACTIONS ALONG FULL PERIPHERAL FIBER LENGTHS IS A KEY DETERMINANT OF MUSCLE FUNCTION**
Yucesoy, Can A.  
*Biomedical Engineering Institute, Istanbul, Turkey*

14:30-16:30  **VIVALDI 1 ROOM**

**Symposium 12: New Advances in Paleohistological Studies**
Organizers: Alexandra Houssaye, University of Bonn  
Dorota Konietzko-Meier, University of Opole, Poland

**S-082 GROWTH IN FOSSIL AND RECENT DEER AND IMPLICATIONS FOR ISLAND EVOLUTION**
Kolb, Christian  
*Palaeontological Institute and Museum of the University of Zurich, Zurich, Switzerland*

**S-082 Bis RECONSTRUCTING MAMMALIAN LIFE HISTORIES FROM HARD TISSUES**
Köhler, Meike (1); Pretus, Joan Lluís (2); Jordana, Xavier (3); Marín, Nekane (3); Moncunill, Blanca (3)  
(1) ICREA at Institut Català de Paleontologia, Universitat Autònoma de Barcelona, Spain; (2) Dep. Ecologia, Universitat Barcelona, Spain; (3) Institut Català de Paleontologia, Universitat Autònoma de Barcelona, Spain
WEDNESDAY, JULY 10TH

S-083 WHY I MAKE MORE SENSE ON TUESDAY
Bromage, Timothy G. (1); Juwayeyi, Yusuf M. (2); Hu, Bin (1); Dimaggio Jr., John C. (1); Smolyar, Igor (3); Munkhondya, Martin M. (4); Chisi, John E. (5)
(1) New York University College of Dentistry, New York, United States; (2) Long Island University, New York, United States; (3) National Oceanic and Atmospheric Administration, Silver Spring, United States; (4) CLICMET Consultants, Blantyre, Malawi; (5) University of Malawi College of Medicine, Blantyre, Malawi

S-084 NANOSTRUCTURE AND DIAGENESIS OF SAUROPOD´S BONE AND DENTAL TISSUES USING ADVANCED CHARACTERIZATION TECHNIQUES
Dumont, Maitena (1); Tütken, Thomas (2); Kaysser-Pyzalla, Anke R. (3); Sander, Martin P. (2)
(1) Max Planck Institut, Duesseldorf, Germany; (2) University of Bonn, Bonn, Germany; (3) Helmholtz-Zentrum Berlin, Berlin, Germany

14:30-16:30 VIVALDI 2 ROOM
Contributed 12: Skeletal Evolution
Chairs: Marcelo Sanchez-Villagra
Rui Diogo

C-078 THE SKELETAL BRIDGE BETWEEN THE CRANIUM AND POSTCRANIUM IN CHAMELEONS
Ččerňanský, Andrej (1); Boistel, Renaud (2); Fernandez, Vincent (3); Tafforeau, Paul (4); Herrel, Anthony (5)
(1) Senckenberg Research Institute and Natural History Museum Frankfurt, Frankfurt am Main, Germany; (2) IPHEP, Université de Poitiers, France; (3) Bernard Price Institute for Palaeontological Research, Johannesburg, South Africa; (4) European Synchotron Radiation Facility, Grenoble, France; (5) UMR 7179 C.N.R.S/M.N.H.N., Paris, France

C-079 SKELETAL DEVELOPMENT AND ADULT OSTEOLOGY OF HYPSIBOAS PULCHELLUS (ANURA: HYLIDAE)
Hoyos, Julio Mario (1); Sánchez-Villagra, Marcelo (2); Carlini, Alfredo (3); Mitgutsch, Christian (4)
(1) Pontificia Universidad Javeriana, Facultad de Ciencias, Departamento de Biología, Bogotá, Colombia; (2) Paläontologisches Institut und Museum, Universität Zürich, Zürich, Switzerland; (3) Paleontología de Vertebrados, Museo de La Plata, La Plata, Argentina; (4) Laboratory for Evolutionary Morphology RIKEN Center for Developmental Biology, Kobe, Japan

C-080 COMPARATIVE EVOLUTIONARY MYOLOGICAL STUDIES DECONSTRUCT THE FORE-HINDLIMB SERIAL HOMOLOGY MYTH
Ziermann, Janine M.; Diogo, Rui
Howard University, Washington DC, United States
C-081 COMPARATIVE ANATOMY, PHYLOGENY, EVOLUTIONARY TRENDS, THE NOTION OF ‘PROGRESS’ IN EVOLUTION, AND THE MYTH OF HUMAN MORPHOLOGICAL COMPLEXITY
Ziermann, Janine M.; Diogo, Rui
Howard University, Washington DC, United States

C-082 PATTERNS OF VARIATION IN SALAMANDER LIMB SKELETOGENESIS
Fröbisch, Nadia (1); Shubin, Neil (2)
(1) Museum für Naturkunde, Leibniz-Institut für Evolutions- und Biodiversitätforschung, Berlin, Germany; (2) University of Chicago, Chicago, United States

C-083 MORPHO-FUNCTIONAL FEATURE OF THE FEMORAL NECK IN CAPTIVE CHIMPANZEEs
Matsumura, Akiyoshi (1); Okada, Morihiko (2)
(1) National Defense Medical College, Tokorozawa, Japan; (2) Teikyo Heisei University, Tokyo, Japan

14:30-16:30
DIAMANT ROOM
Contributed 13: Feeding
Chairs: Tom Geerinckx
Patricia Hernández

C-084 GENETIC AND ENVIRONMENTAL CONTROL OF MANDIBULAR FORM AND FUNCTION IN MICE
Rayfield, Emily (1); Anderson, Philip (2); Davies, Timothy (1); Hadfield, Samantha (1); Renaud, Sabrina (3)
(1) University of Bristol, Bristol, United Kingdom; (2) University of Massachusetts, Amherst, United States; (3) University of Lyon, Lyon, France

C-085 LOCAL VARIATION IN FUNCTIONAL MORPHOLOGY OF THE FEEDING SYSTEM OF TWO HAPLOCHROMINES CICHLIDS FROM LAKE KIVU (RWANDA)
Munyandamutsa, Philippe; Tkint, Tim; Adriaens, Dominique
Ghent University, Morphology and evolutionary of Vertebrates, Belgium

C-086 EVOLUTIONARY CONVERGENCE AND PARALLELISM IN SUCKERMOUTH CATFISH FAMILIES: SURPRISINGLY ALTERNATIVE WAYS TO PERFORM THE SAME VITAL TASK: DON’T LET GO!
Geerinckx, Tom; De Crop, Wannes
Ghent University, Gent, Belgium

C-087 PHYLOGENETIC DISTRIBUTION OF THE PALATAL ORGAN ACROSS CYPRINIFORMES
Hernández, Luz Patricia
George Washington University, Washington, United States

C-088 EVOLUTION OF MORPHOLOGICAL DIVERSITY IN THE JAWS AND HYOID APPARATUS OF EXTANT SHARKS
Kamminga, Pepijn (1); De Bruin, Paul W. (2); Koos, Geleijns (2); Brazeau, Martin D. (1)
(1) Naturalis Biodiversity Center, Leiden, Netherlands; (2) Leids Universitair Medisch Centrum, LUMC, Leiden, Netherlands
C-089 THE FEEDING EXPERIMENTS END-USER DATABASE (FEED) AND AN ONTOLOGY FOR THE ORO-PHARYNGEAL MUSCLES AND BEHAVIORS OF MAMMALS
Druzinsky, Robert E. (1); Crompton, Alfred W. (2); German, Rebecca Z. (3); Haendel, Melissa A. (4); Herrel, Anthony (5); Herring, Susan W. (6); Lapp, Hilmar (7); Mungall, Chris J. (8); Vinyard, Chris J. (3); Williams, Susan H. (9); Wall, Christine E. (10)
(1) College of Dentistry, U. of Illinois, Chicago, IL, United States; (2) Museum of Comparative Zoology, Harvard U., Cambridge, MA, United States; (3) Department of Anatomy & Neurobiology, NEOMED, Rootstown, OH, United States; (4) Department of Medical Informatics & Clinical Epidemiology, OHSU, Portland, OR, United States; (5) Museum National d’Histoire Naturelle, Paris, France; (6) Department of Orthodontics, U. of Washington, Seattle, WA, United States; (7) National Evolutionary Synthesis Center, Durham, NC, United States; (8) Lawrence Berkeley Laboratory, Berkeley, CA, United States; (9) Department of Biomedical Sciences, Ohio U., Athens, OH, United States; (10) Department of Evolutionary Anthropology, Duke U., Durham, NC, United States

16:30-17:00 Coffee Break

17:00-18:00 VERDI ROOM
Symposium 8: Morphology: The Great Integration. Contemporary Relevance of an Old Field
Organizers: Jeanette Wyneken, Florida Atlantic University
J. Matthias Starck, University of Munich (LMU)
S-052 WHAT MORPHOLOGY CAN TELL US ABOUT PHYSIOLOGICAL FUNCTION: CASE STUDIES ON WHALES
Shadwick, Robert
University of British Columbia, Vancouver, Canada

S-053 WHAT CAN MORPHOLOGY DO FOR ME? CHALLENGES FOR THE STUDY OF MORPHOLOGY, AND OPPORTUNITIES FOR MORPHOLOGY AS A MEANS TO GAIN INSIGHT INTO BIODIVERSITY
Blob, Richard
Clemson University, Clemson, United States

17:00-18:00 ROSSINI 2 ROOM
Symposium 11: Functional Morphology of Muscle Extracellular Matrix
Organizers: Nicole Danos, University of California, Irvine
Manny Azizi, University of California, Irvine
S-074 MECHANISMS GOVERNING MUSCLE BULGING DURING LOCOMOTOR ACTIVITIES
Roberts, Thomas; Konow, Nicolai; Gidmark, Nicholas
Brown University, Providence, United States
S-075 FUNCTIONAL MORPHOLOGY OF A UNIQUE MUSCULAR ORGANISATION IN THE PREHENSILE TAIL OF SEAHORSES
Neutens, Céline (1); Adriaens, Dominique (1); Christiaens, Joachim (1); De Kegel, Barbara (1); Dierick, Manuel (1); Boistel, Renaud (2); Van Hoorebeke, Luc (1) Ghent University, Ghent, Belgium; (2) Université de Poitiers, Poitiers, France

17:00-18:00 VIVALDI 1 ROOM
Symposium 12: New Advances in Paleohistological Studies
Organizers: Alexandra Houssaye, University of Bonn
Dorota Konietzko-Meier, University of Opole, Poland

S-085 ADVANCES IN VIRTUAL DENTAL HISTOLOGY FOR PALAEANTHROPOLOGY USING MULTI-SCALE PROPAGATION PHASE CONTRAST X-RAY SYNCHROTRON MICROTMOTOGRAPHY
Le Cabec, Adeline (1); Tafforeau, Paul (1); Smith, Tanya M. (2)
(1) European Synchrotron Radiation Facility, Grenoble France; (2) Harvard University, Cambridge, United States

S-086 3D MICROSTRUCTURE AND IDENTIFICATION OF MUSCLE ATTACHMENTS IN EXTANT AND FOSSIL VERTEBRATES REVEALED BY SYNCHROTRON MICROTMOTOGRAPHY
Sanchez, Sophie (1); Dupret, Vincent (1); Tafforeau, Paul (2); Trinajstic, Kate (3); Ryll, Bettina (1); Gouttenoire, Pierre-Jean (4); Wretman, Lovisa (1); Zylberberg, Louise (5); Peyrin, Françoise (4); Ahlberg, Per (1)
(1) Uppsala University, Uppsala, Sweden; (2) European Synchrotron Radiation Facility, Grenoble, France; (3) Curtin University, Perth, Australia; (4) Lyon University, Lyon, France; (5) Pierre et Marie Curie University, Paris, France
THURSDAY, JULY 11TH

08:30 -09:30  VERDI ROOM
Plenary Lecture IV: Meike Köhler
ICREA Professor, Institut Catalá de Paleontologia and Department of Ecology, Universitat Autònoma Barcelona, Spain
"Abyssal monsters, troglobytes and insular chimaeras: Island-like settings as natural labs" (Abstract PT-004)

09:30 -11:30  VERDI ROOM
Organizers: Nadja Schilling, Friedrich-Schiller-University, Jena, Germany
John Long, Vassar College, NY

S-105  EVOLUTIONARY ORIGIN OF THE VERTEBRAE: IMPLICATIONS FROM THE HAGFISH DEVELOPMENT
Ota, Kinya (1); Oisi, Yasuhiro (2); Fujimoto, Satoko (2); Kuratani, Shigeru (2)
(1) Laboratory of Aquatic Zoology, Marine Research Station, ICOB, Academia Sinica, Yilan, Taiwan; (2) Laboratory for Evolutionary Morphology, RIKEN Center for Developmental Biology, Kobe, Japan

S-106  HISTORY, HOMOLOGY AND RIBS - A HYPOTHESIS FOR MAMMALIAN AXIAL PATTERNING
Buchholtz, Emily
Wellesley College, Wellesley, United States

S-107  THE FISH TAIL AS A DERIVATION FROM AXIAL BODY STRUCTURE
Flammang, Brooke
Harvard University, Cambridge, United States

S-108  COMPUTATIONAL AND MATHEMATICAL MODELING OF FORCES ACTING ON THE VERTEBRAL COLUMN OF SWIMMING FISH
Liew, Chun Wai; Root, Rob
lafayette College, Easton, United States

09:30 -11:30  ROSSINI 1 ROOM
Symposium 13: Sticks, Stones, and Slopes: the Link Between Substrate Characteristics, Morphology, and Biomechanics
Organizers: Anthony Herrel, CNRS Paris
Timothy Higham, University of California, Riverside

S-087  THE EFFECT OF SUBSTRATE DIAMETER AND INCLINE ON LOCOMOTION IN ARBOREAL FROGS
Herrel, Anthony (1); Perrenoud, Mats (2); Abdala, Virginia (3); Manzano, Adriana (5); Pouydebat, Emmanuelle (2)
(1) CNRS, Paris, France; (2) MNHN, Paris, France; (3) Instituto Miguel Lillo, Tucuman, Argentina; (4) CONICET, Diamante, Argentina
S-088 FUNCTIONAL MECHANISMS UNDERLYING THE RELATIONSHIP BETWEEN MORPHOLOGY AND HABITAT USE IN LIZARDS
Foster, Kathleen; Higham, Timothy
University of California, Riverside, Riverside, United States

S-089 NEUROMECHANICS OF SAND-SWIMMING
Sharpe, Sarah (1); Ding, Yang (2); Goldman, Daniel (1)
(1) Georgia Institute of Technology, Atlanta, United States; (2) University of Southern California, Los Angeles, United States

S-090 THE BIRD BAUPLAN AND ITS LOCOMOTOR PLASTICITY: THE CASE OF HOPPING IN PASSERINE BIRDS
Abourachid, Anick (1); Provini, Pauline (2); Hackert, Rémi (1); Decamps, Thierry (1)
(1) Muséum National d’Histoire Naturelle, UMR 7179, France; (2) Gipsa-lab, SAIGA, France

09:30 -11:30 ROSSINI 2 ROOM
Symposium 14: Inside the Vertebrate Nose: Evolution, Structure, and Function
Organizers: Blaire Van Valkenburgh, University of California, Los Angeles
Irina Ruf, University of Bonn
Thimas Eiting, University of Massachusetts-Amherst

S-104 INFLUENCE OF NASAL ANATOMY ON OLFACTION IN CHIMAERID FISHES
Cox, Jonathan (1); Howard, Lauren (2); Holmes, William (3); Ferrando, Sara (6); Maclaine, James (2); Kelsh, Robert (1); Ramsey, Andrew (6); Abel, Richard (6)
(1) University of Bath, Bath, United Kingdom; (2) Natural History Museum, London, Natural History Museum, London, United Kingdom; (3) University of Glasgow, Glasgow, United Kingdom; (4) University of Genoa, Genoa, Italy; (5) Nikon Metrology, Tring, United Kingdom; (6) Imperial College, London, United Kingdom

S-093 BREATHING LIFE INTO DINOSAURS: TACKLING CHALLENGES OF SOFT-TISSUE RECONSTRUCTION AND NASAL AIRFLOW IN EXTINCT SPECIES
Bourke, Jason (1); Ridgely, Ryan (1); Porter, William (1); Lyson, Tyler (2); Schachner, Emma (3); Bell, Phil (4); Witmer, Lawrence (1)
(1) Ohio University, Athens, United States; (2) Yale University, New Haven, United States; (3) University of Utah, Salt Lake City, United States; (4) University of Alberta, Alberta, Canada

S-094 EVOLUTION OF THE MAMMALIAN NASAL CAVITY: NEW EVIDENCE FROM THE ADVANCED CYNODONT BRASILITHERIUM RIOGRANDENSIS (BRASILODONTIDAE)
Ruf, Irina (1); Maier, Wolfgang (2); Rodrigues, Pablo Gusmão (3); Schultz, Cesar Leandro (3)
(1) Steinmann-Institut für Geologie, Mineralogie und Paläontologie, Rheinische Friedrich-Wilhelms-Universität , Bonn, Germany; (2) Fachbereich Biologie, Eberhard-Karls-Universität , Tübingen, Germany; (3) Laboratório de Paleovertebrados, Departamento de Paleontologia e Estratigrafia, Instituto de Geociências, Universidade Federal do Rio Grande do Sul, Porto Allegre, Brazil
S-095 PRINCIPLES OF THE MORPHOLOGY OF THE MAMMALIAN NASAL CAPSULE – WITH SPECIAL REFERENCE TO PRIMATES
Maier, Wolfgang
University of Tuebingen, Fachbereich Biologie, Germany

09:30 -11:30 VIVALDI 2 ROOM
Contributed 14: Locomotion
Chairs: Pauline Provini
Heather Paxton

C-090 LIMB AND BODY MECHANICS OF SMALL ARBOREAL PRIMATES: INTEGRATION OF FOOTFALL TIMING, LIMB STIFFNESS AND WHOLE-BODY FORCES
Schmidt, Manuela
Friedrich Schiller University / Institute of Systematic Zoology and Evolutionary Research, Jena, Germany

C-091 PARAMETRIC MODELING OF HUMAN GRADIENT WALKING FOR PREDICTING THE MINIMUM ENERGY SPENT AND ENERGY SAVING STRATEGIES
Saborit, Gerard; Casinos, Adrià
Dept. of Animal Biology, University of Barcelona, Barcelona, Spain

C-092 INVERSE DYNAMICS ON ROCK CLIMBING WITH AND WITHOUT MEASUREMENT OF CONTACT FORCES
Courtemanche, Simon (1); Provini, Pauline (2); Kry, Paul (3); Martin, Olivier (2); Reveret, Lionel (1)
(1) INRIA Rhone-Alpes, Montbonnot, France; (2) Gipsa Lab, Saint Martin d’Heres, France; (3) McGill University, Montreal, Canada

C-093 FOOTPRINTS, FOOT POSTURE AND BODY WEIGHT DISTRIBUTION IN MAMMALS
Casinos, Adrià; Dzidzishvili, Lika
Universitat de Barcelona, Barcelona, Spain

C-094 INTERVERTEBRAL AND PELVIC MOTIONS IN DOGS DURING LOCOMOTION
Wachs, Katja (1); Nolte, Ingo (2); Fischer, Martin S. (1); Schilling, Nadja (1)
(1) Friedrich-Schiller-University Jena, Institute of Systematic Zoology and Evolutionary Biology, University of Veterinary Medicine Hannover, Foundation, Small Animal Clinic, Germany; (2) University of Veterinary Medicine Hannover, Foundation, Small Animal Clinic, Hannover, Germany

C-095 THE RELATIONSHIP BETWEEN MUSCLE CROSS-SECTIONAL AREA, DISTRIBUTION AND LOCOMOTOR PERFORMANCE IN LIZARDS
Scales, Jeffrey; Butler, Marguerite
University of Hawaii, Manoa, Honolulu, United States
09:30 - 11:30

**DIAMANT ROOM**

*Contributed* 15: **Feeding**

Chairs: Laura Habegger

Stephane Montuelle

**C-099** A MORPHOLOGICAL-KINEMATIC STUDY ON THE ATTACHMENT AND THE BREATHING AND FEEDING MECHANISMS IN BALITORINAE (CYPRINIFORMES, TELEOSTEI)

De Meyer, Jens (1); Geerinckx, Tom (2)

(1) Ghent University, Ghent, Belgium; (2) Ghent University, Ghent, Belgium

**C-100** OPEN WIDE: THE ROLE OF LATERAL MOUTH EXPANSION DURING SUCTION FEEDING IN LARGEMOUTH BASS

Camp, Ariel; Roberts, Thomas; Brainerd, Elizabeth

Brown University, Providence, United States

**C-101** FUNCTIONAL CONSEQUENCES OF PHARYNGEAL JAW VARIATION IN CYPRINIFORM FISHES

Rade, Cristina M. (1); Sanford, Christopher P. (2); Hernandez, L. Patricia (1)

(1) The George Washington University, Washington, DC, United States; (2) Hofstra University, Hempstead, NY, United States

**C-102** SENSORY CONTRIBUTIONS TO PREY CAPTURE KINEMATICS IN SHARKS

Gardiner, Jayne (1); Atema, Jelle (2); Huetter, Robert (1); Motta, Philip (3)

(1) Mote Marine Laboratory, Sarasota, United States; (2) Boston University, Boston, United States; (3) University of South Florida, Tampa, United States

**C-103** FEEDING BIOMECHANICS IN BILLFISHES: INFERRING THE ROLE OF THE ROSTRUM DURING FEEDING IN TWO BILLFISH SPECIES

Habegger, Laura (1); Motta, Philip (1); Dean, Mason (2); Huber, Daniel (3); Dunlop, John (2); Mullins, Gray (1); Stokes, Michael (1); Winters, Danny (1)

(1) University of South Florida, Tampa, United States; (2) Max Planck Institute of Colloids and Interfaces, Potsdam, Germany; (3) University of Tampa, Tampa, United States

**C-104** IN VIVO MEASUREMENT OF CRANIAL KINESIS IN GEKKO GECKO USING XROMM METHODOLOGY

Montuelle, Stephane; Williams, Susan

Ohio University, Athens, United States

11:30-12:00

*Coffee Break*
12:00-13:00  VERDI ROOM
Organizers: Nadja Schilling, Friedrich-Schiller-University, Jena, Germany
John Long, Vassar College, NY

S-109  MORPHO-FUNCTIONAL CHARACTERISTICS OF THE AXIAL SKELETON IN STEM TETRAPODS
Pierce, Stephanie E.
The Royal Veterinary College, Department of Comparative Biomedical Sciences and Structure & Motion Lab, London, United Kingdom

S-110  MECHANICS AND KINEMATICS: UNDERSTANDING THE ROLE OF THE VERTEBRAL COLUMN DURING LOCOMOTION IN STRIPED BASS (MORONE SAXATILIS)
Nowroozi, Bryan N. (1); Brainerd, Elizabeth L. (2)
(1) University of California, Los Angeles, United States; (2) Brown University, Providence, United States

12:00-13:00  ROSSINI 1 ROOM
Symposium 13: Sticks, Stones, and Slopes: the Link Between Substrate Characteristics, Morphology, and Biomechanics
Organizers: Anthony Herrel, CNRS Paris
Timothy Higham, University of California, Riverside

S-091  ARBOREAL VERSUS TERRESTRIAL LOCOMOTOR KINETICS AMONG NON-PRIMATE MAMMALS
Lammers, Andrew (1); Schmidt, André (2)
(1) Cleveland State University, Cleveland, United States; (2) Ohio University, Heritage College of Osteopathic Medicine, United States

S-092  ORANGUTANS EMPLOY UNIQUE STRATEGIES TO CONTROL BRANCH COMPLIANCE
Thorpe, Susannah
University of Birmingham, Birmingham, United Kingdom

12:00-13:00  ROSSINI 2 ROOM
Symposium 14: Inside the Vertebrate Nose: Evolution, Structure, and Function
Organizers: Blaire Van Valkenburgh, University of California, Los Angeles
Irina Ruf, University of Bonn
Thimas Eiting, University of Massachusetts-Amherst

S-096  NASAL STRUCTURE AND AERODYNAMICS: PRE-PROCESSING OF ODORANT INFORMATION?
Zhao, Kai (1); Scott, John (2)
(1) Monell Chemical Senses Center, Philadelphia, United States; (2) Emory University, Atlanta, United States
S-097 ECOLOGICAL CORRELATES OF NASAL TURBINAL SIZE IN CARNIVORANS
Van Valkenburgh, Blaire (1); Pang, Benison (1); Craven, Brent A. (2); Wysocki, Charles J. (3); Yee, Karen K. (3)
(1) University of California, Los Angeles, United States; (2) Pennsylvania State University, University Park, United States; (3) Monell Chemical Senses Center, Philadelphia, United States

12:00-13:00 VIVALDI 2 ROOM
Contributed: 14 Locomotion
Chairs: Pauline Provini
Heather Paxton

C-096 MUSCLES ATTACHING TO THE XENARTHREN 3RD TROCHANTER REDUCE CORONAL PLANE BENDING IN THE FEMUR
Milne, Nick (1); O’higgins, Paul (2)
(1) UWA, Perth, Australia; (2) HYMS, York, United Kingdom

C-097 TURNING IN GUINEAFOWL: MOTION AND MOMENTS
Kambic, Robert; Gatesy, Stephen
Brown University, Providence, RI, United States

C-098 JOINT RANGE OF MOTION ACROSS ONTOGENY IN THE BROILER CHICKEN
Paxton, Heather; Rankin, Jeffery W; Hutchinson, John R.
Structure & Motion Laboratory, Department of Comparative Biomedical Sciences, The Royal Veterinary College, University of London, Hatfield, United Kingdom

12:00-13:00 DIAMANT ROOM
Contributed 15: Feeding
Chairs: Laura Habegger
Stephane Montuelle

C-105 ADAPTATION AND MOTOR LEARNING DURING MAMMALIAN SWALLOWING
German, Rebecca (1); Homan, Shaina (2); Humbert, Ianessa (3)
(1) NEOMED, Rootstown, United States; (2) University of Maryland, Baltimore, United States; (3) Johns Hopkins University, Baltimore, United States

C-106 THE ENERGETIC COSTS OF FEEDING IN SMALL-BODIED PRIMATES AND AN ANALYTICAL FRAMEWORK FOR INTERPRETING FEEDING ENERGETICS
Wall, Christine (1); Hanna, Jandy (2); O’neill, Matthew (3); Perry, Jonathan (4); Glander, Kenneth (1)
(1) Duke University, Durham, United States; (2) West Virginia College of Osteopathic Medicine, Lewisburg, United States; (3) Stony Brook University School of Medicine, Stony Brook, United States; (4) Johns Hopkins University, Baltimore, United States
C-107 FUNCTIONAL SPECIALIZATION IN SEXUALLY DIMORPHIC SKELETAL MORPHOLOGY IN GRAY WOLVES (CANIS LUPUS)
Morris, Jeremy; Brandt, Ellissa
University of Utah, Salt Lake City, United States

13:00-14:30 Midday Break

14:30-16:30 VERDI ROOM
Organizers: Nadja Schilling, Friedrich-Schiller-University, Jena, Germany
John Long, Vassar College, NY

S-111 BUILT FOR SPEED: STRAIN IN THE CARTILAGINOUS VERTEBRAL COLUMNS OF SHARKS
Porter, Marianne (1); Diaz, Candido (2); Sturm, Joshua (3); Grotmol, Sindre (4); Summers, Adam (5); Long, John (6)
(1) Florida Atlantic University, Boca Raton, United States; (2) University of Akron, Akron, United States; (3) University of Pittsburgh, Pittsburgh, United States; (4) University of Bergen, Bergen, Norway; (5) University of Washington, Friday Harbor Labs, United States; (6) Vassar College, Poughkeepsie, United States

S-112 THE KINEMATICS OF THE SALAMANDER’S SPINE: BIOLOGICAL AND ROBOTIC PERSPECTIVES
Karakasiliotis, Konstantinos (1); Schilling, Nadja (2); Cabelguen, Jean-Marie (3); Ijspeert, Auke Jan (4)
(1) Institute of Bioengineering / Biorobotics Laboratory / EPFL, Lausanne, Switzerland; (2) Institute of Systematic Zoology and Evolutionary Biology, Friedrich-Schiller-University Jena, Germany; (3) Neurocentre Magendie INSERM U862, Bordeaux University, France; (4) Institute of Bioengineering / Biorobotics Laboratory / EPFL, Lausanne, Switzerland

S-113 FROM AN ANIMAL TO A BIOMECHANICAL MODEL - RECONSTRUCTION, ASSEMBLING & SIMULATION
Stark, Heiko; Anders, Christoph; Schilling, Nadja
Friedrich-Schiller-University, Jena, Germany

S-114 JUMPING SANS LEGS: USING THE AXIAL MUSCULOSKELETAL SYSTEM FOR A NOVEL FORM OF TERRESTRIAL LOCOMOTION
Ashley-Ross, Miriam (1); Perlman, Benjamin (1); Long, John (2); Gibb, Alice (3)
(1) Wake Forest University, Winston-Salem, United States; (2) Vassar College, Poughkeepsie, United States; (3) Northern Arizona University, Flagstaff, United States
14:30-16:30  ROSSINI 1 ROOM

Contributed 16: General Morphology

Chairs: Julio Rivera
Christy Hipsley

C-108  CHARACTERIZATION OF NEURAL STEM/PROGENITOR CELLS DURING TAIL REGENERATION IN THE LEOPARD GECKO (EUBLEPHARIS MACULARIUS)
Gilbert, Emily A.B.; Vickaryous, Matthew K.
University of Guelph, Guelph, Canada

C-109  PREDICTING OPHIDIAN ECOLOGY FROM VERTEBRAL MORPHOLOGY
McCartney, Jacob
Ohio University, Athens, United States

C-110  MOLECULAR PHYLOGENETICS AND MORPHOLOGICAL EVOLUTION OF MICROHYLID FROGS
Rivera, Julio; Butler, Marguerite
University of Hawaii - Manoa, Honolulu, United States

C-111  A MORPHOLOGICAL STUDY OF THE FIRST CAUDAL VERTEBRA IN A GROUP WITH A NOVEL ROLE FOR THE TAIL
Dawson, Rebekah; Milne, Nick
University of Western Australia, Crawley, Australia

C-112  MESOCOSM EXPERIMENTS VALIDATE AND COMPLEMENT LABORATORY DATA ON PLASTIC RESPONSES: INVASIVE TADPOLES’ INDUCIBLE DEFENSES AGAINST NATIVE AND INVASIVE PREDATORS
Pujol-Buxo, Eudald (1); San Sebastian, Olatz (1); Garriga, Núria (1); Pereira Almeida, Caroline (2); Llorente, Gustavo A. (1)
(1) Departament de Biologia Animal, Universitat de Barcelona, Spain; (2) Departamento de Ciências Biológicas, Universidade Estadual de Santa Cruz, Brazil

C-113  LATITUDINAL MORPHOLOGICAL DISPARITY GRADIENT IN LACERTID LIZARDS (SQUAMATA, LACERTIDAE)
Hipsley, Christy (1); Miles, Donald (2); Müller, Johannes (1)
(1) Museum für Naturkunde Berlin, Berlin, Germany; (2) Ohio University, Athens, United States

14:30-16:30  ROSSINI 2 ROOM

Symposium 14: Inside the Vertebrate Nose: Evolution, Structure, and Function

Organizers: Blaire Van Valkenburgh, University of California, Los Angeles
Irina Ruf, University of Bonn
Thimas Eiting, University of Massachusetts-Amherst

S-098  THE CRIBRIFORM PLATE MORPHOLOGY AS A PROXY FOR OLFATORY INNNERVATION IN CARNIVORA
Bird, Deborah; Pang, Benison; Davydov, Yevgeniy; Amirkhanian, Arsineh; Van Valkenburgh, Blaire
University of California Los Angeles, Los Angeles, United States
S-099 COMPARATIVE ASPECTS OF THE TOOTHED WHALE NOSE: AN OVERVIEW
Huggenberger, Stefan
University of Cologne, Cologne, Germany

S-100 THE EXTENT OF THE TRANSVERSE LAMINA AND ITS ROLE IN OLFACTORY AIRFLOW
Eiting, Thomas (1); Smith, Timothy (2); Perot, J. Blair (1); Dumont, Elizabeth (1)
(1) University of Massachusetts Amherst, Amherst, MA, United States;
(2) Slippery Rock University, Slippery Rock, PA, United States

S-101 RECONSTRUCTION AND MORPHOMETRIC ANALYSIS OF THE NASAL CAVITY OF THE EASTERN GRAY SQUIRREL (SCIURUS CAROLINENSIS) AND IMPLICATIONS REGARDING RESPIRATORY AND OLFACTORY AIRFLOW
Richter, Joseph (1); Rumple, Christopher (1); Neuberger, Thomas (1); Pang, Benison (2); Van Valkenburgh, Blaire (2); Ryan, Timothy (1); Stecko, Timothy (1); Yee, Karen (3); Wysocki, Charles (3); Krane, Michael (1); Craven, Brent (1)
(1) The Pennsylvania State University, State College, PA, United States;
(2) University of California, Los Angeles, CA, United States;
(3) Monell Chemical Senses Center, Philadelphia, PA, United States

14:30-16:30 VIVALDI 2 ROOM
Contributed 17: Skeletal EvoDevo
Chairs: Tiana Kohlsdorf
Paula Mabee

C-114 GENE REGULATION AND MORPHOLOGICAL EVOLUTION IN LIZARDS: A FIVE-DIGIT (OR LESS) PROBLEM
Kohlsdorf, Tiana; Andrade, Fernando; Carvalho, Murilo; Dragalzew, Aline; Roscito, Juliana; Rodrigues, Miguel; Guimaraes, Pedro
University of Sao Paulo, FFCLRP, Ribeirão Preto, Brazil

C-115 USING OSTEOCYTES FOR GENOME SIZE EVOLUTION AND TERRESTRIALITY STUDIES
Stein, Koen (1); Werner, Jan (2); Prondvai, Edina (3)
(1) Steinmann Institut für Geologie, Mineralogie und Paläontologie, University of Bonn, Bonn, Germany;
(2) Department of Ecology, Institute of Zoology, Johannes Gutenberg-University Mainz, Mainz, Germany;
(3) MTA-ELTE Lendület, Dinosaur Research Group, Budapest, Hungary

C-116 CAN ACELLULAR BONE REMODEL?
Shahar, Ron (1); Atkins, Ayelet (1); Habegger, M. Laura (2); Mota, Philip (2); Kalish, Noga (1); Dean, Mason (3); Currey, John (4)
(1) The Hebrew University of Jerusalem, Rehovot, Israel;
(2) University of South Florida, Tampa, United States;
(3) Max Planck Institute of colloids and interfaces, Potsdam, Germany;
(4) University of York, York, United Kingdom
C-117 COMPARATIVE MORPHOLOGY IS INTEGRATED WITH GENETICS AND DEVELOPMENT IN THE PHENOSCAPE KNOWLEDGEBASE
Mabee, Paula  
University of South Dakota, Vermillion, United States

C-118 FROM PHENOTYPE TO GENOTYPE (AND VICE VERSA) IN LIMB DEVELOPMENT
Martinez-Abadias, Neus; Niksic, Martina; Sharpe, James  
CRG - Centre for Genomic Regulation, Barcelona, Spain

C-119 MECHANISMS UNDERLYING THE EVOLUTION OF AN ELONGATE AXIAL SKELETON IN SAURICHTHYID FISHES
Maxwell, Erin (1); Furrer, Heinz (1); Wilson, Laura (2); Sánchez-Villagra, Marcelo (1)  
(1) Universität Zürich, Zürich, Switzerland; (2) University of New South Wales, Kensington, Australia

14:30-16:30  DIAMANT ROOM  
Contributed 18: Locomotion  
Chairs: Sandy Kawano  
Stine Griep

C-120 TWO WAYS OF SWIMMING IN VOLES AND MOLES: A MORPHOFUNCTIONAL ASPECT
Perepelova, Anna; Gambaryan, Peter  
Zoological Institute, RAS, Saint Petersburg, Russian Federation

C-121 TRIPPING THE RAT
Arnold, Dirk; Schilling, Nadja; Fischer, Martin S.  
Institute of Systematic Zoology and Evolutionary Biology with Phyletic Museum, Friedrich-Schiller-University, Jena, Germany

C-122 PECTORAL GIRDLE MOVEMENTS AND THE ROLE OF THE GLENOHUMERAL JOINT DURING LANDING IN THE TOAD, RHINELLA MARINA (LINNAEUS, 1758)
Griep, Stine (1); Schilling, Nadja (2); Marshall, Percy (3); Amling, Michael (4); Hahne, Lisa M. (1); Haas, Alexander (1)  
(1) Biozentrum Grindel und Zoologisches Museum Hamburg, Hamburg, Germany; (2) Institut für Spezielle Zoologie und Evolutionsbiologie, Jena, Germany; (3) UKE Athleticum, Hamburg, Germany; (4) Institut für Osteologie und Biomechanik, Hamburg, Germany

C-123 COMPARISON OF APPENDICULAR GROUND REACTION FORCE PRODUCTION IN MUDSKIPPER FISHES (PERIOPTHALMUS BARBARUS) AND TIGER SALAMANDERS (AMBYSOTAMA TIGRINUM): IMPLICATIONS FOR THE INVASION OF LAND
Kawano, Sandy; Blob, Richard  
Clemson University, Clemson, United States
C-124 CITIUS, ALTIUS, FORTIUS: JUMPING KINEMATICS AND KINETICS IN TWO DISTANTLY RELATED TELEOSTS
Perlman, Benjamin (1); Kawano, Sandy (2); Blob, Richard (2); Ashley-Ross, Miriam (1)
(1) Wake Forest University, Winston-Salem, United States; (2) Clemson University, Clemson, United States

16:30-17.00 Coffee Break

17:00-18.00 VERDI ROOM
Organizers: Nadja Schilling, Friedrich-Schiller-University, Jena, Germany
John Long, Vassar College, NY

S-115 BODY ELONGATION AND THE NEUROMECHANICAL CONTROL OF AXIAL STARTLE BEHAVIORS IN FISHES
Hale, Melina; Liu, Yen Chyi
University of Chicago, Chicago, United States

S-116 THE DYNAMICS OF AXIAL LOCOMOTOR NETWORKS IN SALAMANDERS
Cabelguen, Jean-Marie
INSERM-U862, Bordeaux, France

17:00-18.00 ROSSINI 1 ROOM
Contributed 22: Reproductive Biology
Chairs: Diane Kelly
Dominique Adriaens

C-125 ANATOMICAL ORGANIZATION AND MATERIAL COMPOSITION OF THE PENILE TENDONS IN THE AMERICAN ALLIGATOR (ALLIGATOR MISSISSIPPIENSIS)
Kelly, Diane
University of Massachusetts, Amherst, United States

C-126 DOES BREEDING STRATEGY INFLUENCE HEAD MORPHOLOGY IN MOUTHROODING TILAPIINE CICHLIDS?
Vanden Hole, Charlotte; Tkint, Tim; Adriaens, Dominique
Ghent University, Ghent, Belgium

C-127 OOGENESIS OF THE OLM
Bizjak Mali, Lilijana; Talaber, Iva; Žibert, Urška; Ceket, Dagmar; Habi', Lara; Bulog, Boris
Department of Biology, Biotechnical Faculty, University of Ljubljana, Ljubljana, Slovenia
17:00-18.00  **ROSSINI 2 ROOM**  
**Symposium 14: Inside the Vertebrate Nose: Evolution, Structure, and Function**  
Organizers: Blaire Van Valkenburgh, University of California, Los Angeles  
Irina Ruf, University of Bonn  
Thimas Eiting, University of Massachusetts-Amherst  

**S-102 NASAL FOSSA HISTOLOGY, MORPHOMETRY AND FUNCTIONAL MORPHOLOGY IN THREE SPECIES OF PRIMATES**  
Smith, Timothy (1); Eiting, Thomas (2); Craven, Brent (3)  
(1) Slippery Rock University, Slippery Rock, United States; (2) University of Massachusetts Amherst, Amherst, United States; (3) The Pennsylvania State University, State College, United States  

17:00-18.00  **VIVALDI 2 ROOM**  
**L 1 - Lightning Talks**  
Chair: Michael Thompson  

**L-001 VASCULARIZATION OF THE BALEEN EPITHELIUM IN A NEONATAL GRAY WHALE (CETACEA, MYSTICETI, ESCHRICHTIIDAE)**  
Ekdale, Eric G. (1); Deméré, Thomas A. (2); Berla, Annalisa (1)  
(1) San Diego State University, San Diego, CA, United States; (2) San Diego Natural History Museum, San Diego, CA, United States  

**L-002 BODY TEMPERATURE AS A DETERMINATE OF AXIAL SKELETON DIVERSITY**  
Asher, Robert  
Department of Zoology, University of Cambridge, United Kingdom  

**L-003 SPADE FOR DIGGING? A CASE STUDY OF ASIAN FOSSIL SPADEFOOT TOADS (ANURA: PELOBATIDAE)**  
Bever, Gabriel (1); Chen, Jianye (2); Yi, Hongyu (2); Norell, Mark (2)  
(1) New York Institute of Technology, Old Westbury, United States; (2) American Museum of Natural History, New York, United States  

**L-004 KILLING RATES AND MORPHOLOGICAL EVOLUTION IN SIT-AND-WAIT FORAGING BIRDS**  
Corbin, Clay (1); Miles, Donald (2)  
(1) Bloomsburg University, Bloomsburg, United States; (2) Ohio University, Athens, United States
L-005 PALEONEUROANATOMY OF NEOAETOSAUROIDES ENGAEUS BONAPARTE (LATE TRIASSIC-ARGENTINA) AND COMPARISON WITH OTHER AETOSAURS AND CROCODYLIA
Desojo, Julia Brenda (1); Von Baczko, Maria Belen (1); Taborda, Jeremias Ramon Alejandro (1); Gower, David (2)
(1) CONICET, Museo Argentino de Ciencias Naturales “Bernardino Rivadavia”, Argentina; (2) Department of Life Sciences, The Natural History Museum, United Kingdom

L-006 REDESCRIPTION AND PHYLOGENETIC ANALYSIS OF A STEM TETRAPOD MANDIBLE FROM THE LATE CARBONIFEROUS AND ITS IMPLICATIONS FOR PHYLOGENETICS WITH FRAGMENTARY REMAINS
Sookias, Roland (1); Clack, Jennifer (2); Böhmer, Christine (3)
(1) GeoBio-Center, Ludwig-Maximilians-Universität, München, Germany; (2) University Museum of Zoology Cambridge, Cambridge, United Kingdom; (3) Dept. für Geo- und Umweltwissenschaften & GeoBio-Center, Ludwig-Maximilians-Universität München, München, Germany

L-007 EPIMORPHIC REGENERATION AND TUMOR SUPPRESSORS: THE ROLE OF P53 IN THE REGENERATING ZEBRAFISH FIN
Dickie, Renee; Marshall, Katelyn
Towson University, Towson, United States

L-008 NEW INFORMATION ON THE ENDOCRANIAL MORPHOLOGY OF THE TRIASSIC PROTEROCHAMPSIDS (EUREPTILIA: ARCHOSAURIFORMES) USING CTSCANS: COMPARISON WITH LIVING CROCODYLIA
Paulina Carabajal, Ariana (1); Trotteyn, Maria Jimena (2); Bona, Paula (3); Taborda, Jeremias Ramon Alejandro (4); Desojo, Julia Brenda (4)
(1) CONICET, Museo Carmen Funes, Argentina; (2) CONICET, INGEO, Neuquen, Rivadavia, Argentina; (3) CONICET, División Paleontología Vertebrados, Facultad de Ciencias Naturales y Museo, Neuquen, La Plata, Argentina; (4) CONICET, Museo Argentino de Ciencias Naturales, Neuquen, Buenos Aires, Argentina
FRIDAY, JULY 12

08:30-09:30  VERDI ROOM

Plenary Lecture V: Rainer Schoch
Curator, Department of Paleontology
Staatliches Museum für Naturkunde, Stuttgart, Germany
“Development and evolution in early amphibians” (Abstract PT-005)

09:30-11:30  VERDI ROOM

Contributed 19: Ecomorphology
Chairs: Borja Figueirido
Ioannis Sarris

C-128  STICK WITH IT: COMPARATIVE MORPHOLOGY OF FROG TONGUES
Kleinteich, Thomas; Gorb, Stanislav
Kiel University, Functional Morphology and Biomechanics, Germany

C-129  THE IMPACT OF ENVIRONMENTAL CHANGE ON PREDATORY HABITS IN CANIDS
Figueirido, Borja (1); Martín-Serra, Alberto (1); Janis, Christine M., (2)
(1) Departamento de Ecología y Geología, Facultad de Ciencias, Universidad de Málaga, Málaga, Spain; (2) Department of Ecology and Evolutionary Biology, Brown University, Providence, United States

C-130  GROSS DENTAL WEAR AND DIETARY EVOLUTION OF NORTH AMERICAN MIOCENE TO PLEISTOCENE UNGULATES
Semprebon, Gina (1); Rivals, Florent (2)
(1) Bay Path College, Longmeadow, United States; (2) Institut Català de Paleoeociologia Humana i Evolució Social (IPHES) C. Ma, Tarragona, Spain

C-131  BETWEEN TWO WORLDS: THE CORRELATION BETWEEN MORPHOLOGY AND FORAGING ECOLOGY OF MIGRATORY PASSERINES IN TEMPERATE AND TROPICAL ENVIRONMENTS
Miles, Donald (1); Corbin, Clay (2)
(1) Ohio University, Athens, United States; (2) Bloomsburg State University, Bloomsburg, United States

C-132  CORRELATION OF FOREARM MUSCLE ARCHITECTURE AND LOCOMOTION PATTERNS IN PRIMATES
Hartstone-Rose, Adam (1); Allen, Karl (2); Macneill, Kristen (3); Marchi, Damiano (4)
(1) University of South Carolina School of Medicine, Columbia, United States; (2) Duke University, Durham, United States; (3) Penn State, State College, United States; (4) Università di Pisa, Pisa, Italy

C-133  MAPPING THE CONNECTIONS AMONG MORPHOLOGICAL, FUNCTIONAL, PERFORMANCE AND LINEAGE DIVERSITY IN BATS
Santana, Sharlene (1); Herrel, Anthony (2); Greif, Stefan (3)
(1) University of Washington, Seattle, United States; (2) Museum National D’Histoire Naturelle, Paris, France; (3) Max Planck Institute for Ornithology, Seewiesen, Germany

59
**ROSSINI 1 ROOM**

**Symposium 16: The Origin and Evolution of Turtles**

Organizers: Jacqueline Moustakas-Verho, University of Helsinki  
Scott Gilbert, Swarthmore College, PA

**S-117**  **TURTLES AMONG THE AMNIOTES**

Burke, Ann  
*Wesleyan University, Middletown, CT, United States*

**S-118**  **WHAT DOES IT TAKE TO BE A TURTLE? - FROM EMBRYOLOGY TO GENOMICS**

Kuratani, Shigeru (1); Nagashima, Hiroshi (2); Irie, Naoki (1)  
(1) RIKEN Center for Developmental Biology, Kobe, Japan; (2) Niigata University Graduate School of Medical and Dental Sciences., Niigata, Japan

**S-119**  **THE ROLE OF NEURAL CREST CELLS IN THE FORMATION OF THE TURTLE PLASTRON**

Cebra-Thomas, Judith (1); Rice, Ritva (2); Branyan, Kayla (1); Gilbert, Scott (3)  
(1) Millersville University, Millersville, United States; (2) University of Helsinki, Helsinki, Finland; (3) Swarthmore College, Swarthmore, United States

**S-120**  **THE ORIGIN AND LOSS OF PERIODIC PATTERNING IN THE TURTLE SHELL**

Moustakas-Verho, Jacqueline (1); Zimm, Roland (1); Cebra-Thomas, Judith (2); Seppälä, Netta (1); Kallonen, Aki (3); Mitchell, Katherine (6); Hämäläinen, Keijo (3); Salazar-Ciudad, Isaac (5); Jernvall, Jukka (1); Gilbert, Scott (4)  
(1) Institute of Biotechnology, Helsinki, Finland; (2) Millersville University, Millersville, United States; (3) University of Helsinki, Helsinki, Finland; (4) Swarthmore College, Swarthmore, United States; (5) Universitat Autònoma de Barcelona, Barcelona, Spain

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**ROSSINI 2 ROOM**

**Symposium 17: Evolution of the Rodents: Anatomy, Palaeontology and functional Anatomy**

Organizers: Philip Cox, Hull York Medical School, UK  
Robert Druzinsky, University of Illinois, Chicago  
Lionel Hautier, Cambridge University

**S-129**  **DIVERGENCE TIME AND EARLY RADIATIONS OF RODENTS**

Meng, Jin  
*American Museum of Natural History, New York, United States*

**S-130**  **GEOMETRIC MORPHOMETRICS AS A TOOL FOR DISENTANGLING THE RODENT CLASSIFICATION**

Hautier, Lionel (1); Lebrun, Renaud (2)  
(1) Laboratoire de Paléontologie and Museum of Zoology, Montpellier, France; (2) Laboratoire de Paléontologie, Montpellier , France
S-131  RODENT INCISOR SHAPE IS NOT CONSTRAINED BY THE SPACE AVAILABLE IN THE JAW
Cobb, Samuel N.; Cao, Han
Centre for Anatomical and Human Sciences, Hull York Medical School, University of Hull, United Kingdom

S-132. ONTOGENY OF BITE FORCE AND INCISOR STRENGTH INDICATOR IN TUCO TUCOS (CTENOMYS TALARUM; RODENTIA; CAVIOMORPHA)
Vassallo, Aldo I. (1); Becerra, Federico (1); Echeverría, Alejandra (1); Buezas, Guido (1); Casinos, Adrià (2)
(1) Dept. Biology IIMC CONICET, Universidad Nacional de Mar del Plata, Mar del Plata, Argentina; (2) Dept. Animal Biology, University of Barcelona, Barcelona, Spain

09:30-11:30  VIVALDI 2 ROOM
Contributed 20: Paleontology
Chair: Danielle Fraser
K. E. Beth Townsend

C-138  ANATOMICAL RECONSTRUCTION OF ARCHOSAUR HIP JOINT SOFT TISSUES AND ITS SIGNIFICANCE FOR INTERPRETING HINDLIMB FUNCTION
Tsai, Henry; Holliday, Casey
University of Missouri, Columbia, Missouri, United States

C-139  A NEW LOOK FOR AN OLD BIRD: NEW OBSERVATIONS ON THE MORPHOLOGY OF ARCHAEOPTERYX
Rauhut, Oliver; Foth, Christian
Bayerische Staatssammlung für Paläontologie und Geologie, Munich, Germany

C-140  BACK IN BLACK: NEW EVIDENCE ON THE COLOR AND NATURE OF THE ISOLATED ARCHAEOPTERYX FEATHER
Carney, Ryan (1); Vinther, Jakob (2); Shawkey, Matthew (3); D’alba, Liliana (3); Ackermann, Jörg (4)
(1) Brown University, Providence, United States; (2) University of Bristol, Bristol, United Kingdom; (3) University of Akron, Akron, United States; (4) Carl Zeiss NTS GmbH, Oberkochen, Germany

C-141  BIOMECHANICAL EVIDENCE FOR NICHE PARTITIONING BETWEEN SAUROPODS OF THE MORRISON FORMATION
Button, David (1); Rayfield, Emily (1); Barrett, Paul (2)
(1) School of Earth Sciences, University of Bristol, Bristol, United Kingdom; (2) Natural History Museum, London, United Kingdom

C-142  POST-HATCHLING CRANIAL ONTOGENETIC VARIATION IN THE BASAL ARCHOSAURIFORM PROTEROSUCHUS FERGUSI FROM THE LOWER TRIASSIC OF SOUTH AFRICA
Ezcurra, Martin
Ludwig Maximilian University, Munich, Germany
C-136 IMPACTS OF EXCLUDING EXTINCT TAXA FROM COMPARATIVE MORPHOLOGICAL ANALYSES
Fraser, Danielle (1); Rybczynski, Natalia (2)
(1) Carleton University, Ottawa, Canada; (2) Canadian Museum of Nature, Ottawa, Canada

09:30-11:30 DIAMANT ROOM
Contributed 21: Locomotion
Chairs: Miquel De Renzi
Peter Falkingham

C-146 CENTER OF MASS MOVEMENTS DURING TAIL-ASSISTED ARM-SWINGING IN NEW WORLD MONKEYS
Zeininger, Angel (1); Schmitt, Daniel (1); Rose, Michael D. (1); Turnquist, Jean E. (2)
(1) Duke University, Durham, United States; (2) University of Puerto Rico, San Juan, Puerto Rico

C-147 ANALYSIS OF BACK MUSCLE ACTIVITIES AND GROUND REACTION FORCES IN OPERANT BIPEDAL RATS
Matsumura, Akiyoshi (1); Fischer, Martin S. (2)
(1) National Defense Medical College, Tokorozawa, Japan; (2) Friedrich-Schiller-Universität Jena, Jena, Germany

C-145 FRACTAL DIMENSION, LACUNARITY AND CONNECTIVITY IN CANCELLOUS BONE OF MAMMAL FEMORA—A MEETING POINT FOR METABOLISM AND BIOMECHANICS?
Pérez-Ramos, Alejandro (1); De Renzi#, Miquel (1); Belinchón, Margarita (2)
(1) Institut Cavanilles, Universitat de València, Paterna, Spain; (2) Museo de Ciencias Naturales del Ayuntamiento de Valencia, Valencia, Spain

C-148 EFFECTS OF ATMOSPHERIC OXYGEN ON FEMUR BIOMECHANICS IN ALLIGATOR MISSISSIPPIENSIS
Middleton, Kevin (1); Lujan, Susan (2); Hicks, James (3); Owerkowicz, Tomasz (2)
(1) University of Missouri School of Medicine, Columbia, United States; (2) California State University, San Bernardino, United States; (3) University of California, Irvine, United States

C-149 PLACOID SCALE MORPHOLOGY, ERECTION AND DRAG REDUCTION IN THE SHORTFIN MAKO ISURUS OXYRINCHUS
Motta, Philip (1); Habegger, Maria Laura (1); Lang, Amy (2)
(1) University of South Florida, Tampa, United States; (2) University of Alabama, Tuscaloosa, United States

C-150 USING AVIAN SUBSURFACE 3D FOOT MOTION TO SIMULATE FOSSIL TRACK DIVERSITY
Falkingham, Peter (1); Gatesy, Stephen (2)
(1) Royal Veterinary College/Brown University, London/Providence, United States; (2) Brown University, Providence, United States

11:30-12:00 Coffee Break
12:00-13:00  VERDI ROOM
Contributed 19: Ecomorphology
Chairs: Borja Figueirido
Ioannis Sarris

C-134  INDEPENDENT EVOLUTION OF EXTREME FOSSORIALITY IN TALPID MOLES
Thompson, Richard (1); Schwermann, Achim (2)
(1) University Museum of Zoology, The University of Cambridge, United Kingdom;
(2) Steinmann Institute for Geology, Mineralogy and Palaeontology, The University of Bonn, Germany

C-135  THE INFLUENCE OF VERTEBRAL NUMBER AND SIZE IN BODY SIZE ACROSS EURASIAN VIPERS
Sarris, Ioannis; Marugán-Lobón, Jesús; Buscalioni, Ángela D.
Universidad Autónoma de Madrid, Madrid, Spain

12:00-13:00  ROSSINI 1 ROOM
Symposium 16: The Origin and Evolution of Turtles
Organizers: Jacqueline Moustakas-Verho, University of Helsinki
Scott Gilbert, Swarthmore College, PA

S-121  DO TURTLES FOLLOW RULES? PHYLOGENY, ECOLOGY, AND LATITUDINAL GRADIENTS IN BODY SIZE AND GEOGRAPHIC RANGE OF TURTLES
Angielczyk, Kenneth (1); Burroughs, Robert (2); Feldman, Chris (3)
(1) Field Museum of Natural History, Chicago, United States;
(2) University of Texas, Austin, United States;
(3) University of Nevada, Reno, United States

S-122  MORPHOLOGY MATTERS: GONADAL DEVELOPMENT AND FORM IN MARINE TURTLES INCUBATING UNDER NORMAL AND SIMULATED CLIMATE CHANGE CONDITIONS
Wyneken, Jeanette; Lolavar, Alexandra; Rogers, Micah
Florida Atlantic University, Boca Raton, United States

12:00-13:00  ROSSINI 2 ROOM
Organizers: Philip Cox, Hull York Medical School, UK
Robert Druzinsky, University of Illinois, Chicago
Lionel Hautier, Cambridge University

S-133  EVOLUTIONARY AND BIOLOGICAL IMPLICATIONS OF DENTAL MESIAL DRIFT IN RODENTS
Gomes Rodrigues, Helder (1); Marangoni, Pauline (1); Solé, Floréal (1); Charles, Cyril (1); Tafforeau, Paul (2); Viriot, Laurent (1)
(1) Institut de Génomique Fonctionnelle de Lyon, Ecole Normale Supérieure de Lyon, France;
(2) European Synchrotron Radiation Facility, Grenoble, France
S-134 CONNECTIONS BETWEEN CHEWING MOVEMENTS AND MOLAR CROWN TOPOGRAPHY DURING THE NEOGENE RADIATION OF THE MUROIDEA (RODENTIA, MAMMALIA)
Lazzari, Vincent (1); Charles, Cyril (2); Viriot, Laurent (2); Tafforeau, Paul (3); Guy, Franck (1); Michaux, Jacques (4)
(1) Université de Poitiers, Poitiers, France; (2) Ecole Normale Supérieure de Lyon, Lyon, France; (3) ESRF, Grenoble, France; (4) Université Montpellier 2, Montpellier, France

12:00-13:00  VIVALDI 2 ROOM
Contributed 20: Paleontology
Chairs: Danielle Fraser
K. E. Beth Townsend

C-143 DINOSAUR CEPHALIC VASCULAR ANATOMY AND ITS PHYSIOLOGICAL IMPLICATIONS
Porter, William; Witmer, Lawrence
Ohio University, Athens, United States

C-144 FIRST DEFINITIVE EVIDENCE OF THE POSTCRANIA OF THE BASAL RUMINANT PROTOREODON PARVUS
Townsend, K. E. Beth (1); Holroyd, Patricia (2)
(1) Arizona College of Osteopathic Medicine, Midwestern University, United States; (2) Museum of Paleontology, University of California, United States

C-137 ANATOMY OF THE ‘HELMET-SHAPED’ CREST OF TSINTAOSAURUS SPINORHINUS AND THE EARLY EVOLUTION OF THE SUPRACRANIAL ORNAMENTATION IN LAMBEOSAURINE DINOSAURS
Prieto-Márquez, Albert (1); Wagner, Jonathan R. (2)
(1) Bayerische Staatssammlung für Paläontologie und Geologie, Munich, Germany; (2) Jackson School of Geosciences, The University of Texas at Austin, Austin, United States

12:00-13:00  DIAMANT ROOM
Contributed 21: Locomotion
Chairs: Miquel De Renzi
Peter Falkingham

C-151 INDEPENDENT ACQUISITIONS OF QUADRUPEDALITY IN ORNITHISCHIAN DINOSAURS
Barrett, Paul (1); Maidment, Susannah (2)
(1) The Natural History Museum, London, United Kingdom; (2) Imperial College, London, United Kingdom

13:00-14:30  Midday Break
14.30-16.30  ROSSINI 1 ROOM
Symposium 16: The Origin and Evolution of Turtles
Organizers: Jacqueline Moustakas-Verho, University of Helsinki, Scott Gilbert, Swarthmore College, PA

S-123 THE TURTLE CONTROVERSIES: INTEGRATING PALEONTOLOGY, PHYLOGENY, AND DEVELOPMENT TO EXAMINE TURTLE ORIGINS
Gilbert, Scott
University of Helsinki, Helsinki, Finland, United States

S-124 THE DEEP HISTORY OF THE TURTLE SHELL: INTEGRATING FOSSIL AND DEVELOPMENTAL DATA
Lyson, Tyler (1); Bever, Gabe (2); Scheyer, Torsten (3); Hsiang, Allison (4); Gauthier, Jacques (4)
(1) Smithsonian Institution, Washington, DC, United States; (2) New York College of Osteopathic Medicine, Old Westbury, United States; (3) Universität Zürich, Zürich, Switzerland; (4) Yale University, New Haven, United States

S-125 CRANIAL EVOLUTION AND THE ORIGIN OF TURTLES: INSIGHTS FROM EUNOTOSAURUS AFRICANUS
Bever, Gabriel (1); Lyson, Tyler (2)
(1) New York Institute of Technology, Department of Anatomy, United States; (2) Smithsonian Institution, Washington, D. C., United States

S-126 PECULIARITIES IN THE TURTLE BODY PLAN: THE ORIGIN AND EVOLUTION OF NECK RETRACTION MECHANISMS
Werneburg, Ingmar (1); Hinz, Juliiane (2); Gumpenberger, Michaela (3); Volpato, Virginie (4); Natchev, Nikolay (5); Joyce, Walter G. (1)
(1) Biogeologie, Fachbereich Geowissenschaften der Eberhard Karls Universität, Tübingen, Germany; (2) Paläontologie, Fachbereich Geowissenschaften der Eberhard Karls Universität, Tübingen, Germany; (3) Clinic of Radiology, University of Veterinary Medicine, Vienna, Austria; (4) Paläoanthropologie und Messelforschung, Senckenberg Research Institute, Frankfurt, Germany; (5) Department of Zoology, University St. Kliment Ohridski, Sofia, Bulgaria

14:30-16:30  ROSSINI 2 ROOM
Organizers: Philip Cox, Hull York Medical School, UK
Robert Druzinsky, University of Illinois, Chicago
Lionel Hautier, Cambridge University

S-135 THE ORAL APPARATUS OF RODENTS: VARIATIONS ON THE THEME OF A GNAWING MACHINE
Druzinsky, Robert
College of Dentistry, University of Illinois, Chicago, United States

S-136 FUNCTIONAL MAINTENANCE AND VARIATION IN CRANIAL LENGTH OF THE MOUSE MASTICATORY SYSTEM
Baverstock, Hester; Cobb, Samuel N.
CAHS, HYMS, York, United Kingdom
S-137 THE INFLUENCE OF MANDIBULAR MORPHOLOGY ON THE BIOMECHANICS OF FEEDING IN RODENTS
Cox, Philip
Hull York Medical School, York, United Kingdom

S-138 MORPHOLOGICAL ADAPTATIONS OF THE RODENT INNER EAR
Wannaprasert, Thanakul; Jeffery, Nathan
University of Liverpool, Liverpool, United Kingdom

14:30-16:30 VIVALDI 2 ROOM

Contributed 23: Paleontology
Chairs: Michel Laurin
Jenny Clack

C-154 BONE MICROANATOMY AND LIFESTYLE: RECENT DEVELOPMENTS AND CHALLENGES
Laurin, Michel
MNHN, Paris, France

C-152 NEW TETRAPOD AND FISH FAUNAS FROM THE EARLIEST CARBONIFEROUS OF SCOTLAND
Smithson, Timothy; Clack, Jennifer
Dept. of Zoology, Cambridge, United Kingdom

C-155 BONE HISTOLOGY CONFIRMS DETERMINATE GROWTH AND SMALL BODY SIZE IN THE NOASAURID THEROPOD MASIAKASAURUS KNOPFLERI
Lee, Andrew (1); O’connor, Patrick (2)
(1) Midwestern University, Glendale, United States; (2) Ohio University, Athens, United States

C-156 CONTROVERSIAL ISSUES IN THE ANATOMY OF MESOZOIC ACTINOPTERYGIANS
López-Arbarello, Adriana
Bayerische Staatssammlung für Paläontologie und Geologie, Munich, Germany

C-153 SKELETAL MORPHOLOGY AND EVOLUTIONARY HISTORY OF EUROPEAN LAMBEOSAURINE ‘DUCK-BILLED’ DINOSAURS
Prieto-Márquez, Albert (1); Dalla Vecchia, Fabio Marco (2); Galobart, Angel (3); Gaete, Rodrigo (3)
(1) Bayerische Staatssammlung für Paläontologie und Geologie, Munich, Germany; (2) Institut Català de Paleontologia, Sabadell, Spain; (3) Museu de la Conca Dellà, Isona, Spain
C-157 MORPHOLOGY AND SUBSTRATE: 3-D QUANTIFICATION AND RHEOLOGY OF TRIDACTYL DINOSAUR FOOTPRINTS FROM SPAIN
L. Razzolini, Novella (1); Castanera, Diego (2); Vila, Bernat (3); Canudo, José Ignacio (2); Barco, José Luis (4); Galobart, Àngel (1)
(1) Institut Català de Paleontologia Miquel Crusafont, Sabadell, Spain; (2) Grupo Aragosaurus-IUCA, Paleontología. Facultad de Ciencias. Universidad de Zaragoza, Spain; (3) Grupo Aragosaurus-IUCA and Institut Català de Paleontologia Miquel Crusafont, Paleontología. Facultad de Ciencias. Universidad de Zaragoza, Spain; (4) Grupo Aragosaurus-IUCA and Paleoymas S.L., Zaragoza, Spain

14:30-16:30 DIAMANT ROOM
Contributed 24: Cranial Evolution
Chairs: Vincent Dupret
James Hanken

C-161 3D RECONSTRUCTION AND MECHANICAL ANALYSIS OF THE EARLY TETRAPOD LOWER JAW
Porro, Laura (1); Rayfield, Emily (1); Clack, Jennifer (2)
(1) University of Bristol, Bristol, United Kingdom; (2) University of Cambridge, Cambridge, United Kingdom

C-162 INFERRING THE ROLE OF NERVOUS TISSUE IN THE EVOLUTION OF VERTEBRATE JAW MUSCLES: DEVELOPMENT OF TRIGEMINAL MOTOR NEURONS IN PARROTS
Tokita, Masayoshi (1); Nakayama, Tomoki (2)
(1) Harvard University, Cambridge, United States; (2) University of Tsukuba, Tsukuba, Japan

C-163 FOSSIL EARLY VERTEBRATES SHED LIGHT ON THE ORIGIN OF THE GNATHOSTOME FACE
Dupret, Vincent (1); Sanchez, Sophie (1); Goujet, Daniel (2); Tafforeau, Paul (3); Ahlberg, Per E. (1)
(1) Uppsala University, Uppsala, Sweden; (2) Muséum National d’Histoire Naturelle, Paris, France; (3) European Synchrotron Radiation Facility, Grenoble, France

C-164 DIFFERENCES IN NASAL CAVITY ONTOGENY BETWEEN AVIAN AND MAMMALIAN EMBRYOS
Abramyan, John; Woo, Johnathan; Richman, Joy
University of British Columbia, Vancouver, BC, Canada

17.00-18.00 ROSSINI 1 ROOM
Symposium 16: The Origin and Evolution of Turtles
Organizers: Jacqueline Moustakas-Verho, University of Helsinki, Scott Gilbert, Swathmore College, PA

S-127 THE SHAPING OF TURTLE DIVERSITY THROUGH THE CRETAUCEOUS AND PALEOGENE
Holroyd, Patricia; Hutchison, J. Howard
University of California, Berkeley, United States
FRIDAY, JULY 12th

S-128 GIANTS THAT WENT EXTINCT. NEW FOSSIL TURTLES FROM THE NEOTROPICS; SYSTEMATICS, PHYLOGENY, AND BONE HISTOLOGY  
Cadena, Edwin  
Smithsonian Tropical Research Institute, Panama, Colombia

17.00-18.00 ROSSINI 2 ROOM  
Organizers: Philip Cox, Hull York Medical School, UK  
Robert Drizuinsky, University of Illinois, Chicago  
Lionel Hautier, Cambridge University

S-139 MANDIBLE DIVERGENCE OF HOUSE MICE ON COLD ISLANDS: EVIDENCES OF PARALLEL ADAPTIVE EVOLUTION?  
Renaud, Sabrina (1); Hardouin, Emilie (2); Auffray, Jean-Christophe (3)  
(1) LBBE - CNRS / University Lyon, Lyon, France; (2) Bournemouth University, Bournemouth University, United Kingdom; (3) ISEM - CNRS / University Montpellier, CNRS / University Montpellier, France

S-140 PATTERNS OF DISPARITY IN RODENT EVOLUTION: FILLING ONTOGENETIC AND ADULT MORPHOSPACES  
Wilson, Laura A. B.  
University of New South Wales, Sydney, Australia

17.00-18.00 VIVALDI 2 ROOM  
Contributed 23: Paleontology  
Chairs: Michel Laurin  
Jenny Clack

C-158 HOW CAN WE RELIABLY RECONSTRUCT JOINT AXES IN ARCHOSAUR FORELIMBS WHEN ARTICULAR CARTILAGES ARE LOST?  
Fujiwara, Shin-Ichi (1); Anzai, Wataru (2); Kudo, Kohei (2); Endo, Hideki (2)  
(1) Naogya University, Nagoya, Japan; (2) The University of Tokyo, Tokyo, Japan

C-159 NEUROCRANIAL ANATOMY OF THE PROBLEMATIC CARBONIFEROUS-PERMIAN LEPOSPONDYL BRACHYDECTES NEWBERRYI: NEW INFORMATION FROM μCT  
Pardo, Jason; Anderson, Jason  
University of Calgary, Calgary, Canada

C-160 COMPARATIVE MYOLOGY OF THE HIGHLY REDUCED FORELIMBS OF TYRANNOSAURIDS AND ABELISAUROIDS (DINOSAURIA: THEROPODA)  
Burch, Sara  
Stony Brook University, Stony Brook, United States
POSTER SESSION

POSTER SESSION: SKELETAL EVO-DEVO

P-001 ONTOGENETIC SKULL VARIATION IN THE ARGENTINEAN EXTANT CAIMANS CAIMAN LATIROSTRIS AND CAIMAN YACARE (CROCODYLIA, ALLIGATORIDAE)
Fernandez Blanco, María Victoria (1); Bona, Paula (2); Olivaes, Itatí (3); Desojo, Julia Brenda (4)
(1) División Paleontología Vertebrados, Museo de La Plata, La Plata, Argentina; (2) División Paleontología Vertebrados, Museo de La Plata, La Plata, Argentina; (3) Sección Mastozoología, División Vertebrados, Museo de La Plata, La Plata, Argentina; (4) Museo Argentino de Ciencias Naturales “Bernardino Rivadavia”, Buenos Aires, Argentina

P-002 ANATOMY OF THE LOWER JAW AND DENTITION OF PSEUDOPUS, OPHISAURUS AND ANGUI (anguimorpha, anguidae) AND THEIR INTERRELATIONSHIPS
Klembara, Jozef (1); Hain, Miroslav (2); Dobiałová, Karolína (1)
(1) Comenius University, Bratislava, Slovakia; (2) Slovak Academy of Sciences, Bratislava, Slovakia

P-003 INTRASPECIFIC VARIATION IN THE SKULL MORPHOLOGY OF THE BLACK CAIMAN MELNOSUCHUS NIGER (ALLIGATORIDAE, CAIMANINAE)
Foth, Christian (1); Bona, Paula (2); Desojo, Julia (3)
(1) Bayerische Staatssammlung für Paläontologie und Geologie , Munich, Germany; (2) División Paleontología Vertebrados, Museo de La Plata, La Plata, Argentina; (3) Sección Paleontología de Vertebrados, Museo Argentino de Ciencias Naturales “Bernardino Rivadavia”, Buenos Aires, Argentina

P-004 CARNIVOROUS ADAPTATION IN MAMMALIAN MOLARS: UNIQUE EVOLUTIONARY PATTERN AND MORPHOLOGICAL INTEGRATION AMONG DENTAL TRAITS IN CARNIVORANS
Asahara, Masakazu
Kyoto University Primate Research Institute, Inuyama, Japan

P-005 SUPERSIZE ME: CELLULAR DYNAMICS CONTROLLING SIZE IN THE MAMMALIAN MOLAR
Moustakas-Verho, Jacqueline (1); Christensen, Mona (1); Kallonen, Aki (2); Hämäläinen, Keijo (2); Jernvall, Jukka (1)
(1) Institute of Biotechnology, Helsinki, Finland; (2) University of Helsinki, Helsinki, Finland

P-006 DEVELOPMENT OF THE BASIPTERYGOID PROCESS IN LACERTID LIZARDS
Yaryhin, Oleksandr (1); Klembara, Jozef (2)
(1) I. I. Schmalhausen institute of zoology NAS of Ukraine, Kyiv, Ukraine; (2) Comenius University in Bratislava, Bratislava, Slovakia

P-007 MORPHOMETRIC ANALYSES OF ISOLATED THEROPOD TEETH FROM THE JURASSIC OF NIGER
Serrano-Martínez, Alejandro (1); Knoll, Fabien (2); Ortega, Francisco (3)
(1) Universidad Autónoma de Madrid, Madrid, Spain; (2) Museo Nacional de Ciencias Naturales, Madrid, Spain; (3) Universidad Nacional de Educación a Distancia, Madrid, Spain
P-008 CRANIODENTAL VARIABILITY AND SEXUAL DIMORPHISM IN TWO SPECIES OF THE CANIDAE
Suzuki, Satoshi (1); Peeva, Stanislava (2); Kim, Sang-In (3); Oh, Jinwoo (4); Masuda, Ryuichi (5); Kaneko, Yayoi (6); Kimura, Junpei (4); Raichev, Evgeniy (2)
(1) Fukui City Museum of Natural History, Fukui, Japan; (2) Trakia University, Stara Zagora, Bulgaria; (3) Obihiro University of Agriculture and Veterinary Medicine, Obihiro, Japan; (4) Seoul National University, Seoul, Republic Of Korea; (5) Hokkaido University, Sapporo, Japan; (6) Tokyo University of Agriculture and Technology, Fuchu, Japan

P-009 3D FINITE ELEMENT AND PARAMETRICAL ANALYSIS OF A STEREOSPONDYL AMPHIBIAN (TEMNOSPONDYLI)
Marcé-Nogué, Jordi (1); Fortuny, Josep (2)
(1) Universitat Politècnica de Catalunya, Terrassa, Spain; (2) Institut Català de Paleontologia, Campus de Bellaterra, Spain

P-010 THE HISTOLOGICAL VARIABILITY OF THE INTERCENTRA AMONG TEMNOSPONDYLI
Affiliated with Symposium 12 - Paleohistology
Konietzko-Meier, Dorota; Gądek, Kamil
University of Opole, Opole, Poland

P-011 CORRELATES OF BONE HISTOLOGY QUANTITATIVE DATA WITH LIFE HISTORY TRAITS AND ECOLOGICAL PARAMETERS IN BOVIDS
Affiliated with Symposium 12 - Paleohistology
Marín-Moratalla, Nekane (1); Cubo, Jorge (2); Jordana, Xavier (1); Moncunill-Solé, Blanca (1); Köhler, Meike (3)
(1) Institut Català de Paleontologia Miquel Crusafont, Sabadell, Spain; (2) UPMC Université Paris 06, Paris, France; (3) ICREA at Institut Català de Paleontologia Miquel Crusafont, Sabadell, Spain

P-012 OSTEODERM MICROSTRUCTURE OF PHYTOSAURS AND AETOSAURS (EUREPTILIA, ARCHOSAURIFORMES)
Affiliated with Symposium 12 - Paleohistology
Scheyer, Torsten M. (1); Desojo, Julia B. (2); Cerda, Ignacio A. (3)
(1) University of Zurich, Zurich, Switzerland; (2) Museo Argentino de Ciencias Naturales Bernardino Rivadavia, Buenos Aires, Argentina; (3) Instituto de Investigación en Paleobiología y Geología, Universidad Nacional de Río Negro, Museo Carlos Ameghino, Río Negro, Argentina

P-013 CAN THE ENAMEL INCREMENTAL LINES PROVIDE CLUES ABOUT MAMMALIAN LIFE HISTORIES?
Affiliated with Symposium 12 - Paleohistology
Jordana, Xavier; Marín-Moratalla, Nekane; Moncunill-Solé, Blanca; Köhler, Meike
Institut Català de Paleontologia Miquel Crusafont, Cerdanyola del Vallès, Spain

P-014 LONG BONE HISTOLOGY AND GROWTH PATTERNS IN ANKYLOSAURS: IMPLICATIONS FOR LIFE HISTORY AND EVOLUTION
Affiliated with Symposium 12 - Paleohistology
Sander, Martin; Hayashi, Shoji; Stein, Martina
University of Bonn, Bonn, Germany
P-015 PHYLOGENETIC SIGNAL IN BONE HISTOLOGY OF RATITES (AVES, PALAEOGNATHAE)  
Affiliated with Symposium 12 - Paleohistology  
Legendre, Lucas J. (1); Bourdon, Estelle (2); De Ricqlès, Armand (1); Lamrous, Hayat (1); Tennyson, Alan J. D. (3); Scofield, R. Paul (4); Cubo, Jorge (1)  
(1) UPMC, Université Paris 06, Paris, France; (2) Department of Palaeontology, The Natural History Museum, London, United Kingdom; (3) Museum of New Zealand Te Papa Tongarewa, Wellington, New Zealand; (4) Canterbury Museum, Christchurch, New Zealand

P-016 METABOLIC CONSTRAINTS ON THE MAXIMUM THICKNESS OF AVASCULAR BONE TISSUE IN LEPIDOSAURS AND BIRDS  
Affiliated with Symposium 12 - Paleohistology  
Cubo, Jorge (1); Baudin, Jéromine (1); De Buffrénil, Vivian (2)  
(1) UPMC, Université Paris 06, Paris, France; (2) Museum National d’Histoire Naturelle, Paris, France

P-017 WOUND REPAIR IN DERMAL ARMOUR OF A 380 MILLION YEAR OLD JAWLESS FISH: EVIDENCE FOR ODONTOGENIC STEM CELLS  
Affiliated with Symposium 12 - Paleohistology  
Smith, Moya Meredith (1); Johanson, Zerina (2); Kearsley, Anton (3); Kearsley, Peter (4); Mark-Kurik, Elga (5)  
(1) Moya Meredith, London, United Kingdom; (2) Craniofacial Development and Stem Cell Biology, King’s College London, United Kingdom; (3) Imaging and Analysis Centre, Natural History Museum, London, United Kingdom; (4) Imaging and Microscopy, Dental Institute, King’s College London, United Kingdom; (5) Institute of Geology, Tallinn University of Technology, Tallinn, Estonia

P-018 EVIDENCE OF METASTATIC CANCER IN A STEGOSAUR TIBIA  
Affiliated with Symposium 12 - Paleohistology  
Redelstorff, Ragna (1); Hayashi, Shoji (2); Chinsamy, Anusuya (3)  
(1) Department of Biological Sciences, University of Cape Town, Cape Town, South Africa; (2) Steinmann Institute of Geology, Palaeontology and Mineralogy, University of Bonn, Germany; (3) Osaka Museum of Natural History, Osaka, Japan

P-019 RESOLVING THE HOMOLOGY AND DUAL EMBRYONIC ORIGIN OF THE ENIGMATIC MAMMALIAN SKULL BONE, THE INTERPARIETAL  
Koyabu, Daisuke; Sánchez-Villagra, Marcelo  
Palaeontological Institute and Museum, University of Zurich, Zurich, Switzerland

P-020 EMBRYONIC REMNANTS OF INTERCENTRA AND RIBS IN A PLEURODIRE TURTLE - A CASE OF RECAPITULATION AND FUNCTIONAL REDUCTION  
Werneburg, Ingmar (1); Joyce, Walter G. (1); Maier, Wolfgang (2)  
(1) Fachbereich Geowissenschaften der Eberhard-Karls-Universität, Tübingen, Germany; (2) Spezielle Zoologie, Eberhard-Karls-Universität, Tübingen, Germany

P-021 MORPHOMETRICS FOR EVODEVO: COMBINING MICROCT IMAGING, GEOMETRIC MORPHOMETRICS, AND IMAGE ANALYSIS  
Mayer, Christine; Metscher, Brian; Müller, Gerd B.; Mitteröcker, Philipp  
University of Vienna, Vienna, Austria
P-022 MORPHOLOGY AND DISTRIBUTION OF INTERLACUNAR CANALS IN ELASMOBRANCH MINERALIZED CARTILAGE
Shrivastava, Rishabh (1); Repp, Felix (2); Kollmansberger, Philip (3); Zaslansky, Paul (4); Dean, Mason (2)
(1) VIT University, Vellore, India; (2) Max Planck Institute for Colloids & Interfaces, Potsdam, Germany; (3) Eidgenössische Technische Hochschule, Zürich, Switzerland; (4) Charité - Universitätmedizin, Berlin, Germany

P-023 NEW INSIGHTS INTO THE PATTERN OF CLOSURE OF CRANIAL SUTURES IN THE MOUSE AND ITS EFFECT ON SHAPING OF THE CRANIUM
Fagan, Michael (1); Moazen, Mehran (1); Babbs, Christian (2); Wilkie, Andrew (2); Hoyle, Kathryn (1)
(1) University of Hull, Hull, United Kingdom; (2) University of Oxford, Oxford, United Kingdom

P-024 LIMBS TO FINS: THE REMARKABLE EVOLUTIONARY STORY ABOUT LIMB REDUCTION IN GYMNOPHTHALMID LIZARDS
Kohlsdorf, Tiana (1); Grizante, Mariana (1); Diogo, Rui (2); Abdala, Virginia (3)
(1) University of São Paulo, FFCLRP - Ribeirão Preto, Brazil; (2) Howard University College of Medicine, Washington, United States; (3) Fundacion Miguel Lillo - CONICET, Tucumán, Argentina

P-025 FUSION OF THE MANDIBULAR SYMPHYSIS IN THE PIG
Lee, Eugenia; Herring, Susan W.
University of Washington, Seattle, United States

POSTER SESSION: LOCOMOTION

P-026 MORPHOLOGICAL DIFFERENCE OF POSITION OF TRUNK MUSCULATURE
Omura, Ayano (1); Anzai, Wataru (2); Endo, Hideki (3)
(1) Graduate school of Agricultural and Agricultural Life Sciences, The University Museum, The University of Tokyo, Tokyo, Japan; (2) Graduate school of Biological Sciences, The University Museum, The University of Tokyo, Tokyo, Japan; (3) The University Museum, The University of Tokyo, Tokyo, Japan

P-027 THE RELATIONSHIPS BETWEEN MUSCULOSKELETAL MORPHOLOGY OF LIMBS AND LOCOMOTOR HABITS IN CUBAN ANOLIS LIZARDS
Anzai, Wataru (1); Omura, Ayano (1); Cadiz, Antonio (2); Kawata, Masakado (3); Endo, Hideki (1)
(1) The University of Tokyo, Tokyo, Japan; (2) Havana University, Havana, Cuba; (3) Tohoku University, Sendai, Japan

P-028 COMPARATIVE ANATOMY OF THE SHOULDER GIRDLE MUSCLES FROM SALAMANDERS TO HUMANS
Koizumi, Masahiro
Tokyo Ariake University of Medical and Health Sciences, Tokyo, Japan

P-029 3DGM ANALYSIS OF THE INFLUENCE OF BRACHIATION INTO SHAPING THE PROXIMAL HUMERUS OF SUSPENSOY PRIMATES
Arias-Martorell, Julia; Potau, Josep Maria; Bello-Hellegouarch, Gaëlle; Pérez-Pérez, Alejandro
Universitat de Barcelona, Barcelona, Spain
P-030 QUANTITATIVE ANALYSIS OF THE MUSCLES OF THE ROTATOR CUFF IN DIFFERENT ORTHOGRADE AND PRONOGRADE PRIMATE SPECIES: ADAPTATIONS TO DIFFERENT TYPES OF LOCOMOTION
Potau, Josep Maria (1); Bello-Hellegouarch, Gaëlle (1); Arias-Martorell, Júlia (1); Pastor, Juan Francisco (2); De Paz, Félix (2); Barbosa, Mercedes (2); Diogo, Rui (3); Pérez-Pérez, Alejandro (1)
(1) University of Barcelona, Barcelona, Spain; (2) University of Valladolid, Valladolid, Spain; (3) George Washington University, Washington, United States

P-031 GUENONS VS GREAT APES: THREE-DIMENSIONAL KINEMATIC ANALYSIS OF THE PATELLA DURING MOTION
Pina, Marta (1); Demiguel, Daniel (1); Puigvert, Francesc (2); Marcé-Nogué, Jordi (2); Moyà-Solà, Salvador (3)
(1) Institut Català de Paleontologia Miquel Crusafont, Cerdanyola del Vallès, Spain; (2) Universitat Politècnica de Catalunya - BarcelonaTech, Terrassa, Spain; (3) ICREA at Institut Català de Paleontologia Miquel Crusafont Crusafont and Unitat d’Antropologia Biològica (Departament BABVE) UAB, Cerdanyola del Vallès, Spain

P-032 FORM AND FUNCTION OF THE FOOT AND HALLUX IN THEROPOD DINOSAURS
Hattori, Soki
Tokyo University, Tokyo, Japan

P-033 A GEOMETRIC MORPHOMETRIC ANALYSIS OF THE FEMUR OF HOPPING MARSUPIALS
Milne, Nick; Bird, Nicola; Hadley, Claire; Dawson, Rebekah
University of Western Australia, Crawley, Australia

P-034 IN VIVO FEMORAL STRAINS IN SWIMMING TURTLES: THE INFLUENCE OF LOCOMOTOR MEDIUM ON LIMB BONE LOADING
Young, Vanessa; Blob, Richard
Clemson University, Clemson, United States

P-035 GAIT TRANSITIONS AND MODULAR ORGANIZATION OF MAMMAL LOCOMOTION
Abourachid, Anick; Maes, Ludovic
Muséum National d’Histoire Naturelle, UMR 7179, France

P-036 AQUATIC BURST LOCOMOTION BY HYDROPLANING AND RUNNING IN FEMALE COMMON EIDERS (SOMATERIA MOLLISSIMA)
Gough, William (1); Farina, Stacy (1); Fish, Frank (2)
(1) Cornell University, Ithaca NY, United States; (2) West Chester University, United States

P-038 CONVERGENT PYGOSTYLE MORPHOLOGY IN UNDERWATER FORAGING BIRDS
Felice, Ryan
Ohio University, Athens, OH, United States

P-040 CT ANALYSIS OF SEA OTTER HIP JOINT RELATED TO SWIMMING LOCATION
Mori, Kent; Endo, Hideki
The University Museum, The University of Tokyo, Tokyo, Japan
P-041  MORPHOMETRICS AND GAIT ON DIFFERENT SUBSTRATES IN THE LONG-TAILED LIZARD (TAKYDROMUS SEXLINEATUS): EXPERIMENTS AND MODELS
D’aouût, Kristiaan (1); Karakasiliotis, Konstantinas (2); Ijspeert, Auke Jan (2); Aerts, Peter (1)
(1) Antwerp University, Antwerp, Belgium; (2) EPFL, Lausanne, Switzerland

P-042  DISSECTING A KANGAROO’S FIFTH LIMB
Dawson, Rebekah (1); Milne, Nick (1); Warburton, Natalie (2)
(1) University of Western Australia, Crawley, Australia; (2) Murdoch University, Murdoch, Australia

P-043  PELVIC MUSCLE ARCHITECTURE AND FIBER COMPOSITION IN TERRESTRIAL FROGS
Jorgensen, Michael; Reilly, Stephen
Ohio University, Athens, United States

P-044  PROTECTIVE BUTTRESSING OF THE HUMAN HAND: METACARPAL STRAIN IN BUTTRESSED AND UNBUTTRESSED FISTS
Horns, Joshua; Jung, Rebekah; Carrier, David
University of Utah, Salt Lake City, United States

P-045  FATIGUE EFFECTS ON GAIT PATTERNS IN DEGUS
Schmidt, André; Arnes, Tyler; Biknevicius, Audrone
Ohio University, Athens, United States

P-046  THE MECHANICAL AND ENERGETIC ADVANTAGES OF FOOTFALL TIMINGS IN QUADRUPEDAL WALKING
Miller, Charlotte (1); Johnson, Laura (2); Pinkard, Henry (1); Lemelin, Pierre (3); Schmitt, Daniel (1)
(1) Duke University, Durham, NC, United States; (2) Ross University School of Medicine, Roseau, West Indies, Dominica; (3) University of Alberta, Edmonton, Canada

POSTER SESSION: FEEDING

P-047  PALEOECOLOGY OF MIOCENE KANGAROOS: INFERENCES FROM CRANIODENTAL AND POSTCRANIAL DATA
Janis, Christine (1); Damuth, John (2); Travouillon, Kenny (3); Figueirido, Borja (4); Hand, Suzanne (5); Archer, Michael (5)
(1) Brown University, Providence, United States; (2) University of California, Santa Barbara, United States; (3) University of Queensland, Brisbane, Australia; (4) University of Malaga, Malaga, Spain; (5) University of New South Wales, Sydney, Australia

P-048  FUNCTIONAL ANALYSIS OF THE FEEDING APPARATUS OF THE EARLY ORNITHISCHIAN DINOSAUR LESOTOSAURUS DIAGNOSTICUS
Knoll, Fabien
Museo Nacional de Ciencias Naturales - CSIC, Madrid, Spain

P-049  THE RELATIONSHIP BETWEEN MANDIBULAR SYMPHYSEAL PERFORMANCE AND JAW-MUSCLE ACTIVITY DURING CHEWING IN PRIMATES
Vinyard, Christopher (1); Ravosa, Matthew (2)
(1) Northeast Ohio Medical University, Rootstown, United States; (2) University of Notre Dame, Notre Dame, United States
P-050 FUNCTIONAL MORPHOLOGY OF THE INCISORS IN SUBTERRANEAN RODENTS
Mcintosh, Andrew; Cox, Philip
Hull York Medical School, York, United Kingdom

P-051 AGE-RELATED TOOTH WEAR IN MANDRILLS AND BABOONS
Mayo-Alesón, Mercedes (1); Romero, Alejandro (2); Willaume, Eric (3); Pérez-Pérez, Alejandro (1); Kappeler, Peter M. (4); Charpentier, Marie J. E. (5); Galbany, Jordi (1)
(1) Universitat de Barcelona, Barcelona, Spain; (2) Universidad de Alicante, Alicante, Spain; (3) Société du Parc d’Exploitation de la Lékédi (SODEPAL), Bakoumba, Gabon; (4) Behavioral Ecology & Sociobiology Unit -German Primate Center, Göttingen, Germany; (5) Centre d’Ecologie Fonctionnelle et Evolutive - CNRS, Montpellier, France

P-052 TOOTH SHAPE DIFFERENCES BETWEEN UNTUFTED AND TUFTED CAPUCHINS: POSSIBLE IMPLICATIONS FOR THE TAXONOMY OF CEBINAE
Nova Delgado, Mònica; Galbany, Jordi; Górka, Katarzyna; Pérez-Pérez, Alejandro
Universitat de Barcelona, Barcelona, Spain

P-053 EFFECT OF ROBERTSONIAN TRANSLOCATIONS ON COVARIANCE STRUCTURE AND MODULAR ORGANIZATION OF THE MOUSE MANDIBLE
Martínez-Vargas, Jessica (1); Medarde, Nuria (1); López-Fuster, María José (2); Ventura, Jacint (1); Muñoz-Muñoz, Francesc (1)
(1) Universitat Autònoma de Barcelona, Cerdanyola del Vallès, Spain; (2) Universitat de Barcelona, Barcelona, Spain

P-054 DENTAL SHAPE MODULARITY AND PHENOTYPIC VARIATION IN HUMAN POPULATIONS
Torrij, Stéphanie (1); Romero, Alejandro (1); Galbany, Jordi (2); Gamarra, Beatriz (2); De Juan, Joaquín (1); Pérez-Pérez, Alejandro (2)
(1) Department of Biotechnology, University of Alicante, Alicante, Spain; (2) Department of Animal Biology, University of Barcelona, Barcelona, Spain

P-055 HISTOLOGICAL CHANGES DURING THE POSTNATAL DEVELOPMENT OF THE HOUSE MOUSE MANDIBLE
Martinez-Maza, Cayetana (1); Martínez-Vargas, Jessica (2); López-Fuster, María José (3); Molinero, Amalia (2); Cubo, Jorge (4); Ventura, Jacint (2)
(1) Museo Nacional de Ciencias Naturales (CSIC), Madrid, Spain; (2) Universitat Autònoma de Barcelona, Cerdanyola del Vallès, Spain; (3) Universitat de Barcelona, Barcelona, Spain; (4) Université Pierre et Marie Curie, Paris, France

P-056 CANINE EVOLUTION IN SABRETOOTHED CARNIVORES: NATURAL SELECTION OR SEXUAL SELECTION?
Randau, Marcela (1); Carbone, Chris (2); T.Turvey, Samuel (2)
(1) University College London, London, United Kingdom; (2) Institute of Zoology, Zoological Society of London, London, United Kingdom

P-057 PHYLOGENETIC SIGNAL OF DENTAL SHAPE IN EXTANT AND FOSSIL CATARRHINE PRIMATES: A GEOMETRIC MORPHOMETRIC ANALYSIS OF MOLAR CROWN
Gamarra, Beatriz (1); Nova Delgado, Mónica (1); Romero, Alejandro (2); Galbany, Jordi (1); Pérez-Pérez, Alejandro (1)
(1) Universitat de Barcelona, Barcelona, Spain; (2) Universidad de Alicante, Alicante, Spain
P-058 THE RADIAL SESAMOID OF INDARCTOS ARCTOIDES, THE FIRST EVIDENCE OF A FEEDING RELATED FALSE THUMB
Abella, Juan (1); Valenciano, Alberto (2); Pérez-Ramos, Alejandro (3); Montoya, Plinio (4); Morales, Jorge (5)
(1) Institut Català de Paleontologia Miquel Crusafont, Universitat Autònoma de Barcelona, Barcelona; Museo Nacional de Ciencias Naturales (MNCN-CSIC), Madrid, Spain; (2) Instituto de Geociencias (UCM, CSIC); Departamento de Paleontología UCM, Madrid, Spain; (3) Institut Cavanilles de Biodiversitat i Biologia Evolutiva, Universitat de València, Valencia, Spain; (4) Universitat de València, Valencia, Spain; (5) Museo Nacional de Ciencias Naturales-CSIC, Madrid, Spain

P-059 DENTAL WEAR PATTERN IN RHIZOMYS (RODENTIA, SPALACIDAE)
López Antoñanzas, Raquel
Museo Nacional de Ciencias Naturales, Madrid, Spain

P-060 MECHANISMS AND TIMING OF REPLACEMENT DENTAL LAMINA REGRESSION
Dosedelova, Hana (1); Dumkova, Jana (2); Lesot, Herve (3); Glocova, Kristyna (1); Hampl, Ales (2); Tucker, Abigail (4); Buchtova, Marcela (5)
(1) Department of Anatomy, Histology and Embryology, Faculty of Veterinary Medicine, University of Veterinary and Pharmaceutical Sciences, Brno, Czech Republic; (2) Department of Histology and Embryology, Faculty of Medicine, Masaryk University, Brno, Czech Republic; (3) INSERM UMR1109, team “Osteoarticular and Dental Regenerative NanoMedicine”, Université de Strasbourg, Strasbourg, France; (4) Department of Craniofacial Development, King’s College London Dental Institute, London, United Kingdom; (5) Institute of Animal Physiology and Genetics, v.v.i., Academy of Sciences of the Czech Republic, Brno, Czech Republic

P-061 FUNCTIONAL MECHANICS OF ORNITHOMIMOSAURS
Cuff, Andrew; Rayfield, Emily
University of Bristol, Bristol, United Kingdom

P-062 INTERSPECIFIC DIFFERENCES IN MYOSIN EXPRESSION CHARACTERIZE CYPRINIFORM JAW ADDUCTORS
Hernandez, L. Patricia; Staab, Katie Lynn
George Washington University, Washington, United States

P-063 EFFECT OF LINGUAL SENSORY LOSS ON OROMOTOR FUNCTION IN PIGS
Williams, Susan; Montuelle, Stephane
Ohio University, Athens, United States

P-065 THE FRONTAL SINUSES OF SIMOCYON BATALLERI (CARNIVORA, AILURIDAE) FROM THE LATE MIOCENE OF BATAILLONES-1 (Torrejón de Velasco, Madrid)
Pérez-Ramos, Alejandro (1); Salesa Calvo, Manuel J. (2); Antón, Mauricio (2); Morales, Jorge (2)
(1) Institut Cavanilles. Universitat de València, Paterna, Spain; (2) Museo Nacional de Ciencias Naturales-CSIC, Madrid, Spain
P-066 USING MICROCT AND FINITE ELEMENT ANALYSIS TO COMPARE DEVELOPING ORGANISMS, A 3D-ILEMMA
Peterson, Tim; Müller, Gerd
Universität Wien, Vienna, Austria

P-067 FUNCTIONAL MORPHOLOGY OF THE FEEDING BEHAVIOR IN T. DOBROGCUS, KIRITZESCU 1903 (URODELA, SALAMANDRIDAE)
Kucera, Florian
Universität Wien, Wien, Austria

POSTER SESSION: ALLOMETRY/MODULARITY

P-069 EVIDENCE FOR DIFFERENTIAL ALLOMETRIC EFFECT ON CARNIVORAN SCAPULAR SHAPE
Gálvez-López, Eloy
Dept. of Animal Biology, University of Barcelona, Barcelona, Spain

P-070 DELIMITING THE BODY MASS RANGE OF ANCIENT AVIAN FLYERS
Serrano, Francisco José (1); Martín-Serra, Alberto (1); Palmqvist, Paul (1); Sanz, José Luis (2)
(1) Universidad de Málaga, Málaga, Spain; (2) Universidad Autónoma de Madrid, Madrid, Spain

P-071 THE NATURE OF SHAPE VARIATION IN THE SKULL AND H Horns of the Tapaça Clade of Horned Lizards (Phrynosoma), Based Upon Cranial Geometric Morphometrics of the Greater Short-Horned Lizard (P. Hernandesii)
Powell, G. L. (1); Russell, A.P. (1); Jamniczky, H.A. (2); Hallgrímsson, B. (2)
(1) Dept. Of Biological Sciences, University of Calgary, Calgary, Canada; (2) Dept. Of Cell Biology and Anatomy, McCaig Institute for Bone and Joint Health, Faculty of Medicine, University of Calgary, Calgary, Canada

P-072 RELATIVE GROWTH AND MORPHOLOGICAL VARIATION IN THE SKULL ROOF OF AELUROGNATHUS (THERAPSIDA, GORGONOPSIA)
Norton, Luke A.; Rubidge, Bruce S.; Abdala, Fernando
University of the Witwatersrand, Johannesburg, South Africa

POSTER SESSION: GENERAL MORPHOLOGY

P-073 COMPARATIVE MORPHOLOGY AND HOMOLOGY OF THE PARASPHENOID BONE IN VERTEBRATES
Atkins, Jade (1); Franz-Odendaal, Tamara (2)
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(1) Downstate Medical Center, Brooklyn, NY, United States; (2) Icahn School of Medicine at Mount Sinai, New York, United States; (3) Icahn School of Medicine at Mount Sinai, New York, United States

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# 10th International Congress of Vertebrate Morphology

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PLENARY LECTURES

PT-001
THE EVOLUTIONARY BIOMECHANICS OF GIANT LAND ANIMALS
Hutchinson, John
*Structure & Motion Lab, The Royal Veterinary College, United Kingdom*

My research aims to reconstruct how the terrestrial gait dynamics of tetrapod vertebrates evolved and how body size, morphology and biomechanics influence this evolution. While there might be said to be a reasonable understanding of normal walking and running dynamics in some small to medium-sized tetrapods, I am motivated to fill in the large gaps in the understanding of their giant descendants and cousins. Thus my team takes a multidisciplinary approach to studying the evolutionary biomechanics of land animals, especially in the context of body size. While I conduct very detailed studies of living animals, the ultimate goal of my studies is to pull these analyses backwards through evolutionary time and reconstruct locomotor evolution. To do this, my team must emphasize methods that (1) test their validity by applying them to extant animals in at least as much, if not more, detail and rigour than for extinct taxa; and (2) circumscribe the reliability of conclusions drawn from their results by quantifying the accuracy of any measurements, whether morphological, experimental or simulation. We also thereby contribute new data on living animals that also gives valuable insights into what extinct animals may have been like. I will illustrate these principles by drawing on three examples from projects I have led: the evolution of dinosaur locomotion, the evolution of proboscidean foot form and function, and how stem tetrapods moved on land. A common theme that emerges from these studies is that while land giants are extreme animals that reveal the extreme dominance of gravity upon their morphology and performance, even at very large absolute or relative sizes they can still be capable of surprising abilities. However, at the same time giant land animals may in some ways be more fragile than their size intimates.

PT-002
RECOGNIZING A ONE-WAY STREET - THE ROLE OF AERODYNAMIC VALVES AND UNIDIRECTIONAL AIRFLOW IN THE EVOLUTION OF ARCHOSAURS
Farmer, Colleen
*University of Utah, Salt Lake City, United States*

The reasons for major transitions in the history of life are largely unknown. Since the Carboniferous Period two amniote clades have dominated tetrapod evolution in an alternating manner correlating with fluctuations in atmospheric oxygen. Synapsids were the most common large land animals during the oxygen-rich Carboniferous and Permian Periods; a few families survived the End Permian mass extinction and persisted as the dominant members of their assemblages until the Middle Triassic. Archosaurs subsequently occupied niches of large and active animals with synapsids (mammals) restricted to niches of small body size for the remainder of the Mesozoic. Was this faunal turnover a historical contingency, or did the archosaurs usurp synapsid dominance as atmospheric oxygen plummeted during the Triassic? Fluctuations in atmospheric oxygen may have been a particularly important driver in the evolution of diffusion-dependent processes of respiration; respiration in turn affecting the evolution of aerobic capacities, locomotor capacities, body size, and other key life-history traits that underpin ecomorphological diversification. Thus, understanding the evolutionary history of the amniote lung may shed light on this faunal turnover. Birds are renowned for their abilities to exercise at altitudes where the air is so rarified it induces coma in resting mammals. This capacity arises in part from their pulmonary anatomy. Recent studies show that key features of this anatomy, such as aerodynamic valves and unidirectional airflow through open ended tubular structures, are not unique to birds, but are also present in their sister taxon, the crocodilians. These discoveries, combined with pulmonary studies of lepidosaurs, the sister taxon to archosaurs, are removing the shroud of uncertainty that has obscured the form and function of the respiratory system of the Early Triassic animal that gave rise to the great archosaur radiation and retrodict the evolution of a lineage with great aerobic capacities in low oxygen environments.

PT-003
FUNCTIONAL MORPHOLOGY AND EVOLUTION OF PLACENTAS IN REPTILES
Blackburn, Daniel
*Trinity College, Hartford, CT, United States*

Viviparity (live-bearing reproduction) has originated independently in more than 160 vertebrate lineages, including over 115 clades of reptiles. In all viviparous lizards and snakes (squamates), pregnant females...
maintain their developing embryos by means of placentas formed from fetal and maternal tissues. Our lab uses morphological techniques to analyze squamate placentas in terms of their structure, function, and evolution. The chorioallantoic placenta shows morphological specializations for gas exchange, including increased vascularity and highly attenuated chorionic and uterine epithelia. The yolk sac placenta can exhibit adaptations for nutrient transfer such as specializations for maternal secretion and fetal absorption. By virtue of their functions in oviparous squamates, the uterus and fetal membranes have easily been co-opted for their more extended functions in viviparous forms. In five separate lizard clades, placentas show dramatic specializations for nutrient provision that are strongly convergent on those of eutherian mammals. Among them is an African lizard recently shown to ovulate tiny eggs that undergo invasive implantation into the uterus. Evolutionary convergence is dramatically represented at hierarchical levels ranging from histological through subcellular levels. Reptile viviparity and placentation illustrate several basic principles of evolutionary morphology, including homoplasies, heterochrony, exaptation, constraint, and functional conflict, as well as unidirectional and punctuated equilibrium patterns of evolutionary change.

PT-004
ABYSSAL MONSTERS, TROGLOBITES AND INSULAR CHIMERAS: ISLAND-LIKE SETTINGS AS NATURAL LABS
Köhler, Meike (1); Pretus, Joan Lluís (2)
(1) Institut Català de Paleontologia, Universitat Autònoma Barcelona, Spain; (2) Dep. Ecologia, Universitat Barcelona, Barcelona, Spain.
Vertebrates endemic to isolated environments such as islands, caves or abyssal depths share an important series of otherwise uncommon morphological, behavioral, physiological and life history traits. In these settings, certain laws do not seem to apply, such as the allometric scaling of morphological, physiological and life history traits with body size, or the timing of developmental stages. Thus, vertebrate species endemic to these environments tend to change their body size, reduce their locomotor system (legs, wings, fins), their nervous system (brain, sense organs), behavioral traits (aggression, vigilance, locomotion, courtship), their metabolic rates (BMR, FMR) and their reproductive rates, while they increase their harvesting and digestive capacities and extend juvenile period and life span. These parallel trends indicate that the selective forces behind these adaptations are the same in all these environments that, at a first glance, appear to differ greatly. Common to these environments is the high degree of isolation that allows two main selective forces to operate (i) low extrinsic mortality (release from predation pressure) and (ii) low levels of food supply. Combined, these selection pressures act on key life history traits as the principal source of fitness, triggering shifts in the fundamental trade-offs involving reproductive investment, growth and survival. Many though not all changes in morphological traits are simply a consequence of changes in these life history traits. We will show how these evolutionary processes can be reconstructed in fossil insular mammals.

PT-005
DEVELOPMENT AND EVOLUTION IN EARLY AMPHIBIANS
Schoch, Rainer
Staatliches Museum fuer Naturkunde, Stuttgart, Germany
Modern amphibians have diverse and often complex life cycles, but many taxa share a drastic metamorphosis. This morphological transformation is usually connected with a transition from water to land, and presumed to be the ancient life cycle for the lissamphibian ancestor. Developmental data from the fossil record have recently amounted, permitting analysis of extinct life cycles. These data show that early amphibians also had diverse ontogenies, which were rather different from those of modern taxa in that no drastic metamorphosis occurred. Most early tetrapods were aquatic, with adults retaining gills. Taxa with terrestrial adults transformed slowly within 1–2 years, as skeletochronology revealed. Stem-amphibians (temnospondyls) show a remarkable developmental plasticity, but only in a single clade (dissorophoids) did clear-cut terrestrial adult morphs evolve, and in these taxa a marked metamorphosis was established. The new data show that salamander-like larvae and terrestrial adults evolved together, with metamorphosis as an increasingly short and drastic series of events. Neoteny, the attainment of sexual maturity in the larval state, also first evolved in this clade. Plasticity and canalization were central factors in the evolution of amphibian development, with the ancient life cycles and metamorphosis forming alternative life history strategies.
SYMPOSIA

Symposium 1 – EvoDevo and Vertebrate Morphology: Old Wine, New Bottles (and Also New Wine)
Organizers: Diego Rasskin-Gutman & Gerd B. Müller

S-001
AN ORGANISMAL PERSPECTIVE IN EVODEVO; A LEGACY OF PERE ALBERCH
Wake, David
University of California, Berkeley, United States

Gould’s book “Ontogeny and Phylogeny” was an important factor in the establishment of evodevo as a research enterprise. Pere Alberch was a student already pursuing research in this area when the book appeared, and led the way in formalizing concepts relating to such issues as heterochrony and constraints on the direction of evolution. Although formulated initially as an integrated, organismal approach, individual traits and modules soon came to dominate research strategies. I review early stages in the development of evodevo, with an emphasis on the role Pere Alberch played. I will argue that there is a continued need for an organismal perspective in evodevo research, using examples from current research on vertebrates.

S-002
EVODEVO AND MORPHOLOGICAL NOVELTY: THE VERTEBRATE LIMB
Müller, Gerd B.
University of Vienna, Vienna, Austria

The vertebrate limb is a classical model of EvoDevo research, also used by Pere Alberch. The limb model served to exemplify a number of early EvoDevo concepts, such as heterochrony and developmental constraint, but also more recent ones, such as evolvability, modularity, and novelty. This lecture will concentrate on the latter. Using examples of ongoing work in our lab, it will be examined how the origin of novelty can be addressed with the limb system. Particular emphasis will be given to digit gain and digit loss, and to processes that span the gene regulatory, cell patterning, and physical levels of development. The results will be discussed in light of the ongoing debate on the status of the novelty problem in evolutionary theory. Is novelty a unique type of evolutionary phenomenon, or has it merely informal meaning? Is it part of the adaptive complex, or does it transcend strict adaptivity? Is it experimentally inaccessible, or can EvoDevo solve the novelty problem?

S-003
HOW NATURAL SELECTION SEES MORPHOLOGY? A MODEL BRINGING DEVELOPMENT INTO THE PICTURE
Marin-Riera, Miquel; Salazar-Ciudad, Isaac
Universitat Autónoma de Barcelona, Bellaterra, Spain

How does natural selection “see” morphology? Are all aspects of morphology fine-tuned by natural selection or does it only take into account overall features of form? The complexity of the relationship between genotype and phenotype, or genotype-phenotype map (GPM), arising from development may preclude adaptation by creating a rugged adaptive landscape. However, different ways of “seeing” morphology, that is phenotype-fitness maps, may facilitate adaptation by smoothing the fitness landscape. In this study we use an evolutionary model with a development-based realistic genotype-phenotype map (a model of mammalian tooth development) in order to quantify the ability of different phenotype-fitness maps, to drive adaptation. We implement a fine-tuning phenotype-fitness map based on the Euclidean Morphological Distance (EMD) between two morphologies, in which all the points in the morphology contribute equally to the distance. We also implement a coarse grained phenotype-fitness map that is the Orientation Patch Count (OPC), a multivariate measure of the ruggedness of teeth that has been observed to be correlated to diet in mammals. Evolutionary simulations show that only the coarse grained phenotype-fitness map leads to substantial adaptation when used, because it is degenerate and smooths the whole adaptive landscape. The fine-tuning phenotype-fitness map doesn’t smooth the landscape, thus becoming highly rugged and preventing adaptation. Our results suggest that adaptive morphological change is only possible when natural selection acts on overall features of morphology, when a complex, realistic, genotype-phenotype map is taken into account.

S-004
THE GENERATION OF VARIATION AND DEVELOPMENTAL CONSTRAINTS IN THE VERTEBRATE SKULL
Hallgrimsson, Benedikt (1); Young, Nathan (2); Pavlicev, Mihaela (3); Mitteroecker, Philipp (2); Gonzalez, Paula (4); Martinez-Abadias, Neus (5); Jamniczky, Heather (1); Marcucio, Ralph (2)

Anatomical Record, Volume 296, Special Feature — 123
Pere Alberch’s paper on developmental constraints in the 1982 Dahlem conference volume was influential because it crystallized the developmental constraint concept for so many evolutionary biologists. In this paper, he imagined a discontinuous phenotype space in which the gaps were determined not just by the adaptive landscape but also by the developmental processes that generate variation. Thirty years later much more is known about the mechanisms that generate and structure the expression of phenotypic variation. Evolutionary developmental biology has also matured in this time and concepts such as modularity, integration and novelty have become key theoretical anchors for the field. Still, Alberch’s focus on the generation of variation and, in particular, on the role of development in producing discontinuities in morphospace has tremendous resonance in modern evolutionary developmental biology. Drawing on our work on the collaborative cross mice, various mouse and chick models, human genetics as well as comparative analyses of facial morphogenesis, we show how a focus on the mechanisms that generate phenotypic variation can produce insights into the evolvability of complex morphologies. In this way, Alberch’s contention that the generation of variation imparts structure on the diversity in nature resonates still with our ongoing work on the evolutionary developmental biology of the vertebrate craniofacial complex.

S-005
HOW TO MEASURE HETEROCRONY? MODERN MORPHOMETRICS IN EVODEVO
Mitteroecker, Philipp
University of Vienna, Vienna, Austria
In their influential 1979 paper, Pere Alberch and colleagues introduced the analysis of ontogenetic trajectories in a two-dimensional size-shape space as a tool to compare pathways of animal development. Their approach – one of the few quantitative attempts to EvoDevo – was particularly aimed at assessing heterochrony, i.e., evolutionary changes of developmental timing. While the concept of trajectories in size-shape space was a major conceptual advancement, the univariate notion of shape has also led to numerous problems in empirical morphometric studies, such as the impossibility to reject any hypothesis of heterochrony. Extending the notion of heterochrony to multivariate shape spaces allows for a testable definition of heterochrony, but global heterochrony for all measured traits appears to be unlikely. The challenge of modern morphometrics in EvoDevo is to identify factors of shape variation, for which the underlying growth processes have truly evolved by heterochrony. I illustrate these approaches using geometric morphometric data on human cranial growth, which has often been claimed to be the result of heterochrony.

S-006
EVODEVO, MODULARITY, AND DEVELOPMENTAL CONSTRAINTS: THE TETRAPOD SKULL
Rasskin-Gutman, Diego; Esteve-Altava, Borja
University of Valencia, Valencia, Spain
The latest evolution of EvoDevo, ever since the work of Pere Alberch in the late 70s and 80s, has experienced important developments. Most of them are related, but not limited to, the vertiginous advancement of comparative genomics. However, keywords of the early morphological EvoDevo research are coming back in different flavors. We are going to look at the skull, as the seat of important evolutionary novelties in the morphological history of vertebrates. In our research group we have been testing computer simulations to analyze developmental and evolutionary relationships in the general context of Williston’s Law, a broad morphological trend that describes a reduction in the number of bones in the skull. We base our work on Network Theory, using connectivity patterns among skull bone sutures, enabling not only an efficient description of structural relationships but also in silico experiments. This allows us to rescue old morphological ideas in a new, precise and quantitative framework, and to carry out EvoDevo analyses that include heterochrony, developmental constraints, and modularity. In addition, networks highlight the structural role of each bone and the developmental constraints they might be subject to as a consequence of their connectivity pattern. In this context, constraints can be identified from connectivity relations that point to developmental factors that influence the evolution of the tetrapod skull.

Symposium 2 – The Anatomical, Biomechanical, and Energetic Basis of Hominin Bipedalism
Organizers: David Carrier & Kristiaan D’Aout

S-007
BIPEDAL WALKING IN NON-HUMAN PRIMATES
Aerts, Peter (1); Berillon, Gilles (2); Daout, Kristiaan (1)
(1) University of Antwerp, FunMorph-lab, University of Antwerp, Belgium; (2) Centre National de la Recherche Scientifique, Paris, France

In order to understand the dynamics of bipedal versus quadrupedal locomotion, we collected kinematic, kinetic, and morphometric data on several non-human primate species: a generalist and occasional biped, the bonobo (a “good” model for early hominins?) and the Olive baboon, a specialist terrestrial quadruped also engaging in bipedalism. We report on previously published, and unpublished results of terrestrial quadrupedalism and bipedalism, and climbing on different slopes in the bonobo, and on terrestrial quadrupedalism and bipedalism in the baboon. Moreover, we include results on the dynamic transition from quadrupedalism to bipedalism. Results were compared with literature data on human locomotion.

All species increase stride frequency and stride length to increase speed. Limb excursions are larger than in humans, especially during quadrupedalism. Inverse dynamic analyses of the bonobo reveal that all forms of locomotion are mainly hip powered (unlike humans, which are mostly ankle powered during walking). Both non-human primates transit relatively easily between quadrupedalism and bipedalism and show small fluctuations in mechanical energy. Humans need much higher energy input to transit into upright walking. However, the basic mechanism is shared by all three species and consists of a forward repositioning of the leading limb in front of the centre of mass, enabling the needed upward trunk rotation.

We conclude that overall, gait dynamics between the non-human apes are rather similar but very different from humans. For a facultative or primitive biped (e.g. early hominins) bipedalism, albeit probably relatively easy, was probably costly; transitions between gait types however were probably relatively efficient.

S-008
EVOLUTION OF THE LUMBAR PERIVERTEBRAL MUSCLES IN APES - IMPLICATIONS FROM FIBER TYPE COMPOSITION
Schilling, Nadja
Friedrich-Schiller-University, Institut of Systematic Zoology and Evolutionary Biology, Germany

The axial musculoskeletal system plays a central role in both locomotor and non-locomotor behavior and therefore the musculature surrounding the vertebral column reflects the various demands of the static and dynamic control of the body posture and the integration of the action of the limbs and trunk. As a consequence, major evolutionary changes in the positional habits of a species are accompanied by morpho-functional adaptations of the axial system. Because of the remarkable phenotypic plasticity of muscle tissue, a close relationship exists between muscle morphology and function. One mean to explore major evolutionary transitions in muscle function is therefore the comparative analysis of fiber type composition. In this study, the distribution of slow and fast muscle fibers was analyzed three-dimensionally in the lumbar perivertebral muscles of two non-hominoid (mouse lemur, brown lemur) and five hominoid primate species (white-handed gibbon, orangutan, bonobo, chimpanzee, human) in order to develop a plausible scenario for the evolution of the contractile properties of the axial muscles in hominoids and discern changes in muscle physiology that were associated with the evolution of orthograde. In contrast to all previously studied quadrupedal mammals, which shared the same morpho-functional dichotomy between deep slow contracting local stabilizer muscles and superficial fast contracting global mobilizers and stabilizers, the hominoid primates showed no regionalization of the different fiber types. Rather, all apes possessed a homogeneous fibre composition that is indicative for muscles that fulfill multiple functions by bringing fibers with different contractile properties into biomechanically advantageous positions. This homogeneous fiber composition is suggested to be associated with the high functional versatility that was associated with the evolution of orthograde behaviors and reflects the broad range of mechanical demands acting on the trunk during orthograde behaviors in apes.

S-009
DIFFERENCES IN THE MECHANICS OF CHIMPANZEE AND HUMAN BIPEDAL WALKING
Umberger, Brian R. (1); O’neill, Matthew C. (2); Demes, Brigitte (2); Lee, Leng-Feng (1); Thompson, Nathan E. (2); Larson, Susan G. (2)
(1) University of Massachusetts, Amherst, United States; (2) Stony Brook University, Stony Brook, United States

Human walking is remarkably economical, both in comparison to mammals as a group and especially compared to our closest living relative, the chimpanzee. Identifying factors that underlie the differences in locomotor costs between humans and chimpanzees will further our understanding of human adaptations for habitual bipedalism. While the mechanics and energetics of human walking have been thoroughly described, they are still poorly defined for chimpanzees. Here, we present a preliminary report on three-dimensional joint mechanics and mechanical energetics during bipedal walking in chimpanzees and
humans. Anatomical marker positions and ground reaction forces were recorded from three chimpanzees (Pan troglodytes) and twelve humans (Homo sapiens) walking bipedally overground. The kinematic and kinetic data were combined with segment inertial parameters to compute three-dimensional hip, knee and ankle joint moments and powers over the full stride cycle (stance and swing phases). Stance phase joint moments were biased toward the hip for chimpanzees and the ankle for humans. This places a greater demand on larger, more costly proximal muscles in chimpanzees. Chimpanzees relied more on the knee extensors for energy generation than humans, though the hip and ankle were the major sites of energy generation in both species. Compared with humans, swing phase joint moments and powers in chimpanzees were relatively large, being similar in magnitude to moments and powers generated during the stance phase. This was especially true for the hip joint, in all three planes, suggesting a more actively controlled (i.e., less-pendular) leg swing motion in chimpanzees. Thus, muscle actions during the swing phase may contribute to the higher metabolic cost of walking in chimpanzees relative to humans. These data will form the basis for subsequent computer simulations that will provide more direct insight as to differences in muscle function during locomotion in chimpanzees and humans. Supported by NSF BCS-0935327 and BCS-0935321

S-010
PLANTAR PRESSURE DISTRIBUTION DURING WALKING AND RUNNING IN HABITUALLY UNSHOD HUMANS
Wunderlich, Roshna E. (1); Hatala, Kevin G. (2); Dingwall, Heather (3); Richmond, Brian R. (4)

Numerous recent descriptions of fossil hominin pedal remains as well as the 1.5-million-year-old hominin footprints near Ilorin, Kenya offer new opportunities to analyze the early evolution of the human foot. However, these discoveries have also highlighted the importance and the paucity of quantitative pedal biomechanics data on humans whose feet have not been influenced by modern footwear and the relationships of these biomechanical variables to the morphology of feet and footprints. We examined plantar pressure distribution in two populations, both unshod or minimally shod, and one population of healthy shod western adults. 28 adults from southern Madagascar, 38 adults from northern Kenya (Daasanach), and 295 adults from the U.S. walked barefoot across a plantar pressure mat at self-selected walk, slow run and fast run paces. Video was collected for kinematic analysis, and steps were compared within and across speeds. Peak pressures were generally lower in unshod populations than in shod populations, supporting the findings of D’Aou et al (2009). Significantly lower pressures in the medial heel, metatarsals, and first toe were observed in both unshod populations compared to the shod group. However, differences were also observed between the unshod populations: Malagasy subjects had higher medial midfoot peak pressures, while the Daasanach had higher lateral midfoot and first metatarsal peak pressures. Reduction in metatarsal and heel peak pressures in unshod populations may be due to morphological (soft tissue, foot width) or kinematic features facilitating attenuation of high loads. The higher toe/metatarsal load ratio during walking in unshod individuals is particularly important to our interpretation of fossil forefoot remains (e.g. metatarsophalangeal joints) and footprints in which the loading environment is preserved. The differences in pedal pressures between populations underscore the importance of understanding foot function in habitually unshod people for interpretations of the functional significance of fossil hominin pedal remains and footprints.

S-011
EVOLUTIONARY CONSEQUENCES OF THE REPRODUCTION-LOCOMOTION NEXUS ON HUMAN SEXUAL DIMORPHISM
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Among sexually dimorphic features of the human skeleton, a few are particularly important for locomotion, namely: overall size, the shape of the pelvic girdle, and the proportions and lengths of the lower limbs. Across populations, males are absolutely larger in terms of mass, stature and lower limb length, whereas females have wider pelvies relative to size. Variation between the sexes in these traits has consequences for the energetic cost of transport (CoT) and the speed of travel; we thus expect that these morphological differences lead to sex-specific energetic costs and strategies of mobility. Furthermore, we maintain that sex differences in form, combined with reproduction-related physiological and behavioral...
differences, represent an adaptive suite of characters resulting from sex-specific selection pressures linked to locomotion. We present data on the energetic and thermoregulatory differences between males and females walking with and without loads across a range of speeds and substrates. Without loads, males have significantly faster optimal walking speeds, higher costs at their optimal (minimal CoT) speed, and a more acute optimal walking curve (thus an increased penalty for walking at sub-optimal speeds). People with relatively wider bi-trochanteric breadths (for their mass; generally females) have lower costs at their optimal speed. Additionally, during loaded walking, a relatively wider pelvis increases both stride length and speed flexibility, providing a morphological offset for load-related costs. Without loads, walking females build up less of a heat load than males; however, with loads this pattern is reversed and females choose to walk at slower speeds. This suggests a behavioral compromise that modulates heat load. As minimizing both heat gain and energy consumption are essential for successful reproduction, these data suggest that females’ small size promotes heat loss, their slow speeds prevent excessive heat gain, and their wide pelves provide energetic benefits during loaded and unloaded walking.

S-012
HUNTER-GATHERER ENERGETICS AND LOCOMOTION
Pontzer, Herman (1); Raichlen, David (2); Wood, Brian (3); Mabulla, Audax (4); Marlowe, Frank (5)
(1) Hunter College, City University of New York, United States; (2) University of Arizona, School of Anthropology, United States; (3) Yale University, Dept. of Anthropology, United States; (4) University of Dar es Salaam, Department of Archaeology, United Republic of Tanzania; (5) Cambridge University, Department of Anthropology, United Kingdom

Evolutionary reconstructions of the hominin lineage often assume that metabolic efficiency was a strong selective pressure on locomotor anatomy and ranging behavior. Human locomotor anatomy is thought to reflect an abandonment of the trees, and is also thought to constrain our preferred ranging behavior as humans exhibit a distinct minimum-cost walking speed. Evidence for these assumptions comes mostly from Western, industrialized cultures, where adults rarely climb and appear to prefer walking speeds near their minimum-cost speed, but data from hunter-gatherers (which are better models for our evolutionary past) are lacking. Here, we examine ranging data collected from 47 adult Hadza hunter-gatherers to test whether traditional foragers use a constrained set of energy-minimizing walking speeds, and whether tree climbing is a substantial component of their locomotor regime. Subjects wore a small GPS unit and chest-strap heart rate monitor during daylight hours over a two-week period (n=428 person-days). In separate trials, walking cost (energy/meter) was measured in a subset of subjects (n=14) using respirometry. Results provide only limited support for the hypothesis that energy efficiency is a strong determinant of human ranging ecology. Hadza foragers used super-diffusive Levy search strategies during many forays, particularly when hunting for game; such strategies may maximize encounter rates. However, while Hadza adults exhibited walking costs similar to those of other populations, they did not constrain their walking to minimum-cost speeds. Most recorded walking bouts exceeded the minimum-cost speed by 20% or more. Hadza men also regularly climbed trees to forage for honey, and women occasionally climbed trees to forage for fruits and berries. These results challenge the primacy of energy efficiency as a selection pressure on human anatomy and ranging behavior. We discuss the implications of these findings in light of recent work linking locomotor anatomy and energetics in fossil hominins.

Organizers: Timothy Rowe, Jessica Maisano, Richard Ketcham, Matthew Colbert, & Brian Metscher
Workshop (no abstracts)

Symposium 4 – Vertebrate Limb Development
Organizers: Michael Richardson & Karen Sears

S-013
FROM FIN FOLDS TO FISH WITH FINGERS: A NEW EMPIRICS OF FIN AND LIMB EVOLUTION
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Paired appendages are the locus of a host of adaptations that underwrite much of the diversity of vertebrate form. Their origin was thus a landmark event in vertebrate evolution, making them the subject of intense focus for comparative evolutionary biologists. Historically, this problem has given rise to a series of hypothetical ancestral states drawn from comparative zoology, embryology, and palaeontology. These include hypotheses such as the lateral fin fold theory or Gegenbaur's archipterygium. Concurrently, many palaeontologists preoccupied themselves with the search for ancestors, attempting direct empirical
verification of these ancestor hypotheses. Here we review some of the advances in palaeontological understanding of early jawed vertebrates. We show how palaeontological view of the origin and diversification of vertebrate appendages has changed considerably in the past half century. This is not only due to new fossil discoveries, but also in a fundamental change about how palaeontologists think about fossils. The advent of phylogenetic methods has brought renewed significance to fossil groups that have been known for almost two centuries. What is evident in this great methodological and theoretical shift is that, while some fossils can still be interpreted in terms of classic archetypal forms, the role of fossils is now less direct. Fossils are now seen as sister groups, rather than as ancestors. A fossil that once might have been hailed as confirming an archetypal model might today puncture such a hypothesis simply through its placement in phylogenetic context with other species. In spite of this shift in thinking, there has been a resurgence of interest in archetypal ancestor models in both palaeontological and developmental literature. We explore the future of such models and consider their role against the background of recent progress in palaeontology and systematics.

S-014
PATTERNING THE LIMB
Wolpert, Lewis
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Embryonic patterning can be based on cells acquiring positional information from a concentration gradient of a molecule. Limb pattern is specified along three principal axes; antero-posterior, proximo-distal and dorso-ventral. Patterning across the antero-posterior axis is due to a graded signal of sonic hedgehog, but elements like digits are specified by a Turing mechanism. Specification of proximo-distal positional values is due to the time cells spend in the progress zone, specified by FGF beneath the apical ectodermal ridge. Dorso-ventral patterning involves signals from dorsal and ventral ectoderm. Hox genes are activated at specific positions. The molecular nature of positional values and those involved in the Turing mechanism remain unknown. Muscle patterning is due to the cells migrating to specific positions. Growth of cartilage elements is determined by their positional values, and is remarkably reliable as the two limbs grow to the same length over 14 years.

S-015
THE ROLE OF EARLY DEVELOPMENTAL CHANGES IN LIMB EVOLUTION
Sears, Karen
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The structure of the limb is central to a mammal’s feeding, locomotor, and behavioral adaptations. For example, the wings of bats enable powered flight, the flippers of whales an aquatic lifestyle, and the one-toed hooves of horses rapid locomotion. Diversity in mammalian limb structure has arisen primarily through evolutionary fine-tuning of the limb’s basic segments: a proximal segment with one bone, an intermediate segment with up to two bones, and a distal segment with up to five digits. As such, the major axes of the limb (i.e., anterior-posterior [AP], proximal-distal [PD], and dorsal-ventral [DV]) are conserved among mammals. This has led some researchers to hypothesize that the earliest development of the mammalian limb, which includes patterning of the limb’s axes, is less evolvable (i.e., more constrained) than later limb development. The existence of a constraint on early limb development is supported by several studies that have identified differences in later limb development (i.e., arising after the limb’s axes are patterned) among mammals with diverse limb phenotypes. However, a growing body of research suggests that early limb development is more evolutionarily flexible than originally supposed. Morphometric and gene expression analyses from my lab suggest that early limb development does display significant variation, but that mammalian limb development is constrained at the paddle stage of development. These findings advance our knowledge of how mammalian limbs diversify, and how development influences morphological evolution in general.

S-016
LIMB MORPHOGENESIS AND TERATOLOGY
Vargesson, Neil
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We recently demonstrated (Therapontos et al., 2009) how thalidomide causes limb malformations. Thalidomide was originally prescribed (between 1958-1962) to pregnant women suffering from morning-sickness (typically, but not exclusively, between weeks 5-10) - tragically over 10000 children were born with severe birth defects, notably, and most commonly, limb malformations. The drug is again used around the world today to treat leprosy and multiple myeloma. Tragically a new generation of thalidomide survivors is
being seen in Africa and South America. Through using analogs and metabolic byproducts of the drug, we showed that its the antiangiogenic action of the drug that causes limb defects, through preventing blood vessel migration into the developing limb bud. We further showed how the drug exerts its antiangiogenic effect, through preventing endothelial cell proliferation and migration and thus, preventing vessel tube networks from forming. At the time the limb forms (which in humans is around 5-8 weeks) it has a highly changeable vessel pattern - whereas the rest of the body has a stable vascular network. Thalidomide prevents new vessel outgrowth, which then causes an increase in cell death and loss of limb signalling pathways, stopping limb formation. Can we ever make a 'safe' form of the drug that remains clinically useful? Should we?

S-017
DIGIT LOSS AND THE STEPWISE DISAPPEARANCE OF ANCESTRAL DEVELOPMENTAL PATHWAYS
Richardson, M.K (1); De Bakker, M.A.G (1); Fowler, D.A. (1); Den Oude, K. (1); Dondorp, E.M (1); Garrido Navas, M. C (1); Horbanczuk, J.O (2); Sire, J.-Y (3); Szczerszynska, D (4)
(1) Dept. Integrative Zoology, Institute of Biology, Leiden University, Leiden, Netherlands; (2) Institute of Genetics and Animal Breeding, Polonia, Poland; (3) Evolution & Développement du Squelette, UMR 7138, Paris, France; (4) Department of Poultry and Ornamental Bird Breeding, Western Pomeranian University of Technology, Szczecin, Poland

In several vertebrate lineages, digits have disappeared from the limb. Digit loss may be adaptive, leading to more efficient running or flying; or it can result from disuse, as in the wings of flightless emus. The 'lost' digits may persist for millions of years as transient domains in the embryo. The developmental mechanisms underlying digit loss may include changes in sonic hedgehog (Shh) and Hox gene expression. What is not clear is how these developmental pathways change during evolution. To examine this question, we studied markers of limb and digit development in the clade of archosaurs (the Nile crocodile and five birds). This clade has undergone extensive reduction and loss of adult digits. We find that, in two independent lineages under different putative selection pressures, wing digit I completely disappeared in discrete steps. Bone was lost first, then cartilage, and finally reduction of the pre-cartilage marker Sox9. Digit V pathways were found to be more persistent, retaining Sox9 and cartilage domains 250 million years after the bony digit V disappeared. All limbs, regardless of how many digits they have lost, retain a posterior Shh domain during stages of digit specification. Even in the miniaturised and vestigial emu wing, early expression of posterior limb genes appears normal; there are, however, changes in expression of anterior genes. Our findings are consistent with models based on gradual modification of developmental pathways during evolution, rather than a sudden deletion of an entire digital pathway. The difference in the rate at which digits I and digit V pathways disappear, may be explained by an interplay between selection pressures and developmental constraints. Thus, the constraints may be stronger at the posterior margin of the limb because of the influence of the zone of polarising activity.

S-018
THE MOLE LIMB
Bickelmann, Constanze
Museum für Naturkunde - Leibniz-Institut für Evolutions- und Biodiversitätsforschung, Berlin, Germany

Moles present a new model organism for EcoEvoDevo studies, as the limbs of fossorial moles show a highly derived anatomy. Among other features, moles have extra digit-like structures present in hand and feet, planar enlarged hands compared to feet, and skeletal elements such as the humerus display unique anatomies. These morphological modifications have been related to ecological specialisation, because taxa most specialized ecologically display highly derived anatomies, in contrast to terrestrial, semi-fossorial and aquatic forms. Ecological transformations are gradually seen across phylogeny since mole origins in the Late Eocene. The molecular and chondrogenic development of the mole limb has been studied focusing on several elements. First, transcriptional heterochrony in the expression of Sox9 has been identified to account for pattern heterochrony in chondral limb development and the enlargement of hands compared to feet present in the fossorial Iberian mole *Talpa occidentalis*. Second, 3D reconstructions based on histological serial sections indicate that adult derived features in the humerus of *T. occidentalis* such as the broad- and stoutness, distinct articulations and facets, and the prominent torsion are already specified in miniature cartilage primordium; an example of developmental penetrance. However, in the semi-fossorial Japanese shrew mole *Urotrichus talpoides* and the terrestrial North American least shrew *Cryptotis parva*, the sister taxon of moles, this is not found. Third, although mole long bones show high morphological variation linked to locomotor behaviour, analysis of bone compactness has not been found to differ among taxa, most likely due to their small size. At last, ongoing study of spatial and temporal expression patterns of developmental genes *HoxD9*, *HoxA9*, *HoxD11*, and *Shox2* in *T. occidentalis*, compared to the traditional
model organism mouse, will help to elucidate differences in molecular mechanisms and developmental pathways involved in morphological modification.

Symposium 5 – Evolution of Locomotion: Reciprocal Illumination from a Diversity of Approaches
Organizers: Timothy Higham & Theodore Garland

S-019
LOCOMOTOR ONTOGENY AND THE EVOLUTION OF AVIAN FLIGHT
Heers, Ashley
University of Montana, Missoula, United States

Transitional fossils are the record of evolutionary transformations, key to deciphering the origins of major clades and organismal diversification. Bringing these fossils ‘to life’ to better understand evolutionary transitions involves reconstructing the function(s) of their anatomical features, by investigating how comparable features function in living organisms. Yet, extant adult forms and extinct fossils are often very different and thus difficult to compare. Here, I use theropod dinosaurs and their avian descendants to show how postnatal developmental transformations can help elucidate evolutionary transitions. Though juveniles are not often discussed in extinct-extant comparisons, developing birds share a number of similarities with the extinct theropods whose transitional skeletons and protowings record the origin of avian flight. Many immature birds rely on dinosaur-like, transitional skeletons and protowings to navigate habitats and reach refugia. Though not yet capable of flight, these juveniles use developing anatomies for intermediate locomotor behaviors like flap-running or steaming over water, where wings and legs are used cooperatively. Developing birds can thus elucidate potential locomotor capabilities of extinct theropods with similar anatomies, by actualizing form-function relationships through behaviors that bridge obligately bipedal to flight-capable transitions. To document feather and skeletal ontogeny in the precocial chukar (Alectoris chuka), I (i) used a propeller apparatus to measure aerodynamic forces generated by dried wings, and (ii) used high resolution CT scans and biplanar x-ray videos of different aged birds to quantify skeletal kinematics during various behaviors. My results show that juveniles and adults with highly disparate anatomies employ very similar skeletal kinematics, possibly due to differences in aerodynamic force production by protowings versus wings. Locomotor performance improves through ontogeny, but even young birds generate useful aerodynamic forces. This suggests that extinct theropods might also have been capable of more bird-like wingstrokes and greater aerodynamic force production than implied by their transitional morphologies.

S-020
SELECTION EXPERIMENTS AS AN APPROACH TO STUDY THE EVOLUTION OF VERTEBRATE LOCOMOTION
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The evolution of vertebrate locomotion is commonly studied via comparisons among living species or through examination of fossils. These approaches are highly informative, but are limited for various reasons, including common confounding of independent variables (e.g., diet and activity level), an inability to observe transitional forms (the evolutionary process), and because they can provide only correlational evidence. Selection experiments and experimental evolution approaches can overcome each of these limitations, but are rarely applied to the study of vertebrate morphology. However, several experiments with rodents have targeted aspects of locomotor behavior and/or performance, and are providing new insights concerning the evolution of locomotion. Examples will be reviewed, with emphasis on a long-term, replicated selection experiment with outbred laboratory house mice that has targeted voluntary exercise on wheels. The rodent selection experiments have yielded a range of interesting results, including information about the neural mechanisms that underlie voluntary locomotion (e.g., alterations in the reward system of the brain); skeletal, muscular, endocrine, and immune-system alterations associated with endurance running; “multiple solutions” (alternate adaptive responses) that permit high levels of sustained, aerobically supported locomotion; apparent trade-offs and other negative consequences associated with selection for high (or low) locomotor abilities; genetic correlations between maximal and basal metabolic rates; and the genetic and physiological basis of limits to the evolution of locomotor performance. These results and others encourage a broader use of selection experiments to study vertebrate evolutionary morphology and biomechanics, and could be combined with those from comparative studies to elucidate the interface between micro- and macroevolution. In addition, some limitations of selection experiments will be discussed, from the perspective that, as with all models of complicated phenomena, selection experiments are simplified abstractions of reality (i.e., evolution under natural conditions) that can provide us with important insights if interpreted with due caution.
S-021
WHAT SHOULD WE EXPECT FROM STUDIES OF SELECTION ON LOCOMOTION IN THE WILD?
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Several studies have quantified selection on locomotor performance in natural populations, typically by examining how maximal sprint speed or endurance capacity predicts survival. Whereas there is evidence that maximal locomotor capacity explains survival or other aspects of fitness in some species, this is not a universal finding. Furthermore, the limited data available for locomotor capacity use in nature do not consistently show that animals use maximal abilities in every, or in some cases in any, context. This lack of consistency across studies, combined with the existence of locomotor tradeoffs, questions whether selection does or even should operate on maximal locomotor capacity. I review studies of selection on locomotor performance in nature, field use of locomotion, and tradeoffs among speed and accuracy in performance. These types of studies had a brief flourish of popularity, but there has been little new data or theoretical development on these aspects of locomotor performance in recent years. I synthesize these studies to suggest that instead of expecting animals to typically use maximal capacity, and expecting selection to usually act on maximal locomotor performance, perhaps we should consider the role of mistakes, or failure at a task, in the evolution of locomotion. Understanding the costs and benefits of making mistakes, as well as the probability of being able learn from mistakes in different contexts, may be key to elucidating how locomotion is modulated in nature and how selection shapes it over evolutionary time. This approach may allow investigators to better focus their resources on what can be very time- and labor-intensive studies of selection on locomotion in the wild.

S-022
DIVERGENCE AND NOVELTY IN LOCUMOTOR EVOLUTION: INSIGHTS FROM STUDIES OF WATERFALL-CLIMBING GOBIID FISHES
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Many gobiid fish species living on oceanic islands exhibit amphidromous life cycles, in which larvae are swept to the ocean after hatching, and return to streams as postlarvae that climb waterfalls to reach adult habitats. This distinctive life history found among species living in many island systems, and in streams with different characteristics, has facilitated diverse studies of the evolution of locomotor systems and performance. High-speed videography identified two distinct climbing styles across species: powerbursting, involving pectoral fin adduction followed by axial undulation; and inching, involving alternating advancement of oral and pelvic suckers. How might evolution act on these two styles? Using selection analyses, we found a higher failure rate and stronger predominance of correlational selection in powerburst climbers, as might be predicted for a climbing style that requires more integrated fin and body axis movement. Inching is likely restricted to a single goby genus, suggesting it is a derived trait; moreover, the similarity of oral movements between feeding and climbing among inching climbers suggests that one of these behaviors may have evolved from the other via exaptation. In the Hawaiian Islands, the single inching species penetrates streams with different features: nearshore waterfalls on Hawai‘i emphasize climbing performance, but long meandering streams below waterfalls on Kaua‘i emphasize predator evasion. We found that climbing and predation impose selection favoring contrasting body shapes (streamlined for climbing, tall for predator evasion), and that fish returning to each island have shapes advantageous for the main pressure they encounter. These shape differences also correlate with performance differences that could form the basis for natural selection. Net climbing speeds are similar for fish from both islands, but only because fish from Kaua‘i rest less between bouts. Such differences may contribute to the lower climbing success of Kaua‘i versus Hawai‘i fish over long distances. NSF IOS-0817794, IOS-0817911.

S-023
HOW TRANSITIONS IN MODE OF LOCOMOTION HAVE SHAPED MACROEVOLUTIONARY PATTERNS IN VERTEBRATES
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Vertebrates occupy nearly all of Earth's major habitats, in large part due to the evolution of a rich diversity of locomotor adaptations. Recent phylogenetic and paleontological studies have helped map most major evolutionary transitions in locomotion onto the vertebrate phylogeny, although debate continues to surround the placement of a few. By combining a phylogenetic perspective with new information about the
development and functional morphology of key locomotor innovations, we may begin to answer longstanding questions about the pattern and process of macroevolution. Using a comparative approach, I first review the evidence for consistent trends in locomotor evolution: Does the evolution of new modes of locomotion follow a predictable sequence? I then ask whether evolutionary locomotor transitions are reversible. Certain types of reversals have occurred numerous times (e.g., evolution of walking or running locomotion from a predominantly flying ancestor), but reversals tend to leave an evolutionary signature. Flightless birds, for example, have never re-evolved the quadrupedality of their distant archosaurian ancestors. Locomotor "reversals" frequently do not involve reversion to ancestral morphologies, and are sometimes associated with novel innovations. I outline how past locomotor adaptations and major locomotor transitions have may have promoted, or in some cases constrained, subsequent adaptive diversification, highlighting several interesting patterns for future research.

S-024
MAKING WAVES: SELF-PROPELLED ROBOTS TEST HYPOTHESES ABOUT THE FUNCTIONAL AND EVOLUTIONARY MECHANISMS OF SWIMMING
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For biologists, physically-embodied robots are gaining traction as powerful tools for modeling complex systems. Because they interact directly with the world, embodied robots do not require physics to be modeled. Instead, biologists can focus on the decisions central to modeling the body and its behavior in the world: what hypothesis is the model testing? Which features of anatomy and physiology to include and which to omit? How abstract or simple should the model be? What elements of behavior of the model and the target need to be matched? What makes for a good model? We offer a number of examples of robotic models used to test biological hypotheses related to how fish swim and how they evolve.

S-025
PHENOTYPIC DIVERGENCE IN LACERTID LIZARDS: A COMPARISON OF EVOLUTIONARY RATES BETWEEN CLADES
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The Lacertidae form a speciose (>300 species) family of Old World small- to medium-sized lizards. Phylogenetically, the family comprises two main clades that reflect the distributional range of the species, i.e. the African and the Eurasian clade. Although the pattern and timing of radiation events within the family are still debated, the out-of-Europe hypothesis, positing that lacertids originated in Europe 65 MYA and colonized Africa around 17-19 MYA, seems most feasible. Whereas the European clade has been suggested to have radiated approximately 14MYA, the age of the African clade remains unclear, although recent studies have suggested it to be similar.

Lacertid lizards have been used extensively to test whether and how they are adapted to their environment. The majority of these studies have included European species, leaving African species underrepresented. However, preliminary analyses on external morphology and performance suggest the variation thereof among African lacertids is greater than that found among Eurasian lizards. Also, lacertid lizard communities on the African continent are more complex than the ones in Europe (i.e. comprising 7-8 species versus 2-3 species). We will compare evolutionary rates of locomotion-related phenotypic traits between the two lacertid clades and link them to the ecological diversification found within each clade.

S-026
USE IT OR LOSE IT: THE EVOLUTION OF LOCOMOTION ASSOCIATED WITH THE GAIN AND LOSS OF ADHESIVE CAPACITY IN GEEKOS
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Geckos are known for their remarkable ability to adhere to smooth and/or inclined surfaces. They do so with adhesive toe pads, which are morphologically diverse and have evolved multiple times within geckos. In addition to the acquisition of adhesive capabilities, there are several documented cases of loss of the morphological modifications associated with adhesion. The Pachydactylus clade is a group that exhibits two unequivocal losses of the adhesive apparatus (Chondrodactylus anguiller and Pachydactylus rangei). This clade occupies both sandy and rocky habitats in southern Africa, and the secondary loss of adhesion appears linked to shifts in habitat use from climbing to ground dwelling. Although the gain and loss of adhesion has been documented, little is known about the functional consequences of using or losing

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adhesion. Utilizing the *Pachydyactylus* clade, we examined the morphometric, integumentary, skeletal and muscular changes associated with the loss of adhesion. In association, we examined the high-speed three-dimensional kinematics of locomotion on level and 30-degree inclines of pad-bearing and secondarily padless taxa to determine the functional consequences of the presence and reduction of the adhesive apparatus. We examined 8 species spanning the clade, including representatives of *Rhoptropus*, *Pachydyactylus*, *Colopus*, and *Chondrodactylus*. Kinematics included three-dimensional angles of the hip, knee, ankle, and third metatarsal. In addition, we calculated femur rotation, retraction, and depression. Finally, we assessed patterns of digital hyperextension in relation to incline. To examine morphology and kinematics in a phylogenetic framework, we pruned a published phylogeny that was developed using DNA sequence data consisting of fragments of five nuclear protein-coding genes and one mitochondrial gene. With this, we examined whether traits associated with locomotion become more evolutionarily labile when adhesion is lost. Finally, several mechanistic hypotheses regarding the use of adhesion during locomotion were tested using this system.

S-027
MORPHOLOGICAL INTEGRATION AND EVOLVABILITY IN THE VERTEBRATE LOCOMOTOR SKELETON
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Morphological integration (MI) refers to the inter-dependence between phenotypic traits. This inter-dependence in some cases reflects the traits' shared developmental origins, while in others it reflects their shared function. At the population level, MI is observable as increased covariation among phenotypic traits. MI influences the direction and magnitude of phenotypic (co)variation among traits, and thus bears directly on the evolvability of complex organisms, such as the ability of some traits to evolve independently of others in response to selection. The vertebrate locomotor skeleton illustrates this relationship between MI, evolvability and functional diversification. In the limb skeleton, both developmental and functional factors interact to determine the degree of MI within and among limb bones. For example, tetrapod fore- and hind limbs share a common genetic basis, which is known to increase phenotypic covariation between serially homologous fore- and hind limb elements. This strong covariation can impact the rate and direction of evolutionary change in locomotor function. In cases where fore- and hind limbs share common locomotor functions, for example in terrestrial and/or arboreal quadrupedalism, increased MI may actually facilitate joint evolutionary changes in limbs, by coordinating phenotypic changes between limb bones. However, when new ecological niches or locomotor functions promote morphological divergence between the limbs, such as bipedalism, brachiation or flight, strong covariation may initially act as an evolutionary constraint. Here, using data from the literature, and simulations, I illustrate how the pattern and magnitude of MI in the limb skeleton influences the evolution of tetrapod locomotion. I also present preliminary data from a selection experiment in mice targeting increases in relative tibia length. These data confirm that MI is itself an evolvable property of the tetrapod skeleton, with important consequences for the evolution of locomotion among vertebrates.

S-028
INTEGRATION OF METHODS TO RECONSTRUCT THE LOCOMOTOR EVOLUTION OF ARCHOSAURS
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The evolution of archosaurs (Crocodylia, Aves and extinct relatives such as non-avian dinosaurs) famously includes major changes in locomotor function, including shifts from quadrupedalism to bipedalism, more adducted limbs, alterations of muscle function, and shifts of centre of mass. What was the pattern of change—how reliably can we reconstruct when and how changes occurred? Here we consolidate evidence from a multidisciplinary analysis of morphological change, experimental analyses of extant archosaurs (Crocodylia, Aves) and biomechanical computer modelling to answer these questions. First, we present a basic overview of how extant archosaurs walk, synthesizing prior studies’ findings and some new experimental data. Second, we show major findings from two computational studies of the evolution of morphology on the archosaur line to birds: changes in body centre of mass and its linkages with segmental masses and proportions, and changes in muscle moment arms and architecture. Our synthesis points out areas where we need more data from extant animals (in particular) but also fossil taxa in order to make further progress. Yet while there is relative consensus on overall changes in locomotor function (e.g. early changes in muscle function with bipedalism; relationship of posture and centre of mass position), some surprising new insights into the timing of functional changes emerge from our analysis, putting many major shifts in bipedal locomotor function close to the presumed origin of flight. We discuss whether this concordance is coincidence, evidence of a functional link between bipedalism and flight dynamics/constraints, or uncertain.
S-029
SWING PHASE MECHANICS AS A DETERMINANT OF LOCOMOTOR BEHAVIOR IN MAMMALS
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Mammal limbs display remarkable diversity in length, mass, and weight distribution, presumably reflecting different functional demands. To understand this variation, most biomechanical studies have focused on stance phase mechanics, while swing phase is relatively understudied. The rate of swing and the muscular effort required, which is determined by pendulum length and mass, can influence velocity and energetic costs. It is claimed that as animals move faster stance time shortens, but swing time stays relatively constant, suggesting that mechanical qualities of the limb constrain swing time. Although swing phase may be constant for each species, the time it takes to swing the limb forward should vary as a function of anatomical differences between mammalian species. For example, primates that have relatively more distal weight distribution associated with prehensile hands and feet may experience longer swing times than other mammals. By calculating swing time in a range of mammals including humans, cats, kinkajous, coatis, lemurs, squirrel monkeys and several Old World monkeys, we test the hypotheses that (1) swing phase is constant in relation to speed in a wide range of mammals and (2) primates have relatively long swing durations. In every group within our sample stance duration decreases with increasing speed and swing duration remains nearly constant. However, regardless of body size or anatomy, there were no significant interspecific differences in swing duration. These data are interpreted in the context of variation in angular excursion across species, and suggest that swing phase duration is a limiting factor in locomotor performance in terms of speed, angular excursion, and limb angle at touchdown. Data on swing phase mechanics are critical to understanding the inherent trade-offs in limb design, and improve interpretations of limb anatomy and locomotor behavior in both living and fossil mammals.

Symposium 6A – Quantifying Evolutionary Development Using Non-model Organisms: Integrating Metrical Frameworks, Gene Expression, and Morphology
Organizers: Laura Wilson & Ingmar Werneburg
S-030
HETEROCHRONY ANALYSIS: FROM EVENT PAIRING TO CONTINUOUS ANALYSIS
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With the rise in interest in sequence heterochrony, phylogenies have come to play a more important role than ever in evo-devo. The first method that successfully integrated the phylogeny into the analysis of reasonably large (i.e. with more than ten taxa) comparative datasets of ontogenetic sequences is event pairing. This method requires transforming ontogenetic sequences into event pairs that represent the relative order between two events. However, this approach has drawbacks that have been recognized soon after the method was proposed. Namely, transforming sequences into event pairs discards information that is hard to recover after the analysis, it generates a large number of characters (proportional to the square of the number of events in sequences), which restricts its analysis to simple datasets, it can lead to impossible ancestral state inferences, and it is impossible to select statistically significant events using an explicit probability threshold. Recently, one of the initial justifications of this method was questioned; the lack of universal ontogenetic time markers does not necessarily imply that time must be discarded from the analyses, or that sequences need to be converted into event pairs. The recently-proposed method called “continuous analysis” rests on a simple standardization of ontogenetic timing or sequence position. The data are analyzed through square-change parsimony to infer ancestral (nodal) values and phylogenetic independent contrasts to provide confidence intervals for these values. Simulations have shown that this new method outperforms event pairing with Parsimov (the latest implementation of the method), at least in the tested parameter space. In addition to covering the history of these methods and explaining the underlying assumptions, this presentation will present further refinements of the continuous analysis.

S-031
ANALYZING DEVELOPMENTAL SEQUENCES WITH PARSIMOV
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Since its publication in 2005 Parsimov was used by several researchers to investigate timing of developmental events in various species groups, including amphibians, turtles and snails. Parsimov is a parsimony-based method that identifies sequence heterochronies in all branches of an existing cladogram.
However, the method has been the subject of controversy because it is not always clear how to interpret its outcome in a biological sense. One reason for this is that the program uses non-independent data resulting from event pairing as a basis for its analyses. Here I show that Parsimov has the potential to identify apomorphic characters of developmental sequences of biological species by using anuran larval cranial muscle development as a case study.

S-032
EVOlUTION OF NECK VERTEBRAL SHAPE AND NECK RETRACTION AT THE TRANSITION TO MODERN TURTLES; A GEOMETRIC MORPHOMETRIC APPROACH
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The unique ability of modern turtles to retract their neck into the shell – side-necked (pleurodiran) and hidden-necked (cryptodiran) retraction – is thought to have evolved independently. It has been shown that the stem turtle Proganochelys quenstedti was able to laterally move its neck under the shell given the angular mobility between vertebrae. The anatomical changes that have led to modern vertebral shape, however, are poorly understood. Here we conducted comprehensive geometric morphometric analyses to trace turtle vertebral evolution and reconstruct disparity through time. Alternative topologies of turtle interrelationship were tested and using homologous landmarks, phylogenetic reconstructions were performed. By tracing landmark data over the two most plausible topologies, we reconstructed ancestral vertebral shapes for the basal nodes in turtle phylogeny. We found major changes to occur in the transverse processes of all vertebrae, and, in cryptodires, an elongation of the postzygapophyseal process in the eighth vertebra. The most parsimonious shape change was found in a topology, which resamples latest cladistic reconstructions of stem turtle phylogeny and molecular based relationships of modern taxa. We can conclude that few changes in vertebral shape have occurred – from the ancestral shape and along the stem line of turtles – to reach a vertebral shape that allows modern side-necked retraction mode. Evolving the latter shape was prerequisite to reach the vertebral morphotype of hidden-necked turtles. Compared to stem turtle retraction, side-necked retraction is more flexible. Surprisingly, however, ancestral vertebral shape reconstruction suggests that hidden-necked retraction may have been derived from modified retraction modes of stem turtles and pleurodirans.

S-033
QUANTIFYING EMBRYONIC SKELETAL DEVELOPMENT IN MAMMALS: EVOLUTION, VARIATION, AND CONSTRAINTS
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There is an enormous variation in the mammalian skeleton reflecting a wide spectrum of ecological diversification of this clade. One major drive of skull diversification is heterochrony, change in developmental timing which leads to differentiation of morphology among species. Whilst the majority of heterochronic studies has focused on quantifying changes in size and shape, changes in the timing of discrete developmental events are still largely unexplored. Furthermore, although numerous examples of heterochrony among mammals are described to date, it remains poorly understood how heterochronic variation is related to changes in life history traits. By conducting quantitative description of embryonic skeletal development of 102 mammalian species and 32 reptilian species, I present the largest dataset on ossification heterochronies to date including data for representatives from every major clade of extant mammals. Mapping ossification sequences of 134 amniotes onto a given phylogeny and simulating heterochronic changes at all nodes, the patterns of heterochrony in skeletal development that occurred along the diversification of mammals was investigated. This allowed to reconstruct the hypothetical developmental pattern of the common ancestor of mammals. I report the detected autapomorphic developmental characters of mammals and diversification patterns of skeletogenesis within mammals. Lastly, I discuss the identified hierarchical patterns of skeletal development among amniotes, namely modularity which refers to the strong connectedness of certain traits as well as the loose connection between them. I point out the possibility that independent gene regulatory networks may control different skeletal developmental modules and that such modular pleiotropy at the genetic level may constrain macroevolutionary changes of developmental timings.

S-034
MAMMALIAN SKELETAL CONSTRAINTS AND THEIR MOLECULAR DETERMINANTS
Sears, Karen
University of Illinois, Urbana, United States
Marsupials comprise only 6% of modern mammals and exhibit a limited range of mammalian limb morphologies relative to their sister-group, the eutherians. This discrepancy led researchers to propose that marsupial evolution has been constrained by the functional requirements of their unique mode of reproduction. Relative to eutherians, marsupials give birth after short gestations to immature neonates that crawl to the teat where they attach and continue to develop. This crawl is powered entirely by the forelimbs, and is proposed to limit the flexibility of forelimb development and therefore constrain forelimb evolution. My lab has been testing the existence of this constraint using morphometric and transcriptomic approaches. Morphometric studies of adult limbs indicate that marsupial forelimbs are less morphologically diverse and specialized than eutherian forelimbs, consistent with the existence of a constraint on marsupial forelimb evolution. Transcriptomic analyses suggest that the genetic controls shared by fore- and hind limbs are reduced in at least one marsupial (opossum, Monodelphis domestica) relative to at least one eutherian (mouse, Mus musculus) at the “bud-stage” of limb development. This reduced genetic integration likely contributes to the reduced phenotypic covariation between fore- and hind limbs I have documented within several marsupial species. Based on these data, my working hypothesis is that a breakdown in the genetic integration between marsupial limbs allowed their forelimbs to specialize for the crawl. This, in turn, led to the reduction in developmental variation that I have documented in the marsupial forelimb, and thereby constrained marsupial forelimb evolution.

S-035
PHYSICAL AND BIOLOGICAL MECHANISMS GENERATING COMPLEXITY AND DIVERSITY OF SKIN APPENDAGES IN AMNIOTES
Milinkovich, Michiel; Tzika, Athanasia
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Amniotes exhibit a keratinised epidermis that provides a functional barrier against water loss, and skin appendages that play major roles in thermoregulation, photoprotection, camouflage, display, and defence against predators. Whereas mammals and birds respectively evolved hairs and feathers, reptiles developed various types of keratinised, and sometimes ossified, scales. Despite that their developments seem to share some signalling pathways (Wnt, Hedgehog, BMP), it is unclear whether mammalian hairs, avian feathers and feet scales, and reptilian scales are all homologous, or if some of them evolved convergently. In birds and mammals, a reaction-diffusion mechanism generates a spatial pattern of placodes that develop and differentiate into follicular organs with a dermal papilla and a stem-cell controlled cycling growth of an elongated keratinised epidermal structure (hairs or feathers). On the other hand, scales in reptiles do not form true follicles and might not even develop from placodes. I will illustrate some of our recent results on the physical and biological mechanisms generating complexity and diversity of skin appendages in amniotes by using two very different examples: one in crocodiles and the other in mammals.

Symposium/Workshop 68 – Digital Morphology: 3D Visualization and Analysis with Amira/Avizo
Organizers: Robert Brandt & Alejandra Sanchez-Eróstegui
Workshop (no abstracts)

Symposium 7 – Reptile Skeletal Biology: Investigations into Tissue Morphology, Development, and Evolution
Organizers: Casey Holliday & Matthew Vickaryous

S-036
SKELETAL REGENERATION FOLLOWING TAIL LOSS IN LIZARDS
Vickaryous, Matt; Coates, Helen; Delorme, Steph
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For many species of lizards, a portion of the tail can be shed or autotomized as a defensive strategy. Tail loss is typically followed by a conserved sequence of morphogenetic events resulting in spontaneous tail regeneration. Superficially, the replacement tail resembles the original, although close inspection reveals that different tissues and organs regenerate with different levels of structural fidelity. Here we present new data on tail regeneration in gekkotan lizards, focusing on the axial and integumentary skeletons. In geckos, the original axial skeleton is composed of bony vertebrae and a persistent notochord. Following regeneration, the vertebrae and notochord are replaced by a hollow cone of cartilage. Although distinctly cell-rich, regenerated cartilage is similar to original cartilage in that the matrix contains type II collagen and glycosaminoglycans. Immunohistochemical analysis also reveals that regenerated chondrocytes express Sox9 (a transcription factor required for chondrogenesis) and TGFbeta3 (a cytokine involved in regulating chondrocyte growth). While the replacement tail cannot autotomize, the cartilaginous cone is capable of
regenerating following amputation. Histologically, this secondarily regenerated cartilage is indistinguishable from the cartilage cone that develops following initial tail autotomy. Unlike the axial skeleton, elements of the integumentary skeleton do regenerate with a high degree of structural fidelity. Members of the gecko genus Tarentola develop large numbers of skeletal inclusions within the dermis known as osteoderms. In addition to bone, osteoderms are characterized by a vitreous, acellular capping tissue that is rich in glycosaminoglycans but lacks intrinsic collagen. During tail regeneration, osteoderms are re-developed. Osteoderm regeneration involves the direct transformation of the existing dermis into bone without the formation of a cell condensation (i.e., metaplasia). We demonstrate that regenerated osteoderms are structurally nearly identical to the original elements, but that their pattern of distribution across the tail varies.

S-037
SQUAMATE VERTEBRAL HISTOLOGY AND MICROANATOMY - DEVELOPMENT AND EVOLUTION
Houssaye, Alexandra
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The axial skeleton accounts for an important part of the total skeletal mass in squamates, especially in limbless forms. Together with axial musculature, it plays a major role in locomotion. Many biological studies have focused on the extent to which organisms are morphologically adapted to their environments, and thereby on the relationship between form and function. Bone microanatomical and histological features are considered to be closely linked with the functional requirements and biology (e.g. growth, physiology, life history) of the organisms, respectively. They are thus powerful tools to provide information about the mode of life. The vertebral microanatomical and histological features of modern and fossil squamates are investigated. It enables highlighting the specificity of squamates, as compared to other amniotes, the differences between lizards and snakes, and the peculiarities of some taxa. One objective is notably to analyze the outcome of historical, functional and structural components in explaining microanatomical and histological features in squamates and to discuss the osteogenic processes involved.

S-038
COMPARATIVE SKULL MECHANICS OF THE LIZARDS TUPINAMBIS MERIANAE AND VARANUS ORNATUS
Gröning, Flora (1); Jones, Marc (2); Curtis, Neil (1); O'higgins, Paul (3); Evans, Susan (2); Fagan, Michael (1)
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The two lizard species Tupinambis merianae and Varanus ornatus share many similarities in body shape, habitat and feeding behaviour although they evolved independently, with Tupinambis being native to South America and Varanus ornatus to Africa. This makes the two reptiles interesting for morphological comparisons, particularly with respect to the skulls which show clear differences despite similar feeding behaviour. For example, a postorbital bar is present in Tupinambis but absent in Varanus while the former lacks the mid-frontal suture that is present in the latter. We used computer-based mechanical modelling to examine the effects of these differences on the mechanical function of the skulls. Based on micro-computed tomography scan data and detailed muscle dissections, we built subject-specific dynamic models of Tupinambis and Varanus masticatory systems. The forces generated by these dynamic models during biting simulations were then used to load finite element models of the same specimens. This allowed a direct comparison of stresses and strains between the skulls. In addition, the geometry of the finite element models was altered to study the effects of the absence and presence of features in isolation. The results indicate that strains in the skull bones are in general lower in Tupinambis than in Varanus when physiologically representative anterior bites are simulated and that the strain differences are especially pronounced in the frontal bone. This is probably related to the more compact, and relatively short and wide snout of Tupinambis compared to Varanus. In addition, the presence of a mid-frontal suture in Varanus alters the distribution of strains in the frontal. We conclude that the differences in skull morphology between the two taxa have pronounced effects on how feeding forces are dissipated through the skull.

S-039
A COMPARISON OF TURTLE AND CHICKEN ONTOGENY REVEALS THE BASIS FOR DIVERGENT HARD PALATE MORPHOLOGY
Richman, Joy; Abramyan, John; Leung, Kelvin
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Turtles are an enigmatic group of vertebrates whose divergent skull morphology is still at the forefront of scientific discussion. To understand how these striking differences arose, we investigated the craniofacial ontogeny of a representative turtle, Emydura subglobosa. The primary palates of turtles are similar to all
S-040
HOW DID ENAMEL MATRIX PROTEINS EVOLVE IN REPTILE TEETH AND ARE THEY PRESENT IN OSTEODERMES?

Sire, Jean-Yves (1); Gasse, Barbara (1); Silvent, Jérémie (1); Delgado, Sidney (1); Belheouane, Meriem (1); Buffrénil, Vivian De (2)

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Comparative structural and developmental studies in extinct and extant vertebrates allowed us to build a scenario for the origin and evolution of the dermal skeleton and their tissues (reviewed in Sire et al. 2009; Vickaryous and Sire, 2009). In particular enamel/enameloid and enamel-like tissues were identified early in vertebrate evolution and were easily traceable in most lineages including current terminal taxa. The presence of these tissues strongly suggests that enamel matrix proteins (EMPs) were also early differentiated, but our current knowledge is limited to mammals and a few non-mammalian tetrapods. In the first part of this talk we briefly present the EMP repertoire that we obtained by means of genome and transcriptome sequencing in two reptiles, the iguanid Anolis carolinensis and the crocodylian Alligator mississippiensis. We compare the EMP structure to that of mammalian EMPS and we illustrate some differences in gene expression during amelogenesis in mammals and squamates. However, although the origin and protein composition of enamel is now well known, some questions remain about its relationships with hypermineralized enamel-like tissues that constitute the upper layer of various dermal elements. This is the case of osteodermine, an hypermineralized tissue located at the osteoderm surface in some squamates (Buffrénil et al., 2011). In the second part of this presentation we describe this tissue in various species and we try to detect the presence of EMPS in this tissue. We obtained EMP cDNAs from tooth extracts of the geckonid Tarentola boettgeri, the osteodermes of which possess osteodermine, and looked for EMP gene expression in the cells facing the osteoderm surface.

S-041
DEVELOPMENTAL PLAN OF THE AMNIOTE SHOULDER GIRDLE AND ITS EVOLUTIONARY DIVERSITY

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Due to its morphological diversity, the homologies of the skeletal components in the amniote shoulder girdle have been debated for centuries. In particular, questions concerning the homology of the coracoid, origin of the mammalian supraspinatus fossa, and the modification of the pectoral girdle in turtles have remained unanswered. To solve these questions, we compared the shoulder girdle development between mice, chickens, and Chinese soft-shelled turtles. We found that the primordia of amniote shoulder girdles showed a common embryonic pattern, consisting of three processes, rostral (RP), caudal (CP) and ventral (VP), with comparable gene expressions. The CP formed the scapular blade in non-mammals, whereas it made the infraspinatus fossa, or the caudal half of the blade in mice. The rostral part of the mammalian girdle precursor uniquely possessed a superior process, which differentiated into the mammal-specific supraspinatus fossa. The VP produced the coracoid in all animals, but their developmental patterns differed between mammals and non-mammals, supporting the classical theory on coracoid homology. The shoulder girdle of a turtle embryo initially showed a striking similarity to that of the chicken, suggesting that the ventral
half of the turtle girdle consisted of the acromion and the procoracoid. We concluded that the morphological identities of skeletal components in amniote shoulder girdles are specified in the common precartilaginous precursor, and the diversity of the adult girdles is ascribed to secondary modifications of this common developmental pattern.

S-042
MORPHOLOGY AND FUNCTION OF THE REPTILE MANDIBULAR SYMPHYSIS
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The mandibular symphysis is a morphologically diverse and functionally informative craniomandibular joint. However, only recently has its structure been rigorously explored in reptiles revealing intriguing developmental and evolutionary patterns. Soft tissues including ligament, Meckel’s cartilage and fibrocartilage play critical roles in the structure and function of the sauropsid symphysis. Collagen fiber orientation of the sutural ligament and presence of fibrocartilage and accessory ossifications lend insight into the functional environment of the joint. Meckel’s cartilage adheres to or fuses to its contralateral member in some lizards and crocodylians suggesting an important role in joint stabilization and growth. Histological and immunohistological analysis reveals dynamic changes in tissue growth and interaction during ontogeny. Many of these soft tissues leave osteological correlates identifiable in the fossil record enabling more rigorous hypotheses of feeding function and mandibular evolution in extinct archosaurs and sauropsids to be developed. Two case studies of symphysis evolution will be discussed: the evolutionary morphology of symphyses in archosaurs and the development and function of the Alligator symphysis.

S-043
DEVELOPMENT AND EVOLUTION OF MESOPODIALIZATION IN THE ICHTHYOSAURIAN LIMB SKELETON
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Ichthyosaurs are a group of reptiles showing extensive anatomical modification for a secondarily aquatic way of life. In derived forms, the body is fusiform, the tail supports a semi-lunate fin for axial propulsion, the limbs are modified into flippers and the hind limbs are reduced in size relative to the forelimbs. The limbs of derived ichthyosaurs have received a disproportionate amount of research attention because of a number of unusual morphological characteristics. These include a substantial increase in the number of phalanges per digit and the number of digits, and changes in the proximodistal identity of limb elements. Elements distal to the stylopodium exhibit characteristics of mesopodial morphology, such as a rounded, nodular shape and a loss of perichondral bone on the anterior and posterior surfaces. In order to better understand what appears to be a homeotic transformation in proximodistal identity, we examined the sequence of perichondral bone loss over phylogeny, the histology and microstructure of the elements retaining perichondral bone, and assessed the influence of ontogeny, stratigraphy, and number of phalanges on intraspecific variation in identity loss. Results indicate that the notches seen on the anterior surface of limb elements in derived ichthyosaurs are homologous to the shaft of the long bones in terrestrial tetrapods. Changes in proximodistal identity occurred gradually over ichthyosaurian limb evolution, and included mesopodialization of zeugopodial and autopodial elements and also a shift such that the anterior mesopodial elements became notched. Intraspecific variation in the number of notches is most closely correlated with body size, indicating delayed ossification of the anterior perichondrium plays a role in mesopodialization. We propose a developmental mechanism, the gradual expansion of the polyalanine region of Hoxd13, to explain the progressive loss of limb regionalization and the heterochronic delay in perichondrial ossification in ichthyosaurian limbs.

S-044
FRONTIERS IN THE EVOLUTION AND DEVELOPMENT OF THE REPTILIAN SKULL
Bhullar, Bhart-Anjan (1); Marugan-Lobon, Jesus (2); Racimo, Fernando (3); Bever, Gabe (4); Rowe, Timothy (5); Norell, Mark (6); Abzhanov, Arhat (1)
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Anatomical Record, Volume 296, Special Feature — 139
The embryonic and postnatal development of the reptilian head, with its manifold variations, has recently become a focus of renewed interest from both the neontological and paleontological perspectives. As a focus for the study of developmental mechanisms of large-scale evolutionary transformations, the reptile head is particularly apt given its numerous integrated components and the enormous morphological and functional variation seen among extant and extinct taxa. Enough literature exists on postnatal development to derive some general principles and trajectories of shape change, although quantitative analyses remain scarce. A few attempts have also been made by us and other researchers to develop ways in which to incorporate fossils into ontogenetic studies, and some of these have yielded novel observations regarding both taxonomic synonymy and macroevolutionary processes. Finally, the beginnings of an understanding of the molecular patterning of the skull during large-scale evolution within Reptilia are emerging from our investigations of craniofacial development at the origin of birds.

S-045

CONSERVATION OF PRIMAXIAL REGIONALIZATION IN THE EVOLUTION OF THE SNAKE BODY FORM INDICATES HOMOPLASY IN HOX GENE FUNCTION

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Shifts and reduction in Hox gene expression domains have been proposed as a primary mechanism in the evolution of the elongate, “deregionalized” axial skeleton of snakes and other squamates. Mapped Hox domains do not show a consistent change in expression in the axial skeleton of snakes, however, and the extent of morphological homogenization has not be examined separately for the primaxial and abaxial regions of the skeleton. To test for morphological changes along the primaxial skeleton and their implications for inferring Hox patterning in the snake body form, we quantified vertebral shape in a sample of amniotes including taxa with highly differentiated axial regions and resolved Hox boundaries (Mus, Alligator) and representatives of all major squamates clades including elongate taxa. Geometric morphometric analyses of intracolumnar changes in vertebral morphology along the anterior-posterior axis were used to test against models of differing regionalization and to search for regional boundaries. Testing the method on Mus and Alligator produced strong correspondence between Hox boundaries and quantified shape variation for a four-region model representing cervical, anterior thoracic, posterior thoracic and lumbar regions. Morphometric variation in squamates, including elongate taxa, also best fit a four-region model, despite the absence of additional regional morphologies. Comparisons of morphometric regions in the snake skeleton with mapped domains revealed correspondence between Hox gene expression and morphometric boundaries in the cervical and thoracic regions and a loose correspondence in the lumbar region. These results strongly suggest that primaxial regionalization is retained in the evolution of elongate body forms, and that “deregionalization” results from reduction or loss of the abaxial skeleton.

S-046

IN VIVO CRANIAL BONE STRAINS DURING FEEDING IN THE LIZARDS TUPINAMBIS AND UROMASTYX

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In vivo bone strains have provided direct evidence of skull deformation and strain regimes during feeding across a wide range of mammals. In contrast, such data have been collected for only a handful of sauropod taxa. Here we present bone strains recorded in the skulls of two lizard species during transducer biting and feeding: four individuals of the large, carnivorous teiid Tupinambis merianae and three individuals of the small, herbivorous agamid Uromastyx geyri. Strains were recorded at multiple gauge sites on the cranium (Tupinambis and Uromastyx) and mandible (Tupinambis) along with simultaneous bite force, electromyographic and kinematic data. The skulls of both taxa experience principal and shear strain magnitudes that are substantially higher than those recorded in mammalian crania during feeding. Furthermore, strain magnitudes in the frontal and parietal bones of Tupinambis were higher than those recorded in the maxilla; in contrast, bone strains in the mammalian calvaria are lower than those recorded in the facial skeleton. These data suggest that the crania of Tupinambis and Uromastyx are better optimized to resist feeding forces than are mammalian crania, possibly due to smaller relative brain size in lizards. During feeding, principal strain orientations in the snout of Tupinambis vary with changes in bite point and behaviour; however, strain orientations in the parietal bone are constant, suggesting that the mesokinetic hinge between the frontal and parietal bones of Tupinambis absorbs strain energy associated with forces acting on the snout. Variations in strain orientations in the cranium of Uromastyx are largely due to
differences in feeding behaviours; however, mean principal strain orientations also differ between male and female *Uromastyx* during feeding, potentially due to sexual dimorphism in cranial morphology in this taxon.

S-047
ARCHOSAUROMORPH BONE HISTOLOGY REVEALS EARLY EVOLUTION OF ELEVATED GROWTH AND METABOLIC RATES

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Bone histology has established that birds, dinosaurs, and pterosaurs grew at much higher rates compared to extant crocodylians and other reptiles, but it remains uncertain when these features evolved, temporally or phylogenetically. The study of key fossil taxa allows us to track changes in growth physiology through deep time and in taxa whose character states are not represented among living animals. We reviewed and expanded the histological database of archosaurs and their ancestors to include early archosauromorph, pseudosuchian, and dinosauromorph taxa. Our study differs from previous works in its phylogenetic breadth and level of taxonomic sampling, but also in that we used apomorphy-based identifications for all specimens, and sampled the same location on homologous elements from individuals of comparable ontogenetic stage. This allowed for more rigorous control over other factors affecting histology and interpretations of growth (e.g., differences in ontogeny or biomechanics) and more meaningful comparisons of histology. We then mapped growth and metabolically-relevant characters (osteocyte density, collagen organization, osteonal development, and vascularity) on a recent phylogeny of archosauromorph reptiles to assess where particular adaptations of growth dynamics first evolved, focusing on the lineages leading to Archosauromorpha, Crocodylomorpha, Dinosauria, and Theropoda. Many histological features associated with high growth rates in living birds evolved much earlier than the common ancestor of birds and pterosaurs, and several aspects of the accelerated growth syndrome did not evolve simultaneously. Most of these character changes accumulated in a short segment of the archosauromorph tree, before the end of the Early Triassic. Therefore, many physiological features related to high growth and metabolic rates of living birds evolved not in dinosaurs or the common ancestor of Ornithodira, but before the most recent common ancestor of crocodiles and dinosaurs.

Symposium 8 – Morphology: The Great Integration. Contemporary Relevance of an Old Field

Organizers: Jeanette Wyneken & J. Matthias Starck

S-048
THE PUBLIC HUNGER FOR STORIES ABOUT MORPHOLOGICAL RESEARCH

Hutchinson, John R.

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In the Victorian era, morphologists were among the superstars of science in the public eye as well as in the scientific community. At some point, that status diminished. Here I make the case that there is an opportunity, or even a trend, to recapture some of this prominence. The opportunity has arisen not only from changes in technology, such as 3D imaging techniques and computer modelling/simulation, that make morphology more visually appealing and accessible, but also cultural changes in attitudes toward presenting images of real, and often “gory,” organismal morphology. I make the case that the media has realized that, after somewhat of a lengthy drought of quality public presentations of real morphology, the public wants to see what animals look like inside and how they work. This is despite prevailing negative attitudes toward invasive animal research; always due cause for caution. I’ll weave together my experience with anatomical documentaries like Inside Nature’s Giants, running an anatomy blog, and stories from my/others research to address how there is a renewed general interest in morphology. This personal experience will be put into the context of broader evidence (e.g. the success of Bodyworlds) of (predominantly Western?) cultural change. I argue that imagery that was taboo not long ago (e.g. showing actual dissections) in some cultures no longer may be so taboo. This, in combination with technological changes, means that morphologists are in a prime position to engage the public in interactive discussions of morphology, which is what governments, funding agencies and universities often want us to be doing more of, and already there are superb success stories from researchers that do this. I conclude with some examples of how to capitalize on this opportunity, for the benefit of researchers that feel they have not yet done so and yet wish to.

S-049
MOLECULES OR MORPHOLOGY? DEVELOPMENTAL BIOLOGY NEEDS BOTH
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Morphology is extensively, but often covertly, employed in the modern field of developmental biology. When molecular biology tools were first employed in developmental studies, morphology was often seen to have become redundant and old-fashioned. The truth, of course, is that people simply changed the name from morphology to ‘phenotype’ and carried on relying on it as a key readout in functional studies. Patterns of gene expression in embryos are largely anatomical descriptions; so too are the ‘resultant phenotypes’ in transgenic mice. But a distinction was still drawn between the ‘old’ morphology and ‘new’ molecular biology.

This distinction was indeed reinforced by Stephen Jay Gould who contrasted ‘patterns’ and ‘processes’ in evo devo, a contrast which I argue is not altogether a happy one. More recently, however, a new view has taken hold; a premium is now placed, at least in the field of evo devo, on studies that integrate genes and morphology, treating them not as separate phenomena belonging to different academic disciplines, but as integral parts of the same biological systems. Above all, in the field of evolution and development, morphology has become crucial once because it is that aspect of the phenotype which is so often under natural selection.

S-050
OBSERVATIONS ON OBSERVATION: VISUALIZING STRUCTURE AND MOTION
Brainerd, Elizabeth
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Vertebrate morphology may have broad insights to offer about approaches to observation and discovery, but we also need to re-evaluate our own practices in the face of vast amounts and new kinds of morphological data. Morphology has a long history of formalizing the process of visual observation. Observing gross anatomical structure often includes sketching or drawing, and the process of drawing is well known to improve the quality of observation. Same goes for physical or mathematical modeling of biological mechanisms; formalizing the description feeds back to more rigorous observations. Do new 3D imaging methods (CT, MRI, etc.) require new formalizations to aid observation? Are old formalizations holding us back in the face of new kinds of data, or should we try to apply tried-and-true methods, such as sketching, to enhance observation? (Imagine making a pencil sketch on paper of a 3D rendering on your computer screen. Might you learn something?) New kinds of formalizations may also be emerging. For example, X-ray Reconstruction of Moving Morphology (XROMM) is now yielding 6 degree-of-freedom skeletal kinematics in the context of detailed skeletal morphology. We can create joint coordinate systems that reflect our interpretation of joint shape, and then use the output to test and refine our understanding of the motion and the morphology. XROMM animation makes it easy to visualize the motion of bones relative to an earth-bound frame of reference, or relative to any other bone or object in the scene. This instant point-of-view switching is a surprisingly powerful tool for understanding animal motion. For the future of vertebrate morphology, can we develop new formalizations that improve the quality of our observations, while simultaneously opening our eyes to unexpected discoveries? Might any of these insights about observation, exploration, and discovery transfer to other fields of science, or even medicine, business and entrepreneurship?

S-051
MORPHOMETRY OF THE BOID LUNG AND ITS IMPLEMENTATION FOR THE UNDERSTANDING OF DISEASE DEVELOPMENT
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Morphology is the ultimate integration of biology through evolution, ontogeny, structure and function. In this contribution we exemplify how morphological and clinical studies integrate to understand the functioning of the boid respiratory apparatus by determining its normal design as well as its limitations. Infectious lung diseases play an important role in boid snakes, and often lead to a fatal outcome. Clinical symptoms develop mainly in advanced disease stages making an early intra vitam diagnosis difficult. The aim of this multidisciplinary project therefore was to contribute to the knowledge on the lung efficiency and capacity in boid snakes and the impact of infections on these parameters. Including veterinary as well as biological aspects, the boid lung was characterized functionally as well as morphologically using intra vitam computed tomography in combination with established morphometric methods. Furthermore, the ultrastructure of the healthy lung epithelium was evaluated and changes of the cell and tissue structure depending on ongoing disease processes in early as well as late stages were described. The morphological exchange capacity was quantified using a stereological approach. Results demonstrate that healthy pythons possess an excess oxygen exchange capacity (factor 12 to normal oxygen intake) and are therefore able to compensate...
S-052
WHAT MORPHOLOGY CAN TELL US ABOUT PHYSIOLOGICAL FUNCTION: CASE STUDIES ON WHALES
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The study of physiological processes in whales is hindered by logistical and ethical problems related to conducting invasive in vivo experiments in these animals. Consequently many basic aspects of physiology related to large body size and aquatic lifestyle remain unknown. We use morphology and tissue mechanical properties to infer physiological function in living whales and examples will be presented related to mechanics of lunge feeding, and pressure effects on the circulatory system in rapid and deep diving. For example, we described a structure located within the mandibular symphysis of balaenopterid whales that we propose is a mechanoreceptor. In the absence of direct physiological evidence we combined gross dissection, histology, and medical imaging to show that this structure has sensory papillae with nerves and encapsulated nerve termini that arise from the mandibular division of the trigeminal nerve. Coupled with other morphological evidence we make a strong case that this new organ coordinates control of mouth opening and closing during lunge feeding, an important innovation that supports extreme body size. In fin whales we found the walls of thoracic arteries are highly reinforced with collagen, making them virtually incompressible under normal physiological pressures. Based on the structure and tissue mechanical properties we propose that this unique arterial design protects against large and transient variations in arterial transmural pressures arising from rapid depth-induced ambient pressure changes. In the absence of direct measurements we developed a mathematical model to test this hypothesis. Other aspects of whale physiology we are investigating via morphology are: the pattern of mineral deposition in mandibles as an index of bending loads applied during lunge feeding, the role of muscle in controlling the expansion of the ventral cavity pouch during engulfment, predictions of hydrodynamic drag from numerical analysis of body shapes, and lung function in deep diving whales.

S-053
WHAT CAN MORPHOLOGY DO FOR ME? CHALLENGES FOR THE STUDY OF MORPHOLOGY, AND OPPORTUNITIES FOR MORPHOLOGY AS A MEANS TO GAIN INSIGHT INTO BIODIVERSITY
Blob, Richard
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The rapid pace of scientific discovery in recent decades, combined with limits to the resources available for research support, have led to reevaluations of priorities for decisions ranging from grant allocations to student curricula. Under these conditions, it is critical for fields to demonstrate their broader connections or applicability, or else risk a diminished role in the future. How can morphology meet these challenges? Though morphology has long been connected to medical training, the advent of many human-specific courses, even at the undergraduate level, often reduces the role played by comparative morphology in this context. However, concerns regarding issues such as climate change and habitat degradation remain on the rise, and morphology can provide important insights into the preservation of biodiversity in the face of such environmental challenges. This connection has long been an area of focus among morphologists, reinforcing the contemporary relevance of the field. Several recent studies from our lab highlight the window that morphological studies provide into functional diversity and its origins. For example, in the Hawaiian Island chain, gobid fishes from streams on each island shed larvae out to the ocean, where mixing across islands may occur before juveniles return to freshwater. The islands show different stream characteristics: on Hawai’i waterfalls are nearshore, emphasizing climbing performance, but on Kaua’i streams have long stretches below waterfalls, emphasizing predator evasion. Our studies of the species Sicyopterus stimpsoni show little genetic differentiation across island subpopulations; however, fish returning to each island have shapes advantageous for the main pressure they encounter (streamlined for climbing, tall for predator evasion), and these shapes correlate with performance differences that could form the basis for natural selection. Thus, while considered a single species, morphological variation across its range promotes local adaptation that could factor significantly in recovery from environmental disturbance. NSF IOS-0817794, IOS-0817911.
Symposium 9 – Interdisciplinary and Novel Approaches to Vertebrate Locomotion
Organizers: David Ellerby, Shannon Gerry, Christopher Sanford, & Graham Askew

S-054
LINKING MORPHOLOGY TO SWIMMING PERFORMANCE IN BLUEGILL
Gerry, Shannon (1); Ellerby, David (2)
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Many freshwater fish populations diverge into distinct littoral and pelagic ecomorphs based on their habitat use. Furthermore, this phenotypic variation may be linked to differences in locomotor performance, which may promote divergence within a population and be the first step toward speciation. Bluegill Lepomis macrochirus exhibit a resource polyphenism based on habitat: the littoral form has a deeper body with larger fins and the pelagic form has a fusiform, streamlined body shape. We studied the relationship between this morphological variation and several aspects of swimming performance within a population of bluegill from Lake Waban, MA in order to show trade-offs in performance associated with habitat. We hypothesized that pelagic bluegill would be better suited to steady-swimming at a lower energetic cost, associated with their streamlined body shape. In contrast, littoral bluegill would maneuver quickly and exhibit faster-starts due to their deeper body shape and fins capable of generating a high degree of thrust. To test these hypotheses, we quantified external morphometrics, steady swimming kinematics, aerobic energy costs, maneuverability and fast-start escape responses. We confirmed that pelagic bluegill are more effective and efficient steady-swimmers as indicated by a greater gait transition speed, greater stride length and lower cost of transport. This ecomorph also showed greater accelerations during fast-starts, which was unexpected due to its fusiform body, but is likely associated with greater rates of predation in the pelagic habitat. Littoral bluegill showed higher rates of acceleration and higher rates of turning while maneuvering, related to their deeper body form. This research indicates that the variation in body shape shown by this population of bluegill is linked to a trade-off in locomotor performance. Further research is needed to investigate the internal morphology and physiology of the muscles powering these movements in order to fully understand the integration between phenotypic variation and performance.

S-055
TRACKING MUSCLE ENERGY USE DURING LOCOMOTION
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Muscles fulfill a diversity of mechanical roles during locomotion, potentially acting as motors, stabilizers and brakes. Although measurements of organismal metabolic rate indicate the total cost of locomotion, and muscle level measurements of activity and strain can yield information about mechanical function, it is challenging to ascribe energetic costs to these functions. Without this information locomotor systems are essentially a black box in terms of the distribution of energy use. Although in situ measurements of muscle metabolism are not practical in multiple muscles, the rate of blood flow to skeletal muscle tissue can be used as a proxy for aerobic metabolism. By introducing flow tracers into the systemic circulation, the blood flow to, and energy use by multiple muscles can be determined simultaneously. This approach allows the relative importance of particular muscle functions to be partitioned out within the overall cost of locomotion. Thus far, the technique has been applied to determine muscle-level energy costs during terrestrial locomotion. We have applied the technique for the first time in swimming fish, allowing the energy expenditure associated with thrust production by the myotomal musculature, and the energy costs of fin muscle activity associated with stabilization to be determined. The value of the approach lies not just in its ability to reveal the distribution of energy under steady state conditions, but in its potential to reveal the mechanical factors that underlie changes in locomotor cost associated with movement through unsteady physical environments.

S-056
NEW APPROACHES TO THE STUDY OF HYDRODYNAMICS IN ANIMALS: V3V OR VOLUMETRIC PIV
Sanford, Christopher
Hofstra University, Hempstead, United States
The interaction between organisms and their environment have been central to understanding why animal designs succeed or fail. Organismal design is the result of natural selection, thus knowledge of the environmental forces that drive evolutionary changes in design is a pivotal concept. Biomimetics or biologically-inspired design which builds on this knowledge and understanding is a rapidly emerging discipline, but advances have been hampered in the past by limitations of the technology available. The use of Particle Image Velocimetry (PIV) in biology has been instrumental in advancing our understanding of biologically important fluid flows, but has been limited primarily to 2D or planar PIV. We now have the ability...
to study and visualize biologically relevant fluid flows in 3D. The use of a V3V system or volumetric PIV stands at the forefront of significantly advancing our comprehension of aquatic locomotion. Preliminary findings in a number of diverse areas using the new V3V approach will be discussed. Topics that will be explored will include swimming in fishes, and fishes that remain stationary in flowing water (station holding). Supported by NSF DBI 1126234 and DBI 0963167.

S-057
WHY MIGHT FISHES BE DIFFERENTLY SHAPED
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A long-standing challenge of comparative biomechanics is to determine the contribution of diverse morphological "designs" to varied locomotor performance. In fishes, body shape variation has been implicated as a major determinant of swimming performance. Specifically, the shape of the caudal peduncle and tail fin appears to indicate specialization for maneuverability, thrust generation, or swimming economy. Narrowing studies of such ecomorphological associations to determine the effect of form on function, in isolation from confounding factors, is non-trivial. We used passive, flapping-foil mechanical models of caudal morphology in an attempt to isolate and measure the effects of caudal peduncle depth, stiffness, and the presence or absence of a tail fork on swimming performance. Using force and torque measurements, we were able to determine the speeds, energy, and power consumption of swimming foils with different shapes. By taking concurrent flow visualization data, we were able to identify aspects of the wakes that appeared to be products of different tail morphologies. Our data suggest that morphology-performance correlations in the fish tail may be much more complicated than previously thought. Shape and stiffness had an interacting effect on the self-propulsion speed of the model foils. Energetic cost of swimming and torques generated by swimming undulations also varied with stiffness and shape. Parallel studies looking at the passive hydrodynamics of dead fishes, and performance of extant fishes with variable morphology will inform ecomorphology by determining how specific morphological features interact with their fluid environment.

S-058
VARIATION IN VERTEBRAL NUMBER: CAUSES AND CONSEQUENCES
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For selection to act within a population, heritable variation must exist. Environmental factors are well known to cause variation in certain traits, although the mechanism by which these factors cause meristic variation is generally unknown. In addition, certain variants often have performance advantages over other variants. For example, previous studies have indicated a tight link between axial morphology and locomotion in limbless tetrapods. In this study, we are tracing temperature-induced variation in vertebral number from its developmental causes to the effects of variation in vertebral number on survival. This work has utilized two common model systems: zebrafish (Danio rerio) and axolotl (Ambystoma mexicanum). Clutches from both species were raised at four species-appropriate temperatures during early development and then transferred to the same species-appropriate temperature following somitogenesis. The effect of temperature can be seen during early development; animals raised at lower temperatures have more somites. Further examination has indicated that temperature may be changing somite number by affecting the retinoic acid signaling pathway. The trend continues when looking at adults; individuals raised at lower temperatures tend to have more vertebrae than those raised at higher temperatures. Further, individuals with more vertebrae have higher performance than those with fewer vertebrae. Individuals with the highest performance have the greatest number of caudal vertebrae relative to precaudal vertebrae. In an ongoing study, we are determining whether zebrafish with more vertebrae are less likely to be consumed by natural predator (Xenetodon cancila). This is the first study to determine the underlying mechanism by which environmental conditions affect morphological development and the subsequent effects of morphological variation on performance and survival.

S-059
DIABOLICAL DISPLACEMENT: THE ROLE OF STRUCTURAL COMPLIANCE IN LIZARD LOCOMOTION AND LOCOMOTOR ECOLOGY
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Anatomical Record, Volume 296, Special Feature — 145
Variable structural compliance, or flexibility, is a ubiquitous habitat characteristic. Arboreal habitats, in particular, are characterized by highly variable structural complexity, including compliance. Although the bending and swaying of arboreal structures may have significant effects on animal locomotor capability, ecology, and fitness, these effects have received relatively little consideration, particularly in small animals. Our research on the effects of structural compliance on locomotion focuses on two groups of arboreal lizards, anoles and geckos. Anolis carolinensis, the green anole lizard, can often be found perching on substrates that span a wide range of compliance, from stiff trunks, to highly flexible leaves and twigs. This species, like many other Anolis species, often navigates its habitat by jumping from perch to perch. When an animal jumps from a compliant perch, the perch bends away from the animal due to the force generated during the jump. Part of the energy of the jump is then absorbed by the perch, leaving less for the jump itself, potentially affecting jump speed, distance, and accuracy. While jumping is a common locomotor tactic for many arboreal animals, geckos are generally better known for their striking adhesive abilities. A substantial amount of work has focused on gecko adhesion and locomotion on stiff surfaces, but little is known about how their adhesive capabilities are affected by the compliance of substrates, particularly in relation to animal size, and relative pad size and shape. Here we present findings from our studies of the effects of perch compliance on A. carolinensis jumping performance in the lab, and on jump performance and perch choice in the wild, as well as our results from lab studies of the effects of substrate compliance on gecko locomotion and adhesion, in collaboration with the Polymer Science and Engineering Department at UMass Amherst.

S-060
TOWARDS AN INTEGRATIVE UNDERSTANDING OF THE MECHANICS AND ENERGETICS OF BIRD FLIGHT
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Understanding flight energetics is central to understanding the behavioural ecology and physiology of birds. Over the years different techniques have been used to elucidate flight energetics. The metabolic power requirements of flight can be determined directly, for example, using respirometry in a wind tunnel. However, these measurements can be quite challenging. Given that a large proportion of the flight energy expenditure almost certainly arises as a consequence of the mechanical power generated by the pectoralis muscles (the main source of mechanical power in birds), a more convenient approach is to predict flight energetics from the mechanical power requirements of flight. The mechanical performance of the pectoralis muscles can be estimated using aerodynamic models or measured by integrating measurements of the in vivo muscle length change and activity pattern during flight with in vitro measurements of muscle force generation under simulated in vivo conditions. However, the generation of mechanical power by the pectoralis muscles does not represent the sole use of metabolic energy during flight, and predicting metabolic energy expenditure from the mechanical power requirements of flight is limited by the uncertainties about the efficiency of the flight muscles and the energy consumption of other accessory muscles and other non-muscular physiological systems. Although not a widespread approach, muscle ergometry and myothentic techniques can be used to determine the metabolic cost of producing work, and can help to improve our understanding of the link between the mechanics and energetics of bird flight. Quantifying the metabolic energy expenditure of the pectoralis muscles allows their contribution to the overall energy cost of flight to be determined and can help to overcome some of the limitations of models aiming to predict the metabolic power requirements of flight.

S-061
THREE-DIMENSIONAL MOTION CAPTURE IN THE FIELD: A CASE STUDY OF HOVERING AND GROUP BEHAVIOR IN CLIFF SWALLOWS
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Most of our understanding of animal locomotion comes from quantitatively examining limited behaviors in laboratory settings. For example, the costs and mechanisms of bird flight are best described from wind-tunnel studies of living or taxidermy specimens as a natural comparison to airplane flight. Yet, steady wind-tunnel flight is a poor model for the unsteady flight behaviors critical to an individual’s fitness in natural settings. Three-dimensional motion capture with high-speed video is a fundamental tool for locomotion studies, but setup and calibration in the field have been prohibitive. We are developing an open source package, which uses structure-from-motion camera calibration techniques to rapidly and easily perform 3D video measurement of natural behaviors in the field, with accuracy on par with typical in-lab motion capture. We recorded cliff swallows (Petrochelidon pyrrhonota) flying in loose flocks and hovering in front of their nests – two behaviors impossible to study in the lab. Here, we present the first field three-dimensional...
kinematic comparison between these extremes of flight in a single species, and compare cruising flight at sites differing in elevation by ca. 975 m (Chapel Hill, North Carolina, and Missoula, Montana, USA). When hovering, the swallows increased power output via increasing stroke amplitude (from less than 120° in steady flight to greater than 175° in hovering) and wing beat frequency (from 7-8 Hz to 11-12 Hz). They also use very high geometric angles of attack (>40°) during hovering. As a result, their wings operate with a coefficient of lift at least twice that known from steady level flight – contradicting long-held beliefs regarding the relationship between wing shape and function. Such findings, along with our preliminary investigations of high-speed chases, foraging maneuvers, and flock behavior, provide substantial new insight into the biomechanics of avian flight. Supported by Office of Naval Research MURI (ONR N000141010952).

Symposium 10 – Next Steps: Dynamic Simulations in Paleobiology
Organizers: Eric Snively & Heinrich Mallison

S-063
CONSTRAINTS AND OPPORTUNITIES IN COMPUTATIONAL MODELING OF EXTINCT VERTEBRATES: A CASE STUDY USING PLESIOSAURS
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Plesiosaurs were a successful group of marine reptiles that existed for 160 million years. They had a unique body plan composed of a neck at least as long as the body; a broad, rigid trunk, and both the fore and hind limbs were modified into hydrodynamically-shaped flippers with limited internal mobility. Lacking any extant analogues for comparison, many aspects of the functional anatomy of plesiosaurs remain controversial. However, the computer and the right software provides an opportunity to investigate some aspects of their biology. Fossils of plesiosaurs are commonly found with collections of small stones in the approximate region of the stomach, and it has been proposed these are either a form of ballast or a digestive aid. To investigate the effects of a mass of stones on the buoyancy and equilibrium of immersed plesiosaurs, three-dimensional digital models of three types of plesiosaur were generated. These models include lungs and different regional body densities. The models were subjected to simulated immersion with the effects of body mass, centre of mass, buoyancy, and centre of buoyancy taken into account. The models demonstrate that the masses of stones found with the fossils are insignificant for inducing negative buoyancy, and that substantial lung deflation was still required. Not only are the necks of plesiosaurs extremely long, but the vertebral counts are high, with a recently described form having 76 cervicals. The flexibility and function of the neck has long been debated, with some arguing for mobility, while others proposing rigidity. Using three-dimensional, digital representations of the vertebrae generated with accurate lengths of centra and neural spines, and inter-vertebral separations, the ranges of motion can be investigated. Preliminary results show that the degree of flexibility varies along the neck, and that it is sensitive to assumptions about the size of the intervertebral gaps.
HOW WE CAN USE STRUCTURAL ANALYSIS AND FORCE-DRIVEN SYNTHESIS OF SKULL FORM TO PREDICT DYNAMIC LOADING IN EXTINCT AND EXTANT VERTEBRATES

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Finite element (FE) analysis is an inductive numerical method, useful for investigating mechanical response of individual bony structures. Inaccurate and unrecognized loads can lead to mistakes in strain/stress analyses. FE structure synthesis (FESS), a deductive method, inverts the procedure by creating virtual bony structures by load. Similarity between the synthesized and “real” structures enables us to determine and evaluate likely loads and constraints. FESS assumes that bony structures will be optimized lightweight constructions with minimal material and homogeneous stress distribution; lower forces need only thin structures, and pathways of high forces show greater densities and possibly larger cross sections of bone. Under dynamic loading conditions, accelerations are increased and forces can exceed estimated static values. In life, passive or active tension chords (ligament or muscle) can compensate for and reduce concentrations of high stress induced by dynamic loads. Three examples of FE analysis and FESS are presented, which suggest probable adaptations (including tension chords) to high dynamic loads in vertebrates: 1) The detection of local aggregation of bone and joint surfaces in the mandible of Macaca fascicularis leads to new insights into the process of high dynamic biting. 2) The hypothetical installation of tension chords in skulls of sauropod dinosaurs to compensate for bending gave the idea to dissect skulls of Crocodylus niloticus, to investigate whether this extant archosaurs had structures predicted by FESS. The discovery of an active tension chord in the maxilla suggests a local adaptation to reduce bending of a long snout, synchronized with dynamic biting. 3) Intramandibular joints are found in herrerasaurids and theropods among dinosaurs have been suggested as shock absorbers active during powerful feeding. Kinematical, kinetical, and FE analyses support this hypothesis. These joints combined with active tension chords reduced negative acceleration in critical phases to shield the lower jaw from damaging strains.

PLEUROKINETIC OR MANDIBULAR LONG-AXIS ROTATION? TESTING CHEWING HYPOTHESES IN HADROSAUR DINOSAURS USING MULTI-BODY DYNAMICS ANALYSIS

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Hadrosaur dinosaurs evolved a unique, complex feeding apparatus capable of processing high volumes of plant material. However, the derived nature of the skull and presence of multiple potentially mobile joints has resulted in contentious hypotheses about cranial kinesis and chewing behaviour. Thus, hadrosaur chewing makes for an excellent case study in multi-body dynamics analysis and biomechanical modelling. The skull of Edmontosaurus regalis (NMC 2289) was digitized to build a 3D model and test competing hypotheses of chewing behaviour. All major bone units were modelled as separate structures and constraints and contacts were specified between appropriate bones in the skull. No pre-defined movements between the bones were assigned, and all movements were a result of each bone contacting, pulling, and pushing on one another. Jaw muscles were modelled as a series of spring elements in the software that could be activated and tracked in order to infer the role each muscle played during chewing. Pleurokinesis, a form of cranial kinesis involving mediolateral rotation of the maxillary and palatal elements was tested first, followed by an alternative hypothesis where only bilateral mediolateral translation and long-axis rotation of the mandible were allowed. Finally, a model with no a priori constraints was tested. The two competing kinetic model hypotheses resulted in significant differences in musculoskeletal function and adjusting the constraints between the individual skull bones impacts considerably on the chewing biomechanics in hadrosaurs. Allowing only mandible long-axis rotations and displacements confirms movements hypothesised in other recent studies, whereas constraining/partially-constraining mandibular movements and freeing up other bones in the skull reveals interesting potential kinetic alternatives. The benefits and/or disadvantages and the likelihood of the alternative biomechanical simulations are discussed in detail.

THE INFLUENCE OF OSTRICH HIP MORPHOLOGY ON WALKING AND RUNNING ECONOMY: A TEST CASE FOR USING DETAILED MUSCULOSKELETAL MODELS AND COMPUTER SIMULATIONS TO LINK FORM AND FUNCTION

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Anatomical Record, Volume 296, Special Feature — 148
Ostriches are remarkable for their ability to achieve both fast and economical locomotion (including walking and running), with their high performance suggested to be a result of numerous pelvic limb adaptations. In this study we focus on the hip joint, which has a large number of non-muscular specializations that may be linked to locomotor performance, including a large antitrochanter (a derived feature of birds whose functional importance remains controversial) and three strong ligaments (Ligamentum capsulare, Ligamentum iliopubofemorale, Ligamentum teres) that act to resist femur abduction. The goal of our study was to determine the link between these passive hip structures and walking and running economy. We predict that these structures improve locomotor performance by reducing the total amount of muscle activity, mechanical force and work required during locomotion. To test this prediction we developed a detailed musculoskeletal model of the ostrich pelvis and limbs, consisting of 10 segments and 35 musculotendon actuators representing the major limb muscles. The model was combined with experimental data to develop dynamic computer simulations that estimate the muscle activity and work required to reproduce experimentally observed walking and running motions in two distinct cases: with and without passive support in hip abduction. We found the passive mechanisms markedly reduce the total muscle activity, work and force required during walking and running, and are necessary to balance the high abduction loads experienced at the hip joint during running, which cannot be done by muscle torque alone. Our study highlights the importance of performing sensitivity analyses when detailed information about structures is not inherently available, such as when developing models and simulations of extinct species. Additionally, the avian hip is an excellent example of a joint where non-muscular soft tissues and bony stops deserve careful consideration, especially for fossil taxa, in dynamic analyses of locomotion.

S-068
INTEGRATING CAD AND CAE MODELLING METHODS FOR VERTEBRATE PALAEONTOLOGY
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Various kinematic, kinetic and dynamic Computer Aided Engineering programs offer new approaches to palaeontological and zoological vertebrate research. However, each program has its limitations, so that a fully interventional approach in one of them is not possible. Musculoskeletal modelling in SIMM lacks volumes and inertia transfer, straightforward Computer Aided Design e.g. in Rhinoceros modelling lacks complex physics entirely, and kinetic/dynamic modelling in MSC.ADAMS lacks automated muscle wrapping and good 3D design of natural structures. How can we combine the strength of all approaches to cancel out the weaknesses? One approach involves determining range of motion, muscle paths and volumes in a CAD program, muscle moment arms during motion in SIMM, and joint torques (and thus muscle forces) in MSC.ADAMS. Comparing the theoretically required muscle forces for a given motion in MSC.ADAMS with the CAD-derived possible muscle cross sections allows a rough estimate of an animals’ motion capabilities. Similarly, sensible limits can be put on joint motion ranges in MSC.ADAMS via maximal muscle extension and contraction ranges derived from exact muscle path modelling in SIMM.

Symposium 11 – Functional Morphology of Muscle Extracellular Matrix
Organizers: Nicole Danos & Manny Azizi

S-069
FUNCTIONAL MORPHOLOGY OF INTRAMUSCULAR CONNECTIVE TISSUE: REVIEW
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Our improved understanding of the collagenous structures acting in series with muscle (tendons) has elucidated important mechanisms related to their function in elastic energy storage, power amplification and power attenuation. However, the functional significance of the collagenous extracellular matrix (ECM) that lies within muscle (endomysium, perimysium, and epimysium) remains poorly understood. Intramuscular collagenous tissues form the structural scaffolding for contractile tissues. These structures can function to transmit forces along muscle fibers oriented in series and transmit forces laterally between muscle fibers acting in parallel. These structures also form the myotendinous junction as muscle fibers taper and connect to tendons or aponeuroses. The morphology of muscle ECM is known to change during ontogeny and with certain pathologies. It has also been shown to have significant phylogenetic variation. Thicker intramuscular ECM may translate to stiffer tissues, which in turn may affect the in vivo operating length of muscles, and limit the range of motion at a given joint. However, direct links between changes in ECM morphology and changes in muscle mechanical properties remain largely unexplored. We survey the known morphological variation in ECM from a diversity of vertebrate taxa and summarize the experimental approaches taken to
assess the functional implications of such variation. We then propose an integrative approach to elucidate the direct link between ECM morphology, mechanical properties and organismal function.

S-070
BIOLOGICAL AND MECHANICAL STUDIES BETWEEN THE MUSCLE CYTOSKELETON AND THE EXTRACELLULAR MATRIX
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The skeletal muscle extracellular matrix (ECM) plays an important role in muscle fiber force transmission, maintenance and repair. In both injured and diseased states, ECM adapts dramatically which has clinical manifestations and alters muscle function. Here, we review the structure, composition, and mechanical properties of skeletal muscle ECM as well as the cells that contribute to the maintenance of the ECM and, finally, the changes that occur with pathology. New scanning electron micrographs of ECM structure are also presented with hypotheses about ECM structure-function relationships. We also present a new method to perform three-dimensional reconstruction of specific extracellular collagen cables.

S-071
MUSCLE FIBER-EXTRACELLULAR MATRIX MECHANICAL INTERACTIONS ALONG FULL PERIPHERAL FIBER LENGTHS IS A KEY DETERMINANT OF MUSCLE FUNCTION
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Muscle fibers and the extracellular matrix (ECM) are connected not only at the fiber ends but also via transsarcomelom molecules along their full peripheral length. Consequently, muscle fibers can interact with the ECM and also with each other. Due to that, the following consideration may be mechanically incomplete: muscle fiber is a unit loaded at the proximal and distal ends exclusively, and hence, the force on serially arranged sarcomeres is identical. Instead, the force balance determining the length of a sarcomere is much more involved, including the forces exerted by the ECM and the forces of the sarcomeres located in the neighboring muscle fibers, i.e., myofascial loads. Moreover, muscle has epimuscular connections to its surrounding muscular and non-muscular structures. Muscle length changes and its altered positions relative to such structures cause stretching of these connections and change the interplay of stiffness of the ECM and epimuscular connections. With the resulting epimuscular myofascial loads also included in the above mentioned force balance, muscle fiber-ECM interactions may manipulate the key determinant of muscle function i.e., the sarcomere length. Modeling of muscle in situ allowed us to understand the principles of this mechanism of myofascial force transmission, effects of which are confirmed with MRI analyses performed in human muscles, in vivo. As a consequence, the muscle’s contribution to joint moment and range of movement are dependent on the mechanical conditions within which the muscle operates. This is highly relevant for muscle function in health and disease. Our recent intra-operative data show that spastic muscle stimulated alone may show no abnormal mechanics. However, this changes after another muscle is stimulated simultaneously, causing the conditions of muscle functioning to differ. Our findings indicate also that muscle fiber-ECM interactions are central to the effects of surgical interventions and Botox injections performed to treat muscle spasticity.

S-072
THE MECHANICAL EFFECTS OF CONNECTIVE TISSUE LINKAGES BETWEEN SKELETAL MUSCLES
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In contrast to statements in anatomy texts, skeletal muscles are not clearly identifiable independent entities. Muscles are generally linked by connective tissues at their shared muscle belly interface (i.e., epimuscular myofascial linkages) and often share a tendon (i.e., common elasticity). Thus, when a muscle contracts, there are several pathways via which its action can be linked to its neighbor. Via epimuscular linkages, length changes in one muscle can affect forces exerted at the tendons of adjacent muscles. Mechanical interaction via a common tendon can be measured as nonlinear summation of force. The physiological significance of epimuscular force transmission for in vivo muscle action and neuromuscular control is still subject to considerable debate. Are epimuscular myofascial connections a mere by-product of the musculoskeletal organization or are they functionally relevant? The functional relevance is dependent on the magnitude of the effects found during normal movements. However, many muscle conditions in previous experiments were different from the conditions under which muscles act in vivo. Recent results indicate substantial mechanical interactions between rat synergistic muscles in vivo. In addition, it appears that effects of epimuscular linkages can be counteracted by effects of common elasticity. A second question that
will be addressed is how force transmission is affected by scar tissue formed following invasive surgical procedures. For this purpose, we have performed a series of studies to investigate the effects of scar tissue formation following tendon transfer on muscular force transmission. We found that mechanical effects of transferred muscle can be quite different than its effect predicted based solely on the new moment arm at the joint. This can be explained by scar tissue at muscle-tendon boundaries, which limits force transmission from the transferred muscle via the tendon of insertion to the skeleton. Supported by EC Grant MIRG-CT-2007-203846 and NWO-ALW Grant 864-10-011.

S-073
FUNCTIONAL MORPHOLOGY OF EPIMYSIAL COLLAGEN FIBER ARRAYS AND THE EVOLUTION OF BALLISTIC TONGUE PROJECTION IN FROGS
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Frogs exhibit diverse mechanisms of tongue protraction during prey capture. Tongue projection evolved numerous times independently among frogs from a primitive condition with pad-like tongues that shorten during prey capture. Projectile tongues include both hydrostatic and inertial mechanisms. In contrast to tongues of basal frogs, projectile tongues elongate during projection. Cross-helical fibers surrounding a constant volume hydrostat will re-orient toward angles of 54°44¢ when pressurized, for example by muscle activation. Thus, tongue muscles with collagen fiber angles > 54°44¢ will elongate when activated, whereas tongue muscles with fibers oriented at angles < 54°44¢ will shorten upon activation. We investigated the orientation of epimysial collagen fibers and the kinematics of prey capture in four species of frogs: Litoria caerulea (Hylidae); Bufo (=Anaxyrus) woodhousii (Bufonidae); Rana pipiens (Ranidae); and Hemisus marmoratus (Hemisotidae). Prey capture was studied using high-speed digital imaging (250 Hz). Scanning electron microscopy and polarized light microscopy were used to measure the orientation of epimysial collagen fibers relative to the long axis of the main tongue protracting muscles in each species. During projection, tongues elongate by 210% in Bufo, 200% in Hemisus, and 130% in Rana, whereas the tongues of Litoria shorten by 33% during projection. The corresponding angles of cross-helical collagen fibers surrounding the tongue protractor muscles were 73.6° in Bufo, 89.9° in Hemisus, 60.8° in Rana, and 33.5° in Litoria. It appears that tongue projection during prey capture results not only from changes in the orientation of cross-helical arrays of epimysial collagen fibers in the tongue protractor muscles upon activation but also from transfer of angular momentum from the opening jaws to the tongue. These data suggest that the orientation of cross-helical collagen fibers has played a major role in the function and evolution of prey capture among frogs.

S-074
MECHANISMS GOVERNING MUSCLE BULGING DURING LOCOMOTOR ACTIVITIES
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Muscles change shape when they contract, and it has been demonstrated that this shape change has significant impact on the force and velocity of contraction. Furthermore, shape change within a single muscle can be variable; muscles bulge in different directions depending on the force of contraction. It has been hypothesized that the direction of muscle shape change is governed by the elastic behavior of muscle extracellular matrix (ECM), and driven by intramuscular pressures developed in pennate muscles during force production. While it seems likely that the ECM plays a role in governing muscle shape changes, alternative mechanisms, such as a prominent role of aponeurotic sheets, are also plausible. In vivo, adjacent muscles and connective tissue sheaths bounding muscle compartments likely also influence muscle shape changes. We have developed methods for determining muscle shape changes in vivo via radiopaque markers implanted along muscle fascicles, at the boundaries of the muscle belly, and within the aponeurosis. The 3D position of these markers can be triangulated with high-speed biplanar fluoroscopy during locomotion to determine instantaneous muscle length, width, thickness, and fascicle pennation angle. Studies of jumping and landing in turkeys allow us to compare contractions involving similar forces but very different fascicle length trajectories, with muscle shortening during a jump and mostly muscle lengthening during landing. A comparison of these activities reveals that while changes in muscle width and aponeurosis width are generally qualitatively similar, the magnitude of aponeurosis strain and muscle width change can be very different during high-force activities, suggesting that at least some muscle bulging occurs independent of aponeurosis behavior. Results also show that changes in muscle width are not simply a function of muscle force, suggesting that the simplest model of ECM-mediated shape change may not be sufficient to explain variable bulging in muscles. Supported by NIH grant AR055295.
FUNCTIONAL MORPHOLOGY OF A UNIQUE MUSCULAR ORGANISATION IN THE PREHENSILE TAIL OF SEAHORSES
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Seahorses and pipehorses (Syngnathidae) both possess a prehensile tail, a unique character among teleost fishes, allowing them to grasp and hold onto substrates, like sea grasses. Recent phylogenetic studies suggest that the prehensile tail in syngnathid fishes evolved more than once and also suggest the existence of intermediate forms in the lineage giving rise to the seahorses. Unlike the ancestral organisation of interdigitating cones of myosepta, the caudal hypaxial muscular system of seahorses is characterized by parallel myoseptal sheet spanning multiple - up to eight – vertebrae. In addition, they have distinct ventromedial muscles, which are lacking ancestrally. To form an idea about how this unique seahorse system could have evolved from a conical myoseptal organization, as seen in pipefishes and most other teleost fishes, we compared the epaxial and hypaxial tail musculature of seahorses and several other syngnathid fishes. Two target lineages chosen were: (1) a species belonging to the lineage giving rise to the seahorses, i.e. the ribboned pipehorse (Halichthys taeniophorus) and (2) a pipehorse species that is nested within the pipefish lineages (the alligator pipefish – Syngnathoides biaculeatus). We hypothesised finding an intermediate morphology (between pipefish and seahorse) in the first case, but a potentially convergent strategy towards a prehensile tail in the second case. To test these hypotheses, µCT-scanning and histological sections were combined with virtual 3D-reconstruction. The results partially support this hypothesis. The epaxial muscles of seahorses as well as the hypaxial muscles of the ribboned pipehorse show a reduced conical organisation compared to the ancestral state and an elongation of the myoseptal cones in the alligator pipefish were observed.

S-076
FOSSIL BONE HISTOLOGY "CORRECTED FOR" OSTEOGENESIS AND CUTTING PLANES: WHAT IS FIBROLAMELLAR BONE ANYWAY?
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Fibrolamellar bone is defined as a composite tissue in which rapidly growing, woven fibred (“fibrous”) bone forms the bulk of the tissue encompassing large vascular spaces which then will be partially infilled by centripetally deposited osteonal lamellar bone. Due to its random fibre orientation, woven bone is considered to have isotropic optical behavior as opposed to the birefringent nature of lamellar bone with highly organized fibres. Based largely on the combination of these optical features under crossed plane polarizers, fibrolamellar bone has been identified in the limb bone cross sections of several extinct tetrapods. In these thin sections, all dark regions have been interpreted as fast growing woven bone and all bright parts as slower growing lamellar or parallel-fibred bone with the latter referring to some sort of intermediate fibre arrangement. For instance, extensive dark areas in sauropod limb bone cross sections were considered as explanation and evidence for high growth rate which as such was achieved by deposition of great amounts of fast growing woven bone. When making oriented thin sections it is expected that, per definition, woven bone remains dark no matter in which direction the bone was cut. However, longitudinal sections of sauropod long bones of which transverse thin sections have already been published as fibrolamellar bone with very extensive woven component, revealed a completely different pattern. Differences have been detected in lacunocanalicular as well as optical features of the bone tissues. These deviances have led us to review and revise what is currently known of different bone tissue types and their formation processes, thereby getting a better understanding on the developmental and evolutionary origin of high bone growth rates. Besides challenging the validity of widely used paleohistological concepts and terminologies, this new perspective also shows that “fibrolamellar bone”, as defined, has lapsed into futility.

S-077
BONE HISTOLOGY OF MARINE TURTLE SHELLS THROUGH TIME
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Secondary adaptation to the marine environment has a strong influence on the bone microstructure of vertebrates and the turtle shell bone is similarly affected as are bones of the internal skeleton. Bone histology is thus a powerful tool to not only address life history data, but also to elucidate the palaeoecology of turtles based on their shell bone microstructures. The stem-turtle Eileanichelys waldmani (Middle Jurassic
of Scotland), reportedly a lagoon or lake-dweller bridging the gap between the earlier terrestrial and later aquatic forms, shows shell bones already adapted to the aquatic medium, such as an increasing bone porosity and cortical reduction. Among Testudines, it was mainly the cryptodiran turtles that exploited the marine habitats, although members of several pleurodiran turtle lineages (e.g., Bairdemys) lived in or at least tolerated near-shore marine environments as well. The evolution of marine turtles can be separated in three successive phases – phase one is exemplified by the radiation of near-shore or ‘ littoral’ taxa (e.g., plesiochelyids, eurytestids, ‘thalassemydids’) from the Upper Jurassic of Europe. These taxa exhibit rather compact shell bone microstructures with well developed external cortices and short, thick interior trabecular structures. Phase two occurred during the Lower to Middle Cretaceous and includes protostegid, toxochelyid and chelonchelyid turtles and stem-dermochelyids. Many of these taxa inhabited open marine environments, thus showing trends to further reduce cortical compact bone and homogenise with the internal cancellous bone. The third phase started in the Paleogene and includes also the modern chelonian and dermochelyid taxa. The former generally show high degrees of vascularisation, often leading to a homogenized spongy appearance, whereas in the latter, the thecal shell was completely reduced and a secondary, epicontact mosaic-cover developed. The secondary armour ossicles show well developed external and reduced internal cortices and a growth centre just interior to the external bone surface.

S-078
BONE MICROANATOMY OF TURTLE LIMB BONES: ADVANCES IN PALEOBIOLOGY OF TESTUDINATES
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Turtles have radiated in varieties of habitat during their evolutionary history of more than two hundred million years. Here the authors describe limb bone microanatomical features of terrestrial and aquatic living turtles with an aim to provide clues to reconstruct the biology of fossil turtles. Since previous approaches detecting ecological inference from two-dimensional transverse sections of turtle limb bones were less than successful, the authors focused on three-dimensional bone internal compactness profile data acquired using a microfocus CT scanner. In microanatomical scale, bone internal structure of turtles is generally characterized by a lack of a large open medullary cavity. Among nonmarine turtles, terrestrial species show dominance of cancellous bone in limb bone diaphysis. Meanwhile, local but extreme compactness is found in limb bone diaphysis of nonmarine aquatic turtles. Judging from the morphologies of endochondral cancellous bone and the nutrient canal passing through the periosteal bone, the center of the most compact transverse section is immediately interpreted as the center of ossification, where the embryonic bone initiates the elongating and the thickening growths. This structural difference between terrestrial and nonmarine aquatic turtles is considered to be a result of natural selection pressure due to the advantage of limb bone mass reduction in terrestrial locomotion. Among marine turtles, deep-diving species such as Dermochelys coriacea (leatherback turtle) exhibit secondarily cancellous limb bone inner organization, indicating that the skeletal lightening occurs in relation with body buoyancy control. Since these relationships between limb bone internal structure and lifestyle in turtles are universal in nature in the order Testudines, it will be possible to convincingly reconstruct the paleoecology of extinct turtles in using internal limb bone structure in addition to skeletal morphology.

S-079
WHY ARE SAUROPOD DINOSAURS SO DIFFICULT TO AGE? INSIGHT FROM LOCAL BONE APPOSITION RATES
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Sauropod dinosaurs, as the largest terrestrial animals ever, present particular challenges in understanding their life history. Unlike in other dinosaur groups, quantification of the growth record from cyclical growth marks (GM) in sauropod long bones has been difficult. A qualitative description of sauropod life history is possible, using histologic ontogenetic stages (HOS) that also permit comparison of life histories in an evolutionary context. Sauropod long bone cortices generally consist of laminar fibrolamellar bone or modifications thereof. The growth records of the humerus and the ulna of a mamenchisaurid sauropod individual from the Jurassic of China reveals a possible explanation for the poor development of growth marks in sauropod long bones: a threshold bone tissue apposition rate of 20 µm/day above which GM are not developed. The ulna shows 25 cycles and an external fundamental system (EFS), with a sudden decrease in GM spacing before the final 11 cycles. This decrease is interpreted to represent sexual maturity,
at which there is a shift in resource allocation from growth to reproduction. In the considerably larger humerus, the inner cortex lacks GM, and only the final 11 cycles and the EFS are expressed. Other sauropod humerus and femur samples with GM also support the existence of a threshold apposition rate for GM. Presumably, this threshold is linked to structural constraints in the formation of lamellar fibrolamellar bone and thus may apply more generally than just to sauropods. While GM are well expressed in smaller bones of sauropod skeletons such as ribs, GM in ribs only allow an estimate of age at death. What scanty growth record and model fitting evidence is available suggests that sauropod dinosaurs attained sexual maturity in the second decade of their life, reached full size in the third decade, and continued to live for several years afterwards.

S-080
SLOW GROWING ENANTIORNITHES AMONG FAST GROWING PYGOSTYLIA (AVES)
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Here we analyze the bone histology of unfused metatarsals of Confuciusornis lacustris and Iberomesornis romeralii, two enantiornithine birds from the Lower Cretaceous of Las Hoyas (Spain). These metatarsal cortices are almost entirely formed by avascular parallel-fibered bone tissue containing lines of arrested growth, suggesting that they were formed during a phase of slow growth. We compared these patterns with those of species belonging to more inclusive nodes (Varanus, Crocodylus, Troodon, Confuciusornis), as well as with those of species belonging to less inclusive nodes (Alectura, Megapodus, Anas, Streptopelia, Turdus). Pygostylia (a clade including the last common ancestor of Confuciusornis and modern birds, and all its descendants) are characterized by patterns of rapid growth during most of the ontogeny (forming the fibrolamellar core of the bone cortex), with a slowdown of growth rates when approaching the asymptotic bone size (forming the outer layer of parallel fibered bone). This slowdown occurs earlier in precocial birds than in altricial ones, which has been interpreted as the outcome of the threshold between energy used for locomotion and energy used for growth. Consistently, it has been suggested that the thick outer layer of parallel-fibered bone in enantiornithes may be the outcome of the supposed precocial development of these birds. We show that, in contrast to Megapodiidae and other precocial neornithines (which are precocial runners), enantiornithes may have been precocial flyers that mainly use flapping flight. The high energetic cost of flapping flight in enantiornithine hatchlings may explain the early onset of postnatal slowdown and the thickening of the outer layer of parallel-fibered bone of these birds.

S-081
BODY SIZE AND PHYLOGENETIC SIGNALS IN MAMMALIAN BONE MICROSTRUCTURE AND THE DISTRIBUTION OF MAMMALIAN BONE GROWTH PATTERNS
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Bone microstructure is influenced by many factors, including body size, growth rate, and phylogeny. The literature acknowledges no great differences between marsupial and placental bone histology, leading some to infer a common histological signature for therian mammals. Histological similarity is reasonable for small marsupials and placentals (< ~50g), which have similar growth rates and durations, but larger marsupials grow at lower rates and delay epiphyseal fusion for several years compared to placentals of similar body size and ecology. Given these growth differences, larger marsupials should show histological evidence of extended slow growth, contrasting the fast-growing bone tissues described for placentals. However, the mammalian osteohistological sample is biased toward placentals of economic importance, and only two marsupials have been usefully described. I sampled the mid-diaphyseal femora of over 50 extant and extinct marsupial species, as well as afrotherian, xenarthran, and laurasiatherian placentals. My marsupial sample encompasses all extant orders, spans a 10g-2500kg size range, and comprises mainly wild-caught animals. Small therians do show a common histology of nearly avascular lamellar bone, with lines or arrested growth (LAGs) present in hibernating taxa. Marsupials >50g typically produce well-vascularized woven bone early in life, but after 1-2 years deposit poorly vascularized lamellar bone for several years. This pattern also occurs in many afrotheres, xenarthrans, Solenodon, and bats; but differs from those of the large-bodied ungulates (exclusively well-vascularized woven bone) and primates (heavily remodeled bone) that dominate the literature. I propose that the first condition is plesiomorphic for therian mammals, and that sampling biases have obscured both size and phylogenetic signals in the distribution of mammalian bone growth patterns.
S-082
GROWTH IN FOSSIL AND RECENT DEER AND IMPLICATIONS FOR ISLAND EVOLUTION
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The Mediterranean island of Crete sheltered an outstanding example of Late Pleistocene insular dwarfism, the deer Candiacervus. In contrast stands its close relative Megaloceros giganteus, the Irish giant deer, known from the middle to late Pleistocene of Europe and western Asia. Placing palaeohistological data of Candiacervus and Megaloceros in a phylogenetic context reveals common patterns of growth and life history changes in fossil island forms. Most long bones of newborn Candiacervus start growth with fibrolamellar bone as primary bone tissue and show a mainly plexiform arrangement of vascular canals, as found in adult specimens. Similarity of bone tissue types in Candiacervus, Megaloceros. Dama and other extant deer show a comparable mode of growth. A larger number of growth cycles and thicker growth zones in the cortex of Megaloceros indicate higher longevity and growth rates. Tooth cementum analyses confirm bone histological evidence, indicating a longevity of up to 12 years in Candiacervus and up to 19 years in Megaloceros. A comparison with other deer taxa as Cervus and Alces shows that a combination of lower growth rates and shorter lifespan characterises the paedomorphosis of Candiacervus. In contrast, Megaloceros giganteus reached its size by a combination of high growth rates and a longer lifespan (peramorphosis). Whereas growth rates of the fallow deer Dama are comparable to Candiacervus, its lifespan is similar to that of Megaloceros. Comparison with other evolutionary changes of mammals in islands demonstrates the complexity of island evolutionary key factor interactions. Consequently, different degrees of modifications in skeletal tissues as the deposition of slow growing lamellar-zonal bone in the island goat Myotragus and faster growing fibrolamellar bone in Candiacervus, evolve. The general occurrence of growth marks in extant and extinct deer confirms that rest lines in bone tissue are not indicative of low metabolic rates.

S-082 Bis
RECONSTRUCTING MAMMALIAN LIFE HISTORIES FROM HARD TISSUES
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Timing of life history (LH) events is intimately related to the overall performance of the individual as an evolutionary unit. LH events are amongst the most important fitness-giving components, along with and interdependent with the individual’s reproductive schedule. As natural selection operates through phenotypic traits co-varying with fitness, phenotypic variance of life history traits is the raw material of selection, and is the cornerstone of adaptive evolution to new environments, provided enough genetic grounding. Measured heritabilities of life history parameters are at the lower end of the range for phenotypic traits, supporting the belief that they are heavily inspected by natural selection generation after generation. Complementarily to this view, the environmental component of the variance of LH traits is high, especially on those traits that directly determine survival skills (e.g. size and age at maturity have high phenotypic plasticity), and are lower on those more phylogenetically and allometrically controlled (gestation time). Hard tissues preserve incremental signals left by certain life history events. Because of their very nature, life history events are recorded as single, non-cyclical incremental signals in the microstructure of the growing tissue. The timing of life history events can be calculated by counting the number of dental incremental lines or annual lines of arrested growth in bone. These periodical marks are caused by growth cycles that follow endogenously driven circadian or circannual rhythms. These rhythms are under considerable regulatory control of an internal timing mechanism (clock). They are triggered by photoperiods and match oscillations of the animal’s daily or annual metabolic physiology. Biological rhythms have periods that approximate natural environmental cycles of resource availability and/or energy demands, indicating that they have evolved under natural selection and increase reproductive fitness. Though they might affect the pace of an organism’s LH, they are not LH traits by themselves.

S-083
WHY I MAKE MORE SENSE ON TUESDAY
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Ultimately, we wish to understand the significance of long period biological timing on mammalian growth, physiology, and behavior. Here we compare time-resolved lamellar growth rate variability with trace and ultra-trace element composition from humans of known life history to examine the metabolic flux of materials.
over time and environmental conditions. **Materials and Methods:** We examine midshaft femur cross sections derived from University of Malawi College of Medicine cadavers, for which physical characteristics, characteristics of the living environment and ecology, medical history and social factors, as well as characteristics of the subjects' economic and occupational lives are known. We employ laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) to research variability in the concentrations of 64 isotopes across the breadth of the periodic table along time-resolved lamellar development. **Results:** 

"Bone seeking" elements $^{138}$Ba, $^{64}$Zn, and $^{88}$Sr were evaluated at near-weekly resolution and observed to follow moderately longer term growth rhythms provisionally corresponding to ca. 8 weeks duration. We also plotted regional rainfall data corresponding to lamellar bone deposited during approximately 1981-1996. $^{64}$Zn/$^{88}$Sr ratio composition is observed to roughly correspond with rainfall. **Conclusions:** We observe that the metabolic flux of materials is sensitive to combined environmental and dietary factors and that long period growth rate variability in human bone is comparable to variation in trace element ratios. We know little-to-nothing about long period rhythms; for all we know, one of us (TGB), having a 7-day rhythm, makes more sense on Tuesdays. Analyses of long period metabolomic signatures obtained from the domestic pig are in progress, and a physiological understanding of such rhythms is near. Funding: The 2010 Max Planck Prize administered by the Max Planck Society and Alexander von Humboldt Foundation in support of the Hard Tissue Research Program in Human Paleobiomics, NSF award BCS-1062680, and the NYUCD Summer Research Program.

S-084

NANO_STRUCTURE AND DIAGENESIS OF SAUROPOD’S BONE AND DENTAL TISSUES USING ADVANCED CHARACTERIZATION TECHNIQUES

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The structure of long bones and teeth of large Jurassic sauropods (Dinosauria) from two different geological sites (Tendaguru Formation [Tanzania, Africa] and Morrison Formation [USA]) are investigated using advanced characterization techniques. X-ray diffraction and electron microscopy (SEM and TEM) are applied to the fossil specimens to obtain both biological information (e.g. microstructure, mechanical performance linked to collagen fiber organization) and taphonomical information (e.g. diagenetic effects on fossil tissue nanostructure). Both techniques provide insights into the biomechanics of sauropod long bones by revealing crystallographic parameters such as size and orientation of the bone apatite crystallites. Coupled with chemical composition analysis via EDX (Energy dispersive X-Ray) and diffraction patterns, it is possible to discern different degrees of alteration in the two geological sites. Changes in original bone crystallites and secondary mineral inclusions can be detected. These diagenetic data are then used to reevaluate previous assumptions about the nanostructure of fossil hard tissues.

S-085

ADVANCES IN VIRTUAL DENTAL HISTOLOGY FOR PALAEOANTHROPOLOgy USING MULTI-SCALE PROPAGATION PHASE CONTRAST X-RAY SYNCHROTRON MICROTOMOGRAPHY

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Over the last few years, the development of non-destructive X-ray synchrotron microtomography using propagation phase contrast has revealed internal tooth structure with high fidelity, including dental microstructure. Based on a multiscale approach, this technique can reveal incremental features in fossil teeth, including circadian increments and developmental stresses. One of the most powerful uses of this technique is the detection of the neonatal line, in addition to the incremental long-period line periodicity. The lack of these parameters in previous dental studies has led to broad estimations of developmental timing and of age at death in fossil hominins. The virtual histology approach has enabled us to investigate the dental growth patterns in several juveniles of Neanderthals and early Homo sapiens, which are linked to aspects of life history (overall scheduling of growth and development). Since this first large scale study of hominin dental development, the possibilities of virtual dental histology have dramatically improved through developments at the ESRF, including beamline capabilities and processing and analysis strategies. In particular, virtual dental histology no longer solely relies on 2D slices, as it also fully integrates 3D aspects of the outer and inner surfaces of the teeth. Ongoing work on Plio-Pleistocene hominins imaged at different resolutions reveals their dental development and age at death based on incremental dental features. These recent innovative approaches facilitate the study of large specimens (including sub-adults) with complex fossilization (diagenetic) patterns. This is paving the way for a level of precision never reached before on
exceptional fossils, which would not be possible using classical destructive histological techniques. Supported by NSF Grant BCS 1126470, Harvard University, and ESRF Grant EC697.

S-086
3D MICROSTRUCTURE AND IDENTIFICATION OF MUSCLE ATTACHMENTS IN EXTANT AND FOSSIL VERTEBRATES REVEALED BY SYNCHROTRON MICROCTOMOGRAPHY
Sanchez, Sophie (1); Dupret, Vincent (1); Tafforeau, Paul (2); Trinajstic, Kate (3); Ryll, Bettina (1); Goutenoire, Pierre-Jean (1); Wretman, Lovisa (1); Zylberberg, Louise (5); Peyrin, Francoise (4); Ahlberg, Per (1)
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A major problem in our understanding of extinct organisms is the lack of information of their soft anatomy. The musculature is a vital component in vertebrate morphology and an understanding of soft anatomy has profound implications for evolutionary and biomechanical scenarios and the reconstructions of organisms. However this component of the anatomy is rarely preserved in fossils. The fibrous systems (entheses), which attach muscles to bones, are complex three-dimensional structures that can be used to accurately determine muscle attachment sites. Until now, these fibres could only be visualized in two dimensions (2D) using sectioning techniques. The destructive nature of these techniques has limited their application to extant organisms and certain fossils only. Because 2D information is not sufficient for a complete understanding of muscle attachments, a series of thin sections are necessary and therefore reliant on subjective extrapolation from one thin section to another. These technical limitations have resulted in few comparative investigations of entheses having been accomplished. Here we show that phase contrast synchrotron microtomography is able to distinguish between the three distinct types of entheses embedded in the primary skeletal matrix non-destructively and in 3D in both small extant and extinct taxa. In addition to providing 3D visualisation of the fibre bundles embedded in the bone matrix, using statistical analyses, we could discriminate muscle attachments mediated by the periosteum from unmediated attachments in an extant salamander Desmognathus. We were then able to apply this model to identify muscle attachment sites and orientations in two Devonian fishes: Eusthenopteron and Compagopiscis. The discovery of muscle entheses in these fossil vertebrates contradicts previous hypotheses of muscle position in these taxa. Our results indicate this methodology will provide future data and increased understanding of the soft anatomy which will change perceptions of the evolution and morphology of early vertebrates.

Symposium 13 – Sticks, Stones, and Slopes: the Link between Substrate Characteristics, Morphology, and Biomechanics
Organizers: Anthony Herrel & Timothy Higham
S-087
THE EFFECT OF SUBSTRATE DIAMETER AND INCLINE ON LOCOMOTION IN ARBOREAL FROGS
Herrel, Anthony (1); Perrenoud, Mats (2); Abdala, Virginia (3); Manzano, Adriana (4); Pouydebat, Emmanuelle (2)
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Frogs are characterized by a unique morphology associated with their saltatory lifestyle. Yet, arboreal species show morphological specializations relative to other ecological specialists allowing them to hold on to narrow substrates. Here we study the limb and brain morphology in arboreal frogs of the genus Phyllomedusa. In addition, we quantified the 3D kinematics of forelimb movement for frogs moving across branches of different three diameters (1, 4, 40mm) and two different inclines (horizontal and 45 degrees). Our data show anatomical differences between arboreal species compared with burrowing, terrestrial and aquatic species in the forelimb anatomy and the size of the cerebellum. Moreover, our results show that grip types differed across diameters and inclines. The kinematics of the wrist, elbow and shoulder as well as the body position relative to the substrate showed significant effects of individual, diameter and incline. Kinematic differences involved the durations, velocity of movement and angular excursions with differences being more pronounced for the distal joints. Interestingly, the effects of diameter and incline on both grip type and kinematics are similar to what has been observed previously for primates. Thus the mechanics of narrow substrate locomotion appear to drive the kinematics of movement independent of morphology and phylogeny.

S-088
FUNCTIONAL MECHANISMS UNDERLYING THE RELATIONSHIP BETWEEN MORPHOLOGY AND HABITAT USE IN LIZARDS
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The question of how ecology shapes form and function has captivated biologists for centuries. Historically, the primary emphasis has been on the relationships between morphology and both macro- and microhabitat use. However, the mechanistic basis underlying these relationships is often neglected. Morphological structures can move (kinematics) and interact with the environment (kinetics), but do so through the action of muscles, which are able to execute a range of behaviors. All of these functions will vary with microhabitat use, which can vary dramatically within a single type of habitat. For example, in contrast to what is commonly assumed, animals can climb in a terrestrial habitat or move on horizontal surfaces in an arboreal habitat. Thus, these general habitat categories, though widely used, are insufficient for characterizing the demands placed on the animal. Instead, the attributes of a given habitat are likely driving the selective pressure on morphology and function. Lizards are extremely adept at traversing complex three-dimensional habitats and their locomotion is one of the most spectacular examples of versatility and maneuverability in nature. Thus, lizards provide a rich system for examining the mechanistic links between morphology and ecology. Here, we review the relationship between both external and internal limb morphology and microhabitat structure. We then explore the mechanistic link between morphology and ecology through discussion of kinematic and in vivo muscle strategies for dealing with varying substrate characteristics. Finally, we propose a new framework for categorizing the demands of habitats. Using this standardized framework, we can begin to understand the differences and similarities in demand that animals experience, regardless of habitat type, and therefore identify examples of convergence in response to common selective pressures.

S-089
NEUROMECHANICS OF SAND-SWIMMING
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Animals like the sandfish lizard (Scincus scincus) that live in desert sand locomote on and within a granular medium whose resistance to intrusion is dominated by frictional forces. Recent kinematic studies reveal that the sandfish utilizes a wave of body undulation during swimming. Models predict that a particular combination of wave amplitude and wavelength maximizes swimming speed and minimizes mechanical cost of transport as the sandfish swims. Experiments suggest that the sandfish targets this kinematic waveform template. To investigate the neuromechanical strategy of the sandfish during sand-swimming, we used high speed x-ray and visible light imaging with synchronized electromyogram (EMG) recordings of epaxial muscle activity. During subsurface sand-swimming, EMG revealed an anterior-to-posterior traveling wave of muscle activation that traveled faster than the wave of curvature. Activation intensity increased as the animal swam deeper but was insensitive to undulation frequency. These findings were in accord with empirical force measurements, which showed that resistance force increased with depth but was independent of speed. The change in EMG intensity with depth indicates that the sandfish does indeed target a swimming template. Further work used the model of sand-swimming to explain the increasing phase lag between activation relative to the curvature towards the tail; this phenomenon is referred to as “neuromechanical phase lags” (NPL). The simplicity of the sandfish sinusoidal movement within a friction-dominated and non-inertial resistive environment allows detailed analysis and reveals an important mechanism responsible for the phenomenon; a combination of synchronized torques from distant points on the body and local traveling torques. This mechanism should help explain NPL in undulatory swimmers moving in other environments. Our work can also lead to advances in the design and control of robotic locomotors capable of moving within complex substrates.

S-090
THE BIRD BAUPLAN AND ITS LOCOMOTOR PLASTICITY: THE CASE OF HOPPING IN PASSERINE BIRDS
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Birds are the most diversified clade among extant tetrapods and have attracted attention because of their ability to live in various environments. Despite this ecological plasticity, their bauplan is very conservative and corresponds to a specialization for flying. This specialization necessitates the presence of wings and a rigid trunk. Beside the specialization for flying, the birds are fundamentally bipeds. This feature, basic for the clade, allows them to move on most substrates. As such, birds are able to live and move in trees, on ground, and in water with only adjustments of the limb proportions. The question we address here is the link between the geometrical features of a bird’s bauplan and its efficiency on different substrates. When walking striding birds may use bouncing dynamics at slow speed, that is explained by the crouched limb position in birds...
made possible by their morphology. However, many birds are arboreal, and most of them do not stride, but rather hop when moving over ground or on branches. In arboreal locomotion, the substrate may, depending on the kind of branch, be compliant. We studied the locomotion of a passerine bird (the zebra finch) when hopping on a hard and a compliant substrate. Information on the motion and on biomechanics was collected using X-ray videos and force recording. The dynamics showed typical spring mass model properties and the vertical component of the forces was not different. However, the forward component was smaller when hopping on a compliant substrate and the kinematics of the body segments also slightly differed suggesting that the bird adjusts its internal mechanical parameters to take advantage of the flexibility of the substrate. The geometry of the crouched posture typical of the morphology of birds provides redundancy which could be advantageous in the adaptation to move on variable substrates.

S-091
ARBOREAL VERSUS TERRESTRIAL LOCOMOTOR KINETICS AMONG NON-PRIMATE MAMMALS
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Traveling on tree branches, trunks, twigs, and foliage is common among mammals. Because these substrates are usually cylindrical and narrow, traveling on them presents challenges to body weight support and balance that are not present during terrestrial locomotion. Measuring substrate reaction force and impulse is a useful way to evaluate body weight support and stability during arboreal locomotion. However, most of the data about force and impulse are from primates. To understand how these biomechanical problems are solved by mammals in general, we gathered substrate reaction force data and hand/foot positioning from four species of quadrupedal mammals walking or running on cylindrical supports that were narrower than the width of the animals’ bodies. Two species (squirrels, chipmunks) used asymmetrical gaits, and two (rats, opossums) used symmetrical gaits. Using data that are still being compiled as of this writing, we will test two hypotheses. Both of them compare locomotion on a flat “terrestrial” trackway to a narrow, cylindrical “arboreal” trackway. First, we will test whether foothall position around the arboreal cylinder is correlated with vertical and mediolateral impulses. We predict that more laterally placed hands and feet will generate stronger mediolateral impulse and smaller vertical impulse. Second, we will determine if vertical impulse and peak vertical force is reduced on the arboreal trackway. Posterior weight shift – increased vertical impulse and/or peak vertical force in hindlimbs on arboreal supports – is common among primates, and we will also determine the extent to which this is true among four non-primate mammals.

S-092
ORANGUTANS EMPLOY UNIQUE STRATEGIES TO CONTROL BRANCH COMPLIANCE
Thorpe, Susannah
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Branch compliance presents a major problem for arboreal animals that travel and feed in the forest canopy. Branches taper towards their ends, but the narrowest gaps between trees are situated between the thin terminal branches of adjacent tree crowns. Efficient travel through the rainforest canopy requires animals to minimize the deviations from their travel path, unless such deviations are more energetically efficient than direct travel (although non-energetic factors such as the risk of falls may also influence gapcrossing decisions). In theory, compliant terminal branches may act as external springs adding momentum to jumps and leaps across gaps, but most researchers have suggested that compliant supports increase the cost of arboreal locomotion: quadrupedal monkeys lose energy during take off and landing as branches bend under their weight and jumping lemurs generally lose contact with branches before they recoil, expending energy to deform supports but failing to exploit the elastic energy to aid momentum. Orangutans are the largest habitually arboreal mammal and are the only great ape to have remained exclusively in this great ape ancestral niche. In theory therefore they should have evolved a particularly refined suite of adaptations to facilitate arboreal living. Yet, 75% of wild orangutans (Pongo spp.) treated at rehabilitation centres have healed fractures, dislocations and contusions that presumably result from past falls. This rather suggests an animal operating at the limits of their locomotor and morphological plasticity. In this presentation I will draw on our studies of functional morphology and locomotion to consider the eco-morphological constraints on orangutan arboreal locomotion and to demonstrate that they have evolved unique strategies to control and utilise support compliance.
Symposium 14 – Inside the Vertebrate Nose: Evolution, Structure, and Function
Organizers: Blaire Van Valkenburgh, Irina Ruf, & Thomas Elting

S-093
BREATHING LIFE INTO DINOSAURS: TACKLING CHALLENGES OF SOFT-TISSUE RECONSTRUCTION AND NASAL AIRFLOW IN EXTINCT SPECIES
Bourke, Jason (1); Ridgely, Ryan (1); Porter, William (1); Lyson, Tyler (2); Schachner, Emma (3); Bell, Phil (4); Witmer, Lawrence (1)
(1) Ohio University, Athens, United States; (2) Yale University, New Haven, United States; (3) University of Utah, Salt Lake City, United States; (4) University of Alberta, Alberta, Canada

Nasal passage expansion in many dinosaurs suggests that nasal physiology (air conduction, conditioning, olfaction, phonation, etc.) played an important role in life. However, the lack of soft-tissue preservation in most fossils hampers quantification of physiological abilities. Here we use anatomical and phylogenetic criteria to reconstruct nasal anatomy in representatives of three dinosaur groups (sauropods, theropods, and pachycephalosaurs). Nasal cavities were segmented in Avizo using the extant phylogenetic bracket to identify osteological correlates that were used as proxies for capsular boundaries. Computational fluid dynamics (CFD) analyses were performed using Fluent. Results were compared to our previous CFD work on turkeys, ostriches, alligators, iguanas, and varanids. Shared airflow patterns in extant diapsids suggest potential constraints that can be used as tests of functional flow patterns for dinosaurs. Dinosaur airflow based only on bony-bounded limits differed markedly from extant diapsid patterns, and so their models were modified using Maya to achieve comparable flow patterns. Modifications included the addition of mucosa (based on extant comparisons) and turbinates (based on rare preservation). The more open, less-constrained skulls of theropods and sauropods made airway reconstruction more difficult, whereas the more closed skulls of pachycephalosaurs facilitated reconstruction. The tendency for pachycephalosaurs and some theropods to partially mineralize olfactory and respiratory turbinates provided tighter constraints on nasal capsule interpretation. The addition of mucosa and turbinates greatly affected the flow pattern within the nasal passage, producing more heterogeneous flow patterns similar to those seen in extant diapsids. Airway permutations that produced results similar to those seen in extant diapsids were assumed to reflect morphologies likely to have been present in the living animals. Coupling fluid dynamics with traditional anatomical techniques allows the incorporation of functional criteria in identification of potential soft-tissue locations, providing a more focused search image to test these hypotheses in fossils.

S-094
EVOLUTION OF THE MAMMALIAN NASAL CAVITY: NEW EVIDENCE FROM THE ADVANCED CYNODONT BRASILITHERIUM RIOGRANDENSIS (BRASILODONTIDAE)
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Mammals are unique among vertebrates in having a highly complicated nasal cavity that houses a specific system of turbinates. The twofold function of the turbinates (warming and moistening of air, olfaction) is an essential feature that was correlated to the advance of endothermic and macrosmatic adaptations in therapsids and in early mammals. However, fossil evidence for the transformation of a non-mammalian nasal cavity to the mammalian one is almost missing as no known therapsids and early Mesozoic mammals have yet provided any direct evidence of ethmoidal turbinates; their skeletal support most probably still consisted of cartilage. Ossification of the endocranial nasal capsule and turbinates seems to be a feature that occured only very late in synapsid evolution; if present, the delicate ethmoidal bones are hardly preserved. There have been published several reconstructions of the turbinate system in advanced therapsids and early mammals based on presumed insertions at the interior side of the nasal wall. However, these reconstructions do not well agree with the morphological concepts derived from craniogenetic studies of extant mammals. Thus, understanding of the very early evolution of the mammalian nasal cavity by newly discovered fossils and modern imaging techniques is very important in order to establish the basal mammalian morphotype. Here we provide the first evidence for delicate ethmoidal bones in the brasilodontid cynodont Brasilitherium riograndensis from the Late Triassic of Southern Brazil. Our observations clearly demonstrate that principal features of the mammalian nasal cavity were already present in this sister-group of mammals. Among these characters are a partly ossified nasal septum contributing to the mesethmoid, T-shaped maxilloturbinals, nasoturbinals, the anterionmost ethmoturbinals, and a posteriorly expanded nasal cavity that is ventrally separated from the nasopharyngeal duct by a posterior transversal lamina.
S-095
PRINCIPLES OF THE MORPHOLOGY OF THE MAMMALIAN NASAL CAPSULE – WITH SPECIAL REFERENCE TO PRIMATES
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Morphological studies of the mammalian nasal capsule mostly depend on the monumental mono-graphic treatment of Simon Paulli from 1900. He studied adult specimens of a great number of species, and he presented his data in a specific semi-schematic manner; next to the turbinals he was mainly interested in the paranasal sinuses. However, there exists another line of research based on the study of cranio genesis mainly following Ernst Gaupp and his school. It was soon realized that the differentiation and growth of the nasal capsule of all therian mammals follows a specific pattern, which becomes fully elaborated only in later stages of ontogeny – even after birth. Therefore, the morphology of the nasal skeleton can only be fully understood by considering the morphogenetic process. It can be easily demonstrated that Paulli did not have a well founded theoretical concept for his studies. In recent years, new imaging techniques such as microCT have initiated and stimulated renewed interest in the skeletal morphology of the nasal capsule, which is in fact the least well known regions of the mammalian skull. Naturally, these studies are based almost exclusively on adult specimens of fossil and extant species, and they are often based on inadequate morphological premises. Hence, I attempt to outline the early ontogenetic morphotype ('Bauplan') of the therian nasal capsule or ethmoidal region based on a number of cranio-genetic studies - mostly written in German. I ex emit my presentation by anatomical evidence taken from the Primates, although this arboreal order is characterized by secondary reductions of nasal structures; however, the general therian 'Bauplan' can always be recognized, even in the highly derived anthropoids.

S-096
NASAL STRUCTURE AND AERODYNAMICS: PRE-PROCESSING OF ODORANT INFORMATION?
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Inside the nose of most terrestrial mammals lies intricate and convoluting scrolls and plates of thin bones, collectively known as turbinates that diverge nasal airflow, into complicated channels and circulations with varying speeds, turbulence, and directions. One key function of the nose, olfaction, begins with the transport of volatile chemical molecules by this complicated nasal airflow and subsequent absorption into the mucus lining, before binding to olfactory receptors (ORs) in the nasal epithelium can occur. The airflow rate and frequencies during respiration and sniffing seem to be task-oriented and differ among species; e.g., rodents switch their sniffing frequency from ~2 Hz at the “resting” state to 4–12 Hz when investigating a novel odor, whereas humans sniff in bouts of strong inhalation, often without exhalation in between. Clearly, the stimulus input to ORs in olfaction is not the same as in the ambient environment, but rather is modulated significantly by the odorant transport processes as well as determined by the physical properties of the odorant. All these, combined with the highly dynamic and precise motor control of sniffing behavior, suggest a role for both nasal structure and nasal aerodynamics in pre-processing odor information both spatially and temporally at the pre-receptor level, just as the mechanical properties of the inner ear process acoustic stimuli. We have quantified such modulation computationally among different species: mouse, rats, cat (data being analyzed) and human, based on accurate anatomical models of their nasal structures and the sorptive properties of the odorant. Combining data from histology, in situ hybridization, transgenic mice, electrophysiology recording, and in vivo optical calcium imaging, the preliminary analysis seem to suggest that the nasal structure and sniffing may serve to optimize the pre-receptor odor stimuli presentation.

S-097
ECOLOGICAL CORRELATES OF NASAL TURBINAL SIZE IN CARNIVORANS
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The nasal turbinates of mammals play important roles in olfaction (ethmoturbinals) and respiration (maxilloturbinals). As a result, variation among species in body size and ecological characteristics such as habitat and diet is likely to be accompanied by adaptive differences in turbinal structure and/or size. Using high-resolution CT scans of skulls, we quantified turbinal surface area (SA) in 46 carnivoran species, including both semi-aquatic (e.g. pinnipeds) and terrestrial taxa, ranging in size from meerkat to polar bear. We assumed that ethmoturinal SA corresponded to olfactory epithelial SA, and maxilloturinal SA corresponded to respiratory epithelial SA. Across all species, total turbinal SA relative to body mass scaled with isometry, indicating that larger species have relatively less total turbinal SA. Semi-aquatic species differ
markedly from terrestrial taxa in having very reduced ethmoturbinals for their body mass, presumably reflecting a reduced reliance on olfaction due to foraging under water. Among terrestrial species, differences in turbinal SA are more subtle. Within caniforms (e.g. canids, mustelids), large specialized carnivores that forage over extensive territories (e.g., gray wolves, wolverines) exhibit enlarged ethmoturbinals (olfactory SA) relative to smaller, more omnivorous taxa. Among feliforms (e.g. felids, hyaenids, viverrids), only the large hyaenids have ethmoturbinals that are comparable in size to that of the large carnivorous caniforms. Felids have reduced maxilloturbinals and average sized ethmoturbinals, suggesting a deficit in respiratory function. However, anatomical, histological, and airflow analyses suggest that the assumed correlation between maxilloturbinal SA and respiratory SA is not always correct, particularly in short-snouted felids. In felids, some ethmoturbinals are positioned in the respiratory pathway and function in conditioning inspired air. When this is taken into account, the estimated respiratory SA of felids is similar to that of caniforms, and estimated olfactory SA is reduced, a feature more consistent with behavioral data on felid and canid olfactory ability.

S-098
THE CRIBRIFORM PLATE MORPHOLOGY AS A PROXY FOR OLFACTORY INNERVATION IN CARNIVORA
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As yet, we know very little about olfactory ecology in extinct mammals. While most olfactory anatomy in a fossil is missing or destroyed, there is one feature in the nasal chamber that is relatively well preserved and may offer a view into olfactory function. This is the cribriform plate (CP), a perforated cup of bone that separates nasal cavity from olfactory bulb. Its many foramina usher the passage of olfactory signals and nerves from snout to brain and so provide an osseous imprint of olfactory innervation. CP morphology, specifically its size, the distribution, number, and size of its foramina, varies across mammalian species and likely reflects aspects of olfactory capacity. This suggests CP morphology may be a proxy for olfactory function. Toward this end I compare CP morphology among living Carnivora, a group that includes closely related species from distinct ecologies, offering a view along a spectrum of olfactory demands. In two separate studies I use CT scans and 3-D imaging software to examine CP morphology, first in aquatic vs. terrestrial arctoid carnivorans, and then in two carnivoran groups known for their divergent hunting strategies, felids and canids. Novel spline technology allows the quantification of total cross-sectional area of foramina for the first time, yielding a relative metric for olfactory innervation. Preliminary results reveal that all features of CP morphology are reduced in aquatic carnivorans compared with their close terrestrial relatives, consistent with studies suggesting a reduced olfactory role in aquatic mammals. Likewise, total CP foramina area is smaller in felids than in canids, as predicted by the felids' relatively weaker reliance on olfaction in foraging, suggesting a trade-off between enhanced visual anatomy and olfactory innervation in cats. These methods, when applied to fossils in the future, may hold promising clues to the olfactory ecology of extinct mammals.

S-099
COMPARATIVE ASPECTS OF THE TOOTHED WHALE NOSE: AN OVERVIEW
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In all modern whales (Cetacea, Cetartiodactyla, Mammalia) external nasal openings are situated on the vertex of the head although the terrestrial ancestors of the Cetacea as well as the Archaeoceti, fully adapted to aquatic life, had still subterminal bony nostrils as well as paranasal sinuses. Baleen whales (Mysticeti) show olfactory bulbs, cribriform plates, and nasal turbinates not found in toothed whales (Odontoceti). In contrast, toothed whales are anosmic and the main function of their hypertrophied epicranial (nasal) complex of air sacs and fat bodies is, beside ventilation, the generation and emission of echolocation and communication sounds. Comparison of nasal structures of distantly related toothed whales, such as sperm whales and dolphins, revealed that the nasal air sac system and its musculature as well as the nasal fat bodies have the same topographical relations to each other. Accordingly, these structures may be homologous systems in all toothed whales sharing specific acoustic functions. This implies that echolocation evolved only once in the toothed whale group and thus was one of the main factors in the evolution of this monophyletic group.

S-100
THE EXTENT OF THE TRANSVERSE LAMINA AND ITS ROLE IN OLFACTORY AIRFLOW
Eiting, Thomas (1); Smith, Timothy (1); Perot, J. Blair (1); Dumont, Elizabeth (1)
The objective of this study is to quantitatively investigate the anatomy and functional morphology of the nasal cavity of the eastern gray squirrel (Sciurus carolinensis) using high-resolution X-ray micro-computed tomography (micro-CT) and magnetic resonance imaging (MRI), combined with state-of-the-art anatomical reconstruction and morphometric analysis techniques. By combining micro-CT and MRI scans, a multimodal data set is used to reveal the first detailed view of a sciurid nasal cavity, which includes cross-sectional slices of the anatomy and three-dimensional anatomical reconstructions of the turbinal bones and convoluted nasal airways. Compared with other rodent species, the eastern gray squirrel is found to possess a remarkably complex nasal fossa, particularly within the respiratory portion of nose, where a branching maxilloturbinal fills the nasal chamber. A detailed morphometric analysis is presented that includes regional distributions of airway size and shape (e.g., perimeter, cross-sectional area, surface area). A comparison of these measures with available data for other rodents quantitatively confirms the relative complexity of the squirrel nose. Finally, the functional implications of the nasal anatomy and morphometry regarding respiration and olfaction are considered, where we show that airflow in the squirrel nose is laminar during resting and sniffing.

S-102
NASAL FOSSA HISTOLOGY, MORPHOMETRY AND FUNCTIONAL MORPHOLOGY IN THREE SPECIES OF PRIMATES
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The nasal airway reduction in anthropoid primates is postulated to relate functionally and evolutionarily with a reduction in the olfactory sense. However, this view has been challenged in recent years as an overgeneralization, based in part on emerging evidence that extant primates are highly variable in nasal anatomy. Here we examine the nasal histology, morphometry and functional morphology in one anthropoid primate (*Saguinus oedipus*) and two species of strepsirhine primates (*Nycticebus pygmaeus* and *Microcebus murinus*). We made histological preparations and acquired micro-CT scans of each species. Histological sections were photographed and converted to binary images for morphometric and functional analyses using custom image processing software. In all three species, functional analyses revealed that nasal airflow is laminar and quasi-steady (i.e., transient flow effects are unimportant) during resting breathing. Most of the olfactory mucosa occurs on turbinates in the ethmoid region in the strepsirhines. In *Saguinus*, most olfactory mucosa is distributed on surfaces other than turbinals. Major differences are observed in the region of the olfactory recess. As expected, this space is a vestigial, simple sac in *Saguinus*, although still lined mostly with olfactory mucosa. However, the two strepsirhines possess differing relative sizes of the olfactory recess: the SA is ~19% of total nasal SA in *Nycticebus* compared to 7% in *Microcebus*. In all three species, average nasal airflow speed was slowest anterior to the olfactory recess, the most complex region of the nasal airway in terms of turbinals. The turbinals are elaborate throughout the anterior extent of the olfactory recess in *Nycticebus*, but not *Microcebus*. *Microcebus* exhibits peak complexity anterior to the olfactory recess, where parasanasal recesses are highly inflated. These findings suggest that nasal airflow and odorant transport may vary considerably among living primates, even among those with the most primitive nasal morphology. Funding: NSF grants IOS-1120375 and BCS-0820751

S-103
THE HUMAN NOSE: FUNCTIONS, VARIATION, AND CLIMATIC ADAPTATION
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Anthropologists have long recognized an association between nasal shape and climate as evidence of selection on human facial form. Historically, most anthropological investigations of nasal variation, while often incorporating large and globally diverse samples, have focused exclusively on the external nose. With advances in imaging technology, anthropologists have begun to assess variation in the internal nose and its role in modifying the heat and moisture content of respired air. Internally, nasal heat and moisture exchange are facilitated by a large mucosal surface and a narrow channel for respired air. Many mammalian species have accordingly evolved elaborate branching turbinates that provide a massive mucosal surface and divide the respired air stream into numerous narrow airflow channels. Humans, however, have relatively simple, scroll-shaped turbinates, and as such, appear limited to adjusting the overall architecture of their skeletal nasal cavities in order to maximize mucosal surface area and decrease nasal passage breadth. Thus, given the disparate selective pressures faced by modern human populations living across a diverse ecogeographic distribution, humans from different climates should theoretically exhibit internal nasal architectures which reflect demands for heat and moisture exchange in their respective environments. Collectively, we tested this hypothesis by combining linear and 3D geometric morphometric analyses of skeletal nasal dimensions with CT-based analyses of internal nasal soft-tissue anatomy. Our research has revealed a clinally-distributed pattern in internal nasal cavity dimensions reflecting selection for more efficient heat and moisture exchange in colder and/or drier climates. Specifically, individuals from populations that evolved in colder and/or drier climates consistently exhibit nasal cavities that are narrower, taller, and longer than those from populations that evolved in warmer and more humid climates, likely resulting from adaptive benefits conveyed by this morphology for greater heat and moisture modification of respired air.

S-104
INFLUENCE OF NASAL ANATOMY ON OLFACTION IN CHIMAERID FISHES
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Diffusion times in water are very slow. For a fish to perceive a smell, water containing the dissolved odorant molecules must therefore be actively transported to the nasal region. Once there, the water must then be circulated over the sensory surface where the odorant molecules may then diffuse to the sensory surface for detection by the olfactory receptors. Nasal anatomy has an important influence on both water transport and odorant diffusion. We are interested in how water is circulated in the nasal regions of chimaerid fishes, a
group of fishes related to sharks and rays. The nasal anatomy of chimaerid fishes is unusual in two respects. First, their sensory surface is arranged on a set of radially disposed olfactory lamellae. Second, the lips of chimaerid fishes generate a complex nasal region. We have used micro-computed X-ray tomography and magnetic resonance imaging to characterise in detail the nasal anatomy of chimaerid fishes. We have shown that there are features within the nasal region that may segregate, distribute, facilitate and regulate flow. We believe that the respiratory pump is primarily responsible for circulating water in the nasal region, and that the numerous non-sensory ciliated cells that line the sensory surface propel mucus rather than water, a function that they may perform in all cartilaginous fishes. We have qualified the extent to which secondary folding of the olfactory lamellae enhances the sensory surface area in chimaerid fishes, and identified a protrusion in the incumbent channels of the chimaerid nasal region whose possible function(s) we will discuss. We will also discuss how the chimaerid nasal region is adapted to a benthic environment, and the ability of chimaerid fishes to locate and respond to a scent. Throughout, we will make comparisons to olfaction in sharks and rays.


Organizers: Nadja Schilling & John Long

S-105

EVIDENTIAL ORIGIN OF THE VERTEBRAE: IMPLICATIONS FROM THE HAGFISH DEVELOPMENT

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The hagfish, a group of extant jawless fish, is generally believed to lack vertebrae. However, it has yet to be conclusively shown whether the hagfish truly lacks any form of vertebra-like structure through its body, and whether hagfish somites in the embryonic trunk are dissimilar to the other vertebrates. To address these issues, we examined the axial skeletal morphology in the Japanese inshore hagfish (Eptatretus burgeri). Here we show that the hagfish has small cartilaginous nodules occupying anatomical positions comparable to those of gnathostome vertebrae. To distinguish whether the cartilaginous nodules are certainly homologous to the gnathostome vertebrae, expression patterns of several genes relating to the axial skeletal formation were investigated in the early to late hagfish embryos. In the pharyngular stages, it was observed that the medial ventral side of the somite differentiated into migratory mesenchymal cells with expression of the Pax1/9 and Twist genes, which are known to be sclerotome markers in the gnathostomes. These mesenchymal cells also showed the expression of the Biglycan/decorin (one of the cartilaginous proteoglycan extracellular matrix protein encoding genes) at the ventral aspect of the notochord in the prehatching stage hagfish embryo. These results suggest that the cartilaginous vertebrae and its developmental mechanisms may have been present in the common ancestor of the jawed and jawless vertebrates.

S-106

HISTORY, HOMOLOGY AND RIBS - A HYPOTHESIS FOR MAMMALIAN AXIAL PATTERNING

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Highly variable counts of repeated ‘vertebra + moveable paired rib’ units were present at almost every segmental position in early tetrapods. In contrast, living mammals exhibit regionalized column anatomy and highly conserved counts. The Hox family transcription factors are key players in the regionalization of the axial skeleton during development. In Mus, both the expansion and the silencing of Hox genes with segmentally limited expression generate mice with “atavistic” anatomy: ribless segments revert to ancestral “vertebra + articulating rib” segments. These results suggest that the regionalization of mammalian anatomy evolved by the regionalization of Hox gene expression. Despite its strength, the Progressive Regionalization theory is challenged by experimental evidence that ancestral ribbed morphology can be promoted as well as repressed, and by the sequence of column morphologies observed over geologic time. The coincidence of transitions in column patterning with locations of somite / LPM interaction also suggests a role for the lateral plate in axial regionalization not recognized in the Progressive Regionalization theory. Molecular work identifies three independently patterned rib subunits in Mus. Differential presence of these rib subunits along the vertebral column is suggested by multiple lines of morphological evidence, often observed in taxa with extreme lifestyles and adaptations. Among these are fused proximal costal subunits in the cervical column, medial rib gaps in developmental syndromes, fusions of distal but not proximal subunits of thoracic rib 1, and the AP displacement of selected rib components relative to each other. Rib subunits also interact differently with the somitic vertebral column: transitions in axial anatomy occur only at locations where distal ribs, or other structures with abaxial patterning, interact with the column. I propose that not all mammalian ribs are serial homologs, and that proximal, vertebrodistal, and sternodistal rib subunits have been subject to independent variation and selection over evolutionary time.
S-107
THE FISH TAIL AS A DERIVATION FROM AXIAL BODY STRUCTURE
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As in all vertebrates, the fish tailbud begins to form immediately following gastrulation, followed by a pattern of extension, protrusion, and eversion away from the yolk cell. At time of hatching, the post-anal axial body of fish larvae is extended posteriorly and both somites and lateral fin fold are symmetrical about the longitudinal axis. However, within three days post hatching, this symmetry with the axial body is lost as the ventral portion of the developing tail grows rapidly, displacing the notochord at an angle dorsally. This shift in axis orientation, aided by the migration of trunk neural crest cells, precipitates the formation of a caudal nerve plexus, distinct muscle groups unlike the axial body myomeres, and cartilaginous or bony skeletal elements supporting the developing caudal fin. The adult morphology of the tail varies greatly among extant fishes despite sharing both ontogenetic similarities and the functional need to propel the body through a fluid medium. Both chondrichthyan (sharks) and actinopterygian (ray-finned) fishes control caudal fin musculature independently of axial body myomere activity to modify the stiffness and shape of their tails. For example, sharks and bony fishes possess different structural elements and muscles and move their tails in different ways, resulting in different locomotory hydrodynamic effects and a range of performance variables including speed and maneuverability. For example, the stiffness of the heterocercal, lobate tail of the shark can be modulated during the tail beat resulting in nearly continuous thrust production. In contrast, the highly flexible tail of ray-finned fishes can be manipulated into many different shape conformations enabling increased maneuverability for these fishes. Consequently, the developmental, morphological, and functional derivation of the tail from the axial body has resulted in a diversity of form, the attributes of which may be of evolutionary significance.

S-108
COMPUTATIONAL AND MATHEMATICAL MODELING OF FORCES ACTING ON THE VERTEBRAL COLUMN OF SWIMMING FISH
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In spite of their name, vertebrates first evolved without vertebrae. Both phylogenetic reconstruction and fossil record agree that the hypothetical vertebrate ancestor possessed a continuous, unsegmented notochord as its axial skeleton. Only in jawed fishes did vertebral centra appear, gradually and repeatedly forming as segmental ossifications of perichordal tissue and/or cylindrical walls of the collagenous notochord sheath. Ring centra created intervertebral joints by leaving unmineralized connective tissues between adjacent boy elements. We study the behavioral and locomotive performance consequences of developing centra through the use of computational and mathematical models. In this talk we describe how we combine computational and mathematical models to form virtual fish to explore different hypotheses about the impact of centra. Knowing that vertebræ stiffen the axial skeleton, many predict that vertebrae evolved for enhanced mechanical efficiency and versatility of swimming. We show how we create simulation models using a combination of a mathematical model of a fish-like robot, a propulsion model, and an optimizer (based on a genetic algorithm) for real values, to explore the impact of centra under various scenarios. The simulations are used to make predictions about the effects of centra and we compare those predictions with results from other approaches.

S-109
MORPHO-FUNCTIONAL CHARACTERISTICS OF THE AXIAL SKELETON IN STEM TETRAPODS
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In the study of the origin of tetrapods, and the transition from swimming in water to walking on land, most of the attention has been placed on the evolution of limbs. However, characterising morpho-functional changes of the axial skeleton are of equal importance, as the vertebral column helps to support and mobilise the body during movement. Palaeozoic tetrapods are typified by having a highly complex and diverse vertebral column structure, with each vertebral unit being formed of multiple inter-articulating bones surrounding a persistent notochord. The particular shape and arrangement of these bones has been used to identify and diagnose early tetrapod species for over a century, and a correspondingly intricate terminology has developed to discuss anatomical transformations. The persistence of the multipartite system throughout the Palaeozoic implies that the vertebral column was either phylogenetically constrained and/or that it conferred
a functional advantage that aided the transition to land locomotion. Recently, the three-dimensional vertebral structure of the earliest stem tetrapods was defined using high resolution synchrotron micro-tomography, providing a wealth of data to begin to investigate the functional role of the axial skeleton during the water-land juncture. Within this context, alternative methods for exploring the potential for intervertebral joint movement and assessing relative mechanical performance in the spine of the Late Devonian tetrapods Ichthyostega and Acanthostega will be discussed, including the use of 2D biomechanical indices of function and 3D modelling of intervertebral joint range of movement. Ultimately this work aims to illuminate how the evolution of terrestrial locomotion was influenced by biomechanical constraints of the vertebral column, and provide new explanations for the diverse array of vertebral morphologies seen during the early radiation and subsequent diversification of the tetrapod clade.

S-110
MECHANICS AND KINEMATICS: UNDERSTANDING THE ROLE OF THE VERTEBRAL COLUMN DURING LOCOMOTION IN STRIPED BASS (MORONE SAXATILIS)
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Previous research suggests that the vertebral column and the associated intervertebral joints (IVJs) of fishes may contribute to whole body stiffness, and possibly play a role in elastic energy storage during locomotion. Mechanical testing and kinematic analyses have been performed independently on several species, but never both on a single species to date. Therefore, without knowledge of both mechanics and kinematics, it is unclear whether the vertebral column contributes significantly to whole body stiffness or energy storage. The present study investigates the in vitro mechanical properties and in vivo kinematics of intervertebral joints (IVJs) along the length of the striped bass, Morone saxatilis. We performed cyclic dynamic testing on IVJs postmortem at three frequencies (2, 5, and 7 Hz). Testing of IVJs revealed that a substantial neutral zone of bending, where the IVJs bend freely without resistance, begins at 0 and ranges up to 12° in the cervical region, 10° in the abdominal region, and 15° in the caudal region. Hysteresis was fairly high (30–40%) in all regions. Additionally, high-speed fluoroscopy revealed that the maximum angles of IVJ bending attained in vivo lie within the neutral zones of bending along the different regions of the vertebral column. Using these kinematic and mechanical data, we estimate the magnitude of energy returned to the system by each cervical, abdominal, and caudal IVJ to be 9.0 x 10^-5 J, 3.5 x 10^-4 J, and 1.9 x 10^-4 J, respectively. Taking into account the 24 IVJs present in a single fish, these elastic recoil estimates sum to just 1.2% of the 17.5 W of muscle power required during burst swimming. Thus, it is unlikely that the vertebral column of the striped bass provides substantial contributions to whole body stiffness and elastic recoil in vivo.

S-111
BUILT FOR SPEED: STRAIN IN THE CARTILAGINOUS VERTEBRAL COLUMNS OF SHARKS
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Dynamically bending vertebral columns of fishes have mechanical properties that allow them to operate as springs, storing and returning elastic energy as they change shape during swimming. Because springs only work if they are strained, we hypothesized that the intervertebral joints, where bending occurs, will be the primary sites of elastic energy storage. Alternatively, the vertebrae themselves could undergo large strains and store return elastic energy. This alternative is plausible because compression tests of isolated vertebrae in which large axial strains were imposed did not lead to plastic deformation. To test this hypothesis, our goal was two-fold: to measure axial strains of the intervertebral joints and vertebrae in vivo and ex vivo. For in vivo experiments, we used sonomicrometry to directly measure axial strains of intervertebral joints and vertebral swimming Squalus acanthurus. For ex vivo tests, we dynamically bent vertebral segments in an environmental chamber filled with elasmobranch Ringers. Dynamic testing frequencies ranged from 0.25 to 1.0 Hz at physiologically-relevant curvatures. We found that in vivo both vertebrae and joints undergo significant strain during swimming. These results were replicated when we measured the same patterns of vertebrae and joint axial strains ex vivo. In histological sections, we found that the vertebral column of Squalus acanthurus has an intracentral canal that is open and covered with a velum layer. An open intracentral canal may indicate that the joints are acting as a hydrostat stiffening the vertebral column. These data suggest that the entire vertebral column of sharks, both joints and centra, is mechanically engaged as a dynamic spring during locomotion. This work was supported by NSF IOS-0922605.
THE KINEMATICS OF THE SALAMANDER’S SPINE: BIOLOGICAL AND ROBOTIC PERSPECTIVES
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The rich gait-repertoire of salamanders on land and in water makes them great examples for understanding spinal movements with and without limbs. Numerical modeling was successfully used previously to demonstrate our understanding of the neuronal control of the salamander’s spine as well as to generate hypotheses based on simulation and robotic studies. We used high speed (500 fps) biplanar cineradiography to extract the three-dimensional angular kinematics of two individuals (Pleurodeles waltl).
Our recordings include forward ground stepping, underwater stepping and swimming. We used manual tracking at a rate of approximately 40 frames per locomotor cycle to track more than 50 key points on the salamanders’ body including head, spine, scapulae and limbs. The movements of the spine where captured between each vertebra and in three-dimensions. The detailed kinematics were then used as basis for the development of a simulated model and a robotic platform (Pleurobot) that replicate the kinematics of the animal much more closely than our previous salamander-like prototypes (Salamandra robotica I and II).

FROM AN ANIMAL TO A BIOMECHANICAL MODEL – RECONSTRUCTION, ASSEMBLING & SIMULATION
Stark, Heiko; Anders, Christoph; Schilling, Nadja
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To understand the form-function relationships of organs or organ systems, three-dimensional analyses and reconstructions of the morphology (e.g. using high-resolution imaging, dissection) and simulations (e.g. using force recordings, videofluoroscopy, finite-element-method) are nowadays widely used. One problem of these approaches is that animals constitute of different levels of structural organization. Concerning muscles, the internal architecture has largely been neglected so far, although it is well known that parameters such as pennation angles or the lengths of fascicles have a major impact on the contraction behaviour. Several studies have shown that the internal architecture cannot necessarily be inferred from the superficial appearance. In many cases, the fascicle orientation is much more complex, for example, due to so-called ‘intramuscular inhomogeneities’. To reconstruct the internal muscle architecture and its changes due to contraction, 3D coordinates of several data points along each fascicle were digitized in our studies during layer-wise dissection using ‘Microscribe’. This was done for several muscles of several mammals (pika, rat, chimpanzee, human). Our results provide a detailed database, which will help to improve and extend existing models on muscle morphology and function. Additionally, they contribute to our understanding of the evolution of the musculo-skeletal apparatus, e.g. the trunk stabilisation associated with adaptations to different trunk postures in closely related species. The resulting simulations are increasingly detailed. It is possible to integrate different muscle properties, for example, for the tendinous and fleshy fascicle parts, or different fibre types. Moreover, properties such as stiffness, differing between the fascicle’s longitudinal and transverse axes can be integrated. With these powerful instruments, new questions can be addressed such as: ‘What influence do volume shifts have on adjacent muscles?’ and many others.

JUMPING SANS LEGS: USING THE AXIAL MUSCULOSKELETAL SYSTEM FOR A NOVEL FORM OF TERRESTRIAL LOCOMOTION
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Successful evolutionary invasions of land are commonly associated with the development of appendages (i.e., limbs) that allow for quadrupedal gaits. However, numerous small teleost fishes voluntarily make terrestrial forays of limited duration in order to escape predators or poor water conditions, or to pursue terrestrial prey, despite having no modifications to their paired fins to specialize them for movement on land. Instead, these fish use the axial musculoskeletal system to generate a “tail-flip” jumping behavior: lateral flexion of the body into a C shape, followed by contralateral flexion of the body axis, which propels the fish off of the substrate into ballistic flight. Tail-flips can propel fish multiple body lengths away from their starting position with each movement. Species from fully-aquatic teleost taxa as widely separated as the...
Cypriniformes, Atherinomorpha, and Perciformes are able to jump with varying agility. We hypothesize that morphological computation by bone and connective tissue plays a critical role in jumping, with adept jumpers demonstrating (a) enhanced elastic energy storage through increased body flexural stiffness, and (b) prolonged launch times, giving greater control over the acceleration phase and take-off trajectory. Though no external morphological modifications are evident, particularly adept jumping species appear to have (1) more elongate and less laterally compressed body shape, (2) longer and more acutely angled neural and hemal spines, and (3) enlargement and fusions of the hypural bones supporting the caudal peduncle, which may improve stability during the jump. Terrestrial jumping may come at a price: fast-start aquatic escape performance of adept jumping species is slower than in inept jumpers, suggesting a trade-off associated with this novel use of the axial musculoskeletal system.

S-115
BODY ELONGATION AND THE NEUROMECHANICAL CONTROL OF AXIAL STARTLE BEHAVIORS IN FISHES
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Evolutionary changes in axial elongation necessitate concurrent adaptation of neural circuits to maintain motor function. While simple neural circuits that drive movement have been studied, little is known of how those circuits coevolve with elongation. Startle behavior provides a tractable system for examining such questions. The startle circuit is relatively simple with the Mauthner cells (M-cells), a pair of giant hindbrain neurons that are dedicated to the behavior, at its core. The fundamental model for M-cell function is that one M-cell fires a single action potential activating contralateral axial muscle and inhibiting muscle activity ipsilaterally, causing the animal to form a rapid “C” shaped bend. However, our electromyography studies of diverse taxa indicate that fishes with a moderately elongate body axis (ratios of body length to width of around 5:11) perform at least two discrete axial startle motor patterns and behaviors, the “C” shaped behavior called a C-start and an S-start in which the animal bends into an “S” shape as its initial movement. We found that M-cells function in S-starts but in a fundamentally different way than they do in C-starts, activating bilaterally and exciting motor neurons regionally along the cord. That species with elongate body axes are scattered across the phylogeny of fishes suggests several hypotheses for S-start evolution: 1. There is an underlying capability of the hindbrain and spinal cord to express such movement when fish reach a certain elongation ratio and/or 2. There have been multiple evolutions of circuits that can generate an S-start motor pattern. Additionally, we have found that some larval fish generate S-start motor patterns and support the alternative hypothesis: 3. S-start behavior arose once and occurs commonly in larvae, many of which are elongate, but is retained in the adult stage only when axial elongation persists through development.

S-116
THE DYNAMICS OF AXIAL LOCOMOTOR NETWORKS IN SALAMANDERS
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The axial musculoskeletal system plays a crucial role during locomotion in salamanders. Typically, propagated axial waves generate thrust during swimming and standing axial waves are combined with rhythmic movements of the limbs to increase stride length during land stepping. The mechanisms underlying these two basic axial motor patterns and the switch between the two gaits have been investigated using neurobiology, modelling and bio-inspired robotics (Ijspeert et al., 2007, Science, 315, 1416-1420). In addition to these rather stereotyped locomotor modes, salamanders are capable of displaying a variety of aquatic and terrestrial gaits (e.g. underwater stepping, backward stepping, crawling, paddling). Using kinematic and EMG recordings in intact freely moving animals we have recently been able to characterize the operation of the axial musculoskeletal system during some of these gaits. Importantly, our data showed that the salamander’s tail contributes actively to the dynamic balance during land stepping (acting as a “fifth limb”), while it is passively moved during underwater stepping. Our in vitro experiments on isolated spinal cord revealed that the axial network of salamander is able to generate 3 distinct locomotor patterns (“motor primitives”) which could be related to the locomotor gaits observed in intact animals. They also evidenced that the tail network can be considered as a functionally independent subcomponent of the axial network. Descending inputs and movement-related sensory inputs might provide a mechanism to control the switch between the motor primitives generated by the spinal cord, i.e. the switch between locomotor gaits. A promising approach to address this issue is to combine neurobiology, neuro-mechanical modelling with bio-inspired robotics. Indeed, it is now clear that dynamic systems cannot be properly understood only by using neurobiological investigations (e.g. “cracking of neural circuits”).
S-117
TURTLES AMONG THE AMNIOTES
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The turtle’s shell is a unique variation on the tetrapod body plan. The association of the trunk vertebra and ribs with a specialized dermis to form the carapace results in a novel relationship between axial and appendicular systems. The plastron contains highly modified elements of the secondary pectoral girdle, as well as possibly neomorphic bones. To date, a wide array of tetrapod taxa has been suggested as the ancestral root of turtles. Molecular phylogenies may eventually reach consensus on their phylogenetic position, but as of today the root of this significant branch of amniotes remains controversial. This talk will review the current controversies on the phylogenetic position of turtles among the amniotes, based both morphological and molecular data sets.

S-118
WHAT DOES IT TAKE TO BE A TURTLE? - FROM EMBRYOLOGY TO GENOMICS
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The turtle body plan represents an example of evolutionary novelty, since it exhibits an unusual topography of musculoskeletal elements formation based on the developmental repatterning of the axial skeleton. During the turtle development, growth of the ribs is arrested in the axial part of the body only allowed to grow laterally by the carapacial ridge (CR), a turtle-specific embryonic anlage, folding the lateral body wall medially to encapsulate the scapula. The CR supports the fan-shaped patterning of the ribs concomitant with marginal growth of the carapace by specific expression of some regulatory genes. The turtle body plan can thus be explained with our knowledge of vertebrate anatomy and developmental biology, and is also consistent with the evolutionary origin of the turtle suggested by the recently discovered fossil species, Odontochelys. By generating and analyzing draft genomes of soft-shell turtle (Pelodiscus sinensis) and the green sea turtle (Chelonia mydas), we confirmed a close relationship of turtles to the bird/crocodilian lineage, which split ~267.9-248.3 million years ago (Upper-Permian to Triassic period). We also found extensive expansion of olfactory receptor genes in these turtles. Embryonic gene expression analysis revealed an hourglass-like divergence between turtle and chicken embryogenesis, with maximal conservation around the vertebrate phylotypic period, rather than at later stages that show the amniote-common pattern. Wnt5a expression was found in the growth zone of the dorsal shell, supporting the possible co-option of limb-associated Wnt signaling in the acquisition of this turtle-specific novelty. Our results suggest that turtle evolution was accompanied with an unexpectedly conservative vertebrate phylotypic period, followed by manifestation of their evolutionary novelty.

S-119
THE ROLE OF NEURAL CREST CELLS IN THE FORMATION OF THE TURTLE PLASTRON
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Turtle plastron bones develop by intramembranous ossification, suggesting that they are derived, like the facial bones, from neural crest cells. Using cell-labeling and neural tube explant cultures, we have shown that cells expressing neural crest markers emerge from the trunk neural tube in the turtle for a greatly extended period compared other model amniotes. The neural crest cells that emerge at the end of that period, well beyond the stage of neural crest emigration in chick or mouse embryos, appear to migrate ventrally to form an ectomesenchymal dermis that gives rise to the bones of the plastron. Plastron mesenchyme cells have a gene expression pattern similar to cranial skeletogenic neural crest cells. They also appear to have functional similarities to cranial neural crest cells, as they differentiate readily in culture to form clusters of collagen I-positive cells. However, other types of neural crest derivatives, such as neurons or melanocytes, are not observed. We are currently comparing the time course of neural crest emigration in turtle and chick embryos, and the gene expression profile and in vitro differentiation potential of these late neural crest cells with those that emerge at comparable stages to the trunk neural crest cells in chick embryos. Preliminary results suggest that the late emerging neural crest cells express markers that are typically expressed by cranial neural crest cells, and that could explain their ability to migrate ventrally to the plastron, and undergo intramembranous ossification.
S-120
THE ORIGIN AND LOSS OF PERIODIC PATTERNING IN THE TURTLE SHELL
Moustakas-Verho, Jacqueline (1); Zimm, Roland (1); Cebra-Thomas, Judith (2); Seppälä, Netta (1); Kallonen, Aki (3); Mitchell, Katherine (4); Hämäläinen, Keijo (3); Salazar-Ciudad, Isaac (1); Jernvall, Jukka (1); Gilbert, Scott (1)
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The origin of the turtle shell over 200 million years ago greatly modified the amniote body plan, and the morphological plasticity of the shell has promoted the adaptive radiation of turtles. The shell, composed of a dorsal carapace and a ventral plastron, is a layered structure formed by basal endochondral axial skeletal elements (ribs, vertebræ) and plates of dermal bone, overlain by keratinous ectodermal scutes. Recent studies of turtle development and paleontology have advanced our understanding of the origin of turtles and the genetic interactions that regulate various aspects of bone development in the carapace. However, the genetic regulation of the origin and evolution of the epidermal scutes has not been addressed. We show that scutes develop from an array of patterned placodes and that these placodes are absent from a soft-shelled turtle in which scutes were lost secondarily. Experimentally inhibiting Shh, BMP, and FGF signaling results in the disruption of the placodal pattern. Finally, a computational model is used to show how two coupled reaction-diffusion systems reproduce both natural and abnormal variation in turtle scutes. Taken together, these placodal signaling centers are likely to represent developmental modules responsible for the evolution of scutes in turtles, and the regulation of these centers has allowed for the diversification of the turtle shell.

S-121
DO TURTLES FOLLOW RULES? PHYLOGENY, ECOLOGY, AND LATITUDINAL GRADIENTS IN BODY SIZE AND GEOGRAPHIC RANGE OF TURTLES
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Body size is a key component of an organism’s morphology, with major implications for ecological interactions, resource requirements, and even biomechanics. Relationships between body size and various aspects of geographic range have frequently been hypothesized. For example, large species are expected to possess larger geographic ranges because of their greater resource needs, and Bergmann’s Rule predicts a gradient of increasing body size with increasing latitude. Here we explore the relationship of body size and various aspects of geographic range in turtles, and also test whether the geographic ranges of turtles display latitudinal gradients. Using a sample of 159 species drawn from across the turtle tree, we find little evidence for a strong relationship between body size and geographic range size, or for latitudinal gradients in properties of geographic ranges. However, when individual clades are considered, some patterns do emerge. For example, testudinids show a positive relationship between body size and geographic range size, and emydids display a tight correlation between the northernmost occurrence of a species and the latitudinal span of its range. Taken together, our results suggest a complex relationship between factors controlling turtle geographic ranges, and their influence on morphological traits such as body size.

S-122
MORPHOLOGY MATTERS: GONADAL DEVELOPMENT AND FORM IN MARINE TURTLES INCUBATING UNDER NORMAL AND SIMULATED CLIMATE CHANGE CONDITIONS
Wyneken, Jeanette; Lolavar, Alexandra; Rogers, Micah
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Environmentally directed sex determination, predominantly temperature dependent sex determination (TSD), is common in reptiles, particularly crocodilians, lizards and many chelonians. In the context of accelerated climate change, TSD taxa may be extinction-prone because elevated temperatures skew sex ratios and sea level rise shifts nesting sites. Sea turtles are considered particularly vulnerable to climate change because they have a hot female/cool male TSD system, nest coastally where sea level rise and increased tropical storms directly effect nest site quality, embryonic development and sex ratios. However, these reptiles have a long evolutionary history spanning multiple periods of shifting climate. Their resiliency may lie, in part, within the TSD system and the responses of bipotential gonads under extreme incubation conditions. Natural nests incubated under typical and hot dry conditions and experimental nests incubated under hot wet conditions were sampled to test predicted effects of climate change. We quantified gonad morphology and sex ratios. Testes are fusiform, with a granular surface and are tightly attached to the

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S-123
THE TURTLE CONTROVERSIES: INTEGRATING PALEONTOLOGY, PHYLOGENY, AND DEVELOPMENT TO EXAMINE TURTLE ORIGINS
Gilbert, Scott
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For a group comprising less than 400 extant species, turtles have been a major source of controversy for paleontology and development. One major dispute centers around the ancestry of the Chelonia and when whether this clade derived from terrestrial, aquatic, or marine species. This dispute involves whether the turtles are sister group to a crown group clade (such as archosaurs, crocodiles, or lizards) or if they diverged prior to the crown group and are related to parareptiles such as Eunotosaurus. Corollary to this is whether Cheloniens are primarily or secondarily anapsid. Another set of questions involves whether the mechanism of carapacial bone formation involves extensions of pre-existing skeletal elements from the rib or whether the ribs act as signaling centers whose paracrine proteins convert dermis into bone. The homology of the nuchal bone and the mechanism of pectoral girdle morphogenesis is also disputed, as are the roles of the carapacial ridge in the establishment of the carapacial architecture. This talk attempts to delineate these disputes and suggest some guidelines for resolving these controversies.

S-124
THE DEEP HISTORY OF THE TURTLE SHELL: INTEGRATING FOSSIL AND DEVELOPMENTAL DATA
Lyson, Tyler(1); Bever, Gabe(2); Scheyer, Torsten(3); Hsiang, Allison(4); Gauthier, Jacques(4)
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The origin of the turtle shell has fascinated and confounded evolutionary biologists for more than two centuries. It was not until the recent discovery of the undisputed early turtle Odontochelys semitestacea, however, that the abundant fossil and developmental data could be synthesized into an explanatory model of shell origin that makes predictions for the as-yet un-established early history of the turtle stem. We build on this model by integrating novel data (including histology) for the early Late Permian reptile Eunotosaurus africanus – a species recently inferred to be an early stem turtle. We found Eunotosaurus to share a number of characters with undisputed turtles that directly inform the shell-origin model. These include a highly reduced number (9) of elongate trunk vertebrae, nine pairs of broadened ribs that are T-shaped in cross section, loss of intercostal muscles, an inferred reorganization of respiratory muscles so that they insert on the ventral side of the ribs, (sub)dermal outgrowth of bone from the developing perichondral collar of the ribs, and paired gastralia which lack both lateral elements and a single medial element. These features, together with those expressed in Odontochelys and Proganochelys quenstedti, conform to the sequence of character acquisition predicted by the shell-origin model and provide further support that these taxa represent successive divergences from the phylogenetic backbone of the turtle stem. This expanded model pulls the initial transformations of the turtle shell back to at least the Late Permian, which is congruent with recent molecular-based divergence estimates for the lineage and remains viable irrespective of whether turtles originated inside or outside crown Diapsida.

S-125
CRANIAL EVOLUTION AND THE ORIGIN OF TURTLES: INSIGHTS FROM EUNOTOSAURUS AFRICANUS
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The reemergence of the Late Permian amniote *Eunotosaurus africanus* as a potential stem turtle is based on a number of striking postcranial synapomorphies, many of which are related directly to the evolutionary origin of the iconic turtle shell. These data demand that the long enigmatic cranial morphology of this animal be elucidated and placed within the broader context of amniote cranial evolution and the problem of turtle origins. We undertook this task using high-resolution computed tomography of the relatively few skulls reported in the literature, and most importantly, by studying a previously unknown specimen in the collections of the Council for Geosciences, Pretoria. Our data reveal a cranial morphology characterized by a large number of plesiomorphic features that suggest *Eunotosaurus* lies near the base of Panreptilia and outside the early radiation of pandiapsid forms. A good example is the large supratemporal bone that sweeps forward to broadly contact the postorbital — a character essentially unknown in Pandiapsida. The cranial characters of *Eunotosaurus* that are derived within Panreptilia are variously shared with an interesting taxonomic mix of turtles, parareptiles, and relatively derived diapsids (crownward stem diapsids and crown diapsids). One character that exemplifies this distribution is the slender, vertically oriented quadrafojugal. This is a feature present in the early stem turtle *Proganochelys quenstedti*, a handful of parareptile forms, and as a derived character within Panarchosaurus. Almost none of these derived features are shared with those taxa more nearly contemporaneous with *Eunotosaurus* and that constitute the early portions of the diapsid stem. Such a pattern suggests long-branch attraction may be playing a significant role in the distribution of cranial features and thus influencing our perception of turtle origins. We articulate and compare the models of cranial evolution as dictated by the currently competing hypotheses for the origin of turtles.

S-126

PECULIARITIES IN THE TURTLE BODY PLAN: THE ORIGIN AND EVOLUTION OF NECK RETRACTION MECHANISMS

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Turtles have the unparalleled ability to retract their heads and necks within the body cavity (i.e., within the shell) but little is known about the evolution of this trait. For this study, we examined the mobility of the necks of a sample of extant turtles using X-rays and CT-scans. The amount of mobility in extant turtles was characterized for each cervical joint in the primary two planes of motion (i.e., right/left and dorsal/ventral) to reconstruct mobility in extinct taxa. 25 homologous points were measured from a broad sample of fossil and recent turtles for geometric morphometric analyses of vertebral shapes. Comparison with fossil taxa reveals a low amount of mobility of the neck in stem turtles although the anatomical prerequisites for modern mobility were already established. Stem turtle were therefore not able to withdraw their necks. The presence of formed cervical articulations has no impact on the mobility of vertebrae. Geometric morphometric analyses demonstrate that basal turtles, pleurodires, and cryptodires inhabit discrete areas in morphospace and that the pleurodiuran morphotype is intermediate between the stem turtle and cryptodiran morphotype. CT-scans finally indicate that many extant turtles are able to reach greater amounts of mobility by “overstretching” their joints by dislocating the central articulation. It is unclear, however, when this trait was acquired, and if it is, it has direct implication for reconstructing the mobility of other groups of vertebrates, such as sauropod dinosaurs.

S-127

THE SHAPING OF TURTLE DIVERSITY THROUGH THE CRETACEOUS AND PALEogene

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Recent and ongoing work has brought to light many new fossil turtles at an increasing pace of discovery. In addition to new insights into the earliest evolution of turtles, these fossils fill key gaps in the evolutionary history of extant clades. We can now better constrain the timing of major morphological transformations and phylogenetic splits, and place these events in the context of global climatic and biotic events. Here I provide an overview of key periods in the history of non-marine turtles as known from the fossil record in the northern hemisphere, with a focus on the emergence and diversification of clades that include model organisms in the field of evolutionary development: trionychids (softshell turtles, e.g., *Apalone* and *Pelodiscus*), chelydrids (snapping turtles, e.g., *Chelydra*), and emydids (pond turtles, e.g., *Chrysemys* and *Trachemys*). Based on genus level richness both within and between communities, turtle diversity was...
highest during the Late Cretaceous and earliest Paleogene (approximately 80 to 60 million years ago). Highly aquatic forms dominated these diverse turtle communities, including diverse trionychid lineages, and these communities persisted through the end Cretaceous mass extinction that severely affected other parts of the biota. Late Paleocene climatic cooling followed by earliest Eocene warming was associated with the extinction of many clades and subsequent diversification of testudinoids (such as emydids), as they dispersed in equable climates. The early Paleogene is also a time of morphological diversification, during which we see repeated evolutionary experiments in cranial and shell morphology, e.g., with different evolutionary pathways to shell kinesis and plastron reduction. The morphologies of these diverse relatives of living forms preserved in the fossil record provide a test of morphological transformations as deduced from developmental biology and embryology, and bring new morphological information to help resolve the long branch problems of turtle interrelationships.

S-128
GIANTS THAT WENT EXTINCT. NEW FOSSIL TURTLES FROM THE NEOTROPICS; SYSTEMATICS, PHYLOGENY, AND BONE HISTOLOGY
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Here I present the results of seven years of research on Mesozoic and Cenozoic fossil turtles from the Neotropics, including their phylogenetic, paleoecological, and bone preservation implications. Turtles from the Early Cretaceous (Valanginian) of Zapatoca, Colombia, constitute the most basal pleurodirans of tropical South America including platychelyids, as well as basal euctyodires, and potentially the earliest record of podocnemiodids, group that includes the extant side-necked turtles of South America, Africa, and Madagascar. Early Cretaceous (Barremian-Aptian) turtles from Villa de Leyva, Colombia, represent the earliest record of protostegids, the giant marine Cretaceous turtles. Middle-Late Paleocene turtles from Cerrejón Coal Mine represent one of the most diverse Cenozoic fossil turtle faunas in tropical South America, including closer relatives to the extant freshwater genus Podocnemis, giant podocnemidid turtles as big as a smart car, and one species of bothremydid with one of the most circular shells in the fossil record of turtles. Early Miocene turtles from the Panama Canal Basin represent the first evidence of interaction between North American cryptodires and South American pleurodirans much earlier than the final closure of the Isthmus of Panama. Turtles from the Middle Miocene Castilletes formation include giant examples of Chelus, Podocnemis, and the earliest record of testudinids from South America. All these discoveries show a much higher paleodiversity of tropical turtles compared to the present, and their inclusion in phylogenetic analyses has helped to resolve problematic clades, and also in calibration of molecular clocks. Bone histology and demineralization of bone have shown excellent preservation of bone cells, particularly osteocytes, indicating that the preservation of cells is independent of environmental conditions and age, opening the possibility for future molecular paleontology studies on these fossils.

Organizers: Philip Cox, Robert Drzynskey, & Lionel Hautier

S-129
DIVERGENCE TIME AND EARLY RADIATIONS OF RODENTS
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An unresolved problem in rodent evolution is the discrepancy between the divergence time inferred from the molecular clock and the earliest fossil record. In general, most molecular studies place the origin and initial diversification of crown-Rodentia and several rodent subgroups, such as muroids, deep in the Cretaceous. In contrast, fossils favor a post K-Pg origin and radiation of the group, which depends on how we interpret the transformation of the modern groups of rodents from the stem glires. Some important rodent fossils discovered during the last decade from the late Paleocene-early Eocene of the central Asia cast new light on this critical transformation. These include Yruanomys zhoui, one of the earliest and most primitive rodents from Asia; Erlianomys combinatus, the earliest known member of myodontoidea (consisting of Muroidae and Dipodoidea) and crown-Rodentia; Archetypomyserlianensis, a peculiar miniscule rodent from the late Early Eocene. Along with the Late Paleocene Alagomyidae (Tribosphenomys, Neimengomys, and Alagomys) these fossils display transitional morphologies during the earliest stage of rodent evolution. The dental morphologies show that rodents with ctenodactyloids, myodont and sciurid tooth patterns probably represent the earliest rodent radiations. Because these fossils were collected from denser stratigraphic intervals with well-documented stratigraphic data and chronology, they also provide additional age constraints for molecular clock. With more robust phylogenies based on both morphological and molecular data, it can be argued that the discrepancy between the molecular clock and the fossil record for rodent divergence is not a result of poor preservation, lack of morphological diagnostic features, or potentially hidden fossil records.
Instead, molecular analyses with the new fossil calibrations produced divergence times that are broadly consistent with the paleontological records and the notion that rodents with modern aspects originated and diversified across the Paleocene–Eocene transition.

S-130
GEOMETRIC MORPHOMETRICS AS A TOOL FOR DISENTANGLING THE RODENT CLASSIFICATION
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While exceptional for an intense diversification of lineages, the evolutionary history of the order Rodentia comprises only a limited number of morphological types for the skull and the mandible. These morphotypes were recognized early and used as diagnostic phylogenetical attributes, but many studies have shown that they could not be used to classify rodents at the suborder level due to convergent evolution. Thus, it became necessary to revisit the entire morphological diversity of the masticatory apparatus in extant and extinct rodents. Future morphological input to phylogenetical and systematic studies likely lies in a reassessment of characters in the light of molecular phylogenies with the major challenge to understand morphological evolution. We especially focused on two different parts of the skull: the angular process of the mandible for which the relative position to the plane of the alveolus of the incisor has been used to recognize the Sciurognathi and Hystricognathi suborders; and the infraorbital foramen whose shape was used to define the Protogomorpha, Sciuromorpha, Myomorpha, and Hystricomorpha suborders. Current and past rodent diversity emphasizes the limitations of the qualitative descriptive approach and highlights the need for using integrative quantitative methods. Here, we present the first reanalysis of these diagnostic morphological features, in combining classic comparative anatomy with morphometric methods. We used these methods to explore the patterns of variation of the masticatory apparatus with regard to several factors such as phylogeny and ecology. Then, the analysis of osteological features was compared to myological features in order to understand the biomechanical origin of this morphological diversity.

S-131
RODENT INCISOR SHAPE IS NOT CONSTRAINED BY THE SPACE AVAILABLE IN THE JAW
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The ability of the jaw and teeth to develop in a coordinated manner is integral to the evolution and functional maintenance of the masticatory system. This study aims to assess the role of developmental plasticity of the rodent incisor in response to differences in the available space of the surrounding bone. The sample consists of three different strains of mouse (Mus musculus): a wild-type control (C57BL/6J); brachymorph with a shortened face and neurocranium; and Pten with an elongated face and neurocranium. Both mutations are specific to cartilage development and do not directly affect the development of the dentition. The samples therefore allow the influence of the space in the face and mandible on the size and shape of the developing incisor and the indirect plastic adaptation of the dentition to be assessed. We test the hypothesis that the incisors plastically adapt during development to fit into the space available in the face and mandible. Following micro-CT scanning of the sample and image segmentation, 3D landmarks were taken from the incisors, face and mandible. Overall there are significant interstrain differences in the shape of both the face and mandible, but not in the corresponding incisors. Partial least squares analysis shows low levels of covariance between both the face and mandible and their respective incisors. The findings falsify the hypothesis that the incisors plastically adapt to fit into the space available. This high degree of independence has implications for the coordinated development and evolution of such a complex functional system.

S-132
ONTOGENY OF BITE FORCE AND INCISOR STRENGTH INDICATOR IN TUCO TUCOS (CTENOMYS TALARUM; RODENTIA; CAVIOMORPHA)
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Structural features undergo changes during ontogeny that sometimes entail different functional capabilities. The behaviour of organisms at each stage of development is largely constrained by this fact. Rodents have long, ever growing incisors for gnawing, and a powerful jaw adductor musculature. The incisors are sufficiently long relative to their basal diameter to be affected significantly by bending stresses. This is particularly true in the subterranean genus Ctenomys that uses its long and procumbent incisors during the
excavation of galleries. We measured bite force in individuals of different ages using a force transducer. In these individuals, incisor width and depth were measured using digital calipers to assess the incisor's sectional modulus, considering the incisor cross-section as an ellipse. Incisor length was also measured. A strength indicator (S) was calculated as $S = \text{incisor section modulus} / (\text{biting force})(\text{incisor length})$. We found that, for both sexes, ontogenetic biting force scales to body mass with positive allometry (allometric coefficient 0.90 and 0.95; females and males respectively). However, a two-way ANOVA showed no significant differences in S, either between sexes or among age classes (pups; juveniles; adults). This result indicates similar structural capacity in the gnawing/excavatory apparatus during the ontogeny in this species. This fact correlates well with the observation that pups and juveniles of C. talarum incorporate solid foods shortly after birth (7-10 days old), and are able to dig early in life, at 18-20 days old.

S-133
EVOLUTIONARY AND BIOLOGICAL IMPLICATIONS OF DENTAL MESIAL DRIFT IN RODENTS
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Among mammals, rodents are highly because they encompass a wide range of ecological niches, including various feeding habits. The dental occlusal morphology is traditionally the best indicator used to approach some ecological aspects of extinct and extant species. The investigation of poorly known dental characteristics sheds new light on morpho-functional aspects of rodent dentitions. The aim here was to focus on a striking mechanism only recently observed in rodents: the dental mesial drift. It involves the migration of the whole post-canine dentition induced by the forward pressure of posterior teeth. We described this innovation in African mole-rats (Bathyergidae) and in gundis (Ctenodactylidae). We defined three different degrees of mesial drift. The slight one only involves a weak displacement of teeth without dental loss (e.g. the Cape mole-rat). The moderate mesial drift is defined by dental displacement leading to the loss of a few teeth (e.g. gundis). The strong mesial drift corresponds to the shed of many anterior teeth as the consequence of new molars constantly erupting at the rear of the jaw (e.g. the silvery mole-rat).
Interestingly, we noted that dental drift in rodents is always associated with high-crowned teeth favoring molar size enlargement, and thus, the forward pressure. Such innovation is the consequence of dentitions adapted to withstand high wear, inasmuch as these rodents inhabit desert or underground environments, where dust is abundant. Mesial drift also implies a high activity of bone remodeling and an intense dental resorption when it occurs. A more thorough study of mesial drift in rodents would be very promising from evolutionary, biological and orthodontic points of view.

S-134
CONNECTIONS BETWEEN CHEWING MOVEMENTS AND MOLAR CROWN TOPOGRAPHY DURING THE NEOGENE RADIATION OF THE MUROIDEA (RODENTIA, MAMMALIA)
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Among extant rodents, the superfamily Muroidea (rats, mice, gerbils, hamsters, voles...) displays the highest number of species, molar crown morphologies and modes of chewing. As such it constitutes a relevant model for the study of the mechanisms responsible for molar crown diversification, the Neogene fossil record of the various muroid subfamilies illustrating many cases of parallel and convergent evolution of dental morphologies. Changes in tooth morphology are often associated with shifts in occlusion, besides or in connection with dietary adaptations. The changes in the chewing movements that are responsible for food processing and the necessity of the preservation of an effective occlusion have thus been both hypothesized to functionally constrain crown morphological changes and to induce convergent evolution. To test their respective influence, the amount and the timing of the morphological changes occurring during Neogene in several key eumurid lineages were quantified thanks to 3D-topographic analyses performed on virtual models of M1/1 digitized through X-Ray microtomography. The observed evolutionary trends were then functionally interpreted in the light of the microwear patterns of the sampled rodents. It results that three main dental plans and four occlusal patterns are variously combined in the studied sample of Neogene Muroidea. The relatively well-resolved muroid phylogeny enables to demonstrate that the derived non-interlocking propalinal occlusion, linked to flattened lophodont tooth crowns, has been independently achieved at least seven times within this superfamily, via several evolutionary pathways. Our results emphasize several cases of mosaic evolution in which the changes in direction of chewing and in crown
shape were partly decoupled. The number of possible pathways appears limited due to the strong functional constraints affecting occlusion.

S-135
THE ORAL APPARATUS OF RODENTS: VARIATIONS ON THE THEME OF A GNAWING MACHINE
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Rodents are gnawing mammals. Despite the fact that diversification of the oral apparatus is so striking that traditional sub-ordinal classifications of rodents have been based largely on features of the jaws and masticatory muscles, there are also characteristics of the oral apparatus that are found in every rodent. This consistent group of features forms a suite of synapomorphies that are both definitive for the Rodentia and a functional morphological complex for gnawing. Other mammals gnaw but rodents gnaw with sharpened upper and lower incisors. Sharpening is an active process and it requires purposeful sharpening movements of the lower jaw in which the lower incisors are ground against the upper incisors. Contrary to widespread notions in the literature, the incisors of rodents are not self-sharpening. In fact, the functional complex for gnawing is, in essence, a complex that gives rodents the ability to actively sharpen their incisors. Morphological features of the incisors, jaws, and the cranio-mandibular joints all contribute to this functional complex for gnawing. In concert, these features allow the lower jaws to be protruded in order to grind away dentin on the lingual surfaces of the upper and lower incisors to hone the edges of the teeth. Although this suite of characters appears to be an extremely specialized morphological complex the remarkable diversity of the jaw muscles within the Rodentia demonstrates that it has placed few constraints on the evolution of masticatory apparatus of rodents.

S-136
FUNCTIONAL MAINTENANCE AND VARIATION IN CRANIAL LENGTH OF THE MOUSE MASTICATORY SYSTEM
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Diversity of cranial length is a key morphological variant in mammals. While diversity of form is often attributed to differing dietary behaviours and thus divergent functional needs and performance, a number of authors have shown greater diversity of form than diversity of mechanical advantage. Here we examine the integration of the masticatory lever system and its ability to maintain function through plastic adaptation. The sample consists of three strains of Mus musculus; a wild-type strain and two mutant strains. Both mutant strains have a known specific mutation that selectively affects chondocranial growth, with no direct influence on the development of either the mandible or masticatory musculature. The brachymorph mutant phenotype is characterised by a shortened cranium and mandible whereas the Pten is elongated. The sample therefore allows us to test the plastic response of the masticatory lever system, and in turn mechanical advantage when cranial length and the out-lever are varied. Mechanical advantage was calculated for each specimen as a ratio of muscle in-lever and jaw out-lever for three key masticatory muscles. Using micro-CT scans, levers were calculated from the centroid of the attachment area of each muscle. Jaw out-levers are significantly different between all strains. Jaw in-levers are significantly different between all strains for the superficial and deep masseters but not temporalis. There is no significant difference in the mechanical advantage of each muscle between all strains, with the exception of the deep masseter mechanical advantage in Pten and brachymorph strains. In all muscles the in-levers are highly correlated and negatively allometric with respect to the out-levers. Overall the results here show little variation in the mechanical advantage of the muscles despite significant variation in cranial morphology and the levers between the strains, and the potential of the masticatory system to plastically adapt to maintain function.

S-137
THE INFLUENCE OF MANDIBULAR MORPHOLOGY ON THE BIOMECHANICS OF FEEDING IN RODENTS
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The Rodentia is the largest of all mammalian orders, comprising well over two thousand extant species. Rodents show some of the most complex specializations of the masticatory apparatus amongst mammals, and many of these adaptations have been used to classify the rodents. Specifically, there have been two important and competing classification schemes. Firstly, the morphology of the lower jaw has been used to divide rodents into those that resemble squirrels (sciurognaths) and those that resemble porcupines (hystricognaths). Alternatively, the morphology of the masseter muscle has been employed to categorise the
rodents into squirrel-like, porcupine-like and mouse-like forms (sciuromorphs, hystricomorphs and myomorphs respectively). The recently discovered Laotian rock rat (Laonastes aenigmamus) is unusual (though not unique) within rodents in combining a sciurognath lower jaw with a hystricomorph masseter morphology. In this study, the biomechanical implications of this rare combination of morphologies were investigated using finite element analysis (FEA), a computer-based technique that enables the reconstruction of stress and strain patterns in a digital object subjected to a load. FEA of the mandibles of a squirrel and guinea pig were also undertaken for comparison. Results demonstrate that the Laotian rock rat is very similar to the squirrel in its biting performance; that is, it has a highly efficient bite at the incisors, but is less efficient than the guinea pig when biting at the distal molars. This indicates that it is the geometry of the mandible, rather than the arrangement of the muscles that is the most important factor in the biomechanics of feeding in this species. This may have important implications for our understanding of the large amount of morphological convergence seen within the order Rodentia.

S-138
MORPHOLOGICAL ADAPTATIONS OF THE RODENT INNER EAR
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Rodents place varied functional demands on their sense of hearing and balance to meet the requirements of a broad range of ecological niches and diverse behaviours, from solitary and slow moving subterranean species through to gregarious semi-aquatic species and gliding species. Here we aim to capture and document potentially related adaptations of the organs of hearing, the cochlea, and of balance, the semicircular canals. Techniques including, for example, microCT, 3D reconstruction, and geometric morphometrics were used to study morphological variations of the bony inner ear across 15 rodent species. The cochleae were examined for changes of form (size and shape) whilst the canals were examined for variations in their planar orientations. Results revealed a considerable range of variation of rodent cochlear morphology, represented at one end by the typical mammalian condition seen in, for example, Rattus norvegicus and at the other end by a derived spring like cochlea seen in, for example, Cavia porcellus and Myocastor coypus. Potential links with hearing, ecology and behaviour were explored but proved inconclusive (p>0.05). Results for the canal orientations indicated that the canals of fast moving species (e.g. Pedetes capensis) are no closer to orthogonal than those of slower moving species (e.g. Cryptomys hottentotus).

S-139
MANDIBLE DIVERGENCE OF HOUSE MICE ON COLD ISLANDS: EVIDENCES OF PARALLEL ADAPTIVE EVOLUTION?
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Adaptation to new environments is a key feature in evolution promoting divergence in morphological structures under selection. By accompanying human travels, the house mouse (Mus musculus domesticus) colonized many islands, repeatedly facing there environmental conditions that often differed strongly from the source conditions. Such situations are prone to promote divergence, both due to random processes and adaptation. Both processes are difficult to disentangle, but the occurrence of parallel evolution on several islands displaying similar environment may bring support to the adaptive interpretation of insular differentiation. The mouse response to insular conditions was investigated by quantifying mandible shape using geometric morphometrics in populations from several “cold” islands: Marion and Kerguelen Islands (Sub-Antarctic), and Orkney archipelago (off Scotland). Both insularity and cold environments tending to favor large body size, expectation is a parallel evolution related to allometry, especially since allometry constitutes the main direction of variance in continental populations and hence a “line of least resistance to evolution”. Insular populations indeed diverged in mandible shape from the continental stock. Parallel evolution was observed between two Orkney Islands and the Kerguelen population, whereas Marion mandibles displayed a very peculiar morphology. No general size increased was documented and surprisingly, insular evolution never matched the direction of allometry. This diversity of morphological response may be due to variety of situations beyond the apparent environmental similarity: populations with or without chromosomal fusions, commensal vs. feral mice... Despite this variety, mandibles of insular mice all tend to explore a same zone of the morphological space, suggesting that some common factors of differentiation may drive their evolution.

S-140
PATTERNS OF DISPARITY IN RODENT EVOLUTION: FILLING ONTOGENETIC AND ADULT MORPHOSPACES
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A central goal of evolutionary studies is to identify and understand the processes behind the observed unequal patterning of phenotypic space. The quantitative expression of traits that are coupled over the course of development, or to achieve a certain function, can be extracted as phenotypic covariances, providing an empirical and theoretical framework to examine how phenotypic spaces are patterned. A recent method (allometric disparity) that measures ontogenetic trajectory variability provides an opportunity to examine phenotypic covariance evolution from a developmental perspective. Allometric disparity methods were used to quantify macroevolutionary patterns of allometric trajectory variability for 51 rodent species, comprising equal representatives from each of the major clades (hystricognaths, muroids, sciurids), resulting in a phenotypic space (=allometric space) summarizing the evolution of cranial growth patterns. Results indicate that the evolution of allometric trajectories in rodents is characterized by different features in sciurids compared to muroids and hystricognaths. Sciuridae was found to have a reduced magnitude of inter-trajectory change and growth patterns with less variation in allometric coefficient values among members. In contrast, a greater magnitude of difference between trajectories and an increased variation in allometric coefficient values was evident for both hystricognaths and muroids. Adult disparities were compared to their ontogenetic counterparts for each clade. Disparately filled allometric space, i.e. variability in allometric trajectories, may not necessarily lead to comparatively greater disparity in adult morphospace. Reduced adult morphospace filling may happen as a consequence of reduced adult size variation among species despite comparatively large divergence between allometric trajectories. In reverse, when allometric trajectory patterning is conserved, greater adult disparities may be achieved by increased variation in size in a clade. Hystricognaths and muroids were found to display higher adult disparities than sciurids, suggesting that conservatism in allometric trajectory modification, as exemplified amongst sciurids, may constrain morphological diversity in rodents.

CONTRIBUTED TALKS

Contributed 1 – Respiration

C-001
THE INFLUENCE OF STERNAL MORPHOLOGY ON THE BREATHING MECHANICS OF BIRDS
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Resting metabolic rate (RMR) is an important constituent of the overall daily energy budget and has been established for many species of bird. Despite the potential energetic effect of body stance, very few studies have considered the interaction of resting posture (standing vs. sitting) and RMR. Interestingly, selection of resting posture might be determined according to the requirements of breathing since there is a constraint on ventilation due to posture in birds; standing birds breathe via dorsoventral excursions of the sternum, while sitting birds flare their ribs laterally as the sternum is immobile. Therefore the objective of this study was to determine the energetic effect of posture in birds and how this may relate to breathing mechanics and changing sternal morphology. Under constant environmental conditions, respirometry was used to establish RMR in adult barnacle geese (Branta leucopsis) and domesticated broiler chickens (Gallus gallus domesticus) over development. In both cases maintaining a standing posture coinciding with increased RMR, indicating that this is an important factor when considering avian energetics. Compared to sitting, standing RMR is 25% higher in barnacle geese. The difference between sitting and standing RMR progressively increases over development in broiler chickens. At a body mass of 200g there is little difference but at slaughter weight of 2500g, RMR in standing birds is 23% higher. Increasing pectoral mass is a primary target for artificial selection in these economically important meat birds, resulting in a disproportionately heavy sternum in adults. Dorsoventral sternal movements driven by respiratory muscles, coupled with the activity of postural hindlimb muscles, may therefore become more energetically expensive as the birds grow. A relatively high energetic cost of breathing in broiler chickens may contribute to the multitude of welfare problems and decreased activity levels seen in this breed.

C-002
PULMONARY MORPHOLOGY IN THE LEPIDOSAURIA AND ITS IMPLICATIONS FOR THE AMNIOTE BAUPLAN
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The so-called reptiles were the first amniotes that achieved full terrestriality as they became independent of aquatic habitats for reproduction. This involved the evolution of numerous specialized structures such as extraembryonic cavities during development, absence of a larval stage, impermeable skin in adults and a urogenital system modified for obligatory internal fertilization. Lungs already evolved in their piscine ancestors, and became the exclusive site for respiratory gas exchange. Probably driven by grade/clade logic, the current textbook opinion is that the ancestral type of lung in amniotes was similar to that found in amphibians: a single-chambered and sac-like organ. Putative support of this hypothesis is the apparent presence of single-chambered lungs in the majority of lepidosaurs, including the basal Rhynchocephalia. We performed a large-scale comparative anatomical study of pulmonary structure in all major amniote taxa. These were complemented by new developmental data from the geckonid Paraedura picta and a review of the 19th century embryological literature. We submit that the so-called single-chambered lungs of lepidosaurs in fact represent a simplification of a plesiomorphically branched and multichambered organ, and provide functional, ontogenetic and phylogenetic morphological support. The fundamental consequence is that instead of a single-chambered lung, one must postulate a multichambered lung at the dawn of amniotes. The simplifications found in the extant lepidosaurs are explained by an evolutionary scenario based on the physical properties of different pulmonary baupläne and on the fossil record of the lepidosauromorphian lineage.

C-003
EVOLUTION AND FUNCTIONAL MORPHOLOGY OF THE BRANCHIOSTEGAL APPARATUS IN ACTINOPTERYGIAN FISHES
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Branchiostegal rays are long, thin dermal bones that articulate with ventral elements of the hyoid arch and form the floor of the gill chamber in actinopterygians. The branchiostegal rays are covered by skin to form the branchiostegal membrane. Together, the branchiostegal rays, branchiostegal membrane, muscles and connective tissue make up the branchiostegal apparatus. We surveyed branchiostegal membrane morphology in 401 families across Actinopterygii and found that gill opening restriction, an extreme modification to the membrane, convergently evolved at least 10 times in this clade. Because the branchiostegal apparatus forms part of the gill chamber, its size and morphology have been used as traits to classify variation in gill ventilatory mechanisms. To quantitatively link size of the branchiostegal apparatus with differences in ventilatory function among closely-related species, we studied gill ventilation morphology and behavior in four species of Cottodei (Leptocottus armatus, Myxocoelus polyacanthocephalus, Hemilepidotus hemilepidotus, and Dasycottus setiger). We collected functional (kinematic and pressure recordings) and anatomical data from three individuals of each species. Relative size of the surface area of the branchiostegal membrane correlates with both ventilation rate (r = -0.78, p = 0.003) and the relative duration of the inspiration phase (r = 0.73, p = 0.007). We also found that the four species showed substantial variation in differential pressure profiles on the scale of previously described differences between pelagic and benthic fishes, even though all four species studied are benthic; functional measurements related to these pressure profiles also significantly correlate with relative branchiostegal membrane surface area. Quantifying the morphology and functional role of the branchiostegal apparatus can lead to better understanding variation in gill ventilatory mechanics among Actinopterygii.

C-004
LUNG LOSS: MOLECULAR AND MORPHOLOGICAL CONSEQUENCES
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Organs develop within tightly integrated organ systems governed by pleiotropic genetic networks. Organ loss potentially results from any of a myriad of genetic changes and has far-reaching physiological consequences. One example is lung loss in plethodontid salamanders. All plethodontids lack lungs as adults, but the clade evolved from ancestors that possessed lungs. We have previously shown that lung loss results from degeneration of the morphological lung rudiment in embryos. Despite lacking lungs, plethodontids are the most diverse and successful radiation among living salamanders. It is still not completely known how the respiratory and circulatory systems of plethodontids are adapted to lunglessness. We examined the cardiopulmonary system in plethodontid salamanders and offer developmental evidence to support the hypothesis that two features of lungless amphibians are developmental consequences of lung loss: increased use of cutaneous/buccopharyngeal respiration, and modification of cardiac morphology. Plethodontids compensate for lung loss by relying on respiration through the skin and buccopharyngeal
mucosa. They express surfactant protein C (SP-C), a component of pulmonary surfactant that plays a critical role in respiration. SP-C is present only in the lung epithelium in all other vertebrates examined. Plethodontids instead show novel sites of expression, which may correspond to a shift in primary respiratory sites. Lung loss is also correlated with reconfiguration of the circulatory system, including the possible loss of the atrial septum, which we evaluate in µ-CT imaged embryos. In addition, we explore the molecular-genetic links between lung loss and atrial septum development. Study of the developmental mechanisms of lung loss yields a more complete understanding of its morphological and physiological outcomes, including pleiotropic effects on the development of other organs and the adaptive changes that make it possible for plethodontids to flourish despite their lack of lungs.

C-005
RIB KINEMATICS AND INTERCOSTAL MUSCLE FUNCTION DURING LUNG VENTILATION IN AMERICAN ALLIGATORS
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Lung ventilation in crocodylians is accomplished by a hepatic piston mechanism driven by the m. diaphragmaticus combined with costal and pelvic movements. While the diaphragmatic mechanism is well studied, less attention has been paid to the contribution of intercostal musculature and costal movements. In this study, marker-based X-ray Reconstruction of Moving Morphology (XROMM) was used to analyze rib movements during breathing in American alligators. Intercostal muscle activity was analyzed using EMG recordings. Spherical metal markers were surgically implanted into the tripartite ribs, the sternum and the dorsal scutes of juvenile alligators. Patch and hook electrodes were chronically implanted into the intercostal musculature. Planar x-ray video recordings of breathing alligators were recorded simultaneously with EMG, and then CT scans of the same individuals were collected later (postmortem). 3D animations of rib motion during ventilation were created and rib kinematics and muscle activity patterns were analyzed. Substantial rib movements occur most of the time during ventilation in alligators, and result in dorso-ventral flattening of the rib cage during exhalation and expansion during inhalation. The largest movements occur in the sternal part of the rib, whereas intermediate and vertebral ribs only show small movements. Relative motion between vertebral and intermediate ribs is much smaller than motion between the intermediate ribs and sternal ribs, and often there is no detectable motion at all between the vertebral and intermediate ribs. In contrast to green iguanas, who show mostly bucket handle motion, rib motion in alligators seems to be a combination of pump handle and caliper motion. EMG recordings suggest that liver movements drive most of the volume change in the lungs and active rib movements occur only at the end of a breathing cycle. Generally, although rib movements in alligators contribute to ventilation, they seem to be of less importance compared to birds and lepidosaurs.

C-006
THE EVOLUTIONARY DERIVATION OF THE DIAPHRAGM FROM A SHOULDER MUSCLE: A NEW HYPOThESIS
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The acquisition of the diaphragm, a mammalian synapomorphy contributing to the ventilatory function and the coelomic division, was of paramount importance in mammalian evolution. However, the evolutionary origin of the diaphragm remains unclear, due to the lack of a comparable structure in other living taxa. Here, we present a new hypothesis that the diaphragm evolved from a shoulder muscle, based on developmental biology and comparative anatomy. Recent developmental analyses indicate that the myogenic cells for the diaphragm are likely to be a subpopulation of the migratory cells later entering the forelimb. In light of this, we focused on patterns and positions of brachial plexi, which reflect the migratory routes of forelimb muscle precursors. We surveyed the literature to reexamine the position of the brachial plexus among living amniotes and confirmed that the cervico-thoracic transition in ribs reflects the brachial plexus position. Applying this osteological correlate to fossils, we concluded that the brachial plexi in the stem synapsids were positioned at the level of the fourth–seventh spinal nerves, and that the posterior border of the brachial plexus was translocated caudally, accompanied by a duplication of the anterior part of the brachial plexus in the lineage toward mammals. The topology of the phrenic and suprascapular nerves of mammals is similar to that of subscapular and supracoracoid nerves, respectively, of the other amniotes, suggesting that the diaphragm evolved from the subscapular muscle, which was positioned medial to the pectoral girdle. As seen in some living reptiles, the subscapular muscle of the pelycosaur-grade synapsids probably faced the coelomic cavity at the cranial opening of the thoracic wall, corroborating the historical continuity from the subscapular muscle to the diaphragm.
Contributed 2 – Tooth EvoDevo

C-007
DEVELOPMENT AND REGENERATION OF THE LIFELONG ‘CONVEYOR BELT’ DENTITION IN SHARKS
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Many vertebrates possess the remarkable ability to renew or replace their teeth throughout life. Considerable effort has been devoted to studying the genes regulating both tooth regeneration and replacement accordingly, yet conventional animal models have provided only partial insight into the global network of genes regulating this important developmental process. Sharks replace their teeth throughout life as a conveyor belt-like system in which teeth develop and are sequentially shed and replaced with precise developmental control. The small-spotted catshark, Scyliorhinus canicula, provides an ideal model to study the genetic control of chondrichthyan tooth replacement, offering the potential both for deep insights into vertebrate evolution and the regenerative component of epithelial organogenesis. Using a combination of in situ hybridization and immunohistochemistry, we investigate the expression patterns of known dental patterning genes in the developing catshark dentition and associated epithelial morphodynamics. We further use this molecular morphological approach to study the expression patterns of conserved tooth patterning genes in developing dermal denticles, mineralised structures coating the skin of sharks, functioning as dermal body armour and enhancing hydrodynamic efficiency to confer predatory advantage. This experimental approach provides both parallel insights into the gene regulatory network (GRN) directing chondrichthyan tooth and denticle development and renewed perspective regarding the evolutionary role of GRNs in the generation of functional phenotypic novelty. Collectively, this data provides further insights into the conservation of an ancient ‘toolbox’ of genes, periodically redeploed as developmental modules under semi-independent genetic control and conserved throughout 500 million years of vertebrate evolution.

C-008
HETEROCHRONY AND DENTAL ONTOGENETIC DIVERSITY IN METATHERIAN MAMMALS: CIRCUMVENTION OF CONSTRAINTS IN SOUTH AMERICAN EXTINCT PREDATORS
(SPARASSODONTA)
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Tooth replacement in Metatheria is restricted to a single element, the DP3/dp3, and across the group the timing of dental eruption is variable. We analyzed the sequence of eruption of 77 specimens of marsupials and fossil metatherians, including the Sparassodonta, an extinct basal clade of specialized carnivores. They have patterns that are unique and contrary to otherwise universal patterns. (1) The upper and lower homologous molars erupt more in parallel in sparassodonts, unlike other metatherians where the lower molars precede the homologous upper elements. (2) Sparassodonts show the P3/p3 erupting together, in common with some didelphids. In other didelphids P3 precedes P3, while in the remaining didelphids, some peramelids, one caenolestid, and Pucadelphys, this order is reverse. (3) The canines of larger sparassodonts appear to complete their eruption at the end or after the eruption of the complete adult dentition. Furthermore, the upper canine in thylacosmilids and proborhyaenids is hypsodont and the lower canine in proborhyaenids is semihypsodont. (4) Sparassodonts have different morphologies for the DP3/dp3, suggesting different diets in the juveniles. (5) Deciduous teeth are functional for a long period of time, which extends to thylacosmilids retaining a functional DP3 in the permanent dentition. Dasyuromorphia counterparts have a vestigial and non-functional DP3/dp3. The retention of the DP3 and the hypsodont upper canine of thylacosmilids are examples of heterochronic shifts. In metatherians, during ontogeny all molars function as a carnassial pair until the eruption of the M3/m4, the most specialized pair, constraining the teeth to evolve into different shapes. The timing of dental eruption and deciduous morphology are alternative mechanisms to add variability to the dentition of the specialized sparassodonts. Phorusrhacidae birds, Sebecidae crocodiles and Madtsoiidae snakes were contemporaneous predators in the South American ecosystems. It has to be tested their effect in placing constraint upon the sparassodont adaptative zone.

C-009
WHEN PRIMATES BARE THEIR TEETH: MOLAR PROPORTIONS IN THE LIGHT OF DEVELOPMENT, A NEW KEY TO EVOLUTION
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Recent developmental studies clarify the influence of molar embryonic structuration and cusp interactions on adult molar shapes and proportions. A developmental model has been proposed to explain relative molar proportions according to an inhibitory cascade (IC). This model has been tested on different mammalian orders (Rodentia, Notongulata). It constitutes a precious tool for paleontologists and biologists analyzing differences in tooth patterns in systematic and/or evolutionary frameworks. The aim here is to apply the IC model to Primates, not only for testing the model on another group of mammals but more specifically for the identification of the factors that could influence this model. Primates are characterized by high taxonomic diversity, great variation in size, locomotion, diet, etc. We tested the effect of these factors on molar ratios under the IC model hypothesis. Our work was performed on a sample of 468 specimens of extant primates belonging to 15 families and 65 genera. Our results show that shape space is not fully occupied, attesting to some unrealizable morphologies described by the model. Moreover, for the major part of the specimens, molar proportions follow the values predicted by the IC model with some exceptions. Presence or absence of premolars before molars highly impacts tooth proportions. Diet and body size do not directly influence molar proportions within the order but the suborders display two different morphologicalpatterns attesting to different developmental processes. Our results could lead to robust inferences of cusp interactions in fossil species and their variation through time.

C-010
ORIGIN OF MECHANICAL CONSTRAINTS DURING CUSP PATTERN DEVELOPMENT OF VOLE MOLARS
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In mammals, tooth cusp morphology is species-specific, functionally and evolutionarily linked to diet. The morpho-functional evolution of rodent cusp pattern is convergent but mosaic between the muroid lineages (Lazzari et al., 2008); murines diverged to a parallel-like cusp pattern (confluent), while cricetines kept the alternate cusp pattern of the cricetodontid Miocene ancestor. In 2002, Salazar-Ciudad and Jernvall introduced a lateral bias parameter in their morphodynamic model of molar development. Together with anterior elongation, these biases influence whether cusp patterns are alternate or confluent. The nature of these biases has not been tested experimentally, and here we examined the possible role of the jawbone as a mechanical constraint in the fine-tuning of cusp patterns. The cusp offset of the first lower molar (m1) in voles is lost when the tooth is cultured out of the jaw. Laterally constrained mouse m1 in vitro seems to recover the vole-like cusp pattern offset. Therefore, the alternate cusp pattern of vole m1 may be linguo-buccally constrained during the in vivo development. Laterally constrained mouse m1 in vitro seems to recover the vole-like cusp pattern offset. Therefore, the alternate cusp pattern of vole m1 may be linguo-buccally constrained during the in vivo development. During the co-development of the m1 and the jawbone, it seems that the jawbone can constrain the vole m1 at late stages of development. Moreover, the co-development in vitro suggests an inhibition of the jawbone on the m1. At the opposite in mouse, the m1 grows better laterally, “pushing” aside the jawbone. In vitro, the m1 destroys the jawbone. In conclusion, cusp pattern morphogenesis in vole molars can be influenced by a potential lateral constraint of the jawbone and its inhibition on the m1.

C-011
HOW IS TOOTH REPLACEMENT REGULATED IN NON-AMNIOTES? FUNCTIONAL STUDIES ON THE ROLE OF WNT SIGNALING
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The canonical Wnt signaling pathway has been proposed as an important candidate for regulating tooth replacement in vertebrates. So far, its involvement has been experimentally demonstrated in tooth replacement in squamates and in supernumerary tooth formation in mammals. We used different approaches to mimic overactivation of Wnt signaling in zebrafish; none of these altered tooth replacement. For example, masterblind mutants, carrying a mutation in axin1, mimic overactivation of Wnt. While these mutants lack forebrain and eyes, they displayed a normally patterned dentition with teeth being replaced at appropriate times and positions. LiCl treatment, which activates the Wnt pathway via an alternative mechanism, did not affect tooth development or replacement either. The soluble Wnt inhibitor dickkopf1 (dkk1) is strongly expressed in zebrafish tooth germs. Yet, replacement was not affected when using a
pharmacological compound that specifically inhibits dkk1. Finally, as an alternative strategy to influence Wnt signaling, we attempted to inhibit Wnt signaling by pharmacologically blocking the transcriptional complex formed at the endpoint of the signaling pathway. This too did not affect tooth replacement. Likewise, Xenopus loss-of-function and gain-of-function transgenic lines did not display an anomalous dentition. Teeth were patterned normally, and tooth replacement proceeded as in wild type frogs. The failure so far to influence tooth replacement in Danio or Xenopus by perturbing Wnt signaling stands in sharp contrast to the apparent ease with which manipulating other signaling pathways, such as fgf signaling or retinoic acid signaling, can generate supernumerary teeth, or inhibit tooth formation, at least in zebrafish. We discuss our results in the light of (1) potential technical pitfalls, (2) anatomical and developmental features of functional teeth and their successors, and (3) current findings on the search for a stem cell niche – proposed to be pivotal in tooth replacement - in actinopterygians.

C-012
TESTING THE INHIBITORY CASCADE MODEL IN MESOZOIC AND CENOZOIC MAMMALIAFORMS
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Much of the current research in the growing field of evolutionary development concerns relating developmental pathways to large-scale patterns of morphological evolution, with developmental constraints on variation, and hence diversity, a field of particular interest. Tooth morphology offers an excellent model system for such ‘evo-devo’ studies, because teeth are well preserved in the fossil record, and are commonly used in phylogenetic analyses and as ecological proxies. Moreover, tooth development is relatively well studied, and has provided several testable hypotheses of developmental influences on macroevolutionary patterns. The recently-described Inhibitory Cascade (IC) Model provides just such a hypothesis for mammalian lower molar evolution. Derived from experimental data, the IC Model suggests that a balance between mesenchymal activators and molar-derived inhibitors results in posterior molar sizes, predicting firstly that molars either decrease in size along the tooth row, increase in size, or are all of equal size, and secondly that the second lower molar should occupy one third of lower molar area. Here, we tested the IC Model in a large selection of taxa from diverse extant and fossil mammalian groups, ranging from the Middle Jurassic (~176 to 161 Ma) to the Recent. Results show that most taxa (~65%) fell within the predicted areas of the IC Model. However, members of several extinct groups fell into the regions where m2 was largest, or rarely, smallest, including the majority of the polyphyletic “condylarths”. Most Mesozoic mammals fell near the centre of the space with equality of size in all three molars. The distribution of taxa was significantly clustered by diet and by phylogenetic group. Overall, the IC Model was supported as a plesiomorphic developmental system for Mammalia, suggesting that mammal tooth size has been subjected to this developmental constraint at least since the divergence of australosphenidans and boreosphenidans approximately 180 Ma.

Contributed 3 – Sensory Biology
C-013
UNDERSTANDING EARLY BRAIN EVOLUTION IN PRIMATES
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On average, living primates have larger brains than other mammalian orders. Understanding the evolutionary context of this adaptation requires data from the first adaptive radiation of primates, the plesiadapiforms, and from close fossil relatives of primates. Virtual endocasts are known for two plesiadapiforms: Ignacius graybullianus and Microsyrops annectens. A composite virtual endocast is also available for the stem euarchontogliar Labidolemur kayi. These data were incorporated into a phylogeny of living and fossil primates and euarchontoglians to allow for ancestral state reconstructions using Parsimony and Bayesian techniques. The estimate for the ancestral stem primate from the parsimony analysis yields a value of 3.8 cc for brain size, and an Encephalization Quotient (EQ) between 0.44 and 0.62. In contrast, the common ancestor of living primates had a brain size of 6.3 cc and an EQ between 0.77 and 1.08. This suggests a significant increase in brain size at the euprimate node, but not necessarily at the basal primate node. Three observations add context to these numbers. First, in comparison to all living and fossil primates Labidolemur kayi possessed much larger olfactory bulbs, suggesting that reduction in the size of this part of the brain may have occurred very early in primate or eurachontan evolution. Second, cranial capacity in both plesiadapiform species was quite low, indicating that much of the increase in brain size that characterizes living primates must have happened subsequent to the basal primate node. Third, less development in regions of the brain that relate to visual processing (caudal cortex, temporal lobe) in plesiadapiforms relative...
to early euprimates suggests that improvements to this system may have been responsible for some increases to brain size in the common ancestor of all living primates. In sum, these data allow for an integrated view of the reshaping of the brain of early Primates.

C-014
FUNCTIONAL MORPHOLOGY OF BIOSONAR BEAM FORMATION IN THE BOTTLENOSE DOLPHIN USING FINITE ELEMENT MODELING

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High-intensity anthropogenic sound in the ocean is potentially detrimental to marine mammals. This accentuates the need to better understand the biosonar apparatus in the toothed whales, the organisms with the most acute underwater hearing. Studies with live dolphins are difficult to conduct and require considerable resources. A computerized numerical modeling method allowed us to simulate the vibroacoustic functions of the biosonar apparatus. In order to validate this approach, we developed a vibroacoustic finite element model to recreate sound production and acoustic beam formation in the bottlenose dolphin (Tursiops truncatus). The model is constructed from CT scan data, tissue property measurements, and custom software. The simulations confirm multiple previous hypotheses: (1) skull shape plays a role in the formation of the sound beam; (2) the fatty melon accounts for one quarter of the overall focusing in the transmitted beam; and (3) acoustic beam formation occurs in a series of stages that include contributions from the skull, nasal air sacs, melon topography, and dense connective tissue structures. An unexpected result is that adjustments to the focus and direction of the sound beam can result from small (millimeter scale) changes in the relative position of the sound generation components. A comparison with results from psychoacoustic experiments on live dolphins establishes validation of our vibroacoustic model.

C-016
MORPHOLOGY OF A PUTATIVE VOMERONASAL ORGAN IN THE SOUTH AMERICAN LUNGFISH LEPIDOSIREN PARADOXA

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Lungfish are considered to be the closest living relatives of terrestrial vertebrates; thus, they play a key role in the understanding of tetrapod evolution and the evolution of the vertebrate olfactory system. In general, the olfactory organ of fish is considered to be an undivided, singular system: An accessory olfactory structure—like the vomeronasal organ of amphibians, reptiles and mammals—has not been ascertained beyond doubt. In the olfactory system of the African lungfish Protopterus, epithelial crypts are located in the wall of the nasal sac, at the base of the olfactory lamellae. In the past, these crypts were deemed to have a secretory function. In recent publications, however, these distinct structures are proclaimed to represent a segmented, primordial vomeronasal organ. Hints for this assumption are the cytological structure of the epithelium, as well as the neuronal connection to a specific brain area, which both seem to resemble the tetrapod vomeronasal system. Nevertheless, the facts about this puzzling structure are incomplete and its vomeronasal character still has to be confirmed. Furthermore, it is required to clarify, whether these epithelial crypts are a special feature of the genus Protopterus. In the present study a detailed morphological description of the olfactory system of the South American lungfish (Lepidosiren paradoxa) was accomplished, whereas the West African lungfish Protopterus annectens served as a reference. We were able to demonstrate that the putative vomeronasal crypts do exist in the nasal system of Lepidosiren paradoxa. Each of the numerous crypts consists of a glandular part and a presumable sensory portion. In addition to our histological investigation, immunohistochemical examinations are currently in progress, focussing on the expression of the G protein subunit α. This molecule is typically associated with the signal transduction pathway in mammalian vomeronasal receptor neurons.

C-017
PRESENCE AND DISTRIBUTION OF G PROTEIN ALPHA SUBUNITS IN THE THREE OLFACTORY ORGANS OF THE TOAD BOMBINA ORIENTALIS

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Olfaction is a sense crucial for mating, food detection, and general social behaviour. This sounds quite familiar regarding mammals, but is most likely also true for amphibians. Bombina orientalis sense of smell is (in adult animals) composed of three subsystems: The main olfactory organ, the vomeronasal organ, and...
the widely unknown recessus olfactorius. The latter is of special interest, because amongst other features its function is still unknown. Furthermore, the relation of the recessus olfactorius to other olfactory systems is not yet understood. One example discussed is the potential homology of the recessus olfactorius and the so-called middle chamber epithelium (or water-nose), known from the group of Clawed Frogs like Xenopus. One important aspect that characterises olfactory organs is the implemented signal transduction pathway. Those pathways can for instance be identified by analysing the equipment of sensory epithelia with G-protein alpha subunits, proteins that are closely associated to odorant receptor molecules. We examined the expression of Go1olf and Gao within the three different olfactory subsystems of the toad Bombina orientalis in an immunohistochemical assay. As a reference, antibodies against Go1olf and Gao were also applied to tissue of the nasal region of Xenopus borealis. Our goal was to obtain first insights regarding the functional properties of the recessus olfactorius in comparison to the main olfactory, the vomeronasal and the middle chamber epithelium.

**Contributed 4 – General Morphology**

C-018

**THE DIGITAL BUZZARD – USING CONTRAST-ENHANCED CT SCANNING TO ELUCIDATE HARD- AND SOFT-TISSUE ANATOMY**

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Gross dissection is an established method for gaining detailed information about human or animal physiology, going back several hundred years. Since then, different techniques such as histology or light microscopy have supplemented and refined this approach. Nevertheless, gross dissection has the disadvantage of being a time-intensive and destructive method. Once a specimen has been dissected, it is lost and cannot be re-examined to confirm observations. The recent advances in X-ray computed tomography (CT) scanning technologies and their wide and comparably cost-effective availability, have led to a surge of alternative non-destructive imaging techniques in medical, biological and palaeontological sciences, vastly enhancing the possibility to visualise complex anatomical structures. However, due to the low intrinsic X-ray absorption, CT-scanning rarely provides sufficient resolution of unmineralised soft-tissues. Experimental studies have produced promising results by using contrast-enhancing agents to increase differential attenuation. In particular, iodine staining (sometimes also referred to as Lugol’s iodine or Lugol’s solution) has been shown to represent a fast and inexpensive method of imparting high differential contrast. To demonstrate the full potential of contrast-enhanced CT-scanning using iodine staining, we present the results of a “digital dissection” of a Common Buzzard (Buteo buteo). Detailed studies of the cranial anatomy, in particular the myology, in raptors is rare or only schematic. The digital visualisation of contrast-enhanced soft-tissues thus offers a unique opportunity to describe and illustrate these structures in detail and in an osteological context. Using this approach the cranial musculature (jaw adductor and depressor, hyoid, and neck musculature), muscle fascicle arrangement (length, pennation angles), ligaments, endocranial and neurovascular structures and keratinous tissues are presented, allowing identification, visualisation and quantification these structures. Results of this digital dissection provide valuable information for comparative studies on avian anatomy, input for biomechanical applications, and interpretation of soft-tissue structures in fossil taxa.

C-019

**CRANIAL SHAPE AND GROWTH IN THE DWARF SNAKE GENUS EIRENIS (SQUAMATA, SERPENTES)**

As Revealed by X-Ray Micro-Computed Tomography

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The phenomenon of miniaturization, which designates the evolution of a small adult phenotype from an originally larger ancestor, occurs in all parts of the animal kingdom and evolved through a variety of mechanisms, sometimes even resulting in a novel Bauplan. Miniaturization is thought to have occurred also in lizards and snakes, but the issue has remained poorly investigated. The dwarf snakes of the genus *Eirenis*, comprising 18 species rarely exceeding 600 mm in total length and with sister taxa reaching up to lengths of 2500 mm, are perfectly suited for analyzing and understanding the initial patterns and mechanisms of miniaturization. Using micro-computed tomography and geometric morphometrics we investigated skull shape and cranial growth in more than 300 individuals of all species of *Eirenis* and its outgroups. Our results reveal that miniaturization occurred several times independently in the genus, with several taxa not only showing small skull size but also the evolution of a relatively smaller eye, which is potentially related to secretive life habits. Also, we notice that some taxa with very small skulls possess novel bone contacts in the circumorbital region, whereas other taxa show intraspecific variability in this pattern. Quantitative analysis of both juvenile and adult skull shapes shows that juveniles of the smallest
species are also most similar to the respective adult condition, with all species of *Eirenis* showing an overall paedomorphic, and more specifically neotenic, growth trajectory relative to the outgroups. Comparison of elements strongly affected by ontogenetic and morphological changes, such as the bones from the braincase floor, to those of other miniaturized colubroid taxa reveal nearly identical shapes, suggesting that the evolution of small size in caenophidian snakes is subject to similar morphological constraints.

C-020

REFINEMENTS TO USING LUGOL’S IODINE AS A CONTRAST AGENT IN X-RAY µCT IMAGING OF POST-EMBRYONIC VERTEBRATE SOFT TISSUES

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Visualization methods vastly enhance our ability to appreciate and harness complex anatomical relationships for understanding the nature of morphological change. Most notably, the widespread use of non-destructive X-ray computed tomography (CT) and micro-CT (µCT) has greatly augmented our ability to comprehensively detail and quantify the internal hard-tissue anatomy of vertebrates. However, the utility of X-ray imaging for gaining similar paradigm-altering insights into vertebrate soft tissues has yet to be fully realized due to the naturally low X-ray absorption of non-mineralized tissues. To overcome this limitation, biologists have begun examining various contrast agents to enhance soft-tissue visualization in CT and µCT imaging. Methods using one such agent, Lugol’s iodine (I₂KI), have been employed to study invertebrates, vertebrate embryos, parts of adult rodents and rabbits, and a yearling alligator—in all cases yielding promising results. However, anatomical visualizations among the larger, post-embryonic specimens have remained incomplete. In this study we detail how the soft-tissue anatomy of the head and neck—including differences between white and grey matter of the brain, individual fascicles of the cranial musculature, dural venous sinuses, glands, fat deposits, and the complete pathways of cranial nerves—can for the first time be fully visualized in post-embryonic vertebrates (*Alligator mississippiensis* and *Dromaius novaehollandiae*) using iodine-enhanced (i-e) µCT methodologies. Our research builds on previous studies by systematically testing for optimal staining using differences in contrast levels of resulting i-e µCT images from intact archosaur heads prepared under differing treatments of Lugol’s iodide. We further demonstrate the utility of this method using computer rendering software to describe and quantify the 3-D anatomy of the brain, cranial musculature, and cranial nerves in *A. mississippiensis* and *D. novaehollandiae*.

C-021

PARALLEL EVOLUTION OF “UNIQUE” DERIVED CHARACTERS IN AMPHISBAENIA (REPTILIA, SQUAMATA)

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The fossorial Amphisbaenia are characterized by a suite of derived morphological characters, including limb reduction, body elongation, a highly reinforced skull, reduction of the orbital rim and fusion of the ancestrally paired orbitosphenoid bones. The original view that these apomorphic features evolved only once, at the base of the amphisbaenian tree, is now challenged by molecular phylogenetics suggesting that at least the reduction of forelimbs must have evolved several times independently. Reinvestigation of the extinct Rhineura hatcherii also revealed the presence of paired orbitosphenoids in this taxon, indicating that fusion of these elements occurred separately at least in rhineurids. Here we present additional evidence for the independent origin of amphisbaenian characters by the investigation of the Paleogene rhineurids *Spathorhynchus* and *Dityconastis* using X-ray computed tomography, and by optimizing amphisbaenian postcranial characters onto a phylogeny including fossil and extant taxa. We found that the orbitosphenoids are unfused in *Spathorhynchus* and *Dityconastis*. Both taxa retain complete orbital rims, suggesting that the reduction of eyes was another independent event in amphisbaenian evolution. When mapping the variably reduced pectoral and pelvic girdles of the different clades onto the phylogeny, it becomes evident that only in Rhineuridae, the sister to all amphisbaenians, and in the derived Amphisbaenidae, these elements are almost completely absent. By contrast, the monophyletic Blanidae and Bipedidae, the latter being the only clade with forelimbs, retain large parts of both girdles as do trogonophids, indicating that the nearly complete reduction of girdles occurred two times independently. Based on present evidence, and by considering the fossil stem-amphisbaenian *Cryptolacerta*, only body elongation and reinforcement of the skull may represent derived amphisbaenian characters that evolved only once.

C-022

MECHANICAL TRANSGRESSIVE SEGREGATION AND THE RAPID ORIGIN OF TROPHIC NOVELTY
Hybrid phenotypes often fall within the parental range. However, when morphological traits are complex, hybridization can generate mechanical phenotypes that segregate transgressively. For instance, even when the morphologies of individual musculo-skeletal components forming a complex functional system do not segregate outside the parental range in hybrid offspring, these systems can exhibit emergent phenotypes whose mechanics do transgress parental values. We examined three functional systems in the trophic apparatus of Lake Malawi cichlids to determine both the frequency of mechanical transgression segregation during hybridization and how the evolutionary divergence of parental species influences mechanical transgression. Generally, when genetic mechanisms underlie transgressive segregation, hybrids between more evolutionarily divergent species show greater transgression. However, two of the mechanical systems in the trophic apparatus exhibited a greater proportion of transgressive phenotypes in crosses between more recently diverged cichlid species. Hybridization does occur in the hundreds of co-occurring species and virtually every lineage we used in the simulations produced hybrids with transgressive mechanics. Therefore, mechanical transgressive segregation has likely helped shape the exceptional trophic diversity of the Lake Malawi cichlid radiation.

C-023
VIRTUAL BASAL ACTINOPTYS: 3D FISH MODELS FOR EVO-DEVO
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Evolutionary developmental morphology has always depended on careful examination of specimens, but the particular species or stages of interest - even of extant taxa - may not be readily available. With newly refined methods for fine-detail 3D imaging of fish embryos and larvae it is now possible to construct shareable libraries of high-resolution volume image data representing the detailed morphology of the most sought-after taxa for fish evo-devo. I present a collection of developmental atlases comprising microCT images of whole fish at stages from early posthatching to early juvenile for five key actinopterygian taxa, namely Polypterus, Polyodon, Lepisosteus, Amia, and Onchorhynchus. Samples of each were fixed and stained with phosphotungstic acid to provide clear x-ray contrast among different tissues, and microtomographic images were made using a commercially available lab-based microCT system (Xradia MicroXCT-200). The reconstructed volume images, with final voxel sizes of 2µm to 10µm, are archived as PNG image stacks along with the original projection images and metadata. Several of the sample series are part of other specific research, and all the images will be made available after the first results of the original studies are published. Contrast-enhanced microCT images demonstrate various soft tissues as well as mineralized structures, at resolutions comparable to low-power light microscopy of histological sections. These atlases are especially useful for comparative and quantitative studies of musculatures, sensory organs, nervous systems, and visceral organs, all in their whole-organism contexts. Size-calibrated digital volume images allow unrestricted visualization as well as possibilities for quantitative comparisons within and among specimens. These image sets highlight the increasing importance of voxel data archiving and sharing in morphological research.

C-024
TISSUE TRADE-OFFS: MIND OVER MATTER
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Despite major differences in morphology and ecology, mammalian species have broadly similar metabolic requirements relative to body size. This suggests that the total energy available for meeting the metabolic needs of the various somatic organs and tissues is constrained. Thus, available energy is allocated differentially depending upon the metabolic needs of each species. This is the basis of the Expensive Tissue Hypothesis, which proposes an explanation for how humans are able to maintain large, energy-expensive brains while having resting metabolic rates that are not substantially different from other mammals. Muscle tissue, despite relatively low costs when at rest, requires a substantial portion of overall daily metabolic requirements. Thus, we hypothesize that muscle mass will be lower in primates with relatively large brains. To test this hypothesis, we obtained total muscle mass values via dissection for 12 primate species and combined this information with literature-based data from an additional 11 species. We also compiled muscle mass values from literature sources for 56 non-primate mammals. In addition, we measured endocranial volume (ECV) for each species where muscle mass was available. We compared primates and non-primate mammals in relative muscularity, and examined how muscle mass covaries with ECV. Results indicate that primates are hypomuscular when compared to non-primate mammals.
(P<0.001). We also documented a negative correlation between relative muscle mass and relative ECV (P<0.05). This suggests that mammals may ‘save’ energy by reducing muscle mass, which can then be allocated to the brain and other tissues.

C-025
ADAPTATION AND PLASTICITY OF MYOFIBRILLAR MITOCHONDRIA IN DOMESTIC DOGS
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We study muscle plasticity in response to training in domestic dogs. Subjects of the study are different breeds from aboriginal dogs (Greenland dogs) to modern thorough bred dogs (beagles, FBI, Labrador retriever). The key question is how endurance training affects ultrastructural properties in mitochondria and ultimately the aerobic performance of individuals. For all breeds of dogs we compared healthy individuals in trained and untrained condition; for Labrador retrievers untrained individuals were obese while trained individuals were healthy. We show that endurance training has significant effect on oxygen consumption, muscle histology and muscle ultrastructure, in particular myofibrillar mitochondria. Stereological analysis of transmission electron microscopy slides from Inuit sled dogs, FBI-dogs, Beagles and Labrador retrievers show that the relative size of mitochondria and the area of the mitochondrial cristae increase significantly in response to training. Interestingly, the training induced increase of mitochondria size and inner mitochondrial membrane correlates with a significant decrease of mass specific oxygen consumption of the dogs, indicating an improved efficiency of oxygen consumption. – We also observe between-breed differences in mitochondria size, shape and cristae structure. In particular, transmission electron micrographs of the myofibrillar mitochondria of Inuit sled dogs showed a different structural organization as compared to other more modern domestic dogs. While Inuit sled dogs have larger mitochondria than FBI-dogs or beagles, their inner mitochondrial membrane is less condensed and has much less cristae than in FBI-dogs. These data suggest that inter-cristae distance and size of the mitochondria potentially present important constraints on the transport of metabolites which can be overcome only when the inner mitochondrial membrane is organized in a loose manner.

C-026
ANALYSIS OF THE PROCESS OF CORNIFICATION IN LEPIDOSAURIAN EPIDERMIS
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The identification of genes for epidermal keratin-associated beta proteins (KAbetaPs, formerly beta-keratins) and the sequencing of these proteins in some lizards and snakes have indicated that most belong to High-glycine and High glycine-cysteine proteins. The production of epitope-specific antibodies against representative sequences for these proteins and their ultrastructural localization in the epidermis of lizards and snakes has shown that some KAbetaPs are not only present in the beta-(“hard”)layer but, surprisingly, also in the “softer” alpha-layers. Hydrophobic High-glycine proteins are characteristic of the beta-layer while potentially cross-linking High glycine-cysteine proteins are present in the Oberhäutchen and alpha-layers of lizard epidermis, but are reduced in the beta-layer. High cysteine-glycine proteins are especially present in the setae, Oberhäutchen and alpha-layers in adhesive pads of lizards. Claws contain relatively small amount of KAbetaPs in comparison to the higher levels of specific Cysteine-rich alpha-keratins. The interpretation of these observations indicates that the formation of cytologically distinct layers such as the Oberhäutchen, beta-layer, mesos and various alpha-layers in lepidosaurian epidermis does not result from an alternation between beta-keratins and alpha-keratins in distinct alpha- vs beta-layers, but instead from the relative proportion of different alpha-keratins and specific KAbeta-proteins produced during the shedding cycle in lepidosaurian epidermis. Aside the specific KAbetaPs derived from a fine gene-controlled activation, the process of cornification of the epidermis of reptilian sauropsids is similar to that of the other vertebrates.

Contributed 5 – Ontogeny
C-027
DIVERSITY AND CONSTRAINT IN THE EMBRYONIC ORIGIN OF THE VERTEBRATE SKULL
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The vertebrate skull is derived from embryonic neural crest and mesoderm. The contributions from these two source populations have been revealed in great detail in one amniote model and to a lesser extent in other taxa, but the degree to which patterns of derivation are evolutionary conserved or labile among most lineages remains largely unknown. Amphibians are a non-amniote tetrapod group with a highly derived skull...
morphology and ontogeny. We employed embryonic transplantations, using GFP-transgenic axolotls (Ambystoma mexicanum) as donors, to document the nature and extent of neural-crest contribution to the adult osteocranium in this species. This novel experimental system has allowed us to resolve the embryonic origin of the amphibian skull at a level of detail previously known only from avian studies. Comparisons with chicken and mouse reveal a highly conserved embryonic origin of the skull in most tetrapod clades. Conversely, a comparison between axolotl and the clawed frog (Xenopus laevis) reveals tremendous differences in the origin of skull bones among Recent amphibians. The unique features of Xenopus may be a consequence of the extensive, posthatching cranial metamorphosis that is characteristic of most anurans. The degree to which the embryonic origin of the vertebrate skull is conserved or labile varies according to lineage and is thus subject to evolutionary change. Finally, many accepted and longstanding homologies for bones of the tetrapod cranial vault may be incorrect and need to be reevaluated.

C-028
NEW INSIGHTS ON THE DEVELOPMENT OF THE EXTANT COELACANTH, LATIMERIA CHALUMNAE, BASED ON X-RAY SYNCHROTRON MICROTOMOGRAPHY
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The coelacanth Latimeria is the only extant genus of a group of lobe-finned vertebrates (sarcopeterygian) that originated in Devonian times. Due to its relative deep-sea habitat, the ecology and development of this ovoviviparous fish remain largely unknown. This animal is now considered as the sister group of all other extant sarcopterygians (i.e. lungfishes and tetrapods). One of the most striking anatomical features of Latimeria is the discrepancy between the volume of its brain and that of the endocranial cavity (ENC). In the adult, the brain is confined to the posterior division of the skull, and its volume was grossly assessed to represent 1% of the ENC volume, whereas it was claimed to fill most of the ENC in juveniles. Consequently, the size and position of the brain in adults seems to result from a negative allometric growth of the brain and the ENC during postnatal development. However, little is known about earlier stages of Latimeria ontogeny due to the scarcity of embryonic material. Based on high resolution phase contrast X-ray synchrotron microtomography, a non-destructive method, on a 5cm coelacanth embryo at the ESRF, we present the first data on the anatomy of a coelacanth at an early development stage. The significance of these new data as to development of the skull and brain of Latimeria, as well as lobe-finned fish evolution will be discussed.

C-029
PRIMITIVE BRAINCASE ARCHITECTURE OF CROWN GNATHOSTOMES: UNEXPECTED DATA FROM THE EARLY DEVONIAN OF SIBERIA
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The early history of gnathostomes (Chondrichthyes + Osteichthyes) is a frontier in vertebrate evolutionary biology. The earliest fossil gnathostomes are characterized by diverse, and often incomparable, dermal skeletal anatomies that are often difficult to incorporate in phylogenetic analyses. By contrast, neurocrania provide a rich source of character data comparable across anatomically disparate groups, and therefore underwrite much of our understanding of early gnathostome phylogeny. However, braincases fossilize much more rarely than dermal skeletons, and some recent fossil discoveries have revealed challenging examples of character conflict. Here we present the braincase of an Early Devonian gnathostome from Siberia initially identified as a primitive ray-finned fish. High-resolution x-ray microtomography (micro-CT), reveals the underlying braincase, which bears surprising anatomical details. These traits are inconsistent with an identification of the specimen as a ray-finned fish, or as a crown-group osteichthyian. The fossil can be united with the gnathostome crown group based on the configuration of the endolympathic ducts, and possibly the osteichthyian total group on the basis of its skull roof and features of its skeletal labyrinth. However, this fish combines features previously only seen in placoderms and chondrichthyans. Most surprisingly, the ossification pattern of the braincase is unlike that seen in any bony fish, and is more comparable with the conditions seen in placoderms and some chondrichthyans. In spite of its surprising combination of characters, this new fossil helps simplify and clarify the comparative braincase architecture of early gnathostomes, and provides evidence that many features of chondrichthyan neurocrania previously considered of uncertain polarity are most probably derived specializations.
IT'S IN THEIR FACE: QUANTIFYING ONTOGENETIC AND STATIC ALLOMETRY IN HUMAN MALE FACIES
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A prominent line of research has investigated which shape features in human faces correlate with the attribution of social dominance, masculinity, and attractiveness, whereas a distinct line of research has investigated the influence of body height on patterns of sexual selection. Facial allometry, i.e., aspects of facial shape reflecting body size, might conceptually and empirically link these two approaches, but has been widely neglected in the recent literature. Thus, as a starting point, the aim of this study was to identify size cues in the adult male face. It was hypothesized that tallness is associated with facial shape features of extended postnatal growth. Our sample consisted of standardized frontal photographs of 19 boys (6–11 years) and 25 men (17–33 years). Sixty-nine landmarks and semilandmarks were digitized on each face. Using geometric morphometrics, we assessed allometry through multivariate regressions of facial shape onto log centroid size and onto body height in the full sample (ontogenetic allometry) and within adults only (static allometry). The ontogenetic regressions were highly similar and partly resembled the static regression of adult facial shape on body height: taller men on average have a more elongated lower face and relatively smaller eyes framed by lower and thicker eyebrows. By contrast, the association between adult facial shape and facial centroid size was weaker and statistically non-significant. These results demonstrate significant shape cues to body height in the adult male face (with taller men having more mature facial features) and thus highlight the relevance of human facial allometry in studies of mate preferences and social inference.

C-031
A DEVELOPMENTAL PERSPECTIVE ON STAGES IN THE EVOLUTION OF PHALANGES
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Phalanges (finger and toe bones) develop by outgrowth and sequential segmentation of the digit prechondrogenic condensation. The segmentation point indicates where joints will form during this 4-day embryonic period, thereby determining the final proportions of the animal's digits. The functional importance of digit proportions along with the range of variation observed suggests that this developmental event has been under positive selection throughout vertebrate evolution. Our experimental perturbations during digit morphogenesis have shown that proximal perturbations affect distal joint positioning throughout the digit in predictable ways, indicating developmental modularity of the non-ungual phalanges, while metatarsals are a separate emergent module in the digit. We have observed that phalanges proportion variants throughout all vertebrates plot in a small percentage of proportion morphospace with patterns that suggest evolutionary modularity in the digits of vertebrates. We propose the presence of a developmental bias in the evolution of phalanges proportions, resulting in restricted morphospace occupation and convergence among lineages, with a conserved range of variation observable starting from the earliest tetrapod limbs in the fossil record. We propose specific stages in the evolution of the tetrapod digit, including: 1) a large-to-small phalanges gradient as basal, 2) subsequent separation of a metacarpal/metatarsal module, likely allowing improved terrestrial locomotion, 3) development of a separate ungual phalanx "tip" to add functionality such as digging, 4) elongation of distal non-ungual phalanges in limbs that are not required for terrestrial locomotion.

C-032
HETEROCHRONY AND POSTNATAL GROWTH IN MAMMALS — AN EXAMINATION OF GROWTH PLATES IN LIMBS
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Extant mammals display a broad spectrum of limb specializations coupled with different locomotor strategies and habitat occupation. This anatomical diversity reflects different patterns of development and growth, including the timing of epiphyseal growth plate closure. We investigated the sequence of union in 15 growth plates in the limbs of more than 400 specimens, representing 34 genera and 59 species: 33 placentals, 25 marsupials, and one monotreme. The relative age of the specimens was estimated by dental eruption and wear. We found a common trend of growth plate closure sequence, but one that is universal neither among species nor in higher order taxa. For example, the girdle elements (acetabulum and supraglenoid tubercle) ossify first in marsupials whereas the distal humerus is fused before the girdle in some placentals. Moreover, unlike placentals, marsupials maintain many epiphyses separated during the entire life. Lapsed epiphyseal
growth plate closure is particularly known from reptiles. However, as complete union of all epiphyseal growth plates is recorded in monotremes, the marsupial condition might represent the derived state. Locomotor habitat has no detectable correlation on the growth plate closure sequence. The variation recorded in the sequence of epiphyseal growth plate closure in different breeds of domesticated forms provides clues on the heterochronic patterns that characterize the generation of morphological diversity.

C-033
A MICROMORPHOLOGICAL-EXPERIMENTAL APPROACH TO BACULUM FUNCTION IN BATS
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The baculum (os penis) has been extensively studied as a taxon specific character in bats and other mammals. Its mechanical function, however, is still unclear. There is a wide consensus in the literature that the baculum is probably a sexually selected character that could act as a mating barrier between closely related species. In this study, the following published functional hypotheses have been tested in the common noctule bat, Nyctalus noctula (Chiroptera): 1) Whether the baculum can protect the distal urethra and urethral opening from compression during erection and copulation. 2) Whether the stiffness of the filled corpora cavernosa extends into the tip of the glans via the rigid penis bone, as these are enveloped in a common fibrous structure to form a functional unit. 3) Whether increasing pressure on the distal end of the baculum when the penis is inflated will increase hydrostatic pressure inside the corpora cavernosa. Penises were stained with alcoholic iodine and imaged with a lab-based high-resolution microCT system. We compared flaccid penises with "erect" penises, which were inflated with 10% formalin about 40 hours after the bats had died. Thus far, differences between the flaccid and the "erect" penises in the position of the bone relative to the corpora cavernosa, the urethra, and other soft tissues of the penis support hypotheses 1 and 2.

C-034
EVOLUTION OF THE MAXILLARY NERVE AND THE VERTEBRATE CRANIOLABEL DEVELOPMENT
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The maxillary component of trigeminal nerves is usually regarded as associated with the gnathostome upper jaw. Embryologically, this nerve has been identified as a branch specifically related to the maxillary process (MX), the dorsal growth of the mandibular arch. This definition appears reasonable since the jaw has traditionally been considered as having originated by dorsoventral division of the mandibular arch. Recent developmental studies, however, have shown that the upper jaw has a dual origin: the rostral part (e.g. incisor, nasal septum, premaxilla) derived from the premandibular region (PMR), and the posterior part derived from the MX. Therefore, there is an apparent discrepancy between the trigeminal nerve branching pattern and distribution of the craniofacial primordia. To solve this inconsistency, we compared embryonic development in several gnathostome species including mouse (Mus musculus), chick (Gallus gallus), gecko (Paroedura pictus), sturgeon (Bester: Acipenser ruthenus x Huso huso), and shark (Scyllorhinus torazame). In the mouse, the nasopalatine nerve, or a branch of maxillary nerve, supplied PMR and its derivatives. Yet, the rest of the maxillary nerve was distributed in MX. Although there was no branch comparable to the nasopalatine nerve in the chick and gecko, the sturgeon and shark developed a branch that supplied PMR, similar to mammals. We conclude that the so-called maxillary nerve is ancestrally a composition of two branches, one for the MX and the other (nasopalatine nerve) for the PMR. From the comparison with cyclostome embryos, these divisions were implied to represent partially the ancestral pattern for the entire group of vertebrates.

C-035
REGULATION OF JAW SIZE DURING DEVELOPMENT AND EVOLUTION
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The great success of vertebrates is due in large part to the exceptional ability of the jaw to vary in size during evolution. Our prior work has shown that cells unique to vertebrates called the neural crest control species-specific jaw size. Neural crest cells (NCC) arise during neurulation, become highly migratory, and
generate the jaw skeleton, among other structures. To identify mechanisms through which NCC establish species-specific morphology, we use two non-model vertebrates that differ considerably in their rates of growth and jaw size, and focus on early-, mid-, and late-stages of embryogenesis. First, we compare gene expression in early-stage quail and duck embryos. We analyze brain markers including Foxg1, Pax6, Otx2, Fgf8, and Krox20. Using morphometrics, we find differences in brain shape and patterns of gene expression. We quantify pre-migratory NCC expressing Pax7 and Sox10, and observe no significant differences between quail and duck. Yet after migration, duck have nearly twice as many NCC in their jaw primordia as do quail. To understand how duck achieve such numbers, we analyze Dlx2 expression as well as cell proliferation, and find that duck cells divide faster than quail cells. Subsequent experiments in mid-staged embryos link cell cycle regulation and induction of bone with Runx2 levels and species-specific jaw size. We alter cell cycle and accelerate Runx2 expression, and discover higher endogenous Runx2 levels in quail. Then, by prematurely over-expressing Runx2 we reduce jaw size. Finally, to test if NCC transmit species-specific information during late stages of jaw growth, we transplant NCC from quail into duck and examine effects of donor NCC-derived osteoblasts, which make bone, on host-derived osteoclasts, which resorb bone. We find that NCC control osteoclast activity in a species-specific manner that affects jaw length. Thus, NCC employ sequential but distinct mechanisms throughout development that regulate jaw size during evolution.

**Contributed 6 – Geometric Morphometrics**

**C-036**

**DOES SHAPE CO-VARIATION BETWEEN THE SKULL AND THE MANDIBLE HAVE FUNCTIONAL CONSEQUENCES? A 3D APPROACH FOR A 3D PROBLEM**

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Morpho-functional patterns are important drivers of phenotypic diversity given their importance in a fitness-related context. Although modularity of the mandible and skull has been studied extensively in mammals, few studies have explored shape co-variation between these two structures. Despite being developmentally independent, the skull and mandible form a functionally integrated unit. Here we use 3D surface geometric morphometric methods allowing us to explore the form of both skull and mandible in its three-dimensional complexity using the greater white toothed shrew as a model. Moreover, this approach allows an accurate three-dimensional description of functionally important zones that lack anatomical landmarks. Two block partial least square approaches were used to describe the co-variation of form. Also, a 3D biomechanical model was used to explore the functional consequences of the observed patterns of co-variation. Our results show the efficiency of the method in investigations of complex morpho-functional patterns. Indeed, the description of shape co-variation between the skull and the mandible highlighted the location and the intensity of their functional relationships through the jaw adductor muscles linking these two structures. Our results also demonstrated that shape co-variation in form between the skull and mandible has direct functional consequences on the recruitment of muscles during biting.

**C-037**

**FAMILY TIES OR YOU ARE WHAT YOU EAT – EFFECTS OF SIZE, DIET, AND TAXON ON THE RODENT MANDIBLE**

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The rodent mandible has already served as a model for morphometric analyses mostly in species and subspecies of the house mouse (Mus musculus). Here we investigated 3D micro-CT scans of a wide range of rodent species in order to identify differences in shape associated with size, diet, and affiliation to a certain taxonomic group. The large diversity of rodents provides several examples of parallel changes, thus enabling the study of possible variation and constraints. Besides applying standard procedures of geometric morphometrics we also used new methods which allowed for the separate analysis of influencing factors on individual landmarks. Shape changes for each landmark location could be evaluated in terms of direction, distance, and degree of congruence. Results showed comparable, relatively strong dimensions of effect for all studied factors, depending on the combination of specimens for the analysis. Differences between groups were more pronounced than differences between landmarks, suggesting unexpectedly small influences of ecology and phylogeny on individual landmarks, e.g. on muscle-bearing processes. In spite of the considerable variation in almost all results several clear similarities could be found, particularly on lower-level groupings of specimens for taxon and on higher-level groupings for size and diet, pointing to at least some degree of constraint.
C-038
GEOMETRIC MORPHOMETRIC ANALYSIS OF ANTLER DEVELOPMENT IN IBERIAN RED DEER (CERVUS ELAPHUS HISPANICUS)
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This study describes and quantifies antler shape variation in Iberian red deer (Cervus elaphus hispanicus) from Sierra Morena (Spain) to both characterize age related changes and antler pattern. Thirty-five landmarks were recorded using a MicroScribe 3D digitizer on 209 red deer antlers. Geometric morphometric analyses explored overall antler shape variation and localised morphological variations of the common parts of antlers (beams, trez tines and eye tines). The degree of covariance with antler size and shape of several environmental and developmental factors (age, winter rainfall, presence of bez tines, and capture year) was also assessed. The shape and size analyses indicated that, in young individuals (2 to 5 years), antlers are relatively more elongated near the skull and their beams are closer distally, while the antlers of fully-grown individuals (4 to 9 years) are relatively shorter near the skull and more arched distally. Shape variations linked to age were also identified in specific tines: trez and eye tines were straighter and more vertically oriented in the youngest individuals, becoming longer and more curved in older individuals. The main factors associated with red deer antler size and shape differences were presence of bez tines and age, although the effects of capture year and winter rainfall were also significant. After assigning a pattern score to each antler, based on beam length and symmetry, for example, we carried out a multivariate regression of shape on pattern score and used this to visualize the associated shape variation. Pattern score improved between age classes 2 and 4, with some deterioration in pattern in age classes 5 and 6. These findings have implications for the management and conservation of Iberian red deer in Sierra Morena.

C-039
ALLOMETRY, PHYLOGENY AND FUNCTION IN THE EVOLUTION OF CANIVORAN LIMBS: AN APPROACH BASED ON 3D GEOMETRIC MORPHOMETRICS
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Locomotion is crucial for animal’s ecology, because it is involved in many aspects related to foraging or hunting. Given that limbs are the most important structures for these activities, they must reflect the adaptations towards different modes of locomotion. For this reason, paleontologists have traditionally explored the anatomy of the limb bones in order to find morphological indicators of locomotor strategies that allow the obtaining of inferences for extinct species. However, morphological adaptations are not the only sources of variation in bone shape, as both size and phylogeny are also influencing the shape of the appendicular skeleton in some aspects. In this study, we have explored the influence of phylogeny, allometry and locomotor performance in shaping thefore and hindlimb bones of living and extinct carniores (Mammalia, Carnivora). To further investigate this, we have used landmark-based methods of 3D-geometric morphometrics. The results obtained indicate the presence of strong allometric effects on both limbs. These shape changes result in an increase of robustness and a more upright posture in larger taxa. Furthermore, when allometric effects on the shape of the limb bones are discarded, no correlation with locomotor performance is found. In fact, a size-free Principal Components Analysis of bone shape showed that the main morphological variation of long bones in carniores is described by a change of robustness. Our data suggests that the morphology of the limb bones only can change in a rather limited way, following a gradient of slenderness-robustness. Although this variation could merely reflect a trade-off between energetic efficiency in locomotion (slender limbs) and resistance to stresses (robust limbs), there are many situations which can lead to one or another solution depending on the ecology of taxa. Therefore, the appendicular skeleton represents a remarkable case where one trait can be adaptive in multiple situations.

C-040
LOCOMOTOR ADAPTATIONS IN SCAPULAR SHAPE IN CARNIVORANS
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The relationship between scapular shape and locomotor pattern in Carnivora was studied on 213 scapulas from 101 species representing the whole locomotor range of extant carnivors. The 34 3D-landmarks digitized were analysed using geometric morphometrics. Locomotor-related shape differences were assessed using canonical variate analysis (CVA) and discriminant function analysis (DFA). The first two
canonical variates of the CVA defined a shape space that clearly separated all locomotor categories (all paired comparisons were significant), accounting for 82.4% of shape variation. However, high DFA misclassification rates were obtained when comparing semiarboreal and semifossorial carnivorans, and both with scansorial and terrestrial carnivorans. Due to their extreme locomotor adaptation, aquatic carnivorans had the most characteristic scapular shape, presenting the relatively shortest and widest scapulas with the relatively least protruding spines in the sample. Aquatic carnivorans also presented an expansion of the cranial portion of the vertebral border, and lacked well-developed acromial processes. The secondary adaptation to swimming of semiaquatic carnivorans was evidenced by the mix of features shared with (e.g. short scapular blade, wide and flat supraspinous fossa) and opposed to (e.g. high spine, the smallest infraspinous fossa, well-developed acromial processes) aquatic carnivorans. Several shape changes were associated with increased arboreality (terrestrial – scansorial – semiarboreal – arboreal), namely a shortening and widening of the scapular blade (especially at the infraspinous fossa), a cranial displacement of the proximal portion of the spine (greatly increasing the proximodistal curvature of the spine), a medial shift of the glenoid cavity (which also becomes cranially adducted), and acromion and metacromion becoming coplanar. Finally, although scapular shape in carnivorans is significantly affected by size and phylogenetic relatedness, corrections for both factors had no significant effect on either CVA or DFA results. Thus, locomotor adaptations in the scapular shape of extant carnivorans seem independent of size or shared ancestry.

C-041 INFLUENCE OF LOCOMOTOR STYLE ON THE SHAPE OF THE FORELIMB IN MUSTELOID CARNIVORANS
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The limbs of quadrupeds are subjected to many factors that may influence their shape. For example, limbs need to support body mass without collapsing or breaking, yet at the same time resist the stresses and strains induced by locomotion and other behaviours. In this study, we investigate the influence of locomotor style on the shape of the three long-bones of the forelimb in a group of closely related species of mammals, musteloid carnivorans. To analyse the influence of the locomotor style on forelimb shape, we use quantitative 3D-surface geometric morphometric methods. We use MANOVA’s and phylogenetic MANOVA’s to assess the influence of locomotor style on forelimb shape. We then used phylogenetic ANCOVA’s to assess the relationship between locomotor-style and forelimb shape taking into account the effects of body mass and phylogeny. Our results show that locomotor-style has an influence on the shape of the forelimb. Our results show that aquatic and semi-fossorial species fall in the same part of morphospace and display a robust forelimb with a shape that improves stability and load transfer. In contrast, arboreal and semi-arboreal species are positioned close to one another in a different part of morphospace and show rather gracile long bones in the forelimb. However, our analyses also show that body mass and phylogeny influence the shape of the long bones of the forelimb and thus have to be taken into account to fully understand the evolution of forelimb shape in carnivores.

C-042 MORPHOLOGICAL, DIETARY AND PHYLOGENETIC CONVERGENCE IN THE CRANIA OF DIURNAL BIRDS OF PREY
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Birds are one of the most diverse clades of modern vertebrates, and have historically been regarded as a classic group in which to study adaptation through evolution. Different lineages of birds often display remarkable convergence in their cranial and beak morphologies, frequently presumed to be associated with similarity in dietary niche. We tested this assumption by performing Geometric Morphometric (GMM) analyses within a subset of neognathous birds, the diurnal birds of prey. Recent molecular phylogenies have classified this group as polyphyletic. There are therefore multiple examples of convergence within this subset of birds, for instance between the falcons (Falconidae) and hawks (Accipitridae), or between the Old World vultures (Accipitridae) and New World vultures (Cathartidae). Three-dimensional landmarks and semi-landmarks were collected from the beaks and skulls of diurnal raptors. Principle Components Analysis shows that carrion feeders (the Old and New World vultures) tend to cluster together in morphospace regardless of phylogeny, indicating strong morphological as well as dietary convergence. Elsewhere, while there is considerable morphospace overlap between falcons and accipitrids, skull morphology does not appear to be a strong predictor of dietary niche, even in birds with highly specialised diets. Thus it seems

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that although dietary niche may be predicted based on cranial morphology in some families, ecology alone is insufficient to explain the variety of forms seen in the diurnal birds of prey. This may reflect the fact that all raptors hunt, and many kill, with the talons not the beak, meaning that talon morphology may additionally predict dietary ecology.

C-043
UNDERSTANDING FUNCTIONAL CONSEQUENCES OF VARIATION IN SKULL SHAPE; CROCS, KOOKABURRAS, AND GOANAS
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Comparative analyses are the basis for investigating structure-function questions in biology. Initial studies were necessarily qualitative, but the development of sophisticated statistical approaches (geomorphometrics) now allows functional morphologists to quantify variation in shape and correlate these with measurements of performance. At the same time, recent advances in computational biomechanics reveal the functional consequences of shape variation using a mechanistic approach. Two key questions for comparative biologists are: (1) what level of information on shape is required to accurately capture the traits that determine performance, and (2) to what extent do specific structure-function relationships in one taxon apply to other taxonomic groups? To address the first question, we compared high resolution finite element models (FEMs) of crocodilian mandibles to simplified models based upon beam theory, and evaluated the extent to which the simplified models predict the biomechanics of the high resolution models (discussed in Walmsley et al. 2013, PLoS ONE, 8: e53873). To address the second, we identified the linear/multivariate measurements that showed high within-group correlation with mechanical performance, and compared these for skull models of crocodilians, varanids, and kingfishers. Sample sizes of high resolution FEMs were respectively 7, 13, 9. Measurements were considered to have good predictive power if between-specimen variation in the measurement correlated with between-specimen variation in performance. In some cases, measurements that gave good prediction of performance with a group were also able to predict biomechanics between groups. Compared to crocodiles and kingfishers, however, varanids have a different skull beauplan; measurements that predict skull mechanics in the other two groups had limited use for the varanid skulls. That comparative approaches work best for morphologically similar groups is well known, but combining 3D morphometrics and biomechanics in this way allows the limits of generalisation to be quantified.

C-044
EVOLUTIONARY ORGANIZATION AND VARIATION OF THE SKULL IN BIRDS: SAMENESS WITH CRANIOFACIAL VARIATION IN TETRAPODS
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In the course of their macroevolutionary transition from dinosaurs, birds underwent a dramatic transformation of their skull which involved the acquisition of a strikingly adaptable beak—a hallmark of microevolutionary research—and innovative craniofacial and craniocervical organizations. Many birds exhibit a skull organization that is much more reptilian-like in having both elongated faces and neurocrania (the portion of the skull that houses the brain), and the foramen magnum (the pathway for the medulla) facing backwards. In contrast, there are birds such as crows, pigeons, owls and raptors whose craniofacial organization consists of a much shortened face and more globular neurocranium, with a foramen magnum facing downwards. This pattern of skull structural variation in birds is strikingly similar to that found in mammals, underscoring an important case of sameness in cranial macroevolution. The question, however, is if this sameness in skull patterning can be explained by the same rules of invariance (sensu Alberch; i.e., the same constraints), which would suggest parallelism in tetrapod macroevolution. In mammals, skull phenotypic variation results from a relatively small number of key developmental processes that involve skull modules—the facial skeleton and the neurocranium, specially the cranial base—and brain size. We have found that the distinctive avian skull emerged from shifts in developmental timing (i.e., heterochrony), and that, as in mammals, relative encephalization and trade-off between the facial and cranial proportions explain skull variation on the same equivalent integrative-constraint basis. Furthermore, we have found that the avian skull is less modular than expected and that its adult organization is associated to neck structure, which is congruent with the shared cellular identity of skull parts and neck vertebrae in the early embryo. The pending question is whether mammals follow this rule or not.

Contributed 7 – Tooth EvoDevo
C-045

Anatomical Record, Volume 296, Special Feature — 196
SYNCHROTRON 3D IMAGING OF EARLIEST TOOTH FORMATION IN MOUSE
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Visualizing in microscopic detail the actual 3D organization of initiating teeth within the embryonic jaws has long-proved technologically challenging because these tiny, soft tissue structures are highly radio-translucent. This challenge has made it very difficult to assess empirically at high-resolution the spatial relationships among embryonic tooth and jaw tissues in order to explain the processes that coordinate cranio-dental morphogenesis. We present a synchrotron-based scanning solution to the persistent problem of imaging odontogenesis in situ in 3D. Ten wild-type (C57BL/6J) mice aged embryonic (E) day 10 to birth were collected in ice-cold L-15 media and fixed in ice-cold 4% PFA-5% glutaraldehyde overnight, then dehydrated in ethanol. Before scanning, these whole embryos were stained in 1% protargol at 37°C for 12-32 hours. Each whole embryo was scanned at the BioMedical Imaging and Therapy (BMIT) beam line at the Canadian Light Source Synchrotron. As silver was the contrast enhancement mechanism, the imaging energy was chosen to take advantage of the silver K-edge. Embryos were scanned at 4-10 micron resolution at 28.122 KeV using micro-computed tomography (µCT). Our controls were: unstained and phosphotungstic acid (PTA)-stained embryos synchrotron scanned at BMIT; as well as protargol-stained and PTA-stained embryos scanned on a Skyscan 1172 desktop µCT system. Desktop µCT scans of PTA- and protargol-stained embryos showed internal structures in clear detail. Synchrotron µCT scans of protargol-stained embryos showed even the earliest visible stages of tooth initiation in noticeably finer, clearest detail. This combination of protargol stain and synchrotron-based imaging also visualized many other structures (e.g. eyes, central nervous system, muscles, cartilage and bone) in extreme detail. Protargol stain penetration was optimal for imaging internal structures in whole embryos aged E15 and younger. Our protargol staining method offers another approach to visualize in 3D the earliest onset of odontogenesis in situ at high-resolution.

C-046
THE NATURAL HISTORY OF TOOTH REPLACEMENT IN ADULT GECKOS
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The polyphyodont reptile offers the promise of identifying the cells and signals that are required for tooth renewal. The development of individual teeth or tooth families has been studied in our lab using snake and lizard models. Of the signaling pathways we studied, the main one associated with tooth succession is the Wnt or Wingless-related pathway. Here we extend these studies to the whole dentition by using a new system of recording tooth eruption and exfoliation in adult geckos. The dentition of adult leopard geckos was recorded weekly using wax bites and teeth present or absent recorded. In a subset of these animals we stimulated Wnt signaling by injecting the palate with LiCl or the control solution NaCl daily for 3-5 days. Anti-BrdU and phosphorylated beta catenin antibody (Millipore) staining was carried out. Dental bite registrations, over a 6 week period revealed the following trends: 1) There are 39-40 teeth in adult geckos, 2) when a tooth is lost it is usually replaced the next week 3) rarely was a tooth position unfilled for greater than 2 weeks 4) there is no concordance between the right and left sides of the mouth 5) Since each tooth family consists of 3 generations, it takes 6 weeks for a full tooth family to be renewed. Injections of LiCl significantly raised proliferation in certain regions of the tooth epithelium, the cervical loops, outer enamel epithelium and successional lamina (P < 0.05). These changes correlated with an increase in expression of phosphorylated beta catenin in the nuclei of some cells. Our next step is to determine whether changing the dosage of a ‘stimulus’ or an ‘inhibitor’ will speed up replacement and/or disrupt waves of replacement.

C-047
DEVELOPING INNOVATION THROUGH REGENERATION: EVOLUTION AND DEVELOPMENT OF NOVEL DENTITIONS IN TETRAODONTIFORMES
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The range of morphological diversity represented in the teleost fishes is remarkable. Here we present information on the evolutionary and developmental origins of a unique suite of dentitions observed in the order Tetraodontiformes, which include several families with distinct and divergent dental morphologies. We present data on representative tetraodontiformes including the families of pufferfish (tetraodontidae), and...
C-048

SELF-ORGANIZATION VERSUS FUNCTION IN EXPLAINING SKELETAL STRUCTURES IN VERTEBRATES: TEETH AS AN EXAMPLE

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Several features of vertebrate skeletons are usually shown as examples of perfect adjustment between form and function. Therefore, many authors only invoke functional reasons to explain skeletal structures. However, structures are not built according to finality; they arise throughout embryonic development, a process not related prospectively with the adult individual in which fully developed structures achieve their functions. This is because development involves self-organization processes, linked to the fabrication factor of biomorphodynamics and obeying the laws of physics and chemistry, which are independent of the functioning of the adult organism. Teeth of placental mammals illustrate well these topics because both their microstructures and their general morphologies are well adjusted to their functions. Enamel microstructures have shown to be resistant to wear as well as breaking, and hence contribute to survival. However, microstructures of skeletal mineralized parts (not only teeth) have in common similar physicochemical processes: hydrophobic macromolecules self-organize themselves in order to supply space for mineralization, whereas hydrophilic macromolecules play a role in nucleation and crystal growth of biominerals. General morphology of molar teeth fits well to nutritional requirements. However, tooth morphogenesis doesn’t depend on the whole developing organism; i.e., tooth buds can develop isolated from the embryos. Cusps or ridges have their origin in reaction-diffusion processes involving extracellular signals, which influence locally cell proliferation and differentiation in the developing tooth, with cells interacting mechanically, and intermediate morphologies affecting subsequent processes of gene expression followed by new cyclic epigenetic events. Thus, complex and ordered patterns in both microstructures and tooth morphology result from self-organization processes, such as self-assembling macromolecules that interact electrically with ions, or reaction-diffusion processes and mechanical behavior of cells, hence at a different level from that of the adult organism and its functional requirements. Afterwards, natural selection chooses among the possible morphogenetic products.

C-049

THE FOURTH MOLAR CONUNDRUM: THE INHIBITORY CASCADE IN MARSUPIALS

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The inhibitory cascade (IC) is a developmental and macroevolutionary model for the evolution of relative molar sizes in mammals. It predicts that the relative sizes of molars follow a simple formula, with the middle of three molars being 1/3 of the total row area. We present the first comprehensive test of the model in the second-largest radiation of extant mammals, the marsupials. Marsupials have four molars rather than the general maximum of three in eutherians, in which the model was developed. We digitised tooth outlines for over 300 individuals in over 100 species of extant and extinct marsupials, with molars 1-3 as the first series of three teeth and molars 2-4 as the second series. We found substantial deviation from the predicted IC pattern in some species. In a few species, e.g. koala Phascolarctos cinereus, all four teeth were similarly sized and so both series fell in the centre of the morphospace. In others, both series were close to the IC line, with the first further to the top right than the second. Several species showed one series on the IC line and the other series below it, and in others, both series sat an equal distance below the line. The special case of the nabarlek Petrogale concinna, with continually replacing teeth, showed the first two series fell to

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the top-right of the morphospace, and the remainder close to the centre. Molar ratios for fossil species examined largely followed their closest extant relatives. The inhibitory cascade line appears to form an upper bound in the morphospace in marsupials, but some deviation below the line for one or both series is common. We conclude that the inhibitory cascade is therefore a major controlling factor in molar size patterning in mammals but not the only developmental factor.

C-050
THE GREAT SYNOPSIS: USING A MULTIPROXY APPROACH ON DIFFERENT SCALES TO INFERR FEEDING BIOMECHANICS AND MORPHOLOGICAL CONSTRAINTS OF MAMMAL TEETH
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Tooth morphology in mammals is used to infer diets, ecology and environments as well as taxonomic affinities of extant and extinct mammals. Mammalian dental tissues have undergone evolutionary optimization in terms of fracture- and wear resistance. They thus are highly indicative of biomechanical constraints related to chewing forces however homoplasy in morphology is widespread. Cheek dentitions of ungulates and lagomorphs, representing a large magnitude of dietary traits were evaluated in terms of mesowear (2DM), enamel ridge alignment (2DE), 3D-dental topometry (3DT), and 3D dental surface texture (3DS) analyses. We infer adaptive patterns as well as biomechanical traits. In a multi proxy approach we combine complementary long term (2DM, 2DE, 3DT) and short-term dietary and functional proxies (3DS) derived from tooth crown geometry ranging from nano- to centimeter scale. Larger species and species involved in abrasive feeding (grazers s. l.) express more heterogeneity in their chewing force distribution independent of their feeding type. Their occlusal bauplan allows for the formation of enamel ridges aligned less perpendicular to the chewing stroke than in browsers. Grazers also have lower occlusal relief (2DM) and higher enamel/dentin-ratios. 2DE reveals that gazers and frugivores are characterized by increased complexity of shearing blades at the transition between premolars and molars as compared to leave-browsers, where large species show a more continuous mesio-distal increase of shearing blade complexity. 2DT reveals that average slope of the crown is high in fruit dominated browsers, low in mixed feeders and intermediate in grazers. 3DS is largely independent of tooth morphology but highly reflective of major food sources, their biomechanical properties and abrasiveness as well as occlusal dynamics. Using the multiproxy approach we can differentiate dietary traits and dietary flexibility as well as biomechanical constraints from the impact of phylogeny.

Contributed 8 – Flight: Birds and Bats
C-051
CAN BAT WING MUSCLES OPERATE AS FORCE CONTROLLERS?
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During contraction, muscles may control joint position directly, or alternatively act as force-controllers by producing force and stretching tendon. One hallmark of force control would be shortening of a monoarticular limb extensor muscle without extension of its joint. Studies of diverse species suggest that force control may be widespread in terrestrial locomotion, but we know much less about its role in movements through fluids. It also remains under debate if limb muscles in small mammals are capable of producing sufficient stress to stretch their tendons, which are thought to be relatively stiff. We addressed these questions by studying in vivo function of wing muscle-tendon units in the bat Carollia perspicillata during take-off and climbing flight. We measured shoulder and elbow joint kinematics using biplanar fluoroscopy, muscle strain using fluoromicroscopy, and muscle activity using electromyography. Several indications of tendon stretch were observed: During climbing flight, the triceps (monoarticular head) shortened when the elbow joint was not extending, and the biceps short head shortened when the elbow joint was not flexing. During take-off, however, shortening of the same biceps head was in-phase with elbow flexion. Our results revealed that tendon elasticity influences the action of muscles powering flight, and that at least some small mammal limb tendons can be stretched by muscular and aerodynamic forces, allowing their muscles to operate as force controllers. Work funded by AFOSR.

C-052
INTEGRATING AERODYNAMICS AND ENERGETICS TO UNDERSTAND HOW BATS CHANGE FLIGHT DYNAMICS WITH SPEED
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Some key aspects of animal locomotion include kinematics, mechanics and energetics, and these aspects are dependent on the net forward velocity of the animal. Studies of velocity dependence of locomotor dynamics have shed considerable light on terrestrial locomotion; however, diverse challenges have limited comparable progress in studies of swimming and flight. Theoretical models of animal flight predict a strong velocity dependence of the energetics: generating lift demands substantial energy at low forward velocities, and energy lost to drag increases with flight speed. Empirical studies of flying animals find that the relationship between flight power and speed varies substantially. However, the majority of data come from birds, fewer from insects, and even less from bats. We investigated flight power in Seba’s short-tailed fruit bats, Carollia perspicillata. We observe that aerodynamic power in relation to speed, quantified with Tretiez plane PIV, changes little over a range of flight speeds. In contrast, metabolic power, assessed by the $^{13}$C labelled Na-bicarbonate technique in the same individuals, shows a more U-shaped relationship with speed. We also predicted flight power/speed profiles for this species employing widely used theoretical models, and compared the predictions to our empirical results. The measured aerodynamic power curve resembled the predictions reasonably well, despite their simplifications, including the assumption of fixed wings. Some ecologically important details, however, e.g. minimum power and maximum range speeds, differed. The differences between aerodynamic and metabolic power suggest a flight velocity dependence of locomotor efficiency.

C-053
SEASONAL DIFFERENCES IN THE ENERGETICS AND BIOMECHANICS OF LOCOMOTION IN A HIGH ARCTIC BIRD
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The Svalbard rock ptarmigan experiences extremes of photoperiod and climate in the high Arctic. However, these birds are exquisitely adapted to life in the cold. One of their principle adaptations in the seasonal acquisition of large amounts of body fat during winter that results in a more than doubling of their body mass. This accumulation of weight represents a real challenge to these birds in having to not only gain this relatively large amount of extra mass but also to be able to maintain essential biological processes such as breathing and locomotion. These fat stores are likely to act as a constraint as the fat is distributed around the breast musculature and pelvic regions. Here we discuss differences in the energetics and biomechanics of locomotion and jumping performance in these birds, in response to the seasonal accumulation of large amounts of body fat.

Contributed 9 – Integration, Shape Mobility

C-054
CRANIOMETRIC IMPACT OF SEASONALITY IN CERVIDS
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Antler shedding and testosterone levels in male cervids are strongly linked with seasonality. In high- and mid-latitudes with distinct seasons, a distinct antler cycle can be observed. However, in tropical areas, where seasonality is lacking, cervids do not show a distinct antler cycle; rather, they shed their antlers at irregular intervals, often exceeding a year and differing from individual to individual. In addition, antlers tend to be proportionally smaller in the predominantly smaller-sized tropical species and sexual dimorphism (in this study referring to body size only) is less distinct. This might be due to a decreased reliance on antlers in intraspecific competition, since there is no defined rutting season. From a geological perspective, it has been suggested that modern patterns of antler shedding in temperate and high-latitude species developed in conjunction with global cooling during the Miocene. Smaller species tend to be less sexually dimorphic and the small body size is likely an adaptation to dense vegetation often found in tropical forests, in contrast to cold savannahs in high latitudes. Here, we apply linear morphometrics to investigate the extent to which skulls of temperate and tropical cervid species differ. We ask if and how seasonality manifests itself in cranial phenotype, potentially driving repeated adaptations possibly (but not necessarily) related to differences observed in antler morphology and degree of dimorphism. Using samples of phylogenetically closely related taxa in temperate vs. tropical habitats, we find that 2D linear morphometrics show a significant difference between species exhibiting strong sexual dimorphism (e.g. Alces alces) and those without dimorphism (e.g. Muntiacus sp.). Bimodality of cranial dimensions between males and females.
could be observed for all species of the high- and mid-latitudes in contrast to tropical species, where no bimodality could be found.

C-055
FACTORS INFLUENCING MORPHOLOGY AND PATTERNS OF INTEGRATION ON THE SKULL OF SOAY SHEEP
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Most studies of skull morphology compare the shape of different species, focusing on variation in relation to systematics and phylogenetic position. Only recently have there been successful efforts to understand what factors influence skull shape and how they do so. Several factors such as developmental pathways, genetics, functionality and evolutionary history may influence the shape of the skull, and how its different parts are integrated. Soay sheep, the primitive breed of sheep from the island of Hirta in the St. Kilda archipelago, are a good model to study the causes of shape variation. The Hirta population has been monitored since 1985, and the skulls of the deceased animals collected and stored at the National Museum of Scotland, in Edinburgh. This provides us with a large sample of skulls (around 2,000) from animals of known age, sex and year of birth. Soay sheep have three different types of horn morphology and can, therefore shed some light on the influence of horns on skull shape and patterns of integration. We are using 3D geometric morphometrics to capture shape information, which allows us to assess which factors (sex, age, year of birth and horn type) are associated with variation in skull shape, and what are the anatomical changes related to that factor. It also allows us to estimate integration levels and what factors are influencing them.

C-056
IT’S NOT EASY BEING GREEN: PERFORMANCE AND FLUCTUATING SELECTION IN AN URBAN POPULATION OF GREEN ANOLE (ANOLIS CAROLINENSIS) LIZARDS
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The green anole has long been considered a model organism for the study of ecology and evolution, and is frequently used in studies of whole-organism performance. However, very little is known regarding how selection acts on important morphological and physiological traits such as dewlap size, biting, clinging and locomotion in free-ranging populations of Anolis carolinensis lizards. Here I will describe preliminary data resulting from a long-term mark-recapture study of an urban population of green anole lizards in downtown New Orleans. These results show that morphology and performance traits of urban lizards are subject to multiple fluctuating selection pressures which have important consequences both for the demographic and age structure of this population, and may affect the frequencies of heavyweight and lightweight males as well as the evolutionary trajectory of performance. Data such as these offer a valuable counterpoint to studies of selection in the wild, and suggest that urban populations of green anoles are not exempt from the vagaries of selection.

C-057
INTEGRATION AND MODULARITY OF SHAPE: EXPLORATORY ANALYSES IN AN EVOLUTIONARY CONTEXT
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Analyses of integration and modularity are increasingly widespread. In particular, the complex organization and morphological diversification of the vertebrate skull has stimulated many investigators to seek patterns of integration and modularity. In recent years, new geometric morphometric approaches for the study of integration and modularity have been developed and applied widely in many vertebrate taxa. So far, most studies of cranial integration and modularity have focussed on integration within a particular species. In an evolutionary context, however, both the integration of evolutionary changes across taxa and the evolutionary modification of intraspecific integration are of interest as well. I present an overview of recently developed morphometric methods that address these questions using comparative methods that have an explicit phylogenetic basis. Whereas techniques for testing a-priori hypotheses of morphological modularity are firmly established, exploratory analyses for finding modules in morphometric data have been fraught with conceptual and methodological difficulties. I will discuss possible new approaches that address these problems and should be promising for studies of modularity at multiple levels, from intraspecific analyses and studies of fluctuating asymmetry that aim to uncover the developmental basis of modularity to comparative studies that examine modularity at the macroevolutionary scale.
C-058
USING NETWORK MODELS TO TACKLE MORPHOLOGICAL INTEGRATION AND MODULARITY IN THE HUMAN SKULL
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Connections between skull bones are structural relations essential to recognize homology and novelty in the skull; these connectivity relations make up a framework of analysis of morphology at a structural level, in which we can define the connectivity pattern of bones as the number and the distribution of its connections to other bones. Changes in this connectivity pattern alter the relations of homology between bones, provoke changes in shape, and produce morphological novelties. This variation of the structural arrangement of bones (the connectivity pattern) occurs during both the evolution and the development of the skull due to iterative losses and fusions of bones. Evolutionarily, this generated a trend in bone number reduction known as Williston's Law. Developmentally, the premature fusion of bones produces craniosynostosis: a birth defect that causes characteristic changes in skull shape because of compensatory growth. Modeling these connectivity patterns of skull bones, we have found that the loss of poorly connected bones constitutes a mechanism that underlies a general trend toward an increase in morphological complexity in the evolution of the tetrapod skull. In addition, network models can also be used to capture changes in connectivity patterns during development that lead to the formation of modules and define shape changes. Here, we will show how network models bring about new ways to study morphological integration and modularity in the human skull from an evolutionary and medical perspective.

C-059
FUNCTIONAL APPROACH TO THE EVOLUTION OF THE HUMAN HIP JOINT
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Humans are characterized by a permanent bipedalism resulting in strong mechanical constraints on the coxo-femoral joint. Both stability and mobility are required to ensure a functional interface transmitting forces between trunk and lower limbs. An appropriate three-dimensional orientation of the hip joint, composed of the acetabulum and the proximal femur, is fundamental to ensure an efficient bipedal gait and posture. The aim of the study is, firstly, to quantify variation in the three-dimensional orientations of both the acetabulum and the femoral neck in adult humans and, secondly, to identify patterns of co-variation between these two orientations in order to analyse the degree of morphological integration at the hip joint. Results were interpreted using three-dimensional models of both the acetabular region, and the proximal femur. Our results show no significant patterns of co-variation between the three-dimensional orientation of the femoral neck and the orientation of the acetabulum. In addition, the mean orientations of the two opposing articulating components demonstrated a poor congruity in the normal joint. We suggest that this absence of co-variation and this poor congruity may partly be due to the phylogenetic history of the human species. Although natural selection optimizes the functional locomotory performance of the human hip joint, adaptation is also dependent on, first, the constraints of the inherited structure and, second, the trade-off with other functions. To better understand the evolution of the human hip joint and the constraints acting thereupon, we are expanding our study on an extended sample of Hominoids.

C-060
THE BONY LABYRINTH OF EXTANT HOMINIDS AND ITS BEARING ON PHYLOGENETIC RELATIONS AND LOCOMOTION OF FOSSIL HOMININS
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The bony labyrinth houses the inner ear, including the sense organs of balance and hearing. Comparative analyses have shown that its morphology is species-specific, reflecting aspects of locomotor behavior, hearing capabilities, basicranial architecture, as well as phylogenetic affinities. Studying the bony labyrinth in the context of hominin evolution is therefore particularly informative as it has the potential to reveal new evidence about the emergence of bipedal locomotion and about basicranial changes associated with increases in brain size. Moreover, its morphology can indicate the taxonomic affinities and phylogenetic relations of hominin fossils, with the specific advantage that petrous parts of the temporal bone containing a well-preserved labyrinth are abundant in the hominin fossil record. We study the size and shape of the labyrinth using geometric morphometrics based on 3D landmarks and semilandmarks obtained from micro CT images. Such morphological analyses of hominin fossils require a comparative context of extant hominid taxa, but our current understanding of aspects such as morphological variation and sexual dimorphism is
limited in the case of modern humans, and minimal with respect to great ape species. Hence, we analyzed a large extant comparative data set, which includes, among others, all seven hominid species. Consistent interspecific differences are found, even between closely related taxa like the eastern and western gorillas. As a subsequent step we studied the labyrinth of several South African hominin fossils, attributed to *Paranthropus*, *Australopithecus* and *Homo*. We will present the results of the comparative analyses, and discuss the prospect of applying advanced biomechanical models of the semicircular canal system to gain better insight into the evolution of bipedal locomotor behaviour.

C-061
FOREARM ROTATIONAL EFFICIENCY IN HOMINOIDS
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The rotational movement of the forearm or pronosupination is essential during the locomotion of primates in their habitat. This rotary motion is not only dependent on the muscular power of pronators and supinators, but also on several structural features of the upper-limb skeleton. In this study, we aim to determine if the rotational efficiency of the forearm of several hominoid species reflects their locomotor pattern. Using a previously described biomechanical model, we calculate rotational efficiency of the pronator teres muscle in two positions of the elbow (180° of extension and 90° of flexion) in *Hylobatidae* (N = 26), *Pongo* (N = 21), *Gorilla* (N = 30), *Pan troglodytes* (N = 30) and *Homo sapiens* (N = 29). Our results show that, in elbow extension, species performing knuckle-walking present maximum rotational efficiency greatly displaced to pronation, whereas in arboreal species this maximum is closer to the neutral position of the forearm. Conversely, in elbow flexion, the maximum efficiency is greatly displaced to supination in species that usually perform arboreal climbing, whereas in terrestrial hominoids this displacement is lower. In true brachiators, maximum efficiency in both elbow positions is notably close to the neutral position, which is also seen in humans, especially in elbow flexion. The differences between taxa are related to differences in the orientation of the medial epicondylo, which is a key factor in the determination of efficiency. In conclusion, the forearm rotational efficiency pattern of each taxon analyzed here may be interpreted in the light of morphfunctional and locomotor adaptations. In this regard, rotational efficiency may be useful to reconstruct the locomotor patterns in fossil specimens, contributing to an accurate interpretation of the skeletal adaptation of the hominoid upper-limb.

Contributed 10 – Feeding
C-062
IS THE LEPTOCEPHALUS LARVA CAPABLE OF BITING? ANALYZING THE MORPHOLOGICAL LIMITATIONS OF THE FEEDING APPARATUS IN THE EUROPEAN EEL
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The leptocephalus larva is the unique larval stage of Elopomorph fishes. Being completely transparent, small in size and tied to the ocean’s twilight zone, in depth investigations of the anatomy, physiology and behavior of these larvae are rather scarce and their results are often contradicting. Full of contradictions is the larva’s feeding strategy. Although suction feeding or nutritional intake through the integument could be expected, observations have been made of leptocephali biting potential prey items with their needle-like, forward-pointing teeth. As this counterintuitive feeding strategy would imply morphological modifications at the level of the larva’s feeding apparatus, a functional morphological analysis on the latter is performed. Using a graphical 3D-reconstruction of the musculoskeletal system of first feeding larva of the European eel (*Anguilla anguilla* Linnaeus 1758; Actinopterygii, Elopomorpha, Anguillidae), present modifications at the level of the teeth and the jaws are investigated. Subsequently, 3D data of joints, levers and muscle insertions, as well as muscle data, are derived from the reconstruction and used to estimate theoretical bite forces (± 60μN) at different gape angles (15° and 25°). Preliminary data on kinematics (from video recordings) of jaw and hyoid movements in pre-feeding eel larvae is also taken into account and demonstrates a rather limited ability of jaw movement by both ligaments and muscles. Combining the obtained results, it becomes clear that, if the first feeding leptocephalus larva feeds by biting prey items,
food particles have to be rather soft and/or small. Recent identifications of food items in the guts of these larvae support this hypothesis as the majority of the retrieved fragments belongs to either small and/or gelatinous organisms (Hydrozoa, Thaliacea, Ctenophora, Polyclasteria).

C-063
MULTIBODY DYNAMICS OF FEEDING IN THE THEROPOD DINOSAUR ALLOSAURUS AND DOMESTIC PIGS: PALEONTOLOGICAL SIMULATION AND EXTANT VALIDATION
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Multibody dynamics analyses (MDA) enable simulation of locomotion and feeding in fossil vertebrates and validation against experimental results for extant taxa. MDA entails potential tradeoffs: maintaining anatomical complexity but simplifying physiological assumptions versus simplifying muscle anatomy but incorporating sophisticated force-generation parameters. We explore this tradeoff with simulations of cervicocephalic movements in the theropod dinosaur Allosaurus and of chewing in the domestic pig Sus scrofus. Mass and moment properties of the Allosaurus model controlled for dimensions of air spaces, tissue densities, and parametrically variable muscle reconstructions, but muscle force inputs were simplified. In contrast, the pig model used only centroids of attachment for muscle groups, but incorporated both rigid and deformable solids, realistic contacts, muscle force-length and force-velocity curves, and timing from previous EMG studies. Allosaurus simulations quantified facility for high angular acceleration in lateroflexion, forceful ventroflexion by the muscle m. longissimus capitis superficialis, and the sensitivity of lateroflexion to alternate muscle reconstructions. Despite simplified force-generating parameters, the model resolved likely behaviors of crocodilian-like lateral strikes at prey, but falcon-like retraction of the head and neck for de-fleshing. The chewing simulations for Sus scrofus dramatically approached kinematics documented in radiographic studies. Results were realistic despite simplified muscle architecture, but acutely sensitive to activation timings, optimum muscle fiber length, and muscle velocities. The model combined dynamics with finite element modeling of the mandibular condyle and temporomandibular joint disc. The simulations raise two issues about MDA’s promise and practice. (1) MDA enables testing of how ambiguous inferences of muscle anatomy affect inference of behavioral capability. (2) Realism versus accuracy in validation: Do our validations match experimental dynamics for the “right” reasons or coincidentally with analogous combinations of input parameter values? The flexibility of MDA is ideal for exploring such comparative hypotheses, and for refining essential methodological validations.

C-064
DEVELOPING A MULTIBODY DYNAMICS MODEL OF THE MOUSE MASTICATORY SYSTEM
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Mechanical forces have an essential role in normal embryonic skeletal development but have rarely been investigated in craniofacial development, largely due to the difficulty in testing the influence of mechanical forces in vitro. We are developing a computational model of the mouse masticatory system using multibody dynamics analysis (MDA) that can be used with wild-type, mutant and in silico manipulated mouse morphological variation to investigate the role of mechanical forces on the development of the integrated craniofacial skeleton and musculature. Multibody dynamics modelling provides the possibility to investigate this complicated system and study the pattern of muscle activation. At every stage of jaw opening, jaw closing and mastication, the MDA software calculates muscle elongation and changes in muscle orientation that alter the active and passive forces exerted in the masticatory system. The engineering MDA software package ADAMS is being used in this analysis. It requires a virtual reconstruction of the mouse skull geometry, which is obtained by microCT, and on which are defined the key masticatory muscles. Kinematic data of the mouse masticatory cycle were taken from previous experimental studies, and the maximum force that each muscle can apply was estimated by obtaining muscle weight and fibre lengths from dissection. The muscles were activated in a way that provided sufficient force for the jaw to follow the orthal and propinal movements to replicate the masticatory motion while biting on a food item. The solutions provide estimates of the bite force, joint forces and individual muscle strand activation patterns during every stage of the mastication process. For example, results from the model with simplified partially-constrained temporomandibular joints predict that the maximum bite force at the position of the first molar will be approximately double that during incisor biting.
C-065
MULTIBODY DYNAMICS MODELLING OF A RABBIT SKULL
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Computational modelling and virtual experimentation are invaluable tools for analysing and investigating the mechanics of biological systems, reducing the dependency on laboratory experimentation, which is open to numerous difficulties and complications. Multibody dynamics analysis (MDA) is a powerful technique which can predict musculoskeletal forces occurring within anatomical structures, and has been employed in this current research to simulate the masticatory system of the rabbit. Here we examine how activations of the masticatory muscles, along with bite force magnitudes, vary with bite locations (incisor vs. molar biting) and food stiffness. An MDA model of a rabbit skull was constructed through combining detailed dissections, magnetic resonance imaging and micro–computed tomography scan data, to identify muscular lines of action upon the skull bone geometry. The model simulates physiological masticatory kinematics and predicts the muscle and bite forces associated with molar and incisor mastication of foods with varying stiffness. The model suggests that the bite forces produced during molar biting can be up to 35% greater than those generated during incisor biting, primarily due to an increase in the deep masseter activation. When simulating molar chewing with a short power stroke (0.15-0.25ms), predicted bite forces range between 10N and 60N depending on the hardness of a food particle. This finding agrees with results from published in vivo experiments. To our knowledge this is the first subject-specific MDA model of a rabbit skull, which will be used in future finite element studies to investigate the stress/strain distribution in the mandible associated with mastication. Future model adaptations will include more complex contact conditions at the temporomandibular joint to permit a complete range of jaw movement, enabling simulation of a variety of “crushing” and “shearing” biting activities.

C-066
FINITE ELEMENT ANALYSIS OF BITING MECHANISM IN THE EXTANT COELACANTH, LATIMERIA CHALUMNAE
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The coelacanth Latimeria is the only extant genus of a group of lobe-finned vertebrates (sarcopterygians) that originated in Devonian times. Notably, it is the only extant vertebrate showing a skull divided into an anterior and a posterior part, articulated by means of an intracranial joint. This complex articulation was thought to allow an elevation of the snout by 10° to 20°, thereby enhancing mouth opening distance and velocity, needed to perform powerful suction. Although the cranial anatomy of Latimeria is well known, the function of its kinetic joint during feeding remains poorly understood and has been subject of a number of conflicting hypotheses. Based on the recent dissection of a coelacanth specimen from the MNHN collections in Paris, we re-described the musculo-skeletal anatomy of the coelacanth head, and estimated theoretical bite forces using a static equilibrium model. We observed that strong ligaments associate the anterior and posterior portions of the skull, likely preventing any elevation of the snout. These new data suggest that the intracranial joint may play a role in stress dissipation in response to high bite force generation, rather than in increasing mouth gape. Finite element analysis on the virtual 3D model of a coelacanth head was then used to test this hypothesis. Implications in the skull kinesis and feeding behavior of Latimeria will be discussed, and future directions of this study will be presented.

C-067
MODELING THE FUNCTIONAL TRADE-OFFS OF DUROPHAGOUS TEETH
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Durophagous teeth, used to consume hard-shelled prey exhibit a diversity of morphologies. Two hypotheses could explain this variety in form: tooth shape is selected to prevent teeth from breaking; or to most effectively break the prey item. In any durophagous species, we propose that both of these competing hypotheses will have some degree influence on tooth morphology. We tested these hypotheses using canonical models to isolate the effect of different aspects of tooth morphology on structural integrity and crushing force. We generated three series that varied by 1) occlusal concavity and convexity, 2) cusp height, and 3) how much of the occlusal surface is covered by the base of the cusp. We used finite element
analysis to test how these tooth model morphologies responded to two different loading regimes, simulating large and small hard prey items. By measuring principal strain and strain energy we could determine which shapes were most likely to deform under loading. We found that occlusal concavity led to less deformation than convexity, and that cusp morphology affected the deformability of the models, with taller and narrower cusps deforming the most. To test how well the different model morphologies would be able to break prey items, we measured the force needed by each model to break a snail shell. To reduce variation due to prey we used a rapid prototyper to mass produce shells of identical size, shape, and material composition. The convex tooth models and those with taller or narrower cusps needed less force to break the snail shells. Taken together, these studies indicate a trade-off in durophagous tooth morphology, since effective shapes tend to be the same model shapes that are most likely to deform under heavy loads.

C-068
FEEDING PERFORMANCE OF KING MACKEREL, SCOMBEROMORUS CAVALLA
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Feeding performance is the ability to capture and handle prey successfully. Bite force is a common measure of feeding performance that is constrained in part by the morphology of the head and jaws, muscle physiology and architecture, and lever arms. Other factors including ram speed and dentition may also affect feeding performance. King mackerel, Scomberomorus cavalla, are a fast swimming, large coastal pelagic species that uses ram feeding on teleost fishes. They have a large gape and sharp laterally compressed teeth. This study investigates both static bite force, dynamic force resulting from ram strikes, as well as bite pressure to examine their relative contributions to overall feeding performance. A three dimensional static equilibrium model is used to estimate maximum static bite force. Theoretical values are compared to stimulated tetanic bite force. Preliminary data shows stimulated bite forces of 10 Newtons for an adult king mackerel of approximately 91cm or 5.8kg. Ram speed measurements of 5.6 body lengths per second recorded with a rod and reel incorporated with a line counter and video camera. Using integration of the tooth area as it pierces and enters the prey the changing bite pressure is estimated using theoretical bite forces. Static bite models provide a valid and useful link between performance and fitness for many vertebrates but may not tell the whole story for organisms such as the king mackerel that employ rapid speeds during feeding. Mass specific bite force for king mackerel is relatively low in comparison with other bony fishes and sharks (standardized residual -0.821) suggesting they rely on a rapid strike and sharp teeth to maximize their feeding performance.

C-069
THEORETICAL CALCULATIONS OF BITE FORCE IN BILLFISHES
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Billfishes are a group of large pelagic predators characterized by elongation of the rostrum. This structure is used to seize, stun or spear prey before ingestion, thereby decoupling prey processing from the oral jaw apparatus. Billfishes differ considerably in the relative size of the rostrum. We therefore hypothesize 1) that billfishes will have low mass-specific bite forces compared to other fishes, and 2) that interspecific variation in mass-specific bite force among billfishes will reflect the size of the rostrum and the ability of this structure to be used in prey processing. Theoretical calculations of jaw leverage and bite force were estimated in five species of billfish that exhibit variability in rostrum morphology, ranging from swordfishes with extremely elongated rostra to shortbill spearfishes with short rostra. Bite force estimates were generated using a three-dimensional static equilibrium model of the forces acting on the lower jaw (adductor mandibulare complex, joint reaction, and bite reaction forces), and both absolute and mass-specific bite forces were compared to other non-billfish species reported in the literature. Preliminary results suggest that absolute bite forces in species with short (shortbill spearfish: 202 N) and elongate (swordfish: 202 N) rostra are comparable, whereas mass-specific bite force is greater in species with short rostra. Furthermore, billfish have low mass specific bite forces when compared to other fishes. This study represents the first time that jaw biomechanics have been investigated in billfish. The results will be discussed with regards to the feeding ecology of these top predators.

C-070
BITE FORCE, CHEWING KINEMATICS, AND THE IMPORTANCE OF WORK IN THE PHARYNGEAL JAW OF CYPRINID FISHES
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Vertebrates feed on diverse foods with varying material properties, so we expect biomechanical traits of their feeding systems to vary with diet. Cyprinidae is a trophically diverse fish clade that offers an opportunity to compare how muscle function varies with feeding ecology in a relatively simple, conserved mechanical apparatus. Food is broken down exclusively by the pharyngeal jaws, and just one muscle is responsible for elevating the jaw, pulling the teeth against a dorsal occlusal surface. This system offers clear biomechanical links between muscle physiology and performance, and prior work has shown that the force-length relationship in jaw-closing musculature limits crushing performance in a molluscivore. Using X-ray Reconstruction of Moving Morphology (XROMM), we measured in vivo jaw-closing muscle lengths in two specialists: a molluscivore and a herbivore. We then used in situ electrical stimulation to measure the force-length relationship of this muscle. While chewing, black carp (Mylopharyngodon piceus, molluscivore) used small muscle strains (<10%, N=3, 78 chews), whereas grass carp (Ctenopharyngodon idella, herbivore) used larger muscle strains (>15%, N=4, 196 chews). In vivo differences in muscle strain translated into different physiological operating lengths: both species initiated occlusion at near-optimal muscle lengths (ca. 0.95L0), but the jaw-closing muscle in black carp shortened throughout the occlusion phase to a minimum length of 0.87L0, compared with 0.81L0 for grass carp. This slight difference in operating length led to a striking difference in force: at 0.87L0, the black carp levator maintains much of its potential force (0.5-0.7P0), but at 0.81L0, the grass carp levator only produces a small fraction of its potential force (0.2-0.3P0). We hypothesize that for black carp, force alone is the functional optimality criterion, whereas for grass carp, work (force x distance) is important for shearing plant matter. These results underscore the role of in vivo muscle operating lengths in shaping vertebrate trophic strategies.

**Contributed 11 – Sensory Biology**

C-071

**EVOLUTION OF THE MIDDLE EAR CAVITY: A NOVEL MECHANISM FOR A NEW EAR**

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The non-mammalian amniote middle ear is an air-filled cavity bridged by an ossicle (the stapes or columella), which conducts sound waves from the ear-drum to the inner ear. In contrast, mammals have three middle ear ossicles (the malleus, incus and stapes), created by the transformation of two jaw-bones, the articular and quadrate, into two new ossicles to create a chain. In the early embryo, the middle ear is filled with neural crest derived mesenchyme with the middle ear ossicles developing within it. As development proceeds, a process called cavitation occurs resulting in the formation of an air-filled space surrounded by an epithelial lining within which the ossicles are suspended. This process has been proposed to be driven by invasion and expansion of the pharyngeal endoderm via the forming Eustachian tube, which wraps around the ossicles and forms the middle ear epithelial lining. With the evolution of the mammalian middle ear, an area not previously cavitated would have to be created. We have examined the origin of the middle ear epithelium in a number of transgenic reporter mouse lines, and find it has a dual origin. The ciliated epithelium around the ossicles is derived from the endoderm, as previously suggested, but the simple un-ciliated epithelium forming the middle ear ossicles and along the cochlea is neural crest derived. The neural crest has therefore undergone a mesenchyme-to-epithelial transformation, turning on epithelial proteins and forming a basement membrane. Whether this is a mammal specific process is being investigated by following the fate of the endoderm and neural crest in the chicken embryo middle ear. We hypothesise that with the evolution of mammals, and the advent of a three-chained middle ear, a novel process of cavitation evolved.

C-072

**ENDOCRANIAL RECONSTRUCTIONS OF EXTINCT TURTLES USING µ-CT SCANS: NEW INSIGHTS INTO BRAIN AND INNER EAR ANATOMY**

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To shed more light on the still poorly known paleoneurology of turtles, we compared the endocranium and inner ear of the marine turtle *Plisiochelys etalloni* from the Upper Jurassic of Europe and the terrestrial turtle *Naomichelys speciosa* from the Early Cretaceous of North America using µ-computed tomography. As in extant turtles, the endocasts indicate poorly marked cephalic and pontine flexures, a short olfactory tract and bulbs, and similar cranial nerve patterns. In extant turtles, the small olfactory bulbs generally do not leave impressions on the frontals and cannot be identified on the artificial endocasts. However, the olfactory
bulbs are clearly differentiated in the endocast of P. etalloni, indicating larger bulbs than in any other described extinct or extant turtle, and suggesting a higher capacity of olfaction in this taxon. The inner ears of both species are robust, with low lateral semicircular canals, and a short and conical lagena similar to that described for extant turtles such as Chelydra serpentina and Chrysemys scripta. The main differences between the two extinct taxa are (1) the relative extension of the dorsal expansion of the endocast above the cerebellum, which is strongly prominent in N. speciosa but very low in P. etalloni; (2) the relative length of the passage for cranial nerve VI, which is shorter in N. speciosa; (3) the shape of the semicircular canals, which are more strongly angled in P. etalloni; and (4) the carotid circulation pattern. In P. etalloni the carotid circulation pattern is similar to extant cryptodires, while in N. speciosa the palatine artery is not covered ventrally by bone and the foramen pro ramus nervi vidiani (n. VII) is seen in ventral view. Further comparisons with extant forms, will determine whether or not the brain anatomy and inner ear of extinct turtles are informative for lifestyle.

C-073
FUNCTIONAL MORPHOLOGICAL ADAPTATIONS OF THE INNER EAR IN SCIUROMORPHS (RODENTIA, MAMMALIA)
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The spatial orientation in the three-dimensional space is detected by the vestibular system of the inner ear, more precisely by the three semicircular canals. These canals are located in the bony labyrinth of the petrosal bone of the skull and can therefore be examined in extant but also extinct specimens. Micro CT-scanning allows the noninvasive investigation and virtual reconstruction and measurement of selected structures, like the bony labyrinth of the inner ear. This study focuses on the monophyletic group of sciromorphs (sciurids, glirids and alopodontids), because this clade represents a great diversity of locomotion types (generalistic, fossorial, arboreal, gliding). Functional morphological adaptations of the inner ear were previously found in quantitative parameters of the radius of curvature of the semicircular canals. Based on the investigation of 33 extant taxa of sciromorphs, arboreal and gliding species can clearly be separated from fossorial taxa by the diameter of the semicircular canals. Additionally, we investigated the sensitivity of the inner ear by using mathematical calculations, which account for morphometric parameters and physical constants. The vestibular system of fossorial taxa is more sensitive than in arboreal, gliding or flying species; the latter are represented by bats. The detection of the spatial orientation in the three-dimensional space causes a great input of information into the vestibular system. We assume, that an overstimulation of the inner ear in arboreal, gliding, and flying species is prevented by a minor basal sensitivity of the vestibular system, compared to fossorial taxa. By including fossil specimens of rodents in this solid database, the locomotion mode of extinct taxa can be postulated without any evidence of postcranial material.

C-074
LAONASTES AENIGMAMUS – MIDDLE AND INNER EAR MORPHOLOGY OF A NEW HYSTRICOMORPH RODENT
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According to molecular data, rodents can be subdivided into three monophyletic groups: the “mouse-related clade”, the “squirrel-related clade” and the hysticomorphous Ctenohystrica, containing African Ctenodactylidae and ‘Phiomorpha’ as well as South American Caviomorpha. The recently discovered diamyid Laonastes aenigmamus from Laos and Vietnam has been tentatively included in the Ctenohystrica. As suggested by morphological and molecular data, Phiomorphs and Caviomorpha can be considered as monophyletic Hystricognathi, but Ctenodactylids and Laonastes aenigmamus represent more basal branches. We attempted to find additional morphological evidence for clarifying the systematic position of this new rodent species. For the first time, we describe the middle and inner ear morphology of Laonastes aenigmamus using virtual 3D-reconstructions. Our findings are then compared with the ‘groundplans’ of Ctenohystrica and Hystricognathi respectively, which were reconstructed from data derived from both microCT and histological serial sections of adult and late fetal stages. Among other features, Ctenohystrica are characterized by ‘freely-mobile’ ear ossicles and a vestigial or reduced gonial. Previously, the processus gracilis of the malleus was thought to be a rudimentary gonial, but in Laonastes and Ctenodactyliusa the detached gonial is lining the ventral side of the fissura petrotympanica (Glaseri). The processus gracilis of all Ctenohystrica, in contrast, is exclusively formed by the malleus itself. The cochlear duct of Laonastes has 4 3/4 turns, which is the most advanced state within rodents in particular and mammals in general. Further
derived character states include a short processus styliformis, a vestigial stapedius muscle and an encapsulated tensor tympani muscle. We conclude from our data that a sistergroup - relationship of Laonastes and the Hystricognathi is more likely than that of Laonastes and the Ctenodactylids as has been suggested by molecular systematics.

C-075
TRENDS IN MIDDLE EAR AND BRAINCASE ANATOMY IN DINOSAURIA
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Despite growing studies on braincase anatomy, the evolution of middle ear morphology is still poorly understood in archosaurs, whereas it is well documented in the fossil history of mammals. The development of a mechanism that avoids energy loss in sound transmission by subdivision of the metotic foramen is considered one of the key features for the improvement of amniote hearing. We optimised relevant morphological characters derived from personal studies and previous investigations onto a dinosaur phylogeny in an attempt to unveil the patterns of braincase and middle ear evolution. Preliminary results show that the appearance of a fenestra pseudorotunda occurred at least twice independently among dinosaurs, with several reversals to one single foramen. However, in some taxa, the division is horizontal rather than vertical, and thus more similar to crocodylomorphs. A separate course for the glossopharyngeal nerve appears independently of the subdivision of the metotic foramen in neosauropods. A CN VI running lateral to the pituitary fossa and a separate foramen for the palatine ramus of CN VII are not exclusive of theropods. The complete separation of the ophthalmic and maxillo-mandibular branches of CN V in different foramina occurred at least three times, and although a pinched-off foramen occurs several times independently, it does not seem to represent an intermediate state. Reduction or absence of the fossa subarcuata may represent a plesiomorphy for ornithopods and neosauropods, and confluent carotid canals is a well spread character throughout surveyed taxa. Merging this data with the ones already collected for pseudosuchians will provide a more complete overview of patterns among archosaurs, and will allow for more accurate inferences on the behaviour and physiology of dinosaurs.

C-076
GOOD VIBRATIONS: FUNCTIONAL MORPHOLOGY IN THE ODONTOCETE TYPANOPERIOTIC COMPLEX
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Vibration is intrinsic to all structures. Any object can be characterized by its own distinct family of resonant frequencies. Vibrational analysis allows us to calculate these resonant frequencies based on an object’s geometry and its material properties. The odontocete tympanoperiotic complex (TPC) contains the ossicles and the cochlea. Measuring TPC variation is a key to understanding the functional morphology of sound reception. Recent work suggests that this apparatus selectively filters and/or amplifies various vibrational components of the incoming sounds. The TPCs from eight toothed whales were scanned with microCT, subjected to vibrational analysis, and examined with geometric morphometrics. In the TPC vibrational analysis, the first 60 resonant frequencies or modes were calculated for two porpoises, four dolphins, a sperm whale, and a river dolphin. All 60 modes for each specimen occurred below 190 kHz. There is no distinct trend across species between modes 1-10. Frequency diverged gradually between modes 10-60. The dolphins had both the lowest and highest modes over the entire range. The plots for the spotted dolphin, the porpoises, and the sperm whale were remarkably similar between modes 10-60. The modes for the left and right TPCs from the same specimen were nearly identical, indicating symmetry. Geometric morphometric analysis parses major sources of shape variation in TPC geometry, allowing odontocete TPCs to be sorted into complex morphotypes that are linked to functional differences.

C-077
TRIGEMINAL NERVE MORPHOLOGY IN ALLIGATOR MISSISSIPPIENSIS AND ITS SIGNIFICANCE FOR CROCODYLIFORM FACIAL SENSATION
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Extant crocodilians evolved a derived sense of face touch, in which numerous trigeminal nerve-innervated dome pressure receptors speckle the face and mandible and sense mechanical stimuli. However, the morphological features of this system are not well known, and it remains unclear how the trigeminal system changes during ontogeny and how it scales with other cranial structures. Finally, when this system evolved
within crocodyliforms remains a mystery. Thus, new morphological insights into the trigeminal system of extant crocodilians may offer new paleontological tools to investigate this evolutionary transformation. A cross-sectional study integrating histological, morphometric, and 3D imaging analyses was conducted to identify patterns in cranial nervous and bony structures of Alligator mississippiensis. Nine individuals from a broad size range were CT-scanned followed by histomorphometric sampling of mandibular and maxillary nerve divisions of the trigeminal nerve. Endocast volume, trigeminal fossa volume, and maxillomandibular foramen size were compared with axon counts from proximal and distal regions of the trigeminal nerves in order to identify scaling properties of the structures. The trigeminal fossa has a significant positive correlation with skull length and endocast volume. We also found that axon density is greater in smaller alligators and total axon count has a significant negative correlation with skull size. Six additional extant and fossil crocodyliforms were included in a supplementary scaling analysis, which found that size was not an accurate predictor of trigeminal anatomy. This suggests that phylogeny or somatosensory adaptations may be responsible for the variation in trigeminal ganglion and nerve size in crocodyliforms.

**Contributed 12 – Skeletal Evolution**

**C-078**

THE SKELETAL BRIDGE BETWEEN THE CRANIUM AND POSTCRANIUM IN CHAMELEONS

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A comparative study of the osteology of the atlas-axis complex in different chamaeleonid taxa was conducted. The multipartite atlas-axis complex forms the skeletal bridge between the skull and the postcranium allowing movement between these two regions. It contains surface areas for the origin and insertion of the anterior cervical musculature and for tendons which help to stabilize the cranial region. The comparative vertebral morphology of different genera of chamaeleonids has been generally neglected and some aspects such as the comparative anatomy of the neck region remain poorly known. The atlas and axis were examined for members of all chameleon genera (Brookesia, Rieppeleon, Archiaius, Rhampholeon, Nadzikambia, Bradydodon, Chamaeleo, Calumma, Furcifer, Kinyongia and Trioceros) and show considerable differences in their morphology. Studies of this atlas-axis region may contribute to our understanding of intergeneric relationships and provide an opportunity to study heterochrony in the Chamaeleonidae. The detection of paedomorphosis and peramorphosis requires knowledge of the phylogenetic hierarchy of the taxa concerned so that the “ancestral” (more general or plesiomorphic) and “descendant” (less general or apomorphic) characters (character states) can be identified. Many plesiomorphic characters, such as short posterodorsal processes, the large neural canal, the low neural spine, or the pronounced ventral inclination of prezygapophyses, are identified in the Brookesia clade, but also, for instance, in the Rhampholeon clade. In contrast to that, the Chamaeleo clade possesses many derived characters. A new derived anatomic structure of the parietal is described in Ch. calyptratus – the processus parietalis inferior which contacts the supraoccipital. Acknowledgements: Funding was provided by the Alexander von Humboldt Foundation in Germany. This work was also supported by the Vega Grant Agency, no. 2/0087/13.

**C-079**

SKELETAL DEVELOPMENT AND ADULT OSTEOLOGY OF HYPSIBOAS PULCHELLUS (ANURA: HYLIDAE)

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Osteological and skeletal characters have long been proven to be particularly informative in taxonomic and systematic research. Furthermore, ossification sequences are assumed to be a potential tool to investigate developmental states and developmental modes of fossil and extant skeletal specimens. Herein, we provide a detailed account on adult osteology and skeletogenesis in the Montevideo treefrog, Hypsiboas pulchellus (Anura: Hylidae) based on evaluation of a series of cleared and stained specimens. A consensus sequence of ossification, i.e., the order of appearance of mineralized elements until early metamorphosis could be determined as (parasphenoid, presacral vertebrae I-VII, frontoparietal, exoccipital) – transverse processes of presacral vertebrae I-VII – sacral vertebra – (humerus, radioulna, ilium, femur, tibiofibula, scapula) –
(cleithrum, clavicle, coracoids, metacarpals, tarsals, metatarsals, phalanges, hypochord) – (prootic, angulosplenial, dentary, maxilla, premaxilla, squamosal). Comparing the state of mineralized elements in individual specimens, a number of skeletal elements, including the exoccipital, frontoparietal, parasphenoid and prootic, as well as elements of the shoulder and pelvic girdles, and the phalanges, were found to vary intraspecifically regarding the relative time of their ossification within the ossification sequence.

C-080
COMPARATIVE EVOLUTIONARY MYOLOGICAL STUDIES DECONSTRUCT THE FORE-HINDLimb SERIAL HOMOLOGY MYTH
Ziermann, Janine M.; Diogo, Rui
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Most textbooks and papers state that the structures of the tetrapod fore and hindlimb are serial homologues. These statements seem to be due to a confusion between the supposed serial homology of the vertebrate pelvic and pectoral appendages as a whole and that of their individual structures, leading to a crucial question being overlooked: why are the skeletal and particularly the fore and hindlimb muscles so strikingly similar to each other? We provide an updated discussion of these questions and present a surprising and puzzling result of our comparative myological studies: in phylogenetically derived bipedal species such as modern humans the number of forelimb muscles/muscle groups with topological 'equivalents' in the hindlimb (19) is substantially higher than in quadrupedal mammals such as rats (16), reptiles such as lizards (14) and than in all other tetrapod taxa analysed by us, being similar to that found in phylogenetically and anatomically plesiomorphic amphibians such as salamanders (19). Furthermore, many of the forelimb muscles of tetrapods that have a hindlimb topological 'equivalent' were actually acquired at different geological times and/or from very different embryonic anlagen. These data, together with an extensive review of older and of more recent developmental, functional, paleontological and genetic studies, clearly contradict the hypothesis that the similarity of the individual structures of the tetrapod fore and hindlimbs is due to serial homology. This similarity is instead the result of phylogenetically independent evolutionary changes leading to a parallelism/convergence due to a complex interplay of developmental, functional, topological and phylogenetic constraints.

C-081
COMPARATIVE ANATOMY, PHYLOGENY, EVOLUTIONARY TRENDS, THE NOTION OF 'PROGRESS' IN EVOLUTION, AND THE MYTH OF HUMAN MORPHOLOGICAL COMPLEXITY
Ziermann, Janine M.; Diogo, Rui
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We undertook gross anatomical dissections of the soft tissues of various individuals from each major primate clade (total N = 55). The results obtained from these dissections and from our cladistic analyses may seem paradoxical. On the one hand the cladistic analyses suggest there is a higher number of unambiguous evolutionary steps [NS] from the base of the tree to modern humans than to any other taxon included in the study. On the other hand, our anatomical studies reveal that modern humans have fewer muscles than most other mammals and than most primates, in particular fewer than in strepsirrhines and tarsiforms. For instance, Nycticebus has a NS of 30 and a range of 133-139 head, neck, pectoral and upper limb muscles in total, while modern humans have an NS of 75 but only 123 muscles in total and chimpanzees have an NS of 70, but have 3 more muscles than modern humans in total. The solution to this apparent paradox lies on Stephen J. Gould's contention that the importance given to 'evolutionary trends' and particularly to the supposed examples of human remarkable morphological complexity is best explained by the historical under-reporting of examples of undirected evolution and of morphological 'simplification'. That is, modern humans accumulated more evolutionary transitions than other primates but these transitions did not result in more muscles or bundles per muscle, e.g. since the Pan/Homo split humans have actually secondarily lost muscles that are present in most other primates, such as the m. levator claviculae and m. dorsiopitrochlearis.

C-082
PATTERNS OF VARIATION IN SALAMANDER LIMB SKELETOGENESIS
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Urodeles show a unique pattern in the patterning process of their limb skeleton, which stands in stark contrast to a very conservative pattern seen in all other tetrapods. During early condensation and chondrification, tetrapods show a proximodistal progression in the development of skeletal elements and a
postaxial polarity in the order of digit formation. In contrast, salamander limb skeletogenesis is characterized by preaxial polarity in digit development and a very early formation of distal autopodial elements. This includes specifically the basale commune, an amalgamation of distal carpal or tarsal 1+2 unique to salamanders, and a very early condensation of digits I and II. The evolutionary history, the genetic and potential functional basis of this unique pattern of limb skeletogenesis remain puzzling, although the fossil record indicates that at least some of these features were present in Permian dissorophoids, the stem group of modern amphibians. While the general features, i.e. preaxial polarity and the early formation of the basale commune, are present in all salamander taxa studied to date, a high degree of variation exists surrounding this common theme. Assessing and understanding the range of variation is an essential step in further deciphering the evolutionary history and significance of this developmental pathway. We synthesized the data on salamander limb skeletogenesis for the taxa that have been studied thus far, and provide for the first time data on the pattern of limb skeletogenesis for a cyptobranchid salamander, Cryptobranchus alleganiensis. The results show that variation occurs within three distinct regions of the developing autopod, namely the central and postaxial columns, and the digital arch. While there is no clear phylogenetic signal in the pattern of variation, at least some feature seem to be linked to life history mode and the overall timing of limb development in different salamander taxa.

C-083 MORPHO-FUNCTIONAL FEATURE OF THE FEMORAL NECK IN CAPTIVE CHIMPANZEEs
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Bone morphology well reflects daily behavior of animals. In the past studies, it is known that the cortical thickness of the femoral neck inferior region is larger than that of the superior region in chimpanzees. In order to confirm the mechanical effects of daily locomotion on the femoral neck of chimpanzees (Pan troglodytes), we examined the distribution and density of cortical bone and cancellous bone and analyzed the load burdened on femoral neck. Femora from captive chimpanzees (specimens of Dokkyo University; n=6, right side) were used for the study. We obtained femoral neck serial scans of 5 parts along femoral neck, perpendicular to its long axis by using pQCT (XCT Research SA+, Stratec Medizintechnik GmbH). The relationships of loads on hind limb of chimpanzees and morpho-functional features of femoral neck were discussed in reference to video pictures and preceding studies on chimpanzee locomotion. Cortical cross-sectional area and cortical thickness of femoral neck decreased from the base to distal region along the long axis of femoral neck. Area and density of cancellous bone showed an increasing tendency from the base of neck to distal region. Area moment of inertia of femoral neck cross-sections showed larger value in the direction of diaphysial long axis. The cortical thickness of the inferior region and antero-superior region were larger than the superior region showing the same tendency as in wild chimpanzees. The cortical thickness of chimpanzees being thinner in superior compared to inferior region, though not so clear as humans, is considered to accommodate the loads in the vertical direction reflecting daily locomotion of chimpanzees. Cortical thickness of showing larger value in antero-superior region indicate the large load of gluteus medius muscle attaching greater trochanter. Larger amount of cancellous bone distributing near femoral head indicate various loading directions around distal region of femoral neck.

Contributed 13 – Feeding
C-084 GENETIC AND ENVIRONMENTAL CONTROL OF MANDIBULAR FORM AND FUNCTION IN MICE
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In addition to genetic control on form, bone modelling and remodelling, the deposition or removal of bony tissue in response to high or low strain regimes, enables organisms to plastically modify the shape of their skeletal tissues in response to varying environmental stimuli. Here we characterise whether differences to (1) genetic heritage and (2) environment result in differences in shape in mouse mandibles. Further, we investigate whether such shape differences have functional consequences, and, in the case of environmentally driven plasticity, whether these differences are functionally advantageous. Two inbred strains of lab mice, BALB/c and C5BL/6, have significantly different shaped jaws, with BALB/c mice having more gracile jaws with a less developed masseteric ridge (n = 20). Comparative finite element (FE) models show that BABL/c mice also experience consistently greater deformation when subject to functional feeding-induced loads. Landmark and semilandmark based GMM analysis of the mandibles of two groups of C5BL/6 mice fed either rodent pellets (hard food; n=19) or ground pellets mixed with agar-agar (soft food; n=20) post-weaning documents pronounced differences in shape, most evident at regions of adductor muscle attachment and along the molar tooth row. The mandibles of hard food eaters have a larger
mechanical advantage than soft food eaters when biting at the molar and incisor region using either the
masseter or temporalis muscles (n=39). Second moment of area measurements show that hard food eaters
also have greater resistance to bending and torsion along the length of their jaws than soft food eaters
(n=39). Finally, FE analysis indicates that hard food eaters have lower feeding-induced stresses in their jaws
than soft food eaters (n=4). Genetic and environmental controls on form result in differences in function, and
environmentally driven plasticity leads to adaptive changes that increase the efficiency of food processing in
hard-food eating mice.

C-085
LOCAL VARIATION IN FUNCTIONAL MORPHOLOGY OF THE FEEDING SYSTEM OF TWO
HAPLOCHROMINES CICHLIDS FROM LAKE KIVU (RWANDA)
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Morphology and evolutionary of Vertebrates, Belgium
Eastern-African cichlids are characterized by a rapid adaptive evolution, where changes in trophic
morphology reflect one of the major levels of adaptive radiation. Less well known is to what degree these
patterns also exist at a more localized scale, where trophic divergences could reflect local adaptations of
populations within a single species to divergent ecological niches. This study aims to explore the relation
between the variation in the musculoskeletal shape of the feeding apparatus and morphology-based proxies
for functional performance in feeding, focusing on two sympatric species occurring throughout Lake Kivu
(Haplochromis kamiranzovu and H. insidiae). Both species show shape divergence between littoral and
pelagic populations, so we hypothesize that these differences reflect local adaptations to different feeding
niches (open water in the pelagic zone, versus benthic in the littoral zone). To test this, we compared
morphological evolution in musculoskeletal traits that are known to influence feeding performance, such as
jaw muscle size and attachment (lever system geometries), bite force estimates based on muscle
morphology, and kinematic transmission coefficients for jaw protrusion. Preliminary data shows that in both
species head shape variation and feeding performance exhibits differences at all levels: species, sex, region
(north -south) and habitat (littoral vs. pelagic). Most pronounced was the variation in the length of the
ascending arm of the premaxillary, the volume of the A2 jaw adductor muscle and the extension of the
preorbital region. The relation between the observed shape differences and the differences in habitat is
further discussed.

C-086
EVOLUTIONARY CONVERGENCE AND PARALLELISM IN SUCKERMOUTH CATFISH FAMILIES:
SURPRISINGLY ALTERNATIVE WAYS TO PERFORM THE SAME VITAL TASK: DON’T LET GO!
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Among freshwater teleosts living in fast flowing rivers, various groups evolved a bizarre-looking sucker
mouth with substrate-scraping jaws and teeth pointing externally. This sucker mouth enables them to adhere
to substrates when the current is heavy. The best known of these, the armoured neotropical suckermouth
catfishes or Loricariidae, have been shown to possess an intricate system of differentiated muscles serving
the mouth tissues to create a suction disk allowing respiration during fail-safe attachment. The current
research has investigated the anatomy and performance of two other families that evolved in either a
parallel or a convergent way. High-speed recordings, kinematic analyses, and detailed comparative
morphology have been combined to tell the story of these more-than-lookalikes. Astroblepidae, or naked
neotropical suckermouth, are sister family to Loricariidae, living in the high Andes of South America where
loricariids seldom come. Sharing the same ancestral anatomical tools, Astroblepidae evolved a drastically
different system for suckermouth attachment, enabling them to perform the same tasks of respiration and
simultaneous mouth attachment. An alternative inspiration system (with incurrent gill opening) and different
anatomical organization of the suction disk might perform even better, but has less jaw mobility. Across the
Atlantic, Chiloglanidinae, the African suckermouth catfishes of the Mochokidae family, live in their own fast-
flowing rivers. Having started from a vastly different ancestral anatomy, they did evolve a strikingly
convergent sucker mouth. Examining their kinematics, and looking at their inside, it became clear that their
attachment system is powered by a different set of tools, taking advantage of the complex and apparently
versatile mochokid anatomy. Having more barbels, other muscles are available for fine control of the suction
disk, enabling them to do in Africa, what Loricariidae and Astroblepidae do in South America.

C-087
PHYLOGENETIC DISTRIBUTION OF THE PALATAL ORGAN ACROSS CYPRINIFORMES
C-088
EVOLUTION OF MORPHOLOGICAL DIVERSITY IN THE JAWS AND HYOID APPARATUS OF EXTANT SHARKS
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Morphological variation in the jaws and jaw suspension determines the mode of feeding in fishes. Sharks exhibit four principal feeding types: suction feeding, filter feeding, biting and crushing (with combinations and grades possible between these types). Thanks to pioneering biomechanical studies in a variety of shark species, correlations of jaw and hyoid arch morphology with feeding type are increasingly well understood. This knowledge, coupled with a manageable diversity of sharks (approx. 500 species), and improved phylogenies, provide an excellent system for understanding the evolution of ecomorphological diversity in marine vertebrates.

The goals of this research are: (1) to document the diversity and range of morphological characters relevant to feeding mechanics in modern shark species; (2) document the phylogenetic distribution of jaw and hyoid arch shape in sharks. We use computed tomography (CT) scanning to generate 3D-reconstructions of the jaw and hyoid apparatus of 47 modern shark species covering 16 families. Using 3D-morphometrics, we quantify features of the elements of jaw and hyoid arch that include length, width, height, ridges for the attachment of muscles and ligaments. This allows us to study keys aspects of feeding mechanics such as bite force and closing speed of the jaws, protrusion of the jaws and expansion of the buccal chamber and to study whether morphological groups can be distinguished. By combining this with phylogenetic comparative methods and ecological parameters this research shows functional evolutionary patterns of shape diversity within the feeding system. We can study the separation of morphological groups and whether these groups are highly correlated with phylogeny or show patterns of convergent evolution.

C-089
THE FEEDING EXPERIMENTS END-USER DATABASE (FEED) AND AN ONTOLOGY FOR THE OROPHARYNGEAL MUSCLES AND BEHAVIORS OF MAMMALS
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Anatomical Record, Volume 296, Special Feature — 214
The Feeding Experiments End-User Database (FEED, http://www.feedexp.org) is a multi-species mammalian database that includes EMG, bone strain, bite force, sonomicrometry, and kinematic data collected during feeding behaviors. FEED utilizes a controlled vocabulary of terms for mammalian feeding muscles and feeding behaviors developed through the efforts of the NESCent Mammalian Feeding Physiology Working Group. An important goal of the FEED project is to enable cross-mammalian analyses of character evolution for feeding physiology traits. Toward this goal, FEED will allow scientists to target many important questions about, for example, primitive states for feeding physiology in major groups, including the primitive mammalian feeding pattern; phylogenetic nodes that contain major changes in feeding physiology; the extent of convergence and parallelism in feeding physiology; rates of evolution in physiological variables versus those seen in anatomical structures; and scaling patterns among physiological and anatomical variables. To facilitate our ability to computationally address these and other questions, we have created an ontology for oro-pharyngeal muscles and behaviors (http://code.google.com/p/feedontology/). This ontology contains classes that refer to anatomical structures, behaviors, and other entities involved in feeding, each of which is given a unique identifier and an explicit definition that is interconnected to other entities by logically defined relationships. This structure enables connections and queries across the FEED ontology and other ontologies with which it is integrated, such as Uberon (cross-species anatomy), GO (Gene Ontology), and MA (Mouse Anatomy), as well as the FEED database. Our goals with the FEED ontology are to facilitate the use of FEED across the scientific community and to contribute to the growing framework of ontologies and databases for organizing and analyzing biological data across disciplines and domains. Supported by NSF DBI-0960508, NSF - DBI 1062350, EF-0423641, and a Collaboration Exchange Grant from Phenotype RCN to RED.

Contributed 14 – Locomotion

C-090
Limb and body mechanics of small arboreal primates: Integration of footfall timing, limb stiffness and whole-body forces
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Body mechanics in quadruped mammals depend on a variety of parameters: the timing of the limb contact phases, timing and magnitude of peak forces at each limb, limb compliance, and limb stiffness. The present study examines gait parameters, limb compliance and limb forces in four species of small arboreal primates (mouse lemurs, pygmy lorises, cotton-top tamarin, and squirrel monkeys) to further understand how variation in limb mechanics influences the mechanics of the whole body. Primates are all but uniform in their locomotor modes and the underlying biomechanics, and therefore, they constitute an interesting example to study how natural variations in locomotor parameters, being relevant for whole-body mechanics, influences the variation of the energetics of the center of mass. Data on limb kinematics were obtained by videoradiography. Substrate reaction forces were recorded simultaneously. It turns out that the relationship between maximum limb flexion and limb force differs considerably between forelimbs and hindlimbs. The effective stiffness of the hindlimb is nearly twice the effective forelimb stiffness. Furthermore, the forelimb displays an almost linear spring-like behavior - maximum limb flexion coincides with peak vertical force - while the hindlimb shows a distinct non-linear behavior. Combined with variations in diagonality (the overlap of contact phases), the animals use this differential limb stiffness to adjust whole-body forces in such a way that vertical oscillations of the trunk are minimal. This appears to be one of the mechanisms that are responsible for the compliant and stable locomotion of primates in their discontinuous arboreal habitat.

C-091
Parametric modeling of human gradient walking for predicting the minimum energy spent and energy saving strategies
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The energetic cost of human walking is minimal at a gradient of -10%. Evaluation of oxygen consumption and other experimental results show that minimum energetic demand does not depend on walking velocity. The fact that efficiency is different in positive and negative work is a proposed explanation for these results. In this work a simple model that analyzes the energetic spent in terms of potential energy during locomotion is presented. The model is based on the oscillatory trajectory of the center of mass during human walking and predicts the minimum energetic cost at around -10% gradient correlating this minimum directly with the vertical oscillation of the center of mass. A parameter is introduced as a function of step length, showing that the minimum energetic cost can slightly vary with step length and therefore energy saving strategies rise by adequately adjusting the step length with certain gradient.
C-092
INVERSE DYNAMICS ON ROCK CLIMBING WITH AND WITHOUT MEASUREMENT OF CONTACT FORCES
Courttemanche, Simon (1); Provini, Pauline (2); Kry, Paul (3); Martin, Olivier (2); Reveret, Lionel (1)
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Rock climbing involves complex interactions of the body with the environment. It represents an interesting problem in Biomechanics as multiple contacts in the locomotion task make it an underconstrained problem. In this study we are interested in evaluating how a climber transfers weight through the holds. The motivation of this study is also technical as we are developing an inverse dynamics method that automatically estimates in 3D, not only the usual torques at joint angles, but also the wrenches at contacts. An artificial climbing wall has been equipped with force and torque sensors at six holds for short performance along a 2.5 m height course. Six subjects have been studied on various hold configurations. Kinematics data of the whole body have been recorded with an optical marker-based system (Optitrack). We use the inverse kinematics software of this system to deliver trajectories for joint angles. We compare the results for force contact estimation of our inverse dynamics method with ground-truth measurement from the sensors on the wall. Once contacts are known, torques at joint angles can be deduced. We also compare the results of our method for torque estimation at joints with results from the OpenSim software. In order to complete the validation, we plan to compare these results with EMG measurement of corresponding muscles.

C-093
FOOTPRINTS, FOOT POSTURE AND BODY WEIGHT DISTRIBUTION IN MAMMALS
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This paper presents the results of a research on the scaling between mammalian track dimensions, represented by footprints, against body mass. In order to obtain a comprehensive view of the subject, three different questions were assessed, namely: firstly, how do footprint dimensions increase with body mass?; secondly, does footprint dimensions increase in a different way according to changes in foot posture?; thirdly, given the differential body weight distribution, do footprint dimensions increase differently in fore and hind feet? We studied the footprint dimensions in a large sample of extant terrestrial mammals from data previously published. Altogether 249 tracks from the same number of species, belonging to 11 orders (Carnivora, Proboscidea, Tubulidentata, Perissodactyla, Artiodactyla, Rodentia, Primates, Lagomorpha, Insectivora, Xenarthra, Didelphimorphia) were analysed. With them, the following regressions were calculated: Fore footprint length and width against body mass; hind footprint length and width against body mass; finally for both footprints the product length times width was calculated and regressed to body mass; this product was considered proportional to the surface area of the footprint. Body masses were available for every specimen and used as an independent variable. Both length and width scaled with exponents not significantly different from 0.33, in all the cases, with the only exception of the length of the fore footprint of ungulates. Regarding surfaces, variability was higher. In plantigrades either fore or hind footprints scaled with exponents significantly lower than 0.66, while in unguligrades the allometric coefficients were not significantly different from 0.66. Concerning digitigrades, while the scaling of the fore footprint fitted the theoretical prediction (0.66), the allometric coefficient of the hind footprint was significantly lower than 0.66.

C-094
INTERVERTEBRAL AND PELVIC MOTIONS IN DOGS DURING LOCOMOTION
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Compared to our understanding of limb movements in mammals, our knowledge of the movements of the axial system, especially the intervertebral movements that occur during locomotion, is small. To quantitatively analyze the three dimensional (3D) vertebral and pelvic motions in dogs, we used the non-invasive Scientific Rotoscopy method (X-ROMM). Using a digital high-speed, high-resolution system, we recorded X-ray videos of three Beagles while trotting on a treadmill. X-ray videos were simultaneously recorded in two planes with 500 frames per second. Polygonal 3D models of the vertebrae and pelvis were reconstructed and linked by defining virtual joints (VJ) between the bones to form a hierarchically skeletal marionette. Careful rotations of the VJ’s allowed the exact alignment of the 3D bone models to the pelvic and vertebral positions seen in the x-ray videos. In accordance with previous kinematic data from horses, we
observed biphasic motions of the pelvis in the sagittal plane with a range of motion (ROM) of 10 degrees. This motion pattern could be traced up to the last two presacral intervertebral joints (S/L7, L7/L6) via the according extensions and flexions with a ROM of up to 5 degrees. In the horizontal plane, monophasic motions of the pelvis and the last four intervertebral joints (S/L7-L5/L4) were measured; the ROM of the pelvis and the intervertebral joints was up to 6 degrees. Monophasic motion patterns were also recorded in the transverse plane with a pelvic ROM of 12 degrees. This long-axis rotation was traceable up to the last intervertebral joints and changed more cranially into a biphasic pattern. With this study, we quantify the intervertebral and associated pelvic movements for the first time and provide novel, non-invasive, in-vivo 3D data for their motion patterns.

C-095
THE RELATIONSHIP BETWEEN MUSCLE CROSS-SECTIONAL AREA, DISTRIBUTION AND LOCOMOTOR PERFORMANCE IN LIZARDS
Scales, Jeffrey; Butler, Marguerite
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Locomotor performance is vital to the fitness of many terrestrial vertebrates. Therefore, determining what defines locomotor performance is an integral part of understanding the evolution of morphology, physiology, and behavior of vertebrates. Recent work suggests that the amount of force and the rate at which force is applied to the ground may limit performance, indicating that force production is a key driver of performance abilities. The cross-sectional area (CSA) of a muscle is a significant determinant of peak force production capabilities, suggesting that CSA may influence performance abilities. However, few studies examine how muscle CSA actually impacts performance, especially in a comparative context. Here we examine how the CSA of muscles of the hindlimb are related to acceleration, sprint speed, and exertion in 21 species of lizards. We find that total muscle CSA scales isometrically in these lizards, with increases in both stance and swing phase musculature. Furthermore, speed and acceleration, but not exertion, increase with CSA, and the CSA of stance phase muscles better predicts speed and acceleration abilities than swing phase muscles. Fast lizards show increased stance phase CSA, but the distribution of CSA across joints varies, suggesting that there is more than one way to achieve high speeds and acceleration. We conclude that muscle CSA plays an important role in defining some, but not all performance capabilities, and that there may be multiple muscle designs to achieve similar performances.

C-096
MUSCLES ATTACHING TO THE XENARTHRAN 3RD TROCHANTER REDUCE CORONAL PLANE BENDING IN THE FEMUR
Milne, Nick [1]; O’Higgins, Paul [2]
Armadillos and their fossil relatives the glyptodonts have a 3rd trochanter projecting from the lateral side of their femur. In small armadillos the 3rd trochanter projects from the proximal part of the femoral shaft, in larger armadillos and small glyptodonts it projects from halfway down, but in large glyptodonts it projects from the distal end of the femoral shaft. This study used finite element analysis to examine coronal bending in two Xenarthran femurs. The armadillo (Chaetophractus villosus) weighing about 3 kg and the fossil glyptodont (Neosclerocalyptus) estimated to weigh about 300 kg. The modeling sought to reflect the stance phase in the hindlimb where both longitudinal forces (the body mass and net muscle action), and the abductor muscles, (the lesser gluteals, acting on the greater trochanter) produce coronal plane bending strains in the femoral shaft. The addition of forces acting on the 3rd trochanter (Gluteus maximus and tensor fascia lata) was able to reduce or reverse the coronal plane bending. In the glyptodont the forces applied to the 3rd trochanter were much more effective in countering the bending due to longitudinal and abductor muscle forces. This suggests that the more distal position of the 3rd trochanter in larger Xenarthrans is an adaptation to deal with their larger body mass. This study also demonstrates the utility of geometric morphometrics to interpret and display the results of finite element analyses.

C-097
TURNING IN GUINEAFOWL: MOTION AND MOMENTS
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In extant animals, maneuvering plays a crucial role in navigating complex terrain, finding food, and escaping predators. Despite its importance, maneuvering’s complexity and intermittent nature have resulted in little study compared to steady locomotion. For this research, we used the helmeted guineafowl (Numida meleagris) to examine turning, both starting from a standstill as well as sharp turns performed while walking.
forward. We used marker-based XROMM and explicit Joint Coordinate Systems to acquire high-resolution six degree of freedom joint kinematics from animated bone models. Birds yawed their body relative to a planted foot primarily using long-axis rotation (LAR) of the tibiotarsus, with smaller excursions of femoral LAR to coordinate pelvic roll. We collected simultaneous ground force data for some of these trials. Results from inverse dynamic analysis demonstrate the importance of LAR moments during maneuvers. In fact, LAR moments dominate flexion/extension moments during some phases of the turns. Integrating joint kinetics with limb kinematics remains an ongoing challenge, but our representations of 3D moments animated with the moving skeleton are helpful for visualizing these dynamic relationships. Given that neither the hip nor the knee is hinge-like, our data provide a 3D perspective on the articular morphology, soft tissue anatomy, and range of motion of these joints. For instance, relatively narrow femoral condyles and long collateral ligaments may promote large excursions of tibiotarsal LAR at the knee while still limiting ab/adduction. Similarly, the second articulation at the hip between the femoral neck and antitrochanter appears to facilitate, rather than prevent, femoral LAR. We hypothesize that almost complete reliance on LAR is an avian feature not found in basal therropods. Extinct forms with a more vertical femur likely used a combination of abduction/adduction and femoral LAR at the hip during turning, with corresponding differences in muscle action and ligament function.

C-098
JOINT RANGE OF MOTION ACROSS ONTOGENY IN THE BROILER CHICKEN
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Intensive artificial selection on the broiler chicken for increased body mass (reaching ~3kg in 42 days) and pectoral muscle mass (accounting for ~18% body mass) has led to dramatic changes in appearance and altered walking ability. Walking ability in modern broiler chickens appears to decline progressively with age, but there is much debate about which factors actually impair their ability. Suggestions include problems due to morphology and posture, pathology and pain. Here we consider whether limitations in joint range of motion impair the walking ability of broilers. To address this question, first we collected kinematic data for walking gaits from a total of 30 chickens across ontogeny (at 2, 4 and 6 weeks of age; 15 trials per bird).
Second, we measured joint range of motion (both sagittal and frontal planes; with and without the pelvic limb muscles removed) by manual manipulation of the joints using cadaveric specimens (5 trials per joint, per plane; total of 30 trials per bird). We then quantified the extent that joint range of motion changes across ontogeny in the hip, knee and ankle joint of the pelvic limb, and detail how this is restricted by the passive support structures and muscles that support each joint. We then compare our results to our joint range of motion data collected from broiler chickens during walking, to establish what percentage of their maximal range of motion is used for locomotion. This illuminates underlying causes of reduced walking ability in broiler chickens, an important first step in improving their welfare.

Contributed 15 – Feeding
C-099
A MORPHOLOGICAL-KINEMATIC STUDY ON THE ATTACHMENT AND THE BREATHING AND FEEDING MECHANISMS IN BALITORINAE (CYPRINIFORMES, TELEOSTEI)
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Balitorinae, subfamily of Balitoridae, are freshwater fishes native to Eurasia. These species live in rapid flowing water; their general morphology is characterized by an anterior flattened body and horizontally inserted pectoral and pelvic fins that are broadly and rostrocaudally expanded, and can as such be used as sucker-like adhesive organs. The main focus of our study is to find out how these animals are adapted to their environment by characterizing in detail the anatomical structures used for attachment, respiration and feeding. Therefore, we observed four species: Beaufortia leveretti, Sewellia lineolata, Pseudogastromyzon myersi and Gastromyzon punctatus, of which specimens were used for clearing and staining and/or serial sectioning. A kinematic study was also performed on S. lineolata, P. myersi and B. leveretti. This allows finding out how structures such as fins and head parts are involved in the attachment in both still and fast flowing water and also makes it possible to reveal different actions during feeding stages. We found that the different species use their whole body, including their pectoral and pelvic fins, for attachment on the substrate. Inflow of water is generated by an upward movement of the upper snout, while outflow seems to be often supported by pectoral fin movement. This type of attachment can be adaptive to the environment, as the animals don’t show differences in breathing performance while being in still or flowing water. A comparison of the morphologies with closely related taxa who do not show these peculiar traits, such as Cobitidae, is made. This allows the identification of unique features related to the Balitoriniae.
C-100
OPEN WIDE: THE ROLE OF LATERAL MOUTH EXPANSION DURING SUCTION FEEDING IN LARGEMOUTH BASS
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Brown University, Providence, United States
Most bony fishes capture food with suction, using explosive expansion of the mouth cavity to generate flow and accelerate prey into the mouth. Suction expansion must be both fast and forceful, and so should require substantial muscular power. Expansion of the mouth cavity is driven by three musculoskeletal modules. The dorsal and ventral expansion modules increase the dorsoventral height of the mouth cavity through neurocranium elevation and hyoid depression and retraction, respectively. The lateral expansion module increases the mediolateral width of the mouth cavity through abduction of the suspensoria. However, we know little about how these three modules work together to generate suction expansion. The skeletal kinematics of the lateral expansion module have been difficult to quantify, as they are non-planar, involving both lateral abdution of the suspensoria and caudal translation of the hyoid apparatus. We quantified the skeletal kinematics of the lateral expansion module, and its relation to the total volume change and power of suction expansion. We measured 3D skeletal kinematics, muscle shortening, and intraoral pressure during suction feeding in largemouth bass (Micropterus salmoides). Skeletal kinematics were measured using X-ray Reconstruction of Moving Morphology (XROMM), which combines biplanar x-ray video with 3D bone models to generate 3D animations of skeletal motion. Instantaneous mouth cavity volume was calculated from these XROMM bone model animations. Muscle shortening was measured with fluoromicrometry, which uses biplanar x-ray videos to record distance changes between intramuscular markers. Lateral expansion increased mouth volume through coupled lateral flaring of the suspensoria and ceratohyals. These motions appeared to be linked to neurocranium elevation and hyoid retraction (respectively), suggesting that the dorsal and ventral modules may contribute power for lateral expansion. These results show the importance of all three expansion modules in generating power and volume change during suction feeding.

C-101
FUNCTIONAL CONSEQUENCES OF PHARYNGEAL JAW VARIATION IN CYPRINIFORM FISHES
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The pharyngeal jaw apparatus (PJA) is a second set of jaws behind the gill arches that allows fishes to separate organic and inorganic matter, manipulate prey, and process food items. These jaws promote trophic diversity by decoupling feeding and processing events, thus providing an opportunity for different prey types. Cypriniformes is a diverse clade of over 4,000 freshwater fishes that occupies various trophic niches and is characterized by a novel PJA that has significantly hypertrophied ceratobranchials 5 and a loss of the upper pharyngeal jaws, a feature seen only at the base of this group. The examination of PJAs across cypriniform fishes reveals considerable variation of both pharyngeal jaw shape and associated musculature. Furthermore, exploring pharyngeal jaw muscle physiology of cypriniform species depicts distinct differences in muscle fiber-type profiles. Here, we examine the use of the cypriniform PJA during prey processing in two species that exhibit distinct pharyngeal jaw morphologies by employing sonomicrometry to interpret the kinematics of this novel biomechanical system. Using the positional relationships of five piezoelectric crystals we monitored the movements of the lower pharyngeal jaw in transverse and sagittal planes for goldfish (Carassius auratus) and sailfin suckers (Myxocyprinus asiaticus) to account for phylogenetic, morphological, and behavioral differences, with goldfish being a member of Cyprinidae and sailfin a member of the other major clade, Cobitoidea (catostomids), for which there is currently no published functional work. Goldfish predominantly use the pharyngeal jaws for crushing and grinding, while catostomids presumably use these jaws with less force. Statistical analyses reveal that morphological differences seem to impact processing behaviors. For example, the catostomid generates more chewing cycles per processing event, has a longer total duration time, and exhibits less lateral and dorsal excursions than the cyprinid species. These results suggest that pharyngeal jaw variation has important impacts on processing behaviors.

C-102
SENSORY CONTRIBUTIONS TO PREY CAPTURE KINEMATICS IN SHARKS
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Anatomical Record, Volume 296, Special Feature — 219
The kinematics of prey capture in fishes may be modified in response to changes in pre-strike sensory information. The ram-feeding largemouth bass, *Micropterus salmoides*, switches to more suction-based feeding when deprived of visual cues. This species, like many bony fishes, possesses the morphological characteristics of both ram and suction feeders and can modulate the kinematics of capture by decreasing its forward motion to decrease ram or by opening the mouth more rapidly to increase suction. In contrast, many sharks are morphologically suited for one feeding modality more than the other. In this study, three species of sharks were filmed with high-speed videography while feeding on live prey. The sharks were examined intact and after deprivation of information from the senses (olfaction, vision, mechanoreception, and electroreception), alone and in combination, to elucidate their contributions to the kinematics of prey capture. In response to sensory deprivation, the ram-feeding blacktip shark, *Carcharhinus limbatus*, modulated by changing the amount of ram, while suction remained unchanged and unlike ram-feeding bony fish, they do not switch feeding modalities. Little to no modulation was found in the ram-biting bonnethead shark, *Sphyrna tiburo*. The suction-feeding nurse shark, *Ginglymostoma cirratum*, modulated by changing the amount of ram and opening the jaws more rapidly, but the suction distance was unchanged, which suggests that it may be nearing the functional limitations of suction generation. These results suggest that prey capture is less plastic in elasmobranchs than in bony fishes, possibly due to anatomical differences, and that modulation in response to pre-strike sensory information varies by species, rather than by feeding modality.

**C-103**
**FEEDING BIOMECHANICS IN BILLFISHES: INFERRING THE ROLE OF THE ROSTRUM DURING FEEDING IN TWO BILLFISH SPECIES**
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Perhaps the most striking feature of billfishes is the extreme elongation of the cranial bones comprising the rostrum. Surprisingly, the role of this structure remains controversial as knowledge of the behavioral, structural and material characteristics of this skeletal cantilever are lacking. This study investigates the rostrum from functional, biomechanical and morphological standpoints in order to infer the rostrum’s potential role in the feeding behavior of the swordfish *Xiphias gladius* and blue marlin *Makaira nigricans*. Mechanical testing was performed to estimate stress and stiffness during dorso-ventral and lateral loading. CT scans were used to calculate moment of inertia, polar moment of inertia, and radius of gyration along the rostrum to assess its ability to resist bending, torsion, and buckling. The internal structure of the rostrum was histologically investigated as well. Results showed that stress distribution remained roughly constant along the bill from tip to base by virtue of increasing second moment of area (a geometric description of bending resistance). This was inversely related to the gradient of Young’s modulus (tissue stiffness), which decreased towards the rostrum’s base. Comparing different loading directions for each species, the flexural stiffness in swordfish was considerably higher in the lateral plane suggesting this species may be more likely to strike its prey with lateral movements. In contrast, blue marlin flexural stiffness was similar in both directions suggesting a larger range of motions may be used by this species during feeding. Blue marlin’s bill showed the highest values of flexural stiffness between species during dorso-ventral loading, its rostra required considerably higher loads to reach similar displacements. Histology revealed acellular bone as the principal component of the rostrum, with contributions of hyaline cartilage and adipose tissue becoming increasingly prominent closer to the base. Biomechanical parameters and their implications for feeding are discussed.

**C-104**
**IN VIVO MEASUREMENT OF CRANIAL KINESIS IN GEKKO GECKO USING XROMM METHODOLOGY**
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Ohio University, Athens, United States

Kinetic skulls are characterized by moveable joints within the cranium. While cranial kinesis is a variable feature among vertebrates, the skull of gekkotan lizards is a textbook model for studying cranial kinesis. However, most evidence for cranial kinesis is extracted from manipulating skeletal specimens and experimental data quantifying kinetic movements are rare. Because of the lack of *in vivo* evidence, the ecological relevance of cranial kinesis (i.e., biological role) remains poorly understood. We used the X-ray Reconstruction Of Moving Morphology (XROMM) methodology to quantify mesokinesis, or the movements of the snout with respect to the braincase, in *Gekko gecko* during three routine behaviors: mouth-gaping displays, aggressive biting, and feeding. We chose *G. gecko* because (i) cranial kinesis has been documented in this taxa, and (ii) they are territorial animals that use gaping display and biting to protect their...
C-105
ADAPTATION AND MOTOR LEARNING DURING MAMMALIAN SWALLOWING
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Many factors account for variation in motor function. One factor that has received little attention for feeding systems is motor adaptation, or changes in motor function determined by the CNS in response to sensory challenges. Motor adaptation is an adjustment in movements in a trial-and-error manner in response to a perturbation. It is sometimes called “feed-forward learning” because it requires prediction of consequences in advance of the movement. We tested for the existence of motor learning in both adult and infant swallowing. The standard test for motor learning consists of 1) measuring control baseline; 2) with perturbation, an initial drop below baseline, and followed by a return to baseline and 3) after perturbation, a overshoot of baseline. For both adults (n=8) and infants (n=6), feeding was recorded with videofluoroscopy. In adult humans, we used stimulation of the infrathyroid muscles to make swallowing, as measured by hyoid movement, more difficult. In infant pigs, we anesthetized the hard palate to reduce the sensory information necessary for swallowing, and measured jaw and hyoid movement. The humans were drinking water and the pigs were suckling milk. The adult human data had significant changes for all three criteria, a drop in performance, a return to baseline, and an aftereffect when the perturbation is removed. In the infant pigs, the data show a more complex picture, with motor learning occurring in three of six individuals. These results are evidence of (implicit) motor learning in both adults and in some infants. The differences between adults and infants are likely due to problems in experimental design in the infant study.

C-106
THE ENERGETIC COSTS OF FEEDING IN SMALL-BODIED PRIMATES AND AN ANALYTICAL FRAMEWORK FOR INTERPRETING FEEDING ENERGETICS
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What are the energetic costs of feeding in primates? These costs reflect the mechanical environment during feeding and may be an important selection pressure on morphology and daily energy use. We present data on the energetic costs of feeding in several small-bodied primates (60g–1.2kg), and test the hypothesis that the energetic costs of feeding are correlated with food properties and food preparation prior to mastication. This work is part of a larger study of feeding energetics in primates ranging in size from 60g to 80kg. Our goals are to determine interspecific scaling of feeding costs, and to relate costs to dietary parameters and morphological features of the feeding apparatus. Data were collected for Loris tardigradus (n=1), Microcebus murinus (n=2), Hapalemur griseus (n=4) and Saimiri sciureus (n=3). Rates of O2 consumption and CO2 production were measured while each individual sat in a respirometry chamber and fed. Comparisons were made for foods varying in size and material properties (mealworms, fig, carrot, bamboo, and almond). Mass-specific, net feeding cost (W/kg) was determined by subtracting resting metabolic rate. The lowest feeding costs were for mealworm in Loris and Microcebus (0.4–1.8 W/kg). In Saimiri, large figs cost a similar amount to consume as smaller but relatively tough foods (fig mean=3.4 W/kg, carrot mean=3.3 W/kg, almond mean=3.5 W/kg). The feeding cost for whole objects was greater (>20%) than the cost of chewing alone (e.g., almond whole vs. thin slices) indicating that food preparation is an important contributor to feeding costs. These results suggest that food preparation, size, and material properties correlate positively with the metabolic costs of feeding. We present a framework for interpreting feeding energetics in terms of energy input and output efficiencies and morphology. Supported by NSF BCS-1062239.

C-107
FUNCTIONAL SPECIALIZATION IN SEXUALLY DIMORPHIC SKELETAL MORPHOLOGY IN GRAY WOLVES (CANIS LUPUS)
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Sexual selection theory predicts that male mammals will be more specialized for physical competition than females. Specialization for aggression, however, may result in functional conflicts with locomotor demands. Characters associated with locomotor economy include long, gracile limbs that reduce the cost of transport by increasing stride length and decreasing the energy required to swing the limbs. In contrast, specialization for aggression appears to result in stout bones and large distal muscles with high mechanical advantage that increase force available to strike or manipulate opponents. Gray wolves (Canis lupus) are highly cursorial animals, traveling immense distances to locate and run down prey. Gray wolves also aggressively defend territory through direct competition and kill much larger, highly dangerous prey species. Because both sexes actively participate in these activities, a low level of musculoskeletal sexual dimorphism is expected. However, males often lead in aggressive encounters with conspecifics and, for a period during the mating season, must kill prey without the assistance of the dominant female to provision her and their offspring. Thus, male wolves may exhibit a higher degree of morphological adaptation associated with aggressive activities. To assess sexual dimorphism in gray wolves, a series of skeletal metrics were taken from fresh cadavers and museum specimens of three subspecies. All measures were size-corrected and analyzed to detect relative differences in size and shape. Males were found to have broader skulls or necks in all subspecies, consistent with greater specialization for aggression. In postcranial morphology, however, a continuum of dimorphic traits were found, possibly reflecting differences in selective pressures on pursuit versus handling capabilities based on prey size and distribution. These results indicate differences in sexually dimorphic morphology among subspecies of gray wolves.

C-108
CHARACTERIZATION OF NEURAL STEM/PROGENITOR CELLS DURING TAIL REGENERATION IN THE LEOPARD GECKO (EUBLEPHARIS MACULARIUS)
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An emerging model for the study of spinal cord regeneration is the leopard gecko (Eublepharis macularius). Following tail loss, this species can spontaneously restore a functional spinal cord. We hypothesize that a population of endogenous neural stem/progenitor cells (NSPCs) in the original spinal cord are the source of the regenerated spinal cord. Using immunohistochemistry we conducted a spatiotemporal characterization of original and regenerating tails with a focus on the spinal cord. In particular, we documented expression of: (1) proliferating cell nuclear antigen (PCNA), a marker of proliferation; (2) Sox2, a transcription factor known to be expressed by NSPCs; and (3) Sox9, a transcription factor known to play a role in the maintenance of NSPCs. Tail regeneration begins with the formation of a blastema, a mass of mesenchymal-like cells distal to the original spinal cord. Outgrowth of the blastema is matched by outgrowth of the ependymal tube, a structure continuous with the original spinal cord. Our results show that blastema cells and cells of the ependymal tube are immunopositive for both the proliferation marker PCNA and the neural stem cell marker Sox2. Blastema cells and a subpopulation of ependymal cells show overlapping expression patterns for both PCNA and Sox2. Both of these markers continue being expressed by a subset of cells throughout regeneration in both the original and regenerating tail segments, including individual ependymal cells. The transcription factor Sox9 is not expressed until the later stages of regeneration, and is primarily restricted to a subset of ependymal cells within the regenerating tail. Our findings point towards ependymal cells as a key contributor to the regenerating spinal cord and mark the first demonstration of neural stem/progenitor cell markers during lizard tail regeneration. Our data are consistent with those of other neural regeneration model species, suggesting a conserved role for NSPCs among vertebrates.

C-109
PREDICTING OPHIDIAN ECOLOGY FROM VERTEBRAL MORPHOLOGY
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The fossil record of snakes is primarily composed of isolated vertebral remains, which has made study of various aspects of snake evolution and paleobiology difficult. Here I present a study of the relationship between vertebral morphology and the ecology of extant snakes to assess the possibility of identifying the ecology of extinct snakes using isolated vertebrae. A sample of 45 snakes was selected to include the range of snake phylogenetic and ecologic diversity. In each snake 17 measurements were made on vertebrae at 5%, 10%, 15%, 30%, 50%, 75%, and 100% of precaudal vertebral number. The data for each vertebral position were then analyzed separately using a phylogenetic flexible discriminant analysis, grouping the snakes in one of four ecological categories (arboreal, aquatic, fossorial, or terrestrial). The results
successfully separated snakes by ecology for each vertebral position, with misclassification rates below 22% in each case. To assess the robusticity of this method, extant snakes of known habitat preference were added to the data set as “unknowns” and their habitat preferences were predicted. This revealed the method to be sensitive to vertebral position. A small sample of fossil snakes was added to the data set to predict the habitat preference of these snakes. Some fossil species represented by vertebrae from multiple parts of the column were classified into two or more ecological categories, probably a result of poor alignment of serial identity and/or measurements affected by weathering. Potential difficulties with this method include precisely identifying the relative position of isolated vertebral remains within the spinal column. However, qualitative morphology can identify approximate region, and this problem is further mitigated by the gradual degree of morphological change in the column. This method may be strengthened by pairing with maximum likelihood methods of identifying the position of vertebrae within the column.

C:110
MOLECULAR PHYLOGENETICS AND MORPHOLOGICAL EVOLUTION OF MICROHYLID FROGS
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The third largest amphibian family in the world, the Microhylidae, has a global distribution with 523 known species of which over half (271) are found in Papua New Guinea and northern Australia. The Australo-Papuan microhylids demonstrate classic characteristics of an adaptive radiation but have been largely understudied. This group comprises a myriad of ecologies and morphologies not commonly seen in a single frog clade. Here, we propose that the group is comprised of six ecomorphs: arboreal species (~15mm SVL), scansorial species (~20mm SVL), terrestrial species (~30mm SVL), semi-fossorial species (~50mm SVL), fossorial species (~30mm SVL) and semi-aquatic species (~31mm SVL). We take a phylogenetic approach to study the evolution of morphology, specifically how they are distributed across the phylogeny, whether they have evolved independently, how many times they have evolved, and how conserved they are within independent lineages. We also present the most complete and robust phylogeny for the group, which has been notoriously difficult to resolve. Lastly, we would like to use these data in concert with performance data to study whether morphological diversity evolves as an adaptation to the environment.

C:111
A MORPHOLOGICAL STUDY OF THE FIRST CAUDAL VERTEBRA IN A GROUP WITH A NOVEL ROLE FOR THE TAIL
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The Macropodidae family is the group of Australian marsupials that have hopping locomotion. Kangaroos are the best known and largest of Macropodidae, but the family also includes small species such as quokkas. Although all members of this family use hopping locomotion there is a wide range of abilities and behaviours, which seem to be related to body size; the large kangaroos can hop economically at high speed over long distances. However, at low speeds hopping is energetically very inefficient and pentapedal locomotion is used, where the tail supports the posterior body weight while the hind limbs are raised simultaneously and moved forward. The smaller species can also hop bipedally at high speed but many also use their forelimbs in quadrupedal bounding, and at low speed they also use a slow quadrupedal bound or small bipedal hops. Their tails are relatively smaller and less muscular and are not used to support body weight. This spectrum of locomotor activity is also reflected in their crural index, where the larger species have indices above 2 and in the smaller species it is close to 1. In this morphometric study we use crural index, as a proxy for locomotor strategy and tail use, to investigate the shape changes in the first caudal vertebra of twenty five species of hopping marsupials. In the larger species with high crural index the first caudal vertebral body is longer and more robust, and its transverse process runs the full length of the vertebral body but is short and stout. These features seem to be related to the role of the tail in transmitting load, both as a fifth limb in pentapedal locomotion, and as a counterbalance in fast bipedal hopping.

C:112
MESOCOSM EXPERIMENTS VALIDATE AND COMPLEMENT LABORATORY DATA ON PLASTIC RESPONSES: INVASIVE TADPOLES’ INDUCIBLE DEFENSES AGAINST NATIVE AND INVASIVE PREDATORS
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Anatomical Record, Volume 296, Special Feature — 223
Laboratory experiments testing plastic responses are really useful due to the possibility of applying a tight control of certain variables. However, it has been argued that laboratory outcomes could be biased due to the artificiality of several features of the venue, which poses a trade-off between realism and experimental control. After an experiment testing plastic responses of tadpoles of the invasive anuran *Discoglossus pictus* (Anura: Discoglossidae) confronting native (dragonfly *Anax sp.*) and invasive (crayfish *Procambarus clarkii* and fish *Gambusia holbrooki*) predators in laboratory facilities, we tested the plastic responses of the same prey species confronting native backswimmers (*Notonecta sp.*) and common darter larvae (*Sympetrum striolatum*), but this time using mesocosms. To attain maximum realism, these mesocosms were previously filled with varied algae, macroinvertebrates, and a small number of competitors. Comparing outcomes from the two experiments using both linear and geometric morphometrics we detected some biased patterns due to venues. For instance, fin length and tail musculature of tadpoles were affected by venue according to our analyses. However, although tadpoles reared in mesocosms grew larger, control morphologies and most of the expected plastic responses against predators followed. On the whole, the same allometric patterns in both venues, confirming that *Discoglossus pictus* develops a plastic response to predators of its native range and a milder response to other invasive predators found in its current invasion zone. Thus, the additional data acquired in this second experiment and the use of both geometric and linear morphometrics have validated our laboratory outcomes, leading to a better interpretation of the anti-predator plastic responses of this invasive anuran.

C-113
LATITUDINAL MORPHOLOGICAL DISPARITY GRADIENT IN LACERTID LIZARDS (SQUAMATA, LACERTIDAE)
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The Old World lizard family Lacertidae displays a nearly inverse latitudinal species richness gradient, with its highest diversity in Mediterranean and southern African regions and its lowest diversity around the Equator. To test if taxonomic diversification in this group is matched by morphological variation, we estimated morphological disparity for each of the main clades based on external measurements of museum specimens. Surprisingly, the equatorial clade shows the highest morphological disparity despite its low diversity, followed by the African tropical savanna clades. The southern African arid clade is roughly equal to the paleartic Mediterranean and mesic temperate forms, creating a latitudinal disparity gradient in direct opposition to species richness patterns. To explore the role of ecological opportunity in morphological diversification, we projected phylogenetic relationships among clades into a phylomorphospace, revealing significant overlap in body shape among independent arid-dwelling taxa. Although arid clades are taxonomically diverse, their species are densely packed into a small morphological space, indicating little shape change during evolutionary radiation. To explore shape variation in greater detail, we also applied landmark-based geometric morphometrics to 3D computed tomographic models of lacertid skulls, since a large number of derived traits (>10) are found there. We again found large amounts of morphological overlap among arid-dwelling taxa, including enlarged orbits and nasals and a shortened postorbital region relative to the basal forms, giving an overall paedomorphic appearance. Given that some of these species are short-lived and appear to be "r-selected," we hypothesize that convergent body shapes among arid-dwelling taxa are driven by heterochronic processes and that the low dimensionality of arid and desert niches limits morphological disparity in this group. In contrast, the high morphological variability in body shape and skull morphology of the equatorial clade appears to be driven by arboreality of *Holaspis* and *Gastropholis*.

**Contributed 17 – Skeletal EvoDevo**

C-114
GENE REGULATION AND MORPHOLOGICAL EVOLUTION IN LIZARDS: A FIVE-DIGIT (OR LESS)
PROBLEM
Kohlsdorf, Tiana (1); Andrade, Fernando (2); Carvalho, Murilo (2); Dragalzew, Aline (2); Roscito, Juliana (2); Rodrigues, Miguel (2); Guimaraes, Pedro (1)
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Evolution of different autopodial morphologies likely results from changes in expression patterns of developmental genes. Such patterns are modulated by the differential activity of regulatory regions, which depends on the binding of specific transcription factors. The evolution of non-pentadactyl autopodia in vertebrates probably involved changes in the expression of the 5’Hoxd genes; these are modulated by several regulatory elements located in the Global Control Region, as the CsB. Here we investigated the association between variation in the CsB sequence and the evolution of different autopodial morphologies in
lizards, with special attention to cis-trans interactions. We found that variation in the CsB sequences of gymnophthalmid lizards translates into differences in predicted transcription factor binding sites (TFBS) between pentadactyl and non-pentadactyl species. In Gymnophthalmidae, extremely reduced autopodia have evolved in two lineages, the genus Bachia and three Gymnophthalmini genera. Within the TFBS identified in the CsB fragment analyzed, those for Gli3 and Tbx-5 were predicted in pentadactyl lizards, but the former was not identified in the sequences of Bachia, and the later was not predicted in the CsB of limb-reduced Gymnophthalmini. Variation in the CsB sequence also involved differences in the TFBS for Hox, Sox, Msc and Pax genes. Interestingly, when analyzed within a broader set of vertebrates (including mammals, birds, lizards, amphibians and coelacanth), the CsB sequences of pentadactyl tetrapods show TFBS for both Gli3 and Tbx-5, while binding sites for these two transcription factors were not predicted in the fragment of Latimeria. These results add to the growing knowledge on how changes in gene regulation are related to morphological transitions over evolutionary time.

C:115
USING OSTEOCYTES FOR GENOME SIZE EVOLUTION AND TERRESTRIALITY STUDIES
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Osteocytes and osteocyte lacunae provide a window into bone biology of long extinct organisms. A recent study, for example, demonstrated avian proteins in dinosaur osteocytes using avian antibody staining techniques. More conventional studies have focused on morphology, size and density of osteocyte lacunae in bone histological thin sections. Some authors neglected the three-dimensional aspects of bone, and therefore misinterpreted osteocyte sizes and lacunocanalicular organization. Here, we present guidelines for measuring osteocyte sizes, density and lacunocanalicular orientation in bone histological thin sections. Combining transverse and longitudinal sections of the same specimen provides a better insight in tissue types and the three dimensional organization of their osteocyte lacunocanalicular network. From these complementary views, accurate lacuna volume estimations can be made, and previously reported correlation of lacuna size with genome size can be assessed. Such genome size estimations in fossil taxa may allow reconstruction of large scale evolutionary patterns of genome size in various tetrapod groups (e.g., the large genome of salamanders and small genome of birds). Osteocytes have also been used in growth rate evolution studies. Osteocyte lacuna density (OLD) is one of the factors found to be correlated with growth rate in extant taxa. New results of OLD measured in highly organized primary bone tissues in midshaft femur sections show a strong negative correlation with body mass in most terrestrial amniotes. A general linear trend can be seen among amniotes, but sauropod dinosaurs form an exception. Sauropods are far offset from the trendline, having double the OLD of any other scaled up amniote. For now, it remains unclear why sauropods have such extremely high OLD. Small amphibians are different from amniotes, having extremely low OLD compared to amniotes of similar size. Possibly, their (semi-)aquatic lifestyle and low basal metabolic rate reduces selection for a more effective lacunocanalicular system maintaining bone homeostasis.

C:116
CAN ACELLULAR BONE REMODEL?
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A key to bone’s function as load-bearing skeletal material is its ability to withstand accumulation of microdamage from long-term cyclic loading, by replacing damaged tissue with new bone, a process called remodeling. Osteocytes —cells embedded in all tetrapod bones— play a major role in this, by ‘sensing’ local damage and releasing biochemical signals to orchestrate bone remodeling via osteoclasts and osteoblasts. It is therefore surprising that the bones of many fishes lack osteocytes; this “acellular” bone must possess either unique mechanisms to prevent tissue damage or remodeling capabilities not dependant on osteocytes. Billfish are a group of acellular-boned pelagic fish, characterized by elongated spear- or sword-like rostra, used to spear or stun prey during feeding. Given the large size and high swimming speeds of these fish, and the repeated cantilevered loading of their rostra throughout their long life spans, we expect bones to regularly experience very high, cyclic stresses and strains, and therefore require means to avoid failure from fatigue (microcrack) damage. To test this hypothesis, we characterized material properties of small beams of rostral and opercular bone samples from five species of billfish with distinct bill
morphologies, as well as bone morphology, structure and composition using a variety of imaging/analysis techniques. Except for the total lack of osteocytes, the microscopic appearance of billfish rostral bone bears striking resemblance to tetrapod secondary osteonal bone, with the typical appearance of overlapping “osteons” with distinct borders (reminiscent of cement lines) suggesting intense remodeling. Mechanical tests showed that billfish bone can be as stiff as mammalian cortical bone, although large inter-species variation exists (Young’s modulus: 8-22 GPa), probably related to the structural and compositional differences observed in our morphological study. These results confirm that acellular bone is capable of remodeling, and highlight previously undescribed morphological and mechanical diversity in this skeletal tissue.

C-117
COMPARATIVE MORPHOLOGY IS INTEGRATED WITH GENETICS AND DEVELOPMENT IN THE PHENOSCAPE KNOWLEDGEBASE
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Descriptions of the rich morphological diversity that characterize vertebrates reside primarily in the legacy literature. In contrast to rapidly increasing stores of genomic data, morphological data have been uncomputable, thus impairing the ability of investigators to integrate morphology across studies or link it to relevant genetic and developmental information. By using ontology-based methods to represent free text descriptions, the Phenoscope team has prototyped a knowledgebase (KB, kb.phenoscape.org) where the morphological variation of fish species is linked to genetic mutants of zebrafish (zfin.org). Using the reasoning enabled by the ontology-based structure, and assuming a high-level of conservation of developmental processes across taxa, candidate genes can be automatically inferred for morphological features that characterize clades and species. We selected two features that characterize Siluriformes (catfishes), the loss of scales and absence of basihyal, and we examined the KB-predicted tissue-specific expression patterns of candidates eda, edar, and brpf1 in the channel catfish, Ictalurus punctatus. As predicted, brpf1 and eda were not expressed in the appropriate tissues at the expected developmental stage. These data support the broad-scale utility of this approach to integrate genetic and phenotypic data in formulating devo-evo hypotheses. Morphological data in this computable format can be browsed, sorted and aggregated in ways that present unprecedented possibilities for data mining and discovery. Current work by the team includes development of methods for rapid retrieval of similar phenotypes (semantic similarity), scaling up taxonomically to include extinct and extant vertebrates with a focus on the fin/limb skeletal transition, and inclusion of genetics and phenotypes from mouse and Xenopus model organism databases.

C-118
FROM PHENOTYPE TO GENOTYPE (AND VICE VERSA) IN LIMB DEVELOPMENT
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The embryonic mouse limb is a classical model system for studying biological patterning and development. Over a period of 2-3 days, the mouse limb grows from a bulge of undifferentiated cells to a limb bud with 5 differentiating digits. Although this developmental process is widely conserved among vertebrates and detailed knowledge about genes participating in limb patterning is available, the genetic networks coordinating limb morphogenesis still remain obscure. Looking into the dynamics of gene expression domains across developmental time and assessing for covariance patterns between genes and limb morphogenesis in normal development may reveal underlying genetic interactions and suggest further functional and developmental relationships between genes and the limb bud. We analyzed limb bud morphology in association with the gene expression domains of two relevant genes for proximo-distal limb patterning, Hoxa11 and Hoxa13, in large samples of C57Bl6 mouse embryos between stages E10-E12 using a novel combination of geometric morphometric and statistical methods. Limb bud shape was quantified by recording the coordinates of curve semilandmarks located along the outline of limb buds, whereas gene expression domains were segmented from whole-mount in situ hybridization experiments. Elliptical Fourier analysis of gene expression domains of Hoxa11 and Hoxa13 revealed highly dynamic spatiotemporal patterns of gene expression, alternating periods of strong shape changes with periods of relative stasis. Hoxa11 and Hoxa13 expression patterns were strongly correlated with each other and with limb morphology, as indicated by Partial Least Squares analysis. Analysis of the temporal progression of expression patterns during development enabled us to identify key time points for pattern formation, and to define a genotype-phenotype temporal continuum in normal limb development.
C-119
MECHANISMS UNDERLYING THE EVOLUTION OF AN ELONGATE AXIAL SKELETON IN SAURICHTHYID FISHES
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Axial elongation has evolved independently multiple times in fishes, and always involves either an increase in the number of embryonic axial segments or an increase in segment length. Among actinopterygians, axial elongation has only been studied in detail in extant teleosts. Basal taxa, however, are characterized by relatively greater diversity in the construction of the axial skeleton, and consequently may evolve elongate axial morphologies via novel pathways. The extinct clade Saurichthyidae, a group of piscivorous fishes characterized by a long, slender body and posteriorly displaced dorsal and anal fins, presents an ideal system in which to examine the mechanisms underlying axial elongation in basal actinopterygians. - We found that in contrast to teleosts, axial elongation in Saurichthyidae could not be attributed solely to the addition and elongation of axial segments. In basal fishes, there are typically four chondrifications per axial segment, termed arcualia, of which two ossify to form the neural and haemal arches. In saurichthyids, all four of these arcualia are well-developed and form neural and haemal arches, resulting in four ossified components per embryonic segment. This represents a novel way of increasing the number of axial elements independent of somitogenesis. In order to assess whether saurichthyids also increased the number of somites, we reconstructed segment counts in basal actinopterygians using squared-change parsimony. Results indicate that chondrosteans as a group are characterized by an increase in the total number of segments, with saurichthyids showing an additional increase. However, whereas in chondrosteans the added segments were equally distributed between the abdominal and caudal regions, saurichthyids are characterized by a disproportionate increase in the number of abdominal segments. Thus, the elongated body plan of saurichthyids evolved via a novel combination of meristic increase in abdominal segment number and morphological convergence between the basidorsal and interdorsal arcualial derivatives.

Contributed 18 – Locomotion
C-120
TWO WAYS OF SWIMMING IN VOLES AND MOLES: A MORPHOFUNCTIONAL ASPECT
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Some species of voles (Rodentia) and moles (Insectivora) are adapted to aquatic mode of life: e.g., Ondatra zibeticus (Cricetidae) and Desmana moschata (Talpidae). The later have common features in the hindlimb musculature: flexors of knee-joint, extensors of ankle-joint and finger flexors are well developed. Such transformations occur to provide a powerful stroke against the water. However the swimming mechanism is quite different. In Ondatra hindlimbs and tail participate in the propulsion. That is why the force and relative weight of their muscles are bigger than in forelimbs. In Desmana, not only hindlimbs work in the motion but also forelimbs and the tail is specialized to body stabilization during the alternate work of the extremities. In moles the forelimbs are stronger than hindlimbs and play a main role in the digging. In the desman the force of the hindlimbs increases and as a result the limbs become equal in strength. Like in moles the forelimbs and hindlimbs of the desman move sidewise. To realize such an action muscles teres major, subscapularis, ectopectoralis and gluteus superficialis increase in the force and relative weight in comparison with the corresponding muscles of Ondatra. In Ondatra, on the contrary, the forelimbs and hindlimbs move parasagittally as in most voles with terrestrial locomotion. Thus, the difference in the swimming mechanism of Desmana and Ondatra depend on the evolutionary basic type of locomotion specific to both of families.

C-121
TRIPPING THE RAT
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With our investigations, we want to answer the following questions: How do quadrupedal mammals compensate for disturbances during running and how quickly can they react? By addressing these questions, we attempt to identify the existence of peripheral pattern generators in mammals. We used synchronized cineradiography and EMG recordings to analyse the motions of the limb skeleton and to correlate them with muscle activity. For the EMG measurements, the animals had two monopolar electrodes implanted within each biceps and triceps brachii muscle of both sides of the body. The electrodes consisted of silicon-coated strands of platinum-iridium wires and a 20 pin micro connector was sutured to the neck of the animals. Movements were filmed at 300 Hz and the sampling rate of the EMG system was 4096 Hz.
the fourth postoperative day, the instrumented animals 1) ran on a treadmill which was partly perforated with
holes 3 cm in diameter and 2 cm deep and 2) stepped on a trap door. The trap door simulated breaking
through ice, whereas the treadmill simulated stepping into an unexpected hole. Initial results of the treadmill
experiments show that activation started at the moment of the estimated ground contact when the rat
stepped into the hole. Biceps and triceps muscle activities were both greater than during touch down in the
undisturbed control situation. In the following swing phase, the paw was more elevated and the step length
shortened. For trap door trials, limb touch down activated the door. At the beginning of stance, the activation
pattern was unaffected, but as the door reached its lowest point, muscle activity increased in both forelimb
muscles. On-going analyses will answer how fast the rats reacted.

C-122
PECTORAL GIRDLE MOVEMENTS AND THE ROLE OF THE GLENOHUMERAL JOINT DURING
LANDING IN THE TOAD, RHINELLA MARINA (LINNAEUS, 1758)
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Compared to anurans from other families, landings of toads (Bufonidae) during saltation appear well
coordinated and the initial landing impact is absorbed exclusively by the forelimbs. Although the forelimbs
and particularly the pectoral girdle have been suggested to be important for shock absorption, the functional
roles of its various elements have not been evaluated in detail. This study addresses open questions
regarding the kinematics of the forelimbs during landing in Rhinella marina using X-ray reconstruction of
moving morphology and scientific rotoscoping. The kinematic analysis clearly showed that additionally to
motions in the shoulder and elbow joints, substantial movements of the pectoral girdle in toto as well as of its
elements relative to each other do occur during landing. The pectoral girdle showed first and foremost
rotations about its latero-lateral axis as well as dorso-ventral translations relative to the spine. Additionally,
our results quantify the extent of flexion and extension in the suprascapula-scapular synchondrosis during
landing. Forelimb kinematics in R. marina differed from that of other anurans in starting elbow extension
relatively early during the landing process, which likely prevents the chest from contacting the ground.
Furthermore, the animal regains an upright and ready-to-hop-again position quickly and the recovery phase
is short compared to other anurans. Humeral kinematics and anatomy confirm that the glenohumeral
interlocking mechanism guides the humerus during the initial landing phase. Cranio-ventral ridges on the
humeral head and the paraglenoid cartilage interlock in anteverted and slightly retroverted humeral
positions. This occurs at the beginning of the landing. When interlocked, adduction/abduction as well as
long-axis rotation of the humerus are restricted. During the course of landing, the humerus retroverts and is
gradually freed from interlocking restrictions due to a smoother relief at the caudal aspect of the humeral
head.

C-123
COMPARISON OF APPENDICULAR GROUND REACTION FORCE PRODUCTION IN MUDSKIPPER
FISHES (PERIOPTHALMUS BARBARUS) AND TIGER SALAMANDERS (AMBYSTOMA TIGRINUM):
IMPLICATIONS FOR THE INVASION OF LAND
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The water-to-land transition in tetrapod evolution was a revolutionary event that was associated with major
shifts in morphology, physiology and ecology. The fossil record indicates that limb-like appendages likely
originated in aquatic environments. Since both fins and limbs existed prior to the invasion of land, what
morphological properties of limbs contributed to their predominance among terrestrial invaders, and what
aspects of fins limit them primarily to the aquatic realm? Although paleontological and experimental
analyses suggest the early origin of “hindlimb-driven” locomotion in tetrapods, how did forelimb function
contribute to the terrestrial transition? To compare the propulsive contributions of fins and limbs during
locomotion on land, we measured three-dimensional ground reaction forces (GRFs) produced by isolated
pectoral fins of African mudskipper fishes (Periophtalmus barbarus) and isolated forelimbs and hindlimbs of
tiger salamanders (Ambystoma tigrinum), two amphibious taxa that have been proposed as functional
models for early tetrapodomorphs. Our results indicate numerous locomotor differences between the
pectoral appendages of mudskippers and salamanders. Compared to forelimbs, pectoral fins bore lower
overall GRF magnitudes and had a more medial GRF orientation. Salamander forelimbs and hindlimbs
demonstrated numerous similarities, including nearly identical mediolateral and vertical GRF components,
suggesting that the forelimb could have played an important role in locomotor support that may have been
and sexual selection. We hypothesize that different breeding strategies are reflected in body and head speciation and adaptive radiation, with morphologies resulting from an interplay between natural selection and sexual selection. We hypothesize that different breeding strategies are reflected in body and head morphologies.

C-124

**CITIUS, ALTIUS, FORTIUS: JUMPING KINEMATICS AND KINETICS IN TWO DISTANTLY RELATED TELEOSTS**

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Many fish stranded on land will use axial movements to generate C-jumps in efforts to return to water. However, mangrove rivulus, *Kryptolebias marmoratus* (Cyprinodontiformes), generate coordinated jumps on land using a tail flip to locate new food resources, avoid predators, escape poor water conditions, or return to water. How do the mechanics of such directed jumps differ from those of typical stranded fishes? We quantified and compared the ground reaction forces (GRF) generated during directed jumps by *K. marmoratus* with those produced by similarly-sized largemouth bass, *Micropterus salmoides* (Perciformes), performing typical jumps of stranded fishes. Individual specimens were placed on a force platform that recorded the GRF in three dimensions (fore-aft, mediolateral, and vertical). Forces were normalized to the body weight of each animal. Two Phantom high-speed video cameras recorded the duration of the jump (from initial movement to launching off the force platform) and the jump trajectory with respect to the ground. Horizontal forces were greatest for *K. marmoratus* with peak GRF occurring at ~75% through the jump. *M. salmoides* had the greatest vertical GRF, occurring at ~60% of the jump. The trajectory of the bass C-jump was ~90° with respect to the ground compared to lower jump trajectories in *K. marmoratus*, leading to greater horizontal displacement in the latter. *M. salmoides* had faster jump durations (~40 ms to reach maximum body curvature), whereas *K. marmoratus* reached maximum body curvature at ~75 ms. While the jumps of *M. salmoides* strongly resemble aquatic fast starts, differences in force production and motion trajectory in *K. marmoratus* may indicate the use of different motor patterns to increase duration (and thus impulse) of the jump.

Contributed 22 – Reproductive Biology

C-125

**ANATOMICAL ORGANIZATION AND MATERIAL COMPOSITION OF THE PENILE TENDONS IN THE AMERICAN ALLIGATOR (ALLIGATOR MISSISSIPPIENSIS)**

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Penile erection in the American alligator (*Alligator mississippiensis*) is notable because the penis is everted by cloacal muscles without inflation and stiffening in the penile shaft. Eversion appears to be effected indirectly because the penis lacks direct muscular attachments to either the cloacal wall or the pelvis. Instead, the penile epithelium is continuous with the cloacal lining and the penis is attached to the ischia by two collagenous structures: the ventral penile tendon and the ligamentum rami. The ventral penile tendon, which connects the proximal end of the penile shaft to the ventral ischia, is short, stiff, and seems to act as a fixed point that the penis rotates around during eversion and retraction. The ligamentum rami are paired structures that originate on the dorsal ischia and pass between the penile crurae to attach to the dorsal surface of each crus. They are longer, thinner, and more extensible than the ventral penile tendon, and it has been suggested that they function as a spring to return the penis to its resting orientation after eversion.

Histological examination of the ventral penile tendon and ligamentum rami shows that both are primarily made up of collagen fibers arranged parallel to the long axis of the structure, suggesting that the differences in their mechanical behavior and function are the result of differences in the arrangement of the tissue within each structure rather than differences in material composition.

C-126

**DOES BREEDING STRATEGY INFLUENCE HEAD MORPHOLOGY IN MOUTHPROODING TILAPIINE CICHLIDS?**

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Cichlids are morphologically very diverse. They are considered an excellent model to study explosive speciation and adaptive radiation, with morphologies resulting from an interplay between natural selection and sexual selection. We hypothesize that different breeding strategies are reflected in body and head
morphology, both at an interspecific and an intersexual level (the latter through sexual dimorphism). More specifically, we expect that the mouthbrooding species will exhibit sexual dimorphism in buccal morphology that is more pronounced than in the non-mouthbrooders. In addition, for mouthbrooding species, we expect the mouthbrooding sex to attain the largest body size or the largest buccal cavity, as this could increase reproductive success. A larger buccal volume is assumed to allow for more eggs or larger eggs to be held in the oral cavity and a higher ventilation efficiency of the eggs. To test these hypotheses, we compared the body shape of males and females of four species of tilapiine cichlids that reflect the different breeding strategies within Cichlidae (maternal mouthbrooding, paternal mouthbrooding, biparental mouthbrooding and substrate brooding (nest building)). Considering the highly integrated nature of the buccal system, being involved in several biological functions and roles (including mouthbrooding but also feeding, respiration, agonistic display and nest building), we also expect to see differences at the interspecific level, in relation to different feeding strategies and differences in diet.

C:127
OOGENESIS OF THE OLM
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The reproductive biology of the Olm (Proteus anguinus anguinus), an obligate neotene cave-dwelling salamander, has not been fully explored. It is well known that Olm reach sexual maturity very late, and that the females lay eggs at any time of the year with a preference for the winter. The Olm’s reproductive period is very extended and the reproductive cycles in females are extremely long and consequently it is expected that maturation of the oocytes requires several years. Studies of the Olm’s ovaries and its oogenesis were performed to gain a better understanding of its reproductive biology. We used the ovaries of 20 animals that had been collected in previous years (from 1972 to 2009) for other research purposes, with permission of the Ministry of the Environment and Spatial Planning of the Republic of Slovenia (*). The morphology of the ovary during different seasons of the year, the stages of oocyte development and their histological characteristics, as well as the frequency and morphology of follicular atresia in the ovaries were assessed. The ovaries are asynchronous in nature and different oocyte stages were present concomitantly. Developing oocytes were classified according to their external appearance, histology, color and size into five stages: two previtellogenic (stages I and II) and three vitellogenic (stages III, IV and V). The presence of oogonia in the cortex of all ovaries sampled indicated the ability of the new generations of oocytes to proliferate during adult life. The mitotic divisions of the oogonia, and mature vitellogenic oocytes occurred in the ovaries independently of seasons, suggesting that females potentially could lay eggs at any period of the year. The ovaries with vitellogenic oocytes showed atretic follicles, seen more frequently in the ovaries of food-deprived specimens. The affected oocytes were mainly in the vitellogenic stages, suggesting that yolk resorption by the phagocytic follicular cells can be an important energy-conversion process essential for support of the normal development and maturation of the remaining oocytes in the ovaries and to ensure the reproductive potential of the species. (*) Licence numbers for the last two five-year periods are 35701-81/2004-9 and 35601-1/2010-6

Contributed 19 – Ecomorphology
C:128
STICK WITH IT: COMPARATIVE MORPHOLOGY OF FROG TONGUES
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Frogs (Anura) use their sticky tongues to capture a variety of prey items like insects, annelids, and small vertebrates. Despite this general pattern of tongue feeding, there is a wide diversity on how the tongue is used during the feeding strike. Tongue feeding behavior in frogs ranges from species that use a quick forward lunge and only protrude the tongue little over the tip of the jaw to species, which can fire their tongues ballistically onto distant prey objects. These differences in feeding behavior make frog tongues an interesting system for comparative functional morphology. We used µCT-imaging and scanning electron microscopy to study the morphology of frog tongues from the macroscopic to the microscopic scale. We compared species from five different groups within the Anura, comprising active hunting species, sit-and-wait predators, as well as specialist and generalist feeders. We found an astonishing diversity in frog tongue shape, architecture, and surface microstructure. The shape of the tongue was either rod like with an almost circular cross-section in Oophaga histrionica (Dendrobatidae), ellipsoid and very voluminous in Rana pipiens (Ranidae) and Ceratophrys ornata (Ceratophyidae), or almost circular and extremely flattened in Megophrys nasuta (Megophryidae) and Litoria infratrenata (Hylidae). Surface structures on frog tongues comprised fungiform and filiform papillae, which were either distributed over the entire dorsal surface of the frog tongue or concentrated to the distal part only (in O. histrionica). In C. ornata, filiform papillae are
absent; the tongue surface is covered by longitudinally running ridges. We hypothesize that the regionalized rod like tongue in *O. histrionica* is related to a specialization of this species to small arthropod prey. Besides this special case, the observed variability of frog tongues may actually rather be based on the evolutionary origins of sticky tongues in the different lineages within the Anura than on functional demands.

C-129
THE IMPACT OF ENVIRONMENTAL CHANGE ON PREDATORY HABITS IN CANIDS
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The predatory behaviour of extinct canids (family Canidae) can be determined by elbow-joint shape, and we use these data to investigate whether changes in behaviour are associated with major climatic and ecosystem change over the later Cenozoic (the past 37 Ma). Elbow-joint shape (shape of the distal humerus) is an established morphological indicator of locomotor adaptations in carnivores. While fast-running (pursuit) predators cursing over long distances have a restricted range of motion at the elbow, less specialized predators retain the more generalized mammalian ability to supinate their forelimbs, which allows them to grapple with their prey. We examined elbow-joint shape patterns in North American canids (subfamilies Hesperocyoninae, Borophaginae, and Caninae) from the Oligocene (~37 Ma) to the end of the Pleistocene (~0.01 Ma) using a canonical variates analysis, in comparison with a wide sample of living terrestrial predators classified within the three present-day predation modes (pursuit, pounce-pursuit and ambush predators). Both canonical functions clearly discriminated the three predatory modes of living carnivores. When both functions were applied to fossil taxa a directional change in elbow-joint shape was revealed: from those reflective of wide joints among the basal hesperocyonines through the intermediate-shaped joints of borophagines to the more “box-like” elbows of more recent derived canines that reflect restricted elbow rotation. Furthermore, elbow-joint shape data arranged chronologically indicates that during the first ~10 Ma of canid evolutionary history only ambush predators were present. The first appearance of canids specialized towards pounce and pursuit modes of predation was coincident with major environmental changes of the later Cenozoic. This study adds to previous ones showing change in herbivorous mammals in response to Cenozoic environmental change, and reveals that their predators may also change their modes of predatory behaviour when the herbivores change their foraging behaviour.

C-130
GROSS DENTAL WEAR AND DIETARY EVOLUTION OF NORTH AMERICAN MICENO TO PLEISTOCENE UNGULATES
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The assessment of gross cusp morphology has proven to be useful for testing paleodietary inferences made on fossil taxa. Assessing the attrition-abrasion wear gradient or mesowear (i.e., cumulative wear) and the microscopic enamel scar topography (microwear) of molar teeth have lent themselves particularly well to dietary studies involving large samples and spanning vast periods of evolutionary time. Here, we compare mesowear and microwear results for both Tertiary and Quaternary representatives of the families Antilocapridae, Camelidae, Dromomerycidae, Equidae, and Merycoidodontidae. Our results offer insights into the origin of hypsodonty in certain lineages and also confirm recent studies that show that the classic story in paleontology regarding the timing of changes in mammalian communities in North America due to the spread of savanna grasslands replacing more closed habitats is greatly oversimplified. This study clearly shows that the widely ascribed idea that brachydonty is indicative of browsing, mesodonty is indicative of mixed feeding, and hypsodonty is indicative of grazing is in need of serious revision and more applicable to extant versus extinct ungulates.

C-131
BETWEEN TWO WORLDS: THE CORRELATION BETWEEN MORPHOLOGY AND FORAGING ECOLGY OF MIGRATORY PASSERINES IN TEMPERATE AND TROPICAL ENVIRONMENTS
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Many studies have shown significant differences in morphology between migratory and resident bird species. The premise for such studies is that selection for efficient flight should favor modification of the wings and pectoral girdle. However, an overlooked question is whether the morphological adaptations for flight in migrants impose a trade-off in other traits including foraging site selection and foraging behavior.
Migrant species must feed in two distinctly different environments as well as numerous stopover habitats. Morphological adaptations favoring long distance flight may constrain the abilities of migrant birds to feed in certain habitats or substrates. Differences in habitat structure and prey availability between breeding and wintering environments may favor different foraging tactics in migrants and resident species. A relevant question is whether ecomorphological patterns of migrants differ from resident species in tropical and temperate environments. We used published and unpublished estimates of foraging data collected in the temperate zone and the Neotropics. Morphological differences between migrant and sedentary species from seven localities (both temperate and Neotropical) were determined by using eight external measurements taken from museum skins. Migrant species were smaller than tropical residents, but had relatively smaller wings and bills. However, migrants had longer wings, shorter tarsi and wider bills than temperate residents. The foraging behavior of migrants in the temperate zone was similar to their behavior when overwintering in the Neotropics. Migrants differed from temperate and tropical residents in foraging behavior. Our analyses found different ecomorphological configurations between migrants and residents. Notably, the regression plane for migrants was displaced relative to temperate or tropical residents. In other correlations the migrants showed significantly different ecomorphological patterns relative to residents of both temperate and tropical habitats. Our analyses suggest that migrants are “between” two worlds with respect to correlations of morphology and foraging behavior.

C-132
CORRELATION OF FOREARM MUSCLE ARCHITECTURE AND LOCOMOTION PATTERNS IN PRIMATES
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We measured wet mass (MM), linear dimensions, and fiber length (FL) for each antebrachial muscle and calculated physiological cross sectional area (PCSA) for six strepsirrhines, six platyrrhines and seven catarhines spanning nearly the entire primate body size range (from Galago to Gorilla). These variables were studied for each muscle and across muscles groups (flexors, extensors, and “others” – i.e., supinator, pronators, etc.) using RMA regression (alpha = 0.05). Total forearm (TFor) PCSA is tightly correlated with TFor MM across the whole sample and within each suborder and is slightly positively allometric across the whole sample and within strepsirrhines and catarhines (but not platyrrhines). Similar correlations and allometry between MM and PCSA are found within the flexor and extensor compartments. However, FL is not highly correlated with total MM variables and instead correlates with locomotor patterns. Thus primate forearm muscles have relatively consistent (though slightly positively allometric) crosssections, but vary according to FL, suggesting locomotor adaptations in stretch and flexibility, but not force production. Therefore the variation in the anatomy of the epicondyle likely relates to adaptations for mechanical advantage and not muscle force as has been previously hypothesized.

C-133
MAPPING THE CONNECTIONS AMONG MORPHOLOGICAL, FUNCTIONAL, PERFORMANCE AND LINEAGE DIVERSITY IN BATS
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One of the most active research areas in biology focuses on understanding how morphology maps onto function and performance, and how adaptations in these traits may allow lineages to diversify. Bats constitute an excellent system for investigating these connections because it is possible to explicitly quantify cranial traits and functional properties that are relevant to biting performance, and this group exhibits an outstanding diversity of dietary specializations within a relatively simple anatomical template. We present a comprehensive, quantitative dataset on the cranial morphology, muscle function and in vivo bite forces across several families of bats. We use these data in phylogenetic comparative analyses to determine how morphological diversity maps onto functional and performance diversity, and assess which and how morphological and functional traits are related to lineage diversification. Our results indicate a strong influence of body mass on the functional and performance diversity of the feeding apparatus in bats. Upon removing the effects of body size and phylogeny, disparity in some morphological variables exceeds the disparity in functional and performance traits. Similarly, changes in rates of character evolution seem to be more dynamic in morphological than in functional and performance traits. These results provide support for many-to-one mapping hypotheses of cranial anatomy to bite function, and could be linked to differences in the patterns of lineage diversification within bats.
C-134
INDEPENDENT EVOLUTION OF EXTREME FOSSORIALITY IN TALPID MOLES
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The family Talpidae, consisting of 17 extant genera, exhibits some of the most pronounced apomorphies amongst mammals. Although best known for their unique lateral scratch adaptation for fossoriality, a number of genera exhibit semi-aquatic adaptations (Desmana, Galemys, Condylura) or possess a more generalised, semi-fossorial body plan (Urotichus, Neurotichus, Uropsilus and Dymecodon). Two distinct clades, the Eurasian Talpini and predominantly American Scalopini exhibit extreme fossoriality and gross similarity in their forelimb anatomy; however their level of relatedness remains controversial. The most recent morphological phylogenies suggest a reasonably close relationship between these two highly fossorial clades, with a general trend for increasing levels of fossoriality throughout the talpid radiation. Molecular phylogenies, by contrast suggest the potential for convergence in the Talpini and Scalopini, or the loss of fossoriality in semi-aquatic and semi-fossorial forms. Such evolutionary problems can be better explored with the establishment of a robust talpid phylogeny that fully encompasses both molecular and morphological data, while including both extinct and extant taxa. Towards that end, we have studied the skeletal remains of the majority of extant talpid genera along with four exceptionally preserved extinct talpids, *Mygalea jaegeri, Geotrypus montisasini, Geotrypus antiquus* and *Proscapanus sansaniensis*, and incorporated our observations into a new combined phylogenetic analysis of the family. We describe the changes in the locomotor skeleton of the major talpid tribes, and the role played by fossil specimens in understanding the evolution of this unique mode of locomotion. Our findings clearly demonstrate independent specialisation into extreme fossoriality in the Scalopini and Talpini, who evolved, along with semi-aquatic and semi-fossorial forms, form a fossorially competent ancestor.

C-135
THE INFLUENCE OF VERTEBRAL NUMBER AND SIZE IN BODY SIZE ACROSS EURASIAN VIPERS
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The most extreme expression of limblessness in reptiles is the snake’s body plan. In these organisms, the acquisition of this organization implies a process of vertebral shape homogenization along the entire axial skeleton. However, vertebral size along the vertebral column varies significantly leading to an inevitable question: Do vertebral sizes determine body size in snakes? In principle, one could think that increasing vertebral sizes would increase body size, yet so far pleomerism is the most accepted hypothesis, i.e., that there is a positive correlation between vertebral number and body size in all snakes. To address this issue, we have quantitatively analyzed the precloacal vertebral size variation of 15 viperine snakes, including the European V. *berus*, V. *urinsi*, V. *aspis*, V. *latastei* and V. *ammodytes* and the Asian V. *xanthina*, V. *palaestinae*, and Daboia. Our results show that: vertebral size in snakes varies serially; all studied species exhibit a bell shaped pattern; and the number of vertebrae determines both vertebral mean size and size variation along the axis. Remarkably, in European vipers pleomerism does not account for body size, yet it does so for Asiatic vipers. Indeed, body size in Asian vipers results from a combination of both pleomerism and vertebral size. We suggest that vertebral number positively correlates with vertebral growth rates, such that the combination yields larger (longer) body sizes. This hypothesis is congruent with previous observations that Asiatic and European species differ by heterochrony.

**Contributed 20 – Paleontology**

C-136
IMPACTS OF EXCLUDING EXTINCT TAXA FROM COMPARATIVE MORPHOLOGICAL ANALYSES
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Modern morphologists are quickly developing new and innovative ways of testing evolutionary hypotheses (evolutionary rates, key innovations, and correlated evolution). However, many comparative methods require a complete phylogeny and accurately estimated branch lengths. Phylogenetic trees that include all extant taxa are often termed “complete.” Paleontologists are, however, acutely aware of the fact that the number of living taxa is a fraction of the historical diversity for many clades and that it is therefore theoretically and practically impossible to build a complete phylogenetic tree for any group. Highly incomplete phylogenetic trees may introduce potential bias in the evolutionary interpretation of morphological data. In historically diverse clades with reduced modern diversity, correlated traits may appear uncorrelated due to non-random extinction and functional diversity may appear quite low. We therefore simulated pairs of uncorrelated,
correlated, and weakly correlated traits as well as phylogenetic trees with low (15%), medium (50% of taxa), and high (80% of taxa) levels of extinction. We then tested for the effects of tree completeness on type I error rate using phylogenetic generalized least squares (PGLS) regression both including and excluding extinct taxa. We also compared the response of the type I error rate among three evolutionary models: Brownian Motion (stochasticity), Ornstein-Uhlenbeck (stabilizing selection), and a variable evolutionary rate model (ACDC). We show that the exclusion of a large number of extinct taxa from comparative analyses can lead to the overestimation of type I error rates (often from significant to non-significant) and therefore the biological interpretation of the data, especially under models of stabilizing selection. The exclusion of extinct taxa does not, however, affect relative model fits. Our analyses show that the inclusion of as many extinct taxa as possible in comparative studies increases the accuracy with which we can identify correlated evolution among morphological traits.

C:137
ANATOMY OF THE ‘HELMET-SHAPED’ CREST OF TSINTAOSAURUS SPINORHINUS AND THE EARLY EVOLUTION OF THE SUPRACRANIAL ORNAMENTATION IN LAMBEOSAURINE DINOSAURS
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The lambeosaurine dinosaur Tsintaosaurus spinorhinus (Campanian Jingangkou Formation of eastern China) has traditionally been reconstructed with an elevated, hollow, spike-like crest composed entirely of the nasal bones, although this has been disputed. Here, we provide a new reconstruction of the premaxillonasal complex and supracranial crest of this species based on reexamination and reinterpretation of the morphology and articular relationships of the nasal, premaxilla, and prefrontal bones of the type skull (IVPP V725) and a fragmentary cranial crest (IVPP V829). We confirm the presence of a supracranial crest composed of the elevated nasal bones, but also including the premaxillae. We hypothesize that the crest is a tall, helmet-shaped, mediolaterally compressed structure that projects dorsally and slightly caudally a distance greater than the height of the skull along the quadrate. In our reconstruction, the nasal passage does not enter through the hollow nasal tube, but rather passes rostral to it. T. spinorhinus is rediagnosed on the basis of a suite of cranial autapomorphies that includes a bony external narial fossa subdivided into three accessory fossae, prefrontal with ascending rostral process and lateral flange, nasals fused sagittally to form elongate tubular process that rises dorsally from skull roof, each nasal being expanded rostrocaudally into a rhomboidal distal process, and a helmet-shaped medial processes of premaxillae at summit of cranial crest inserted between rhomboidal processes of nasals. Tsintaosaurus spinorhinus lacks characters that are present in more derived lambeosaurs (parasaurolophins and lambeosaurins), such as folded nasals that laterally enclose part of the nasal cavity and participate in the formation of the walls of the common median chamber, and a smooth narial fossa lacking ridges and accessory fossae.

C:138
ANATOMICAL RECONSTRUCTION OF ARCHOSAUR HIP JOINT SOFT TISSUES AND ITS SIGNIFICANCE FOR INTERPRETING HINDLIMB FUNCTION
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Reconstructing the appendicular joint anatomy of archosaurs is critical for understanding their posture, locomotor behavior, ecology, and evolution. Soft tissue significantly contributes to the shape and size of archosaur joints, such that fossil archosaurs often exhibit incongruent subchondral surfaces. This study infers the amount of soft tissue once present in archosaur hip joints via congruence tests, as well as investigates the intrinsic hip joint anatomy of archosaurs. Differences in the mediolateral depth, as well as dorsoventral and craniocaudal diameters of the femoral head and the acetabulum are used to test for congruence of the hip joint in each axis. Hip joints of suchians and basal dinosaurs (i.e. Alligator, Shuvosaurus and Coelophysis) are more congruent along the cranio-caudal axis than those of derived non-avian dinosaurs (i.e. hadrosaurids, sauropods, tetanurans). Furthermore, sauropods and tetanurans exhibit mediolaterally longer femoral subchondral surface than the depth of the acetabulum, whereas basal dinosaurs and suchians exhibit mediolaterally wider acetabulum than the femoral subchondral surface. Dissections and histology of extant archosaur hip joints show that articular cartilage exhibits localized morphological differences (e.g. fibro- and hyaline cartilage). These localized differences leave clear osteological correlates on the skeletal hip joint, and is hypothesized to associate with assumed loading regimes. These results indicate that an increased amount of femoral- and acetabular cartilage is associated with the medial rotation of the proximal femur during non-avian dinosaur evolution, which impact our hypotheses of femoral regional homology, hip joint axes of rotation, and hindlimb function.
C-139
A NEW LOOK FOR AN OLD BIRD: NEW OBSERVATIONS ON THE MORPHOLOGY OF
ARCHAEOPTERYX
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Bayerische Staatsammlung für Paläontologie und Geologie, Munich, Germany
The iconic Late Jurassic "urvolgel" Archaeopteryx has played a central role in our understanding of the origin of birds. However, several aspects of the cranial anatomy have remained enigmatic, and, although feather impressions are known from most specimens, our knowledge of the plumage are mainly based on the London and Berlin specimens. New investigations of the skulls of the seventh and tenth specimens show that the configuration of the skull roof shows many detailed similarities with that of more basal theropod dinosaurs, e.g. in the sutural contacts of the lacrimal and the closed postorbital bar, for which we present the first clear evidence. The latter feature contradicts the idea of an avian-like kinesis in the skull. We furthermore confirm a theropod-like development of the paranasal air sinus system in this taxon, in which a maxillary fenestra and promaxillary foramen are present in the maxilla and a lacrimal fenestra in the lacrimal. Furthermore, new observations on the braincase of the Munich specimen show that it had marked similarity with the braincase of non-avian coelurosaurian theropods, especially in pneumatic features, which include an anterior, posterior and dorsal tympanic recess, a basisphenoid recess, and a basipterygoid recess. A theropod-like epipterygoid is also present. The newly discovered 11th specimen of Archaeopteryx has most of the plumage preserved in exquisite detail. The body plumage seems to have extended all the way to the head, and the presence of long contour feathers on the tibia can be confirmed. However, in contrast to the "four-winged" dromaeosaur Microraptor, the hindlimb feathers are narrow and symmetrical in shape. For the first time, the complete tail feathers are preserved. Posterior tail feathers are considerably longer than previously assumed and lateral rectrices are asymmetric. Furthermore, the posterior end of the feathery tail seems to be forked.

C-140
BACK IN BLACK: NEW EVIDENCE ON THE COLOR AND NATURE OF THE ISOLATED
ARCHAEOPTERYX FEATHER
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Archaeopteryx has been regarded as an icon of evolution ever since its discovery from the Late Jurassic limestone deposits of Solnhofen, Germany in 1861. The mosaic of plesiomorphic and derived anatomical traits in these fossils has inspired a rich scientific literature on Archaeopteryx and the origin of birds, yet the animal's color, a diverse and multifunctional trait in modern birds, has remained only speculative. Additionally, unresolved questions have persisted regarding the anatomical identity and composition of the isolated feather specimen, which was the first described Archaeopteryx fossil and the only one preserved as a dark trace. Here we report the first evidence of color from Archaeopteryx, based on scanning electron microscopy and energy-dispersive x-ray analyses that reveal the presence of fossilized color-impacting melanosomes in the isolated feather (MB.Av.100). Using a phylogenetically diverse database of 115 extant bird feathers (representing 87 taxa from 27 orders), quadratic discriminant analysis of five properties of melanosomes predicts that the original color of the Archaeopteryx feather was black, with 95% probability. Furthermore, reexamination of the feather's morphology leads us to interpret it as an upper major primary covert, contrary to previous interpretations. Additional findings reveal that the specimen is preserved as an organosulfur residue, and that barbule microstructure identical to that of modern bird feathers had evolved as early as the Jurassic. As in extant birds, the extensive melanization would have also provided structural advantages to the Archaeopteryx wing feather during this early evolutionary stage of dinosaur flight. Our results demonstrate how modern imaging techniques and statistical analysis can be coupled to reconstruct and further the understanding of plumage color and function in extinct dinosaurs.

C-141
BIOMECHANICAL EVIDENCE FOR NICHE PARTITIONING BETWEEN SAUROPODS OF THE
MORRISON FORMATION
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The sauropod dinosaurs represented one of the most important groups of megaherbivores during the Mesozoic, and included the largest terrestrial vertebrates to have ever inhabited the Earth. Given the extreme nature of their biology the sauropods present many problems and paradoxes, not the least of which

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was how they secured sufficient food intake. Furthermore, many sauropod faunas are highly diverse, implying sophisticated resource allocation between them. The high craniodental diversity observed between sympatric sauropod taxa has often been used to support notions of niche partitioning. This is particularly so for the well-known fauna of the Morrison Formation of North America, which contains a high diversity of sauropod taxa, with the common _Camarasaurus_ and _Diplodocus_ representing extreme end-members in the spectrum of sauropod cranial morphology. However, whilst biomechanical modelling has investigated potential specialized feeding behaviours in _Diplodocus_, no such work has been previously reported on _Camarasaurus_. To rectify this deficit the skull of _Camarasaurus_ was produced from CT scan data, with the adductor musculature then reconstructed on the basis of osteological correlates. Myological reconstruction demonstrates a greater importance of the external adductor muscles relative to the pterygoideus musculature than in _Diplodocus_. The more vertical arrangement of the muscles, coupled with the greater mechanical advantage of the jaw, facilitated the production of greater bite forces in _Camarasaurus_ than _Diplodocus_. Finite-element modelling of the skull of _Camarasaurus_ demonstrated that it was able to accommodate these feeding-related forces; additionally it allowed for the possibility of different feeding behaviours to be investigated. Tugging and raking behaviours are biomechanically feasible; however more specialized “branch-stripping” motions as exhibited by _Diplodocus_ appear unlikely. The results here provide biomechanical evidence for niche partitioning between Morrison sauropod taxa, with _Camarasaurus_ capable of dealing with coarser, and potentially a greater range, of foodstuffs than sympatric diplodocoids.

C-142
POST-HATCHLING CRANIAL ONTOGENETIC VARIATION IN THE BASAL ARCHOSAURIFORM _PROTEROSUCHUS FERGUSI_ FROM THE LOWER TRIASSIC OF SOUTH AFRICA

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The basal archosauriform _Proterosuchus fergusi_ is known from multiple specimens collected from the Lower Triassic of South Africa. This relatively large sample is important because ontogenetic studies of Mesozoic reptiles are restricted to a handful of well-known species. The phylogenetic position of _Proterosuchus_ as the most basal archosauriform means that it is a critically important taxon for understanding the successful evolutionary radiation of this group during the Mesozoic. Qualitative and quantitative analyses of cranial ontogenetic variation in _Proterosuchus_ were conducted based on 13 post-hatching specimens. The smallest individual is 37% of the size of the largest one and osteohistological evidence suggests that four specimens had not reached sexual maturity at the time of death. Allometric coefficients were calculated from standardised major axis regressions of 68 log-transformed cranial measurements, using skull length as a standard measurement. Most of the recovered allometric coefficients showed isometric trends (73%). Positive allometric trends were mostly associated with measurements of cranial height (e.g. maximum height of skull, minimum height of maxillary horizontal process and height of jugal anterior process and infratemporal fenestra) and the length of the infratemporal fenestra. Negative allometric trends were found mostly associated with dental measurements (e.g. number of maxillary and dentary teeth and height of maxillary teeth). Thus, through ontogeny the skull of _Proterosuchus_ became proportionally taller, the infratemporal fenestra larger and teeth more isodont and numerous but with apicobasally shorter crowns. Additional changes in medium to large specimens include less interdigitated sutures in the skull roof, proportionally narrower parietals between the supratemporal fenestrae and the appearance of a pineal fossa. The elongated snout and enlarged premaxilla that are characteristic of proterosuchids underwent isometric growth. This new information on _Proterosuchus_ cranial ontogeny provides a basis for the future identification of heterochronic events during the early evolution of Archosauriformes.

C-143
DINOSAUR CEPHALIC VASCULAR ANATOMY AND ITS PHYSIOLOGICAL IMPLICATIONS

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Large dinosaurs experienced high heat loads due to their low surface-to-volume ratios, risking sensitive cephalic neurosensory tissues. Extant outgroups deploy three regions (orbital, nasal, and oral cavities) for heat exchange, facilitating thermoregulation. We tested the hypothesis that dinosaurs exploited these same three sites for thermoregulation. The necessary evidence is written into bone as osteological correlates (OCs). When OCs are analyzed in the context of extant outgroups, we gain insight into vascular patterns in extinct taxa, potentially illuminating physiological processes. The extant phylogenetic bracket approach and vascular OCs in birds, crocodilians, and lizards were used to formulate hypotheses of dinosaur vascular anatomy. These hypotheses were tested by characterizing OCs on dinosaur fossils using direct observation and CT scanning. Dinosaur vascular anatomy was reconstructed in Avizo and restored in Maya. OCs for blood vessels were observed in Majungasaurus, Tyrannosaurus, Camarasaurus, Diplodocus, Stegosaurus,
Triceratops, and Stegoceras. OCs corresponding to branches of the maxillary vessels were observed within the maxilla. The large subnarial foramen between the maxilla and premaxilla in sauropods indicates that the oral and nasal regions were highly vascularized. OCs relating to the nasal region were observed within the nasal bones, indicating the course of the lateral nasal vessels. In the orbital region of dinosaurs, grooves were found along the dorso medial aspect of the orbit that correspond to the supraorbital vessels. These OCs reveal the course of vessels that supply and potentially drain all three sites of heat exchange. The veins of the orbital region share anastomotic connections with the dural sinuses, allowing blood to cool neurosensory tissues. This evidence indicates a conserved diapsid pattern is present within dinosaurs and their extant relatives and offers insight into the role blood vessels play in the thermoregulation of dinosaur neurosensory tissues.

C-144
FIRST DEFINITIVE EVIDENCE OF THE POSTCRANIA OF THE BASAL RUMINANT PROTOREODON PARVUS
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The postcrania of early artiodactyls are poorly known but could provide important information on the diversification among ruminants (deer and sheep), suids (pigs and peccaries), tylopods (camels and llamas), and whales. *Protoreodon parvus* is a middle Eocene species from the Uinta Formation, Uinta Basin, eastern Utah, U.S.A. that has been considered either an agriochoerid oredont or one of several Eocene taxa near the base of ruminants. The genus is currently best known from younger, more derived species, and many of these species may represent new genera. A better understanding of this, the type species, is key to making it useful to future students of either agriochoere alpha taxonomy or diversity and to systematists interested in including it in phylogenetic analyses. Based on a reexamination of the type material, as well as new collections that include the first associated skeleton of *Protoreodon parvus*, we present a detailed description of the morphology of specimens attributed to *P. parvus* that allow us to more firmly characterize the type species of the genus. The postcrania show many morphological differences from the slightly younger and larger species indicating that previously published scoring in phylogenetic matrices may not be representative for the genus. The most notable differences from other species of *Protoreodon* are in the tarsal complex, the ankle, and the elbow in features associated with differing degrees of cursoriality and body mass. This variation among the species attributed to *Protoreodon* suggests differences in locomotor behavior even among species currently thought to belong to this genus, as well as in comparison to other small Eocene artiodactyls. Our findings strongly suggest a need for more comprehensive reexamination of basal artiodactyls to determine how much postcranial morphological diversification occurred in the early evolution of artiodactyls.

Contributed 21 – Locomotion
C-145
FRAC TAL DIMENSION, LACUNARITY AND CONNECTIVITY IN CANCELLOUS BONE OF MAMMAL FEMORA—A MEETING POINT FOR METABOLISM AND BIOMECHANICS?
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Femora and humeri of mammal limbs contain cancellous bone at their epiphyses; this tissue has a typical fractal structure. These bones are involved in supporting body mass, and compressive, tensile and shear forces arise in the stationary and running animal, affecting both cancellous and cortical bone. In addition, trabecular tissue in epiphyses contains marrow within the hollow spaces closed by trabeculae, with a hematopoietic function. Hence these spaces play an essential role and can be quantified as lacunarity, which is not depending on fractal dimension. Finally, trabeculae show certain continuity since they coalesce in more or less large portions. This feature may be quantified as connectivity. We have studied femora of five wild animals with known body mass: rat, rabbit, goat, wild boar and puma. Data sustain our main hypothesis, namely, that fractal dimension and connectivity increase with body mass because they measure the reinforcement of bone faced with stresses and load supporting. In addition, increasing body mass correlates negatively with lacunarity, fractal dimension and connectivity. Since fractal dimension doesn’t depend geometrically on lacunarity, any relationship between fractal dimension and lacunarity, and connectivity as well, will have biological meaning, as a consequence of compromises between biomechanical functioning and metabolism. There is an inverse relationship between body mass and metabolic rate; e.g., measured as rate of oxygen consumption. Small animals (rat, rabbit) have very high metabolic rates; i.e., their need an enhanced hematopoietic function (high lacunarity) but don’t need
strengthen mechanically their bones (small fractal dimension and connectivity). Connectivity is also related to the biomechanics of locomotion. Therefore, differences in resistance to impact loads are reflected as differences in connectivity between the hoofed wild boar (higher value), and puma, a digitigrad animal (lower value). These considerations open a promising way to understand metabolism and biomechanics of extinct mammals.

C-146
CENTRAL MOVEMENTS DURING TAIL-ASSISTED ARM-SWINGING IN NEW WORLD MONKEYS
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Bimanual suspensory locomotion is rare among mammals but occurs in several primate species. Hylobatids are long-armed and tail-less and appear to swing in a pendular fashion in which potential and kinetic energy are exchanged in the sagittal plane and energy loss due to vertical redirections of the whole body center of mass (bCOM collisions) is minimized. Spider monkeys (Ateles) and wooly monkeys (Lagothrix) perform tail-assisted arm-swinging. Lagothrix has shorter limbs and less joint mobility than either Ateles or hylobatids. Anectodotal and limited kinematic data suggest that, like hylobatids, Ateles restricts its motion to a sagittal plane while Lagothrix experiences more lateral sway throughout a stride. This study is the first to quantify three-dimensional movements of the bCOM, potential for energy exchange, and reduction of redirectional losses in Ateles fusciceps (n=2) and Lagothrix lagothricha (n=2) using tri-planar video recordings during arm-swinging along a horizontal pole with self-selected handhold spacings. In Ateles, elbow extension in the support arm allows the bCOM to swing vertically through a wide sagittal plane arc. During double hand contact in Ateles, elbow flexion in the trailing arm and shortening of the effective length of the tail result in fore-aft redirection of the bCOM backward and upward, thereby increasing potential energy for the next swing. During swing phase in Lagothrix, the laterally-facing trunk swings out, then rotates anteriorly and medially as the body swings back toward the handhold. Simultaneously, the swing arm is abducted and moves along with the trunk. Thus, the bCOM travels laterally through a wide arc in Lagothrix, allowing for energy exchange in the mediolateral plane. These data suggest that primates adopt a diversity of strategies to solve the mechanical challenges associated with this unusual locomotor mode and that, in part, these strategies are driven by anatomical differences between species.

C-147
ANALYSIS OF BACK MUSCLE ACTIVITIES AND GROUND REACTION FORCES IN OPERANT BIPEDAL RATS
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The aim of this study is to examine the relationships between back muscle activities and ground reaction forces of rats during bipedal standing behavior by using an improved bipedal training box with force plates, multiple electrodes (16 electrodes, double line), and a high speed camera system. Simultaneously, back muscle activities were measured during the course of bipedal standing behavior by the double line electrodes attached on the surface of the rat back muscles, at both sides of the lumbar vertebrae. Four operant conditioned bipedal rats of Wister strain (female, body weight of 240g in average) were used for this study. In the bipedal training box, a rat can take an upright bipedal posture in which the hip and knee joints are extended nearly to the maximum. While a rat was standing bipedaly on a force plate (Kistler), the measured forces continued (5-10 second in many cases) to reflect the static bipedal standing posture. When a rat was standing on two force plates, right foot on one plate and left foot on another plate, the amount of forces corresponded to its body weight in each moment. In the beginning of rising or crouching posture, not only ground reaction forces but also the values of back muscle activities were not stable both lengthwise and between lateral electrodes. However, when a rat was half standing and about to rise, the muscle activities became larger and the relationships of the magnitude among the electrodes became stable in both directions.

C-148
EFFECTS OF ATMOSPHERIC OXYGEN ON FEMUR BIOMECHANICS IN ALLIGATOR MISSISSIPPIENSIS
Middleton, Kevin (1); Lujan, Susan (2); Hicks, James (3); Owerkowicz, Tomasz (2)
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Anatomical Record, Volume 296, Special Feature — 238
Atmospheric oxygen varied widely over geologic time, ranging from 30% or more during the Permian to as low as 15% in the Late Triassic. Analyses of the microanatomy and cross sectional geometry of limb bones are often used to infer growth, locomotor ability, and life history strategies of fossil vertebrates based on studies of extant relatives carried out in the present-day, normoxic environment. Because hypoxia and hyperoxia have been shown to affect the growth of vertebrates such as birds and rodents, the validity of comparisons between extinct and modern taxa merits investigation. With an evolutionary history spanning most atmospheric extremes, Alligator mississippiensis is an excellent model to test for effects of environmental oxygen on skeletal growth and biomechanics. We incubated eggs and reared hatchlings from 8 clutches in hypoxic (16% O₂) and hyperoxic (26%, 31%, 36% O₂) conditions (n = 179). At 6 intervals from 2 to 104 weeks, alligators were sacrificed and the femora prepared for analysis. Undecalcified specimens were dehydrated, and morphometric whole-bone measurements taken prior to histological thin-sectioning. Using femur length as covariate to account for differences in body size, analyses of covariance on cross sectional area, second moment of area, and polar moment of inertia revealed no significant differences among oxygen treatment groups. Combined allometric analyses of all groups showed that cross-sectional area scaled with significant positive allometry and that all moments of inertia (minimum, maximum, and polar) scaled with significant negative allometry. We hypothesize that the right-left shunt in the alligator heart allows the maintenance of optimal oxygen saturation across a range of ambient oxygen levels. Our result suggest that atmospheric oxygen may have negligible influence on basal archosaur bone structure.

C-149
PLACOID SCALE MORPHOLOGY, ERECTION AND DRAG REDUCTION IN THE SHORTFIN MAKO ISURUS OXYRINCHUS
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(1) University of South Florida, Tampa, United States; (2) University of Alabama, Tuscaloosa, United States

The shortfin mako Isurus oxyrinchus is perhaps the fastest swimming shark and exhibits a suite of physiological and morphological adaptations for sustained and rapid swimming. We investigated placoid scale morphology, flexibility and attachment and compared this to the scales of the slower swimming blacktip shark Carcharhinus limbatus in order to gain an understanding of putative drag reduction mechanisms during fast swimming. Scanning electron microscopy, histological staining, and manipulation of scales along the body of the sharks revealed regions on the flank with extremely small (0.18 mm crown length) and flexible scales that can be manually erected to at least 50 degrees in mako sharks. Highly flexible scales were also found at the trailing edge of the pectoral fins. Conversely, blacktip scales were larger (0.32 mm) and less flexible. Scale flexibility appears to be related to the length of the scale crown and base, the shape of the base, and the anchoring to the dermis. These flexible scales on the flank and pectoral fin occur in regions most prone to flow separation and reversal. We hypothesize that scale erection most likely occurs passively at these regions due to flow reversal that occurs right before global flow separation from the body. Experiments with mako shark flank skin demonstrate a reduction in flow reversal, which disappears when the scales are painted over, indicating that passive scale erection reduces pressure drag.

C-150
USING AVIAN SUBSURFACE 3D FOOT MOTION TO SIMULATE FOSSIL TRACK DIVERSITY
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(1) Royal Veterinary College/Brown University, London/Providence, United States; (2) Brown University, Providence, United States

The fossil track record is our primary window on the locomotor capabilities and behaviours of extinct animals, yet the variation seen among footprints is daunting, both at the assemblage level and even within trackways. In order to make solid inferences about trackmaker, locomotion, or behaviour, we must understand how pedal anatomy, distal limb kinematics, and substrate interact to generate track morphology. Our aim was to begin to decouple this complex system by simulating tracks of different depth while holding foot structure and motion constant. We first analysed a chicken-like bird, the helmeted guineafowl, traversing a bed of poppy seeds using X-ray Reconstruction of Moving Morphology (XROMM) to reconstruct the 3D kinematics of the distal limb both above and below the surface of the compliant substrate. We then imported these 3D kinematics into computer simulations of substrate, carried out using the Discrete Element Method (DEM). Changes in depth alone produce a wide diversity of resultant tracks, both at the exposed surface and at intermediate levels. The shallow angle of the metatarsus and digits at entry and exit cause elongation of the surface morphology as the foot sinks deeper. Slipping of the digits results in parallel scratch marks when the foot sinks very little. Halux orientation changes as the foot sinks down and forwards into the substrate. The variation seen in these simulated tracks bears striking resemblance to many of the tracks in the Hitchcock collection, held at the Beneski Museum of Natural History, Amherst. Our kinematic data and
C-151
INDEPENDENT ACQUISITIONS OF QUADRUPEDALITY IN ORNITHISCHIAN DINOSAURS
Barrett, Paul (1); Maidment, Susannah (2)
(1) The Natural History Museum, London, United Kingdom; (2) Imperial College, London, United Kingdom
Bipedality is the primitive condition for dinosaurs, but reversions to obligate quadrupedality occurred on at least four independent occasions within the clade (in Sauropoda, Thyreophora, Ceratopsidae and Hadrosauridae). Abandonment of a bipedal stance was particularly prevalent in ornithischian dinosaurs, but few studies have attempted to investigate either the anatomical and functional changes involved in these transitions or place these changes within a phylogenetic context. We compiled an extensive dataset on ornithischian fore- and hind limb skeletal anatomy that allowed us to reconstruct the myology of quadrupedal and bipedal ornithischian limbs using extant birds and crocodilians as models. These data enabled modelling of hind limb moment arms in these taxa, investigation of limb scaling patterns, and phylogenetic optimisation of skeletal features associated with locomotion in order to examine the sequences in which quadrupedal character complexes were assembled. Different ornithischian clades were found to use a variety of functional pathways to achieve a quadrupedal stance, which involved clade-specific combinations of stances (upright vs. crouched), gaits (wide vs. narrow), moment arms, and reduction, enlargement, or change in function of specific limb muscles. Although such features are clade-specific, the order in which 'quadrupedal' features are acquired is broadly comparable between clades. Hence, although the underlying skeletal anatomy is superficially similar, consideration of reconstructed soft tissues implies that limb function varied considerably between the three quadrupedal clades. In addition, few general trends are identifiable in ornithischian moment arm evolution, which displays a mosaic pattern.

Contributed 23 – Paleontology
C-152
NEW TETRAPOD AND FISH FAUNAS FROM THE EARLIEST CARBONIFEROUS OF SCOTLAND
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The Early Carboniferous Tournaisian interval has long been considered as an almost blank period for vertebrate fossils, in particular tetrapods, and forms the earlier part of what has been called 'Romer's Gap'. Recent discoveries are now filling this gap with finds from southern Scotland and northern England in the Ballagan Formation. We report here the richness of the vertebrate assemblage from one locality in Scotland. Conformable vertical strata represent a time interval of about 15 million years. We recognise at least two new taxa of small tetrapod represented by skull and/or skeletal material. These specimens do not fall into any currently known taxonomic grouping, but suggest, along with tetrapod cranial material from other sites that likewise represent new taxa, that there was an explosive radiation of tetrapod morphologies in the Tournaisian. Along with the previously described earliest known articulated pentadactyl foot, from the CM palynozone of the Tournaisian, we have now discovered very small tetrapod elements from the base of the formation (VI palynozone), close to the Devonian-Carboniferous boundary. A variety of femoral morphologies are found within these collections, indicating diverse locomotory mechanisms. We have recovered from our key site a wealth of fish remains including actinopterygians, lungfishes, and a range of rhizodonts and gyracanths that have yet to be studied. Tetrapods, rhizodonts and gyracanths found so far show a remarkable increase in size from the base to the top of the sequence. These discoveries are building up a picture of the recovery of both terrestrial and aquatic vertebrate faunas following the end-Devonian mass extinction.

C-153
SKELETAL MORPHOLOGY AND EVOLUTIONARY HISTORY OF EUROPEAN LAMBEOSAURINE ‘DUCK-BILLED’ DINOSAURS
Prieto-Márquez, Albert (1); Dalla Vecchia, Fabio Marco (2); Galobart, Angel (3); Gaete, Rodrigo (3)
(1) Bayerische Staatsammlung für Paläontologie und Geologie, Munich, Germany; (2) Institut Català de Paleontologia, Sabadell, Spain; (3) Museu de la Conca Dellà, Isona, Spain
The Late Cretaceous lambeosaurines are megaherbivore dinosaurs possessing hyperthrophied, caudodorsally extended nasal passages enshrouded by hollow supracranial crests. Although their fossil record is rich in North America and Asia, that of Europe is comparatively poorly known. We document the anatomy and re-evaluate the diversity, phylogenetic relationships, and historical biogeography of European
Suggestions relatively slow growth. Moreover, our quantitative analysis shows that the average indiv
is not the juvenile form of larger
application of mixed
measur
 growing forms of bone. To simultaneously estimate age at death and reconstruct growth trajectories, we
Bright
growth. We histologically sampled a growth series of elements consi
Maastrichtian
Noasauridae is a clade of ceratosaurian theropods that evolved small body size independently of other non
(1)
Lee, Andrew
NOASAURID THEROPOD
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A proba
between bone microanatomy and lifestyle (aquatic to terrestrial) has been recognized for
nearly a century, but statistical tests of this link using large comparative datasets were first performed in the
1980. Statistically-informed tests on such datasets are more recent still, harking back barely to 2004. Most
such tests used variance partition with phylogenetic eigenvector regression (PVR), a method that has been
criticized in recent studies and demonstrated to inadequately account for phylogenetic non-independence in
comparative data through simulations. The first valid phylogeny-informed tests about the link between bone
microanatomy and habitat were thus published only in 2009 (with limited success), with more convincing
results obtained more recently still. The long delay between development of phylogeny-informed
comparative methods (in the 1980s) and their application to bone microanatomy results partly from the fact
that lifestyle has to be scored as a discrete character, for practical reasons (i.e. the lack of relevant
quantitative data about habitat use), and the fact that most comparative methods were developed for
continuous data. The latest datasets on bone microanatomy were analyzed through pairwise comparisons,
which can easily accommodate a combination of discrete and continuous data, while incorporating the
phylogeny into the analysis. Fortunately, these studies, based on extensive datasets (155 amniote species
for a study on the femur and 98 therian mammal species for a study on the vertebral centrum) confirm the
presence of a link between microanatomy and habitat. These recent studies validate the growing use of
microanatomical data in paleobiological inference. A challenge for the near future is the integration of the
phylogeny into paleobiological inference models.

C-154
BONE MICROANATOMY AND LIFESTYLE: RECENT DEVELOPMENTS AND CHALLENGES
Laurin, Michel

MNHN, Paris, France
A probable link between bone microanatomy and lifestyle (aquatic to terrestrial) has been recognized for
nearly a century, but statistical tests of this link using large comparative datasets were first performed in the
1980. Statistically-informed tests on such datasets are more recent still, harking back barely to 2004. Most
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presence of a link between microanatomy and habitat. These recent studies validate the growing use of
microanatomical data in paleobiological inference. A challenge for the near future is the integration of the
phylogeny into paleobiological inference models.

C-155
BONE HISTOLOGY CONFIRMS DETERMINATE GROWTH AND SMALL BODY SIZE IN THE
NOASAURID THEROPOD MASIAKASARUS KNOPFLERI
Lee, Andrew (1), O’Connor, Patrick (2)
(1) Midwestern University, Glendale, United States; (2) Ohio University, Athens, United States
Noasauridae is a clade of ceratosaurian theropods that evolved small body size independently of other non
avian theropods. The best preserved and most complete noasaurid is Masiakasaurus knopfleri from the
Maastrichtian-age Maevarano Formation in Madagascar. An abundance of skeletal material from several
individuals spanning a wide range of ontogeny makes Masiakasaurus an ideal candidate for the analysis of
growth. We histologically sampled a growth series of elements consisting of four femora and three tibiae.
Bright-field and circularly polarized light microscopy were used to distinguish between slowly- and rapidly-
growing forms of bone. To simultaneously estimate age at death and reconstruct growth trajectories, we
measured the perimeters of growth lines in each specimen and fitted models to these data using a novel
application of mixed-effects regression. Our histological results show an external fundamental system in the
largest tibial specimen and confirm that Masiakasaurus grew determinately, matured at small body size, and
is not the juvenile form of larger-bodied theropods. Parallel-fibered bone is unusually prominent and
suggests relatively slow growth. Moreover, our quantitative analysis shows that the average individual took
about 8–10 years to get to the size of a large dog. Although Masiakasaurus grew 40% faster than crocodilians, it grew about 40% slower than comparably-sized non-avian theropods. Slowed growth may have evolved as a means to minimize structural and maintenance costs while living in a semi-arid and seasonally stressful environment. Dimorphism does not appear related to asymptotic size or growth rate but seems to reflect the degree of skeletal maturity.

C-156
CONTROVERSIAL ISSUES IN THE ANATOMY OF MESOZOIC ACTINOPTERYGIANS
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Bayerische Staatssammlung für Paläontologie und Geologie, Munich, Germany
Most living actinopterygians are teleosts, the clade including about 50% of living vertebrates. The origin and early history of this major group of fishes is still very poorly understood, mainly due to the lack of knowledge of most non-teleostean actinopterygians. Although very diverse and well represented in the Mesozoic, these later fishes have been comparatively poorly studied. For systematic purposes, during the last seven years I have been studying the anatomy of several non-teleostean actinopterygians, mainly from the Jurassic. These studies resulted in the recognition of several details and structures that are relevant to understand the evolution of some anatomical units. Among them are the presence of an interoperculum in lepisosteiforms and aspidorhynchids, the fusion of the quadratojugal and the quadrate in some ginglymodians, the serial homology between the anterior infraorbitals and the other infraorbital bones in ginglymodians, the mobile articulation between basal fulcra and radials in the median fins of some ginglymodians, and the presence of a cusp or caudal filament in non-acipenseriform chondrostean. All these features have an impact on the phylogeny of actinopterygians, either for establishing hypotheses of primary homology, by reducing homoplasy of some significant characters or by simply completing missing information. - Non-teleostean neopterygians were extremely diverse and numerous during the Mesozoic, but are currently only represented by one amiiform and seven species of gars. The inadequate representation of non-teleostean actinopterygians nowadays hampers molecular phylogenetic studies as well as those cladistic analyses based on the morphology of living forms only. Therefore, detailed anatomical studies of Mesozoic actinopterygians and the incorporation of this information in phylogenetic analyses is essential to elucidate the still controversial phylogenetic relationships between teleosts and other neopterygians.

C-157
MORPHOLOGY AND SUBSTRATE: 3-D QUANTIFICATION AND RHEOLOGY OF TRIDACTYL DINOSAUR FOOTPRINTS FROM SPAIN
L. Razzolini, Novella (1); Castanera, Diego (2); Vila, Bernat (3); Canudo, José Ignacio (2); Barco, José Luis (4); Galobart, Àngel (1)
(1) Institut Català de Paleontologia Miquel Crusafont, Sabadell, Spain; (2) Grupo Aragosaurus-IUCA, Paleontología. Facultad de Ciencias. Universidad de Zaragoza, Spain; (3) Grupo Aragosaurus-IUCA and Institut Català de Paleontologia Miquel Crusafont, Paleontología. Facultad de Ciencias. Universidad de Zaragoza and, Spain; (4) Grupo Aragosaurus-IUCA and Paleoymas S.L., Zaragoza, Spain
Traditionally, morphology of vertebrate tracks has been assimilated to the true morphology of the animal’s foot. This assumption has sometimes led to the misinterpretation among possible producers, although it is now acknowledged that different track-makers can produce similar tracks and vice versa. Inaccurate representations of track morphology can distort particularly important data. Recently, ichnologists have started to consider tracks as a dynamic and interactive three-dimensional ensemble between the foot and the substrate, adding rheology as an important component in the morphological track analysis. In the fossil record, three-dimensional models created on dinosaur tracks enhance the insights on footprint shape and disclose the importance of quantifying the substrate deformation produced by the track-maker. Experimental ichnology can reveal how substrate consistency plays an important role in determine track morphology. The great variety of tridactyl tracks reported in the Berriasian of two localities (Las Cerradicas and El Frontal) of the Iberian Range (Spain) represent a substantial sample to evaluate whether this morphological spectrum is consequence of a biological diversity or rather represents a morphological continuum of different substrate consistencies. Here we show the pivotal importance of combining 3-D quantification of morphological features and parameters (track dimensions, digit thickness, interdigital angles, digital and heel pads, hallux and claw marks) with substrate characteristics and mechanics in order to discern the track-maker identity. Three-dimensional models based on photogrammetry techniques together with detailed sedimentary and stratigraphic analysis (layers) help the identification of diagnostic features such as the presence of manus or hallux impressions. This information together with associated track features (displacement rims, pressure release structures) around the track might shed some light on the track production. The troublesome dichotomy between ornithopod and theropod track identification is tentatively smoothed by 3-D technologies and rheology analysis.
C-158
HOW CAN WE RELIABLY RECONSTRUCT JOINT AXES IN ARCHOSAUR FORELIMBS WHEN ARTICULAR CARTILAGES ARE LOST?
Fujiiwara, Shin-ichi (1); Anzai, Wataru (2); Kudo, Kohei (2); Endo, Hideki (2)
(1) Naogya University, Nagoya, Japan; (2) The University of Tokyo, Tokyo, Japan
Determining joint axis position on limb skeleton is important for more precise biomechanical musculoskeletal modeling in extinct archosaurs, such as dinosaurs. As far as the bones are closely-attached to each other via chondroepiphyses at the joint, the joint axis position can be estimated from the joint motion which is guided by the curvatures of the joint surfaces. However, the relationship between the geometries of chondroepiphyses that is decomposed postmortem and the structures of underlying bone remains unclear even in extant archosaurs. It is therefore difficult to reliably estimate joint axis position of forelimbs in extinct archosaurs. To improve the accuracy of estimating shoulder and elbow joint axes positions from bones, we determined structures that give an index of the chondroepiphysis geometry and the joint axis position on the forelimb bone. We CT-scanned forelimb elements of extant crocodilians and birds and compared the three-dimensional form of chondroepiphysis with the geometry of calcified epiphysis and the ligament positions of the joint. The indices were determined on bones of well matured specimens: chondroepiphysis was uniformly thick in the glenoid and the humeral head, and the curvatures of the calcified epiphyses reflect those of the chondroepiphyses; geometry of calcified epiphysis did not reflect that of the chondroepiphysis in the elbow joint, but the centers of the curvatures of chondroepiphyses at the humeral distal condyles were located along the line connecting origins of collateral ligaments of the elbow. When the positional relationships of forelimb elements were assumed to be preserved in fossil archosaurs, the abovementioned structures on forelimb bones can be used as indices for estimating the curvatures and the axes positions of shoulder and elbow joints.

C-159
NEUROCRANIAL ANATOMY OF THE PROBLEMATIC CARBONIFEROUS-PERMIAN LEPOSPONDYL BRACHYDECTES NEWBERRY: NEW INFORMATION FROM μCT
Pardo, Jason; Anderson, Jason
University of Calgary, Calgary, Canada
The origins of salamanders, frogs, and caecilians remains a subject of persistent debate, and two major radiations of early tetrapod (Temnospondyl and Lepospondyl) have been proposed as potential candidates for either the lissamphibian stem or the stem-group of specific lissamphibian orders. Within Lepospondyl, Lysorophia, a group of enigmatic elongate-bodied anamniotes, has been suggested as potential stem-lissamphibians, stem-salamanders, or stem-caecilians in both comparative morphologic and phylogenetic investigations. Recent attempts to address this problem have invoked novel interpretations of bone homologies without direct treatment of lysorophian morphology, and existing descriptions of lysorophian morphology lack sufficient detail in descriptions of the endocranium to be integrated into new datasets being developed using μCT methods. To address this, I have μCT scanned skulls representing a partial ontogenetic sequence of the lysorophian Brachydectes newberryi. The anterior braincase is heavily ossified, with both a median (’sphenethmoid’) and lateral (’orbitosphenoid’) ossifications with a posteriorly-extensive solus nasalis. The columella ethmoidalis is partially ossified in larger specimens. Dorsal projections of the basisphenoid (’pleurospheonuids’) are robust and brace the parietals against the palate. A fenestra between the posterior sphenoid ossification and the prootic is partially bisected into separate foramina for a vein dorsally and the maxillary branch of the trigeminal ventrally, in a similar arrangement described for Carrolia craddockii. The occiput is roofed by a dorsal ossification of the synotic tectum (’supraoccipital’) which projects anteriorly to roof much of the posterior braincase and is exposed dorsally between the postparietals. The occipital condyle is unpaired and concave. Neurocranial anatomy is highly dissimilar from that seen in lissamphibians, but is consistent with that seen specifically in brachystelechid ’microsaurs.’ Morphological convergence with the burrowing aquatic salamander Amphiuma is proposed.

C-160
COMPARATIVE MYOLOGY OF THE HIGHLY REDUCED FORELIMBS OF TYRANNOSAURIDS AND ABELISAUROIDS (DINOSAURIA: THEROPODA)
Burch, Sara
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Forelimb reduction occurred independently in multiple lineages of theropod dinosaurs, with highly divergent morphologies exhibited by each lineage. Although tyrannosaurs are famous for their tiny, two-fingered forelimbs, the degree of their reduction is surpassed by abelisaurids, which possess an unusual morphology...
distinct from that of other theropods. This study provides the first look at the morphology and musculature of both tyrannosaurs and abelisaurids in a comparative context to assess how different modes of forelimb reduction affected the functional capabilities of the limb. Phylogenetically-based reconstructions of the musculature were used in combination with close examination of the osteology in each clade to create detailed muscle maps of the limbs. Differences in the shape of the scapular blade and the development of the proximal humerus point to an emphasis on humeral abduction in tyrannosaurs at the expense of adduction, whereas abelisaurids show retention of well developed adductor musculature accompanied by a de-emphasis on abduction. Both taxa exhibit reduction of the musculature relating to humeral protraction and retention or development of the retractor musculature. The antebrachial pronators and supinators along with the muscles acting on the wrist were modified to be entirely flexors and extensors of the elbow in abelisaurids, although these muscle retained their plesiomorphic attachments and actions in tyrannosaurs. Much of the intrinsic manual musculature was likely lost in abelisaurids, whereas tyrannosaurs retained these muscles in the two remaining manual digits. Tyrannosaurs and abelisaurids share some morphological features that appear to be related to forelimb reduction in general, but the antebrachial muscles of abelisaurids have undergone dramatic shifts in their morphology and action that are not exhibited by tyrannosaurs. The lack of the complete reduction of the musculature in either taxon suggests these divergent morphologies are the result of differing functional demands and not just the vestigialization of the limb.

**Contributed 24 – Cranial Evolution**

**C-161**

**3D RECONSTRUCTION AND MECHANICAL ANALYSIS OF THE EARLY TETRAPOD LOWER JAW**

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The invasion of the land by vertebrates is one of the great transitions in the history of life, necessitating changes in breathing mode, feeding, locomotory and sensory systems that are reflected in skeletal evolution. Of particular interest is an explosive radiation during the Carboniferous in which tetrapods evolved into diverse forms that colonized and exploited terrestrial niches. Our study focuses on the morphological and mechanical evolution of the lower jaw, which features an orderly and gradual series of shape changes across the fish-tetrapod transition. The skulls of seven early tetrapod genera were CT scanned; most specimens date from the Carboniferous but our study incorporates taxa from the Late Devonian to the Early Triassic. CT data was segmented to digitally separate bone from matrix and the individual bones of the skull from each other. Work completed thus far has revealed new anatomical details, such as suture morphology and previously undescribed skull elements. In particular, the palate and medial aspect of the lower jaw, which are poorly known in several early tetrapod taxa due to incomplete preparation of specimens, are visualized and described for the first time using CT data. When necessary, damage to specimens was repaired, missing elements duplicated across the sagittal midline, and elements from multiple specimens scaled appropriately. Individual bones were articulated in 3D space to create a series of ‘retrodeformed’ computer models that will serve as the basis for finite element analysis (FEA). Our ultimate aim is to use FEA to understand the functional and ecological implications of specific changes in jaw shape during the early evolution of tetrapods.

**C-162**

**INFERRING THE ROLE OF NERVOUS TISSUE IN THE EVOLUTION OF VERTEBRATE JAW MUSCLES: DEVELOPMENT OF TRIGEMINAL MOTOR NEURONS IN PARROTS**

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Vertebrates have achieved great evolutionary success due in large part to the anatomical diversification of their jaw complex, which allows them to inhabit almost every ecological niche. Although jaw muscle morphology is critical for determining the mode of feeding, much remains to be understood about the mechanisms to produce its morphological diversity. In this study, we focus on a parrot species (Cockatiel, *Nymphicus hollandicus*), which has acquired anatomically unique jaw muscles, and describe the development of their trigeminal motor neurons that innervate jaw muscles, to infer the role of nervous tissue in the evolution of vertebrate jaw muscles. In parrot embryogenesis, the trigeminal motor nerves extend their branches distally into the precursors of novel jaw muscles in concert with the growth of the muscles. This observation supports the idea that muscular tissue primarily determines the nerve branching pattern, possibly by providing molecular guidance cues for axons. By contrast, the trigeminal motor nucleus, which is composed of somata of neurons that innervate major jaw muscles, of parrot embryos is relatively larger than that of quail embryos, even in early embryonic stages at which jaw muscle morphology and nerve branching pattern are almost identical in two species. In conclusion, our data suggest that although nervous tissue may
not have a major impact on initial patterning of jaw muscles, it may play an important role in subsequent muscle growth and alterations in nervous tissue development may underlie diversification of jaw muscle morphology.

C-163
FOSSIL EARLY VERTEBRATES SHED LIGHT ON THE ORIGIN OF THE GNATHOSTOME FACE
Dupret, Vincent (1); Sanchez, Sophie (1); Goujet, Daniel (2); Tafforeau, Paul (3); Ahlberg, Per E. (1)
(1) Uppsala University, Uppsala, Sweden; (2) Muséum National d’Histoire Naturelle, Paris, France; (3) European Synchrotron Radiation Facility, Grenoble, France
Jawless cyclostomes and jawed gnathostomes show very different face patterns. Cyclostomes have a single median nasohypophysial duct, an anterior hypophysis and a short telencephalon, while gnathostomes have a pair of nasal sacs opening externally, a more posterior separate hypophysis open in the palate and a longer telencephalon. Embryonic processes differ as well. In cyclostomes, premandibular crest cells migrate forwards either side of the nasohypophysial placode to form the upper lip; in gnathostomes they migrate between the hypophysial and nasal placodes to form the trabecular region. Supraoptic neural crest remains posterior to the nasohypophysial duct in cyclostomes; it moves forward to create the nasal capsules in gnathostomes. Some fossil forms illustrate a transition between these two patterns. The jawless galeaspid *Shuyu* (−430 Ma) has a nasohypophysial duct, short telencephalon, and anteriorly oriented hypophysis, but the paired nasal sacs and hypophysis are separated by a rudimentary trabecula. The jawed primitive placoderm *Romundina* (−415 Ma) shows a cranial cavity reminiscent of that of *Shuyu* (anteriorly directed hypophysis, very short telencephalon). The trabecular region is long and wide, the nasal capsule is small and located far behind the tip of the snout but just in front of the orbits. We interpret these features as uniquely primitive among gnathostomes. The premandibular crest of *Romundina* formed a trabecular region extending as anteriorly as the tip of the snout (like in extant cyclostome and the fossil *Shuyu*). The position of the nasal capsule suggests that the supraoptic crest had not migrated forwards. We suggest that the evolutionary sequence for the creation of the extant gnathostome face from a cyclostome pattern involved 1) separation of the nasal and hypophysial placodes (galeaspid), 2) loss of the nasohypophysial duct (placoderms), and 3) lengthening of the telencephalon and the migration of the nasal capsules to the snout tip.

C-164
DIFFERENCES IN NASAL CAVITY ONTOGENY BETWEEN AVIAN AND MAMMALIAN EMBRYOS
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The external nares connect with the nasal cavity internally via paired choanae. In mammals, which are obligate nose breathers at birth, the nasal cavity is completely separated from the oral cavity by the secondary palate. Thus, there is an initial anterior choanal opening termed the “primitive” choana (homologous to the choanae in non-mammalian amniotes) and subsequent posterior choanal openings into the nasopharynx. In non-mammalian vertebrates (except crocodilians), the choanae open directly into the anterior oral cavity in a similar manner to the mammalian “primitive” choana. While these openings seem superficially homologous, their ontogeny is surprisingly variable. In mammals, the nasal cavity initially begins as an external nasal pit which grows dorsally and is separated from the oral cavity by an oronasal membrane. Upon the rupture of this membrane, the external nares connect with the nasal cavity via the primitive choanae. In amphibians, which have also been studied extensively, a groove forms which connects the choana and the external nares, subsequently fusing ventrally to form a choanal tube. Other major clades however have been largely ignored. In this study, we used optical projection tomography and histology to obtain 3D reconstructions of the nasal cavities of chicken and mouse embryos. We found that avian embryos do not form an oronasal membrane. Instead, the outgrowing frontonasal process and maxillary process leave a groove (similar to that of amphibians) between them which connects the external nares and the oral cavity. Subsequently, the maxillary and globular process of the frontonasal mass fuse around this groove, leaving a choanal tube posterior to the fusion zone, connecting the external nares to the choana. These results suggest that the formation of a groove is the basal condition in vertebrates and that mammals specifically have derived a different ontogenetic process for the connection of external nares and the choanae.
L-001
VASCULARIZATION OF THE BALEEN EPITHELIUM IN A NEONATAL GRAY WHALE (CETACEA, MYSTICETI, ESCHRICHTIDAE)
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Baleen is a neomorphic keratinous structure unique to Mysticeti (baleen whales) employed in filter feeding. Baleen laminae originate from the lateral borders of the epidermis covering the hard palate, and the gingival tissue from which the baleen develops is highly vascularized. Filamentous dermal papillae extend deeply from the gingiva into the lumens of individual tubules within the baleen plates. However, the arterial source of the baleen vasculature is unclear. Lateral nutrient foramina and sulci mark the palate of extant and extinct baleen whales, including some early mysticetes that retained teeth into adulthood, and the foramina are positioned in the location of an embryonic superior alveolar groove that closes early in ontogeny. In extant mysticetes, rudimentary teeth begin to develop within the groove but are resorbed prenatally prior to baleen development. The location of the lateral nutrient foramina suggests that a superior alveolar branch of the maxillary artery would supply blood to baleen epithelium. Alternatively, because baleen has an epidermal origin, the tissues might be supplied by branches of the greater palatine artery, which supplies blood to the hard palate epithelium in terrestrial mammals. Through a combination of latex injection of the internal carotid artery and distal vessels, computed tomography, and traditional dissection of a neonatal gray whale (Eschrichtius robustus), we confirm that the baleen receives its blood from vessels within the superior alveolar canal of the maxilla. The medial palatine vessels do not supply the baleen, but more likely the superficial palatal tissue, which represents the generalized mammalian condition. It is unclear if the alveolar vessels that feed the epithelium from which the baleen develops are the same vessels that feed the neonatal teeth, but the vessels occupy the same bony canal and are similarly oriented. Thus, the possibility of homology between teeth and baleen can be raised.

L-002
BODY TEMPERATURE AS A DETERMINATE OF AXIAL SKELETON DIVERSITY
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Segmentation is a major developmental process in animals that helps to determine the form of repeated structures such as vertebrae and ribs. Like any other cellular process, temperature plays a key role in the rate at which segmentation occurs, with predictable consequences for adult form. Here, we investigate if and how levels of skeletal diversity among (and within) mammals are influenced by body temperature during development, starting with an examination of the ways in which levels of axial diversity show correlations with core body temperatures, and tolerances in thermal variation, across clades. While mammals are as a rule endothermic, and can generally withstand only minimal swings in temperature, the exact level of this tolerance varies substantially across clades. For example, core temperatures are reported to not only be lower, but also to fluctuate more in a sloth or hyrax when compared with a rodent or carnivoran. We present data on vertebral number variation and anomalies to explore the extent to which they correlate with body temperature. Specifically, we focus on the possibility that animals with low metabolic rates, and correspondingly low core body temperatures, exhibit a higher degree of variability in vertebral number and a higher frequency of axial skeleton anomalies, as would be predicted if body temperature during development were a determinant of adult skeletal phenotype.

L-003
SPADE FOR DIGGING? A CASE STUDY OF ASIAN FOSSIL SPADEFOOT TOADS (ANURA: PELOBATIDAE)
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Spadefoot toads (Pelobatidae) are a group of frogs characterized by an enlarged bony spade in their hind limbs. Modern spadefoot toads are adapted to a fossorial lifestyle. In adapting to this behavior, the enlarged metatarsal prehallux in the hind limb is used as a spade for burrowing. Other modifications include the robustly built skull with dermal sculpture; proportionally longer femur compared to the tibiofibula, rigid sacral-urostyle articulation, and shortened urostyle. Although living spadefoot toads are only distributed in Europe and North America, three fossil taxa have been found in East Asia, from the late Paleocene, Oligocene and Miocene. Different from European fossil taxon Eopelobates, which is abundant in numbers but has no bony
spade, all three Asian fossils have the bony spade developed. This intrigues the question about when and where the morphological adaptations for burrowing begin to evolve. A phylogenetic analysis of archaeobatrachians was conducted to examine the observed pattern. Results show that the late Paleocene Asian fossil occupies the base of the spadefoot toads, confirming that the presence of the enlarged bony spade is a synapomorphy of the Pelobatidae. The *Eopelobates*, by contrast, are closely related to the modern genus *Pelobates*, indicating that the loss of the spade in *Eopelobates* is secondarily reversed. Except for the presence of the spade, however, the Paleocene Asian fossil lacks other specializations for burrowing, but instead retains an unsculptured skull, longer urostyle, relatively slender limbs and femur as long as the tibiofibula. This indicates that the evolution of the enlarged spade is decoupled with the evolution of burrowing, with the fossorial behavior evolving later. This work also has biogeographic importance in that East Asia plays an important role in the early diversification of spadefoot toads, which cannot be revealed by studying solely modern taxa.

L-004
KILLING RATES AND MORPHOLOGICAL EVOLUTION IN SIT-AND-WAIT FORAGING BIRDS
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Scaling theory predicts one-to-one covariation of body size of birds and their prey. Additionally, smaller birds enjoy a relatively low metabolic scope, but may be constrained to a smaller range of prey items. In contrast, larger birds exhibit low mass-specific metabolic rates and are thought to have greater potential for switching prey items when larger ones are not available. These patterns predict an increase in the waiting time and a decrease in the killing rate with increasing predator body size. However, allometric shape changes, particularly in morphological traits associated with flight may help to offset any scaling constraints due to a particular body size. We tested whether body size and/or shape was related to the search and attack behavior using foraging observations and morphological measurements on 49 species of passerine birds. Regression analyses indicate that body size (mass, total length, and PC1) has a larger allometric coefficient with killing rate in these birds than predicted by existing models. The positive relationship between waiting time and body size is apparent in subgroups of smaller birds but much less so in larger birds. Surprisingly, there is only a slight (non-significant) relationship between morphological shape (i.e. wing length, tail length, etc.) and either of the performance behaviors. These patterns are maintained when accounting for phylogeny. Hence, our data indicate that within ambushing birds, energetic constraints of a given body size may, in fact, eclipse allometric ecomorphological patterns, and possibly constrain morphological diversification to a greater extent than previously thought.

L-005
PALEONEOUROANATOMY OF NEOAETOSAURIOIDES ENGAEUS BONAPARTE (LATE TRIASSIC-ARGENTINA) AND COMPARISON WITH OTHER AETOSAURS AND CROCODYLIA
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The paleoneurology of pseudosuchian archosaurs, based on examination of the inside of braincases and a few artificial endocasts is generally poorly known. Among aetosaurs, only one endocast has been described, by Case, 90 years ago: Desmatosuchus spurensis. We studied the encephalon of Neoaetosaurus engaeus from the Los Colorados Formation (Late Triassic) northwestern Argentina. We used three partial skulls (PULR 108; PVL 4363; PVL 5698), two of which (PVL 4363; PULR 108) bear the first natural endocast reported for an aetosaur. The olfactory bulbs, position of cranial nerves I-XII, the orbitocerebral vein, medial cerebral vein path, and parts of the semicircular canals of the inner ear were identified. The endocast of *Neoaetosaurus* was compared with a new tridimensional endocast reconstruction of the aetosaur Aetosaurus ferratus (SMNS 5775) and the endocast of *D. spurensis* (UMMP 7476), and with the living pseudosuchian Alligator mississippiensis. Some structures previously documented for *D. spurensis* were reinterpreted, such as the olfactory tracts and the position of cranial nerves VII and VIII. The olfactory tracts of *Neoaetosaurus* are longer than in *D. spurensis*, and the olfactory bulbs located more anteriorly in the former. The cerebral hemispheres of *Neoaetosaurus* and *A. ferratus* have a length:maximum width proportion of 2:1, contrasting with a 1:1 proportion in *D. spurensis*. The width of the telencephalon doubles from its anterior edge to the widest region of the cerebral hemispheres in Neoaetosaurus and *A. ferratus*, in which these taxa resemble living crocodilians, and differ from the telencephalon of *D. spurensis* which has a more even width. Cephalic flexures are similar among the sampled aetosaurs, ranging from 125° to 140° in the Neoaetosaurus and *D. spurensis* specimens. The overall pattern of cranial nerve positions is
similar in Neoaetosauroides and Desmatosuchus, and the overall morphology is conservative for aetosaurs and living crocodylians.

L-006
REDESCRIPTION AND PHYLOGENETIC ANALYSIS OF A STEM TETRAPOD MANDIBLE FROM THE LATE CARBONIFEROUS AND ITS IMPLICATIONS FOR PHYLOGENETICS WITH FRAGMENTARY REMAINS

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The lower jaw of an unidentified Late Carboniferous tetrapod from Nova Scotia is redescribed in light of recent tetrapod discoveries and work on evolution of tetrapod mandibular morphology. Several features resemble baphetids (=loxommatids) and temnospondyls including dermal ornamentation, absence of coronoid teeth, and presence of coronoid shagreen. Dentary dentition is most similar to Baphetes and Loxomma. A parasymphysial toothplate may not preclude temnospondyl affinity, but infradentary arrangement lessens its likelihood. An apparent large exomeckelian fenestra, with the dorsal foraminal margins formed by an unossified element echoes the morphology of Sigournea and may provide an example of an intermediate stage in Meckelian evolution, though otherwise the jaw bears similarities to baphetids, temnospondyls and Caerorhachis. Phylogenetic analysis places the specimen amongst or at the base of the baphetids or temnospondyls, sometimes as sister taxon to Megalocephalus, Eucritta, or Loxomma. A sister relationship with Caerorhachis is often found, but may be due to morphological convergence. The jaw may thus be the only well preserved representation of the mesial surface of a baphetid other than Megalocephalus. Results using only mandibular and cranial characters provide less resolution than when using the whole skeleton, but are broadly similar in their placement of the jaw. Thus the presence of important phylogenetic information in purely mandibular remains is evidenced.

L-007
EPIMORPHIC REGENERATION AND TUMOR SUPPRESSORS: THE ROLE OF P53 IN THE REGENERATING ZEBRAFISH FIN

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Animals capable of regenerating body parts as well as animals with long life spans both would seem to benefit from robust tumor suppressor mechanisms to maintain tissue homeostasis. The tumor suppressor protein P53 is required for regeneration in several species and is mutated in the majority of cancers. We investigated the effect of inhibition of p53 on tail fin regeneration in adult zebrafish. Regenerative outgrowth and blood vessel formation was compared in fish homozygous for mutant p53, fli-EGFP fish treated with a p53 inhibitor, and control wildtype fish. All treatment groups regenerated tail fins but vascular endothelial sprouting occurred earlier in fish in which the tumor suppressor protein was inhibited. The results suggest that while p53 affects angiogenesis in the regeneration blastema, this tumor suppressor is not a requirement for fin regeneration.

L-008
NEW INFORMATION ON THE ENDOCRANIAL MORPHOLOGY OF THE TRIASSIC PROTEROCAMPSIDS (EUREPTILIA: ARCHOSAURIFORMES) USING CTSCANS: COMPARISON WITH LIVING CROCODYLIA

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The braincase anatomy of aquatic proterochampsid archosauriforms has been recently revealed based on new detailed descriptions. Additionally, new CT scans of Proterochampsia barrionuevoi (PVSJ 77), Chanaresuchus ischigualastensis (PVSJ 567), and Tropidosuchus romeri (PVL 4601), shed some light on the poorly known paleoneurology of these taxa. To better understand the endocranial morphology of this group, we compare the cranial endocast and inner ear with extant aquatic pseudosuchians, such as Gavialis, Caiman, from which we made complete artificial brain and inner ear endocasts; and Crocodylus, based on published information. Although the digital reconstructions of the fossil taxa are incomplete, the partial endocasts show similar morphology, represented by subhorizontal brains (cephalic and pontine
flexures not well marked), with poorly developed dorsal expansions and relatively small pituitary. The cerebral hemispheres seem to be slightly laterally projected unlike the strongly projected ones in living crocodylians. Partial labyrinth of the inner ear were reconstructed for *Chanaresuchus* and *Tropidosuchus*, showing slender semicircular canals. In *Chanaresuchus* the angle between the anterior and posterior semicircular canals is approximately 90-100°. The CT scans showed that the middle ear of proterochampsids is poorly pneumatized relative to the studied extant forms. In *Chanaresuchus* and *Tropidosuchus* it is noteworthy the presence of a foramen on the occipital plate, dorsal to the paroccipital process, communicating anteriorly with the middle ear. We identify this small passage as correlated with the craniouquadrate passage present in Crocodylia. Further research is necessary to determine if this structure is homologous to the craniouquadrate and its implications for an aquatic lifestyle.

**POSTERS**

**Skeletal EvoDevo**

P-001

ONTogenetic skull variation in the Argentinean extant caimans *CAiMAn lAtirostris* and *CAiMAn yACAre* (Crocodylia, alligatoridae)

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The extant species of *Caiman, C. crocodilus, C. yacare* and *C. latirostris* are widely distributed in South America. The Argentinean species *C. yacare* and *C. latirostris* have been the focus of several morphological studies. Even though several quantitative and qualitative analyses of interspecific morphological variation have been done, intraspecific variation has been poorly explored. We studied 53 post hatching skulls of *C. yacare* and *C. latirostris*. An allometric analysis was performed with 12 linear variables. Morphological variation was assessed using principal component analysis (PCA). To test cranial allometry, a simple regression was performed using the scores of the first principal component (PC1) as a size proxy. Comparisons of the slopes were made for both species. All the variables showed high correlation coefficients and negative allometry. Comparative analysis showed common slopes and different intercept for most variables except the anterior width of the snout (AJs). Trajectories of length variables showed higher intercept values in *C. yacare*, although trajectories of snout width variables exhibited higher intercept values in *C. latirostris*. The AJs presented the highest slope in *C. latirostris*. Ontogenetic variation of the snout was assessed with a regression between width and length of the snout. *C. latirostris* displayed isometry and higher values of slope than *C. yacare*, which showed negative allometry. Similar trajectories may reflect a common ontogenetic pattern of morphological skull change established early in ontogeny for all variables except AJs. The modeling of the snout during ontogeny in *C. yacare* results in adult forms with generalized snout shapes, which is probably a derived condition within caimans that is associated with ecological requirements.

P-002

ANATomy of the Lower Jaw and Dentition of *Pseudopus, OphisaUrUs AND anguis* (anguiMorph, anguiDae) AND their Interrelationships

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The anatomy of the lower jaw and teeth is described in detail in a legless lizard *Pseudopus apodus* (Eurasia) and compared with those of other species of the subfamily Anguinae: seven species of *OphisaUrus* (North America, North Africa and South-East Asia) and *Anguis fragilis* (Europe, West Asia and North Africa). The anatomy of the mandible and teeth of *P. apodus* differs in many respects from those in *OphisaUrus* and *Anguis*. In contrast, there is a big similarity in the anatomy of the lower jaw and teeth of *OphisaUrus* and *Anguis*. The teeth of North American *OphisaUrus ventralis* and *O. attenuatus* are slender, cylindrical and the shafts are mesiodistally compressed and bulged lingually; the apices are curved posteriorly and bear weakly developed cutting edges. The species of South-East Asia (*OphisaUrus harti* and *O. gracilis*) and North Africa (*OphisaUrus koellikeri*) have conical teeth with broadened bases, the apices are distinctly curved posteriorly, and the cutting edges are distinctly developed. In *Pseudopus* and *OphisaUrus*, the lingual surfaces of the tooth apices are striated. The anatomy of the lower jaw of *OphisaUrus* is very similar to that in *Anguis*, however, the teeth of *Anguis* are longer and strongly curved posteriorly. The result of the phylogenetic
analysis rendered six equally parsimonious trees. *Anguis* has three alternative positions: 1) it is the sister taxon to a clade formed by *Ophisaurus* and *Pseudopus*; 2) it is the sister taxon of *Ophisaurus*; and 3) it forms a clade with *Ophisaurus* which is the sister group to *Pseudopus*.

P-003

INTRASPECIFIC VARIATION IN THE SKULL MORPHOLOGY OF THE BLACK CAIMAN *MELANOSUCHUS NIGER* (ALLIGATORIDAE, CAIMANINAE)

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*Melanosuchus niger* is a caimanine alligatorid, which is widely distributed in the north of South America. This species has been the focus of a number of ecological, genetic and some morphological studies, but investigations on intraspecific variation such as ontogenetic variation and sexual dimorphism are rare. Here we present the first assessment of intraspecific variation in the skull of *M. niger* using a two-dimensional geometric morphometric approach. The crania of 52 sexed individuals of different sizes were analyzed to quantify shape variation and to assign observed shape changes to ontogenetic variation, sexual dimorphism and bite force performance. Most of the variation in this species affects relative snout length, skull depth, orbit size and the width of the postorbital region, which is strongly correlated with the ontogenetic variation. During ontogeny the snout becomes longer, narrower (in dorsal view) and deeper (in lateral view), and the snout tip becomes blunter. A subnarial gap develops between the premaxilla and maxilla due to ventral expansion of the anterior part of the maxilla. The postrostrum becomes flattened and relative orbit size decreases, whereas the jugal region becomes broader and deeper. The postorbital region becomes shorter, but expands postero-laterally and the jaw joint moves substantially posterior to the posterior end of the skull roof. Comparing ontogenetic changes in *M. niger* with those of other crocodylian taxa indicates that ontogenetic trajectories are highly constrained within Crocodylia. Statistical support for cranial sexual dimorphism in *M. niger* is ambiguous, but allometric skull shape variation is strongly correlated with bite force performance. This correlation between shape and function indicates that the observed ontogenetic variation could be related to the generation of higher bite forces and a decrease in mechanical stress along with a change in diet.

P-004

CARNIVOROUS ADAPTATION IN MAMMALIAN MOLARS: UNIQUE EVOLUTIONARY PATTERN AND MORPHOLOGICAL INTEGRATION AMONG DENTAL TRAITS IN CARNIVORANS

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Mammalian dental morphology has evolved in association with dietary adaptations. Carnassial teeth, which function to cut flesh, have evolved in parallel in several orders of carnivorous mammals. In the lower dentition, the carnassial is first lower molar in the Carnivora, but is the last molar in the Creodonta, which is the extinct sister order of the Carnivora. The last molar tends to have a carnassial function in the marsupial order Dasyuromorpha. A developmental model called the inhibitory cascade model explains the relative sizes of the lower molars in mammals according to the balance of activation and inhibition molecules during dental development. If activation is high and inhibition is low, the first molar is bigger and the distal molars become smaller, and vice versa. I investigated diversity of relative molar sizes in Carnivora, Creodonta and Dasyuromorpha with respect to dietary adaptations and compared them to the inhibitory cascade model. The Carnivora exhibit a unique inhibitory cascade pattern; relative size of the first molar and other molars varies more than previously reported in mammals. This pattern contributes to the evolutionary plasticity of dental function, i.e., the proportion of cutting and crushing functions, and therefore, the diet. The Creodonta and Dasyuromorpha exhibit different patterns that have less evolutionary plasticity than the Carnivora. Additionally, the correlation between two traits, relative molar sizes and relative sizes of trigonid and talonid on the first molar, differ among carnivoran species and individuals in a raccoon-dog population. Therefore, the two traits are considered to be linked and to have evolve convergently in the Carnivora. The trigonid of the first molar exerts a carnassial function. These results indicate that the Carnivora have a superior dental pattern with greater evolutionary plasticity, which may have contributed to the long-term survivability and broad adaptation of this order.

P-005

SUPERSIZE ME: CELLULAR DYNAMICS CONTROLLING SIZE IN THE MAMMALIAN MOLAR
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A central question in evolutionary morphology and developmental biology is how diversity in the size of structures is achieved. The scaling of patterning, the size when organs attain their shape, in relation to final organ size is lacking rigorous analyses. A model system in which to ask this question is the mammalian dentition. Mammalian molar teeth are developmentally integrated such that they form sequentially along the distally elongating dental lamina and are typically graded in size anteroposteriorly. Tooth development proceeds through a series of morphogenetic movements and signaling interactions between ectodermal epithelium and neural crest-derived mesenchyme. Evidence on mouse molar development has shown that the initiation and size of distal molars depends on previous molars through a dynamic balance between intermolar inhibition and mesenchymal activation. We compare molar development in two rodent species with similar tooth shape, but nearly a twofold difference in size: mouse and rat. We examine changes in size and morphogenesis throughout the development of the molars using microcomputed tomodraphy and in situ hybridization. We further combine this interspecies comparison with experimental evidence from transgenic mice to investigate the cellular dynamics controlling tooth size.

P-006

DEVELOPMENT OF THE BASIPTERYGOID PROCESS IN LACERTID LIZARDS

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In the embryogenesis of the chondrocranium in most lizards, the basipterygoid process first appears as a lateral extension of the posterior end of the trabecle and articulates with the pterygoquadrate cartilage. However, in Lacerta agilis the basipterygoid process first appears as an independent nodule of cartilage positioned close to the posterior end of the trabecle and only later in ontogeny fuses with it. Similar ontogeny of the basipterygoid process was described in the chamaeleon Microsaura pumila. We studied the ontogenetic origin of the basipterygoid process in the growth stages of Lacerta viridis, Darevskia armeniaca and Eremias arguta, and compared it with the conditions in L. agilis. The stages were determined using the table of normal development for Zootoca vivipara. In the Stage 32 of all studied species, the dense mesenchyme of the future pterygoquadrate cartilage is clearly visible. It chondrifies in the Stage 33. In this stage, the basipterygoid process is present as a condensation of the mesenchymatous cells interposed between the posterior end of the trabecle and the basal portion of the ascending process. However, only in L. agilis the basipterygoid process appears as an independent center of condrrification. In all other species, and even in the closely related L. viridis, the basipterygoid process chondrifies as a process of the trabecle. Thus, we conclude 1) that the independent ontogenetic origin of the basipterygoid process is rather exceptional within lizards, and 2) that the pattern of the ontogenetic origin of the basipterygoid process varies even within the genus.

P-007

MORPHOMETRIC ANALYSES OF ISOLATED THEROPOD TEETH FROM THE JURASSIC OF NIGER

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Isolated theropod teeth are common fossils in the continental Mesozoic deposits. Unfortunately, they are usually difficult to identify with precision on the basis of discrete characters because these features, such as denticle shape, are strongly subjected to homoplasy. Over the last decade, biometric methods have been developed to address this issue. Available databases can be used to assess isolated specimens by means of Discriminant Function Analyses (DFA) or Canonical Variate Analyses (CVA), which yield a high probability of accurate identification. Eight well-preserved crowns from the Iharazé Group (Middle Jurassic) in Niger were examined. These specimens can be divided into two morphotypes. The first includes two “spinosaurid-like” teeth, viz. subconical with apicobasal ridges on the enamel. The teeth of the second morphotype do not show any distinct diagnostic characters. Therefore, morphometric analyses had to be performed to help identify them. The results of the DFA and of a scatter plot of the first and second canonical functions generated by the discriminant analysis were in agreement for a single specimen. They suggested that it is from a megalosaurid. Of the five remaining specimens, three are consistent with an abelisaurid affinity, whereas two may be from a non-abelisaurid ceratosaurs. However, one of the latter crowns has a textured enamel that is similar to that of the megalosaurid tooth. In conclusion, our sample from the Nigerian Iharazé Group probably comprises representatives of the clades Megalosauridae and Abelisauridae. The occurrence of basal (non-abelisaurid) ceratosaurs is uncertain as the specimens in question may...
actually be from basal tetanurans (megalosauroids). The presence of possibly the earliest spinosaurids is worth stressing.

P-008
CRANIODENTAL VARIABILITY AND SEXUAL DIMORPHISM IN TWO SPECIES OF THE CANIDAE
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The family Canidae (Carnivora, Mammalia) is an ecologically diverse family. Differences in ecological conditions affect inter- and intraspecific morphological diversity. Therefore, widely distributed species frequently exhibit considerable morphological diversity. We suspect that such diversity stems from high morphological variability and plasticity within species. To test this hypothesis, both geographic and intrapopulation variation should be clarified in many species. In this study, we examine variations of craniodental measurements within populations of two phylogenetically and ecologically distant species of canids, red fox Vulpes vulpes from Bulgaria and raccoon dog Nyctereutes procyonoides from South Korea. The red fox is one of the most widely distributed species among Canidae, living across the Holarctic region, whereas the the raccoon dog is confined to East Asia, where it is widely distributed across latitudes. Therefore, these two species are expected to have high morphological variation, in particular the fox.
Contrary to our predictions, however, variations in traits were not higher than in other canid species and interspecific differences of variation were detected in few traits. Traits with higher variation were measurements of mandible, canines, anterior premolars and molars in both species. The most remarkable one is the length of the lower first premolar, which showed an extremely high variation in the raccoon dog. Since this tooth is marginally functionally significant, selection pressure acting on it may be weak. On the other hand, mandibles and molars that showed relatively high variation are important as masticatory organs. They may reflect weak dietary selection pressure in these two populations due to stable conditions in these regions.

P-009
3D FINITE ELEMENT AND PARAMETRICAL ANALYSIS OF A STEREOSPONDYL AMPHIBIAN (TEMNOSPONDYL)
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Stereospondyls were Permian and Triassic temnospondyl amphibians characterized by dorsoventrally flattened and strongly ossified skulls. Some groups of Stereospondyls, like tematosaurids, metoposaurids and capitosaurids, acquired medium to gigantic size, becoming the aquatic top predators of the Permian and Triassic ecosystems. Different morphological characters in these groups probably resulted in different feeding strategies. One of these characters was the position and size of the orbits. We analysed the mechanical role of the orbits using Finite Element Analysis (FEA) and Parametric Analysis (PA). PA is an excellent method that allows tests of changes in the morphology or polarity of vertebrate structures for comparing different results (stress and displacements) and provides understanding of the evolutionary patterns and plasticity of characters in this group of early tetrapods. We performed 3D analyses in the skull of Edingerella madagascariensis (a basal capitosaurian from the Early Triassic of Madagascar) using both PA and FEA. The digital model was obtained from a CT scan and the boundary conditions applied to different biting cases included bilateral, unilateral and lateral bites. The PA was done by modifying the values of two variables separately: the position of the orbits along the principal axis of the skull and the size of the orbits, and observing the influence in the values of maximum Von Mises stress and displacements in the skull. The size and position of the orbits did not affect the mechanical capabilities and stress distribution of the Stereospondyl skull, demonstrating the plasticity of the size and position of the orbits in the different groups, thereby allowing great phenotypic plasticity of the Stereospondyls.

P-010 [Affiliated with Symposium 12 – New Advances in Paleohistological Studies]
THE HISTOLOGICAL VARIABILITY OF THE INTERCENTRA AMONG TEMNOSPONDYL
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The histology of the vertebrae of Temnospondyli is poorly known. For the first time, we describe the histological variability of Permian and Triassic taxa from different localities is presented. The 12 intercentra (Eryops sp., Trimerorhachis sp. and six Stereospondyli: Plagiosuchus sp., Gerrothorax sp., Plagiosternum sp., Mastadosaurus sp., Cylotosaurus intermedius and Metoposaurus diagnosticus krasiejowensis) were sectioned histologically. All intercentra have trabecular structure but density of the trabeculae in Mastadosaurus, Cylotosaurus and Metoposaurus is higher than in the other taxa. Calcified cartilage covers the endochondral domain in all taxa, but is visible between the trabeculae only in Stereospondyli. The parallel-fibred periosteal cortex is present on the ventral and lateral sides below the parapophysis, but also on the dorsal side in Gerrothorax. Sharpey’s fibers are present below the parapophyses. In Eryops, the arrangement of vascular canals in the cortex is irregular; Cylotosaurus and Mastadosaurus have regular rows of simple canals. In Metoposaurus, the cortex is thin with numerous erosion cavities. In Plagiosuchus, regular rows of canals perpendicular to the long axis of vertebrae are visible. In Plagiosternum, six canals run transversally from the outer surface to the centre, and between them, canals parallel to the long axis dominate. In Gerrothorax, the canals are longitudinal. Growth marks are visible in Metoposaurus and Plagiosternum intercentra as annuli and zones without Line of Arrested Growth (LAGs). In Plagiosuchus, six LAGs are present. The presence of calcified cartilage between the trabeculae may be the plesiomorphic character for all Stereospondyli. The periosteal bone on the dorsal side in Gerrothorax proves pleuro- and intercentrum origin of this centrum and the centra of other plagisaurids indicate only an intercentrum origin. The different thicknesses of the cortex and the size of vascular canals may be a manifestation of an adaptation, especially among Stereospondyli, to different positions in the water column.

P-011 [Affiliated with Symposium 12 — New Advances in Paleohistological Studies]
CORRELATES OF BONE HISTOLOGY QUANTITATIVE DATA WITH LIFE HISTORY TRAITS AND ECOLOGICAL PARAMETERS IN BOVIDS
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Growth rate is an important life history trait that depends heavily on environmental conditions and contributes to an organism’s fitness. Primary compact bone tissue is commonly categorized in different typologies that are related with the rate of bone deposition following Amprino’s Rule: the rate of bone deposition is higher in highly vascularised fibrolamellar tissue than in poorly vascularised or non-vascular parallel-fibred or lamellar bone. These bone typologies form a continuum with all possible intermediate stages regarding matrix organization and vascularisation. However, only a few studies have correlated quantitative data on bone microstructure with growth rate or other life history traits, and no study on quantitative bone histology has been conducted in large mammals hitherto. Here we aim to correlate quantitative histological data with life history traits (body mass, growth rate, brain mass, age at sexual maturity) throughout extant Bovidae. Bovids are a highly diverse group, dwelling in all terrestrial biomes and presenting a huge array of body masses (3-900 kg), which make them an essential group to assess how histological features vary with the life history. We analyzed 27 species of bovids (55 individuals from the wild) with known body mass and sex. Histological data were obtained by analyzing femoral cross sections under polarized and transmitted light microscopy. Quantitative histological features are grouped into vascular (orientation and density) and cellular (size, shape and density) parameters. Statistical analyses were carried out in R using phylogenetic generalized linear model with CAIC package to control for the phylogenetic relationships among species. Body mass (birth and adult) and growth rate correlate with most bone histology variables, but age at sexual maturity only correlates with vascular orientation. These results are consistent with the Amprino’s rule and highlight the important effect of body mass in mammalian bone histology.

P-012 [Affiliated with Symposium 12 — New Advances in Paleohistological Studies]
OSTEODERM MICROSTRUCTURE OF PHYTOSAURS AND AETOSAURS (EUREPTILIA, ARCHOSAURIFORMES)
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We analysed the osteoderm microstructure of several archosauriforms. The phytosaur sample consists of osteoderms of Leptosuchus sp., Paleorhinus sp., Pseudopatus sp. and Phytosauria indet. (all from North America) and cf. Mystriosuchus sp. (Germany). The aetosaur sample included osteoderms of Aetosaurus ferratus and Paratypothorax andressorum(Germany), Stagonolepis olenkae (Poland), and Adamanasuchus eisenhardtii, Calyptosuchus cf. wellesi, Desmatosuchus smalli and D. spurensis, Paratypothorax sp.,
remodeled bone may have improved the mechanical properties of the Haversian bone.

increased mechanical loading. Abundant structural fibers observed in the p

the protective osteodermal structures in juveniles to subadult stages, which lead to further remodeling due to

ankylosaurian body armor. Metabolic amounts of their primary tissue early in ontogeny. This anomaly may be linked to the late ossification of the

extensive remodeling in derived North American taxa. In contrast to other taxa, ankylosaurs substitute large

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architecture. The bone matrix type in ankylosaurs is closes

and Sauropodomorpha. Ankylosaur long bone histology is characterized by a fibrolamellar bone

Nodosauridae. The histology was compared to that of other dinosaur groups, including other Thyreophora

histology in the Ankylosauria. This study is the first description of ankylosaurian long bone histology based

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Previous studies on other dinosaur taxa have revealed growth patterns, life history and evolutionary

The ankylosaurs are one of the major dinosaur groups and are characterized by unique body armor.

Previous studies on other dinosaur taxa have revealed growth patterns, life history and evolutionary

mechanisms based on their long bone histology. However, to date nothing is known about long bone

histology in the Ankylosauria. This study is the first description of ankylosaurian long bone histology based

on several limb elements, which were sampled from different individuals from the Ankylosauridae and

Nodosauridae. The histology was compared to that of other dinosaur groups, including other Thyreophora

and Sauropodomorpha. Ankylosaur long bone histology is characterized by a fibrolamellar bone

architecture. The bone matrix type in ankylosaurs is closest to that of Stegosaurus. A distinctive mixture of

woven and parallel-fibered bone together with overall poor vascularization indicates slow growth rates

compared to other dinosaurian taxa. Another peculiar characteristic of ankylosaur bone histology is the

extensive remodeling in derived North American taxa. In contrast to other taxa, ankylosaurs substitute large

amounts of their primary tissue early in ontogeny. This anomaly may be linked to the late ossification of the

ankylosaurian body armor. Metabolically driven remodeling processes must have liberated calcium to ossify

the protective osteodermal structures in juveniles to subadult stages, which lead to further remodeling due to

increased mechanical loading. Abundant structural fibers observed in the primary bone and even in

remodeled bone may have improved the mechanical properties of the Haversian bone.

P-013 [Affiliated with Symposium 12 – New Advances in Paleohistological Studies]  
CAN THE ENAMEL INCREMENTAL LINES PROVIDE CLUES ABOUT MAMMALIAN LIFE HISTORIES?  
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Teeth grow incrementally preserving a record of their growth in the form of microscopic lines. The

ameloblasts, enamel-forming cells, secrete their matrix with a circadian periodicity that leads to the formation

daily incremental lines. As this tissue does not undergo remodelling during the entire life of the animal, it

can be used as a tool to determine the timing and rate of dental development. Crown formation time is

widely used as a proxy in fossil mammals for the overall pace of life history. However, crown formation rate

(CFR) is less frequently used as it has been argued that there might be an allometric relationship between

crown height and extension rate. CFR is primarily a combination of two factors: the amount of enamel

secreted daily by the ameloblast (daily secretion rate, DSR) and the number of ameloblasts actively

secreting enamel per day along the enamel-forming front (daily extension rate, DER). Covariation of these

factors with life history traits in mammals has been poorly studied. The aim of this work is to test whether

CFR may be a reliable proxy of the pace of life in mammals, or whether ecological factors and/or phylogeny

would have a more important role in enamel growth. We used for this study a sample of extant wild

ruminants of different climate regimes, body masses and degrees of crown height. Thin sections of lower

molars were analysed in polarized light microscopy. Our results show that DER is more important than DSR

for the increase in the CFR in herbivorous mammals. Furthermore, crown height (hyposodonty index) is the

principal factor in determining differences in CFR among ruminant species. However, when controlling for

the degree of hyposodonty, CFR is a reliable proxy for the pace of life history in herbivorous mammals.

P-014 [Affiliated with Symposium 12 – New Advances in Paleohistological Studies]  
LONG BONE HISTOLOGY AND GROWTH PATTERNS IN ANKYLOSAURS: IMPLICATIONS FOR LIFE HISTORIES AND EVOLUTION  
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The ankylosaurs are one of the major dinosaur groups and are characterized by unique body armor.

Previous studies on other dinosaur taxa have revealed growth patterns, life history and evolutionary

mechanisms based on their long bone histology. However, to date nothing is known about long bone

histology in the Ankylosauria. This study is the first description of ankylosaurian long bone histology based

on several limb elements, which were sampled from different individuals from the Ankylosauridae and

Nodosauridae. The histology was compared to that of other dinosaur groups, including other Thyreophora

and Sauropodomorpha. Ankylosaur long bone histology is characterized by a fibrolamellar bone

architecture. The bone matrix type in ankylosaurs is closest to that of Stegosaurus. A distinctive mixture of

woven and parallel-fibered bone together with overall poor vascularization indicates slow growth rates

compared to other dinosaurian taxa. Another peculiar characteristic of ankylosaur bone histology is the

extensive remodeling in derived North American taxa. In contrast to other taxa, ankylosaurs substitute large

amounts of their primary tissue early in ontogeny. This anomaly may be linked to the late ossification of the

ankylosaurian body armor. Metabolically driven remodeling processes must have liberated calcium to ossify

the protective osteodermal structures in juveniles to subadult stages, which lead to further remodeling due to

increased mechanical loading. Abundant structural fibers observed in the primary bone and even in

remodeled bone may have improved the mechanical properties of the Haversian bone.
The level of phylogenetic signal in osteohistological variation has recently been debated in the literature. We performed a comprehensive study in which we quantified such signal in thirty-one bone histological features in an exhaustive sample including all extant and extinct (but one) ratite genera. We have found a significant phylogenetic signal in many osteohistological features and we used this empirical background to discuss the different meanings of the concept of phylogenetic signal in cladistics and in the phylogenetic comparative method. In cladistic analysis, primary homology becomes either a single statement of secondary homology (a strict synapomorphy) or multiple statements of secondary homology (convergent evolution). In contrast, the statistical phylogenetic comparative method tests whether phenotypic variation has a phylogenetic structure or a random distribution, regardless of whether this phylogenetic structure corresponds to a single or to multiple statements of secondary homology. In the statistical approach we used regressions on the original distance matrices, and phylogenetic eigenvector regression (PVR). The performance of this last method has been hotly debated in recent literature because it uses arbitrary methods of eigenvector selection and because it does not assume an explicit evolutionary model. Here we evaluate another, original, aspect of PVR method: the effectiveness of using PVR in distinguishing strict synapomorphies from homoplasy. We conclude that the outcome of these statistical approaches is not necessarily congruent with that of cladistic analyses because, in many cases, a statistically significant phylogenetic signal is obtained from a homoplastic pattern of variation and, in other cases, no significant phylogenetic signal is obtained from patterns involving unambiguous synapomorphies.

Osteocytes are assumed to obtain nutriments and oxygen, and to evacuate their metabolic byproducts, through cytoplasmic expansions located inside canaliculi and connected to vascular networks. These vascular networks are housed within bone cortices, and in the inner (perimedullar) and outer (periosteal) connective tissues associated with the bones. The cortices of small bones in adult lepidosaurs and birds are avascular, so that osteocytes perform metabolic exchanges exclusively with the inner and outer connective tissues. The maximum thickness of avascular bone in lepidosaurs and birds could be explained by two distinct (though not mutually exclusive) hypotheses: (1) the osteocytes of endotherms have higher energetic expenditure and produce more metabolic byproducts than those of ectotherms, so we expect significantly higher thickness of avascular bone tissue in lepidosaurs than in birds; (2) the main function of osteocytes is the transduction of biomechanical signals (bone strain), so for a given body mass we expect no significant differences between the thickness of avascular bone in lepidosaurs and birds. On the other hand, we analyzed the scaling of bone vascular density in the bones that actually display vascular canals. Two antagonist factors could possibly explain the variation of this feature: (1) considering that resting metabolic rate (oxygen consumption, in ml, per body mass, grams) decreases as body mass increases, we expect that bone vascular density decreases as body mass increases; (2) as bone size increases, the relative importance of vascular supply of periosteum and endosteum decreases because bone surface (containing vascular supply) increases proportionally to the second power of bone length, whereas bone mass (to be supplied) increases proportionally to the third power. So we expect that bone vascular density increases as body mass increases to compensate the smaller relative importance of vascular supply of periosteum and endosteum.

WOUND REPAIR IN DERMAL ARMOUR OF A 380 MILLION YEAR OLD JAWLESS FISH: EVIDENCE FOR ODONTOGENIC STEM CELLS

Smith, Moya Meredith (1); Johanson, Zerina (2); Kearsley, Anton (3); Kearsley, Peter (4); Mark-Kurik, Elga (5)

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Fossil skeletal tissues preserve characters associated with their living state, recording ghosts of cells as spaces, and continued cell activity as sequential incremental growth lines. We report biological and diagenetic inferences of a unique response to ongoing wear in heterostracan dermal bone of the 380mya *Psammocephalus* armour, with extensive damage from a surface wound. New observations come from back-scattered electron imaging of polished surfaces and EDX analysis, with laser confocal microscopy of equivalent sections. We find that migratory odontoblasts leave tubule tracks in the dentine that can trace their invasive growth course from site of origin to live cell position at death. This shows, together with spacing of incremental lines, that dentine grows from the tubercle pulps, and concomitantly fills adjacent ampullar shaped crypts between the superficial dentine tubercles. From both these sites dentine spreads throughout the bone and this invasive property is co-opted to repair a deep wound in the spongy bone, exclusively with dentine with little contribution from bone (aspidin). This despite bone forming the major component of dermal armour with dentine normally restricted to tubercles at the surface. Dentine forms in a chaotic manner in the wound, also incorporating sand grains into this hard tissue repair. We propose a developmental model that, by comparison with extant tissues, defines the location of dentine-producing cells (stem odontoblasts). These migratory odontoblasts develop from tubercle pulp cavities and from surrounding, flask-shaped crypts. We suggest that these crypts, associated with surface pores, are a stem cell niche capable of producing odontoblasts for secondary dentine in the pulps and invasive repair, within the complex canal system of the bone.

P-018 [Affiliated with Symposium 12 – New Advances in Paleohistological Studies] EVIDENCE OF METASTATIC CANCER IN A STEGOSAUR TIBIA
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A palaeopathology found in a *Stegosaurus* tibia (YPM57509) exhibits spiculated periosteal reactive growth perpendicular to the bone surface, and a well-defined cavity (lesion) with lytic margins within the mid-cortical region of the bone wall. The lesion is partially infilled with trabeculae. The spiculated periosteal reaction, also called ‘hair-on-end’ reaction, is highly suggestive to be the result of Ewing’s sarcoma (a malignant type of bone tumor), osteosarcoma (a malignant type of bone tumor), metastasis (another malignant type of tumor that spreads to bones) or osteomyelitis (infection). Although it is most suggestive of Ewing’s sarcoma, the lytic margin and the absence of a transition zone in the stegosaurus tibia are characteristic of metastatic cancer. In contrast, Ewing’s sarcoma, osteosarcoma and osteomyelitis are defined by the presence of a sclerotic margin (thickening of the margin of the lesion), as well as a zone of transition, in which the surrounding tissue is infiltrated by the cancer/infection. Trabeculae can occur within an osteosarcoma but are chaotic in appearance, unlike the growth of trabeculae from the lesion margin as seen in the palaeopathology in the tibia, which is rather suggestive of multiple metastases affecting the bone. Two possible lytic lesions in a thin section of a sympatric *Stegosaurus* femur (YPM4634) may suggest multiple metastases in this animal, however, in this case other characteristics such as periosteal reactive growth and trabeculae are absent. Metastatic cancer is rare in dinosaurs, reported in an indeterminate long bone from the Upper Jurassic Morrison Formation and an *Edmontosaurus* vertebra from the Late Cretaceous. The occurrence of three possible metastatic cancers in two stegosaurs and an unidentified dinosaur from a geographically localised region (the Morrison Formation) may reflect an elevated incidence of cancer, which may be related to diet, prevailing climatic conditions, or possibly inherent susceptibility to cancer.

P-019 RESOLVING THE HOMOLOGY AND DUAL EMBRYONIC ORIGIN OF THE ENIGMATIC MAMMALIAN SKULL BONE, THE INTERPARIETAL
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The homologies of mammalian skull elements are now fairly well established, except for the controversial interparietal bone. Its presence, development, terminology and homology across living and fossil synapsids are poorly known and largely undocumented, with contradictory statements in literature. A previous experimental study reported an intriguing mixed origin of the interparietal whereby the medial portion is derived from neural crest cells, and the lateral portion from mesoderm. The evolutionary history of this mixed origin remains unresolved, and contradictory reports on the presence or absence and developmental patterns of the interparietal among mammals have complicated the question of its homology. Here, we provide a novel perspective on the evolutionary identity of the interparietal, based on a comprehensive study across more than 300 extinct and extant taxa, integrating embryological and paleontological data. Although the interparietal has been regarded as being lost in various lineages, our investigation on embryos...
demonstrates its presence in all extant mammalian orders. The generally accepted paradigm has regarded the interparietal as consisting of two elements that are homologized to the postparietals of basal amniotes. The tabular bones have been postulated as being lost during the rise of modern mammals. However, our results demonstrate that the interparietal consists not of two elements but of four. We propose that the tabulars of basal amniotes are conserved as the lateral interparietal elements, which quickly fuse to the medial elements during embryogenesis, and that the postparietals are homologous to the medial elements. Hence, the dual developmental origin of the mammalian interparietal can be explained as the evolutionary consequence of the fusion between the crest-derived "postparietals" and the mesoderm-derived "tabulars.

P-020
EMBRYONIC REMNANTS OF INTERCENTRA AND RIBS IN A PLEURODIRE TURTLE - A CASE OF RECAPITULATION AND FUNCTIONAL REDUCTION

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A broad sample of extant turtles possesses a series of paired bones in their necks that are situated between the cervical vertebrae. These paired bones were originally proposed to be cervical rib remnants, but have more recently been argued to be vestiges of intercentra. Here, we document, for the first time, the neck development of the pleurodire turtle Emýdura subglobosa and identify blastematosus structures, which partially recapitulate the ribs and intercentra of the plesiomorphic tetrapod condition. We identify blastematosus bridges between intercentra and the corresponding ribs, which we homologize with the vestiges visible in extant turtles and with the paraphyseal articulation processes of some stem taxa. Only the intercentrum of the atlas is retained in adult turtles, but intercentra are recapitulated along the entire vertebral column during development indicating that they are an integrated part of the signaling cascade and muscle fiber aggregation during embryogenesis. We also identify two rib rudiments in the occipital region, which may indicate that at least two vertebrae are integrated into the cranium of turtles in particular and of amniotes in general.

P-021
MORPHOMETRICS FOR EVODEVO: COMBINING MICROCT IMAGING, GEOMETRIC MORPHOMETRICS, AND IMAGE ANALYSIS

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Morphometrics, the measurement of organismal form, is central to the connecting of research in developmental biology, to the quantitative core of evolutionary theory. Modern imaging technology allows for 3D representations of embryos at microscopic scales, but the parameterization of embryonic form during development is limited by the current morphometric methods. Most morphometric tools can only be applied to traits that are present in all observed specimens and hence do not enable studies of the emergence of new structures; whereas the standard methods in image analysis do not sufficiently account for biological homology. We thus combine existing methods from the domains of microCT imaging, geometric morphometrics, and voxel-based image analysis to model spatial and temporal processes during development. Organismal form is parameterized by geometric morphometrics methods, including semilandmarks on curves and surfaces. Non-affine registration of the microCT images based on these parameters allows for a statistical analysis of tissue densities and cell proliferation patterns, including the emergence of novel anatomical structures during development. We illustrate these methods by applications to embryonic tail fin development in the rainbow trout.

P-022
MORPHOLOGY AND DISTRIBUTION OF INTERLACUAR CANALS IN ELASMOBRANCH MINERALIZED CARTILAGE

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The osteocytes embedded in tetrapod bone are connected to one another via an extensive meshwork of long, narrow channels (canaliculi), through which the osteocytes communicate via tendril-like cell processes. This network is paramount to the vitality and mechanosensing ability of tetrapod bone. Similar cell-rich networks are lacking in tetrapod mineralized cartilage, as chondrocytes typically die during mineralization of the matrix. In elasmobranch fishes (sharks, rays and relatives), chondrocytes remain alive...
Despite encasement in mineralized tissue, their lacunae connected via short passages, which we term interlacunar canals. We examine this cellular network by monochromatic, high-resolution absorption synchrotron microCT tomography of mineralized tissue from a stingray species (*Urolophus halleri*), using quantitative 3D image analysis to characterize the orientation, density and morphology of the lacunae-canal system. Interlacunar canals link consecutive ovoid lacunar spaces into long uni-directional lacunar strings, radiating outward from the center of each tessera (the individual mineralized tiles that cover the skeleton), with non-radial (i.e. vertical or circumferential) canals nearly non-existent. The originating point for lacunar strings is a dense collection of rounded cells at the center of each tessera. Interlacunar canals in elasmobranch cartilage are considerably shorter (<10µm long) and they are roughly an order of magnitude wider (>5µm in diameter) than bone canaliculi, resulting in a distinct “string of pearls” morphology for lacunar strings. Tesserae are characterized by wedge-shaped zones of higher mineral density, radiating like wheel spokes from the center of each tile: lacunar strings are concentrated in between these spokes, resulting in alternating cell-rich and mineral-dense zones. We propose that the different cell populations in tesserae (central cells vs. lacunar string cells) serve separate roles in the mechanics and mineralization of the skeleton, and that the existence of elasmobranch cell networks suggests a level of parallelism in early chondrocyte and osteocyte evolution.

P-023
NEW INSIGHTS INTO THE PATTERN OF CLOSURE OF CRANIAL SUTURES IN THE MOUSE AND ITS EFFECT ON SHAPING OF THE CRANIUM

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The processes involved in the growth of the mammalian skull and closure of the cranial sutures are not well understood, but are most likely influenced by genetic, hormonal and mechanical factors. The growing brain exerts pressure on the intracranial skull surface, stimulating growth of the cranial bones and maintenance of suture patency. Here we present a study investigating closure of the sutures of wild-type (WT) and mutant (MT) mouse skulls (Crouzon-type with premature fusion of the coronal suture) and resultant variation in skull shape. Two ontogenetic series of WT and MT skulls were imaged by microCT. Each series was represented at 6 ages (2.5 to 6 weeks) with up to 10 specimens at each age. The crania were characterised by 37 landmarks, skull geometry (10 characteristic dimensions) and individual suture status (typically assessed every 0.2 mm along each suture’s length). Of the measurements taken from the two series, all showed a significant difference between WT and MT individuals with the exception of the posterior width (between the post-tympanic hooks); although the anterior width (across the palatine bone) was always greater in the MTs. The crania of the WTs had a greater overall length at all ages, which was still increasing at week 6, while the length of the MTs varied very little after week 5. Conversely, the height of the MTs was always greater than the WTs, with the latter remaining relatively constant from week 3, compared to week 4 for the MT mice. The results provide an interesting insight into how the mouse cranium grows and can compensate for premature fusion of the coronal suture to continue to accommodate the expanding brain. The long-term aim of this research is to simulate this growth *in silico* and thereby understand more about the role played by biomechanics in skull development.

P-024
LIMBS TO FINS: THE REMARKABLE EVOLUTIONARY STORY ABOUT LIMB REDUCTION IN GYMNOPTHALMID LIZARDS

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Transitions in body shape permeate the evolutionary history of vertebrates. Among those, the evolution of morphologies characterized by elongated bodies with limbs reduced or absent is particularly frequent, and non-pentadactyl autopodia are widespread among tetrapod lineages. The tetrapod limb is composed by different tissues, such as muscles, bones, tendons. Most developmental and comparative studies about the relationship between hard and soft limb tissues focus on pentadactyl models, and the implications of such studies must be tested by taking into account deviations of the pentadactyl norm, such as the extreme cases of digit reduction/loss observed in some vertebrate lineages. Here we investigate the relationships between muscles and bones in the tetrapod limb through a comparative analysis of limb morphology among gymnophthalmid lizards, which exhibit a remarkable variation in limb morphology and different grades of digit and limb reduction. In gymnophthalmids loss of only one forelimb digit implies 1) a slight reduction of the musculature, which is somewhat decoupled from bone reduction, and 2) new patterns of muscle attachments that seem to be related to both the topological position and morphological identity of the bones where the muscles attach. Transitions from the plesiomorphic pentadactyl limb morphology to a spine-like...
appendage dramatically affect the configuration of bones and muscles. Moreover, different lineages where digit loss has evolved apparently exhibit different patterns of limb myology, suggesting that muscle reorganization during these events did not follow exactly the same pathway.

P-025
FUSION OF THE MANDIBULAR SYMPHYSIS IN THE PIG
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In most mammals the symphysis remains unfused throughout life and is often very mobile. However, postnatal fusion into a single mandibular bone has evolved several times, including in anthropoid primates, camels and pigs. At least in humans and pigs, external fusion of the symphysis begins around the time of weaning, but the histology of this process is little known. We examined pig (Sus scrofa dom.) symphyseal histology at three stages, late fetal (n=6), 3-8 weeks (weaning, n=8) and 12-20 weeks (juvenile, n=3). Composition of the symphyseal tissue showed individual variation even when location and age were the same. The symphysis was patent in all fetuses and 6 weanlings. Except for a small pad of cartilage at the lingual border of the posterior extremity, it was completely ossified in the juveniles and one 8-week pig, with no remaining trace of an articulation. Cartilage was the major constituent of the fetal and weanling symphysis. In most fetal specimens, the posterior region featured an encapsulated midline cartilage, interpreted as the fused termination of Meckel’s cartilage. This was flanked by larger, irregular, bilateral cartilages, interpreted as secondary cartilage. Where Meckel’s cartilage was not present, the secondary cartilages were sometimes separated by a collagenous mesenchyme and sometimes abutted so closely that they resembled a double growth plate, with a perichondrial small cell layer near the midline progressing laterally to hypertrophic, mineralizing cartilage at the bone fronts, which were ossifying endochondrally. As the symphysis matured, the perichondrium was lost, leaving a midline secondary cartilage. This region may function as a growth center while the symphysis is patent. Initial osseous fusion was not endochondral, as indicated by one 5-week specimen, which showed bony bridging of the cartilage-poor central region. Because all other symphyses were either completely patent or completely fused, ossification is a very rapid process.

Locomotion
P-026
MORPHOLOGICAL DIFFERENCE OF POSITION OF TRUNK MUSCULATURE
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Our aim is to identify environmental adaptations of morphological structure of trunk musculature by studying the Urodela. The Urodela is an important model because they use their trunk for lateral movement during walking and swimming. In particular, we focused on regional variations in trunk musculature in three groups; epaxial muscles, lateral hypaxial muscles, and ventral muscle. We quantified these muscle groups in six species from three habitats; Amphiopus tricladylum and Necturus maculosus (aquatic), Cynops pyrrhogaster and Cynops ensicauda (semi-aquatic) and Ambystoma tigrinum and Hynobius nigrescens (terrestrial). Cross sectional areas of each trunk muscle were measured in three parts; anterior part, middle part, and posterior part. The aquatic species have smaller difference among three parts of each muscle group than the terrestrial species. The terrestrial species possess smaller epaxial muscle and ventral muscle, and larger lateral hypaxial muscles in anterior and posterior parts than in middle part. The aquatic species show smaller difference of each muscle cross-sectional area than the terrestrial species, presumably because they do not need to support their own weight in water and use their whole body for undulatory locomotion. In contrast, the trunk musculature of terrestrial species needs to maintain posture and stabilize their bodies on land. Additionally, the anterior and posterior trunk musculature of terrestrial species, located near limbs, also need to sustain body weight. Epaxial and ventral muscles in middle part are employed more to stabilize and keep posture than are the anterior and posterior parts.

P-027
THE RELATIONSHIPS BETWEEN MUSCULOSKELETAL MORPHOLOGY OF LIMBS AND LOCOMOTOR HABITS IN CUBAN ANOLIS LIZARDS
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Limbs are functional-morphologically important traits for understanding the evolution of the lizards, because they may produce various locomotion styles. Nevertheless, few morphological studies have detailed form and function of the appendicular skeletal muscles among lizards living in different habitats. Anolis lizards have radiated adaptively in the Caribbean Islands. Different morphologies and behaviors have evolved in this genus in different environments. Additionally, sexual dimorphism is remarkable in most species of Anolis, with only males showing courtship displays using expanding dewlaps and head-bobbing. We measured and compared muscle mass and length of moment arm of limbs in two Anolis species from different habitats in Cuba, terrestrial A. sagrei, and arboreal A. porcatus and determined how the appendicular muscle morphology is related to locomotor style, habitat and courtship display. Anolis sagrei possesses large extensor muscles in its hindlimbs, which are advantageous for running, whereas the humeral and femoral retractors are larger in A. porcatus, allowing these lizards to hold up their bodies and occupy tree substrates. Thus, habitat type affects appendicular muscular traits of limbs. Comparisons between the sexes show different trends in the two species. Male A. sagrei, which occupy broad surfaces on the ground or tree trunks, are equipped with a strong humeral adductor. In contrast, male A. porcatus, which inhabit narrow branches or leaves, have larger elbow extensor and humeral protractors. The muscles that maintain display posture are developed only male of each species. Thus, the specific displays of males may be related to forelimb musculoskeletal morphology, which varies among species depending on their microhabitat.

P-028

COMPARATIVE ANATOMY OF THE SHOULDER GIRDLE MUSCLES FROM SALAMANDERS TO HUMANS

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The shoulder girdle of tetrapods showed notable morphological changes during the evolution of terrestrial locomotion. We elucidated the morphological evolution of the shoulder girdle muscles and determined the morphological significance of the muscles located between the trunk and the limb muscles. The observations were performed by dissecting the shoulder girdle muscles together with the supplying nerves in amphibians (giant salamanders), reptiles (monitor lizards and green iguanas), monotremes (platypuses and echidnas), marsupials (koalas and possums) and placental mammals (cats, rhesus monkeys and humans). This study focuses on the following three observations; 1) The appearance of the supra/infraspinitus muscles has been made in monotremes, in which the reduction of the coracoid bone and the formation of the supraspinous fossa have not yet occurred. Thereafter, the coracoid bone in therians has dwindled and the new scapular element, supraspinous part, is formed. 2) The origin of the subscapularis muscle in monotremes develops over the external surface of the scapula and this external part is innervated by the independent branch that is homologous with the branch to the scapulohumeralis posterior muscle in reptiles. These results suggest that the mammalian subscapularis muscle has a complex origin. 3) In reptiles and monotremes, serratus anterior and levator scapulae muscles form a continuous muscular sheet. In therians, both muscles have clearly been separated. The rhomboideus muscle appears in mammals. In many mammals, the lateral cutaneous branches of the upper intercostal nerves are observed to innervate additionally the serratus anterior and/or scalenus longus muscles. The homology of the layered arrangement of the nerve fibers supplying these muscles supports the idea that the dorsal shoulder girdle muscles (levator scapulae, serratus anterior, rhomboideus muscles) have the same morphological significance as the trunk muscles, not as the limb muscles.

P-029

3DGM ANALYSIS OF THE INFLUENCE OF BRACHIATION INTO SHAPING THE PROXIMAL HUMERUS OF SUSPENSORIAL PRIMATES

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Brachiation is a highly specialized form of locomotion that orthograde Primates use to negotiate below-branch traveling. However, only the Hylobates genus is able to successfully and regularly conduct the most extreme form of brachiation, the rachetral brachiation, which possibly implies several anatomical specializations present all over the hylobatid morphotype. One of the most compromised regions when engaged in effective brachiation is the glenohumeral joint of the shoulder. This joint is responsible for the arm’s full range of movement, sometimes being about 360°, but also of the arm’s stability, aided by the rotator cuff musculature. The compromise between high degree of mobility and arm stabilization is a key component to a successful undertaking of brachiation and its diverse presentations across the Primate taxa that use it. We used 3D geometric morphometrics to explore the form of the proximal humerus of six brachiating taxa (Hylobates, Pongo, Pan, Gorilla, Ateles and Lagothrix) and also in a non-brachiating group.
Colobus, to explore to what extent locomotion, and what type of locomotion, if possible, is driving the shaping of this main constituent of the glenohumeral joint. Brachiation certainly plays a role into shaping the proximal humeral form. Also, the results indicate that the two main structures of the humeral head, the articular surface and the insertion sites of the rotator cuff’s muscles, respond to different selective pressures. The range of movement seems to be more involved in the shaping of the articular surface, being Hylobates the taxa with higher movement range at this particular joint. However, the placement and orientation of the rotator cuff muscles’ insertion sites in the tubercles seem to be specialized in dealing with the diverse stresses operating at the joint (shearing, compressive or tensile stress) associated with the locomotor behavior of the taxa.

P-030
QUANTITATIVE ANALYSIS OF THE MUSCLES OF THE ROTATOR CUFF IN DIFFERENT ORTHOGRADE AND PRONOGRAD PRIMATE SPECIES: ADAPTATIONS TO DIFFERENT TYPES OF LOCOMOTION
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Primates can be divided into orthograde and pronograde according to their anatomical corporal pattern. Orthograde primates include gibbons, orangutans, gorillas, chimpanzees, bonobos and humans, and all of them are characterized by dorsally placed scapulae and other anatomical traits that enhance the mobility of the glenohumeral joint. Pronograde primates include all non hominoid primates and they are characterized by more laterally placed scapulae and a more rigid glenohumeral joint. We analyzed the mass proportion of the four muscles of the rotator cuff (subscapularis, supraspinatus, infraspinatus and teres minor), the main stabilizer structure of the glenohumeral joint, in different orthograde and pronograde primate species. Our aim was to find differences that could be related to the particular functional demands of the different types of locomotion performed by these species. There are not great differences in the mass proportion of the rotator cuff muscles between the two groups of locomotion observed in the orthograde primates, the more arboreal gibbons and orangutans compared to the more terrestrial gorillas and chimpanzees. On the contrary, we have found significant differences between orthograde and pronograde primates, especially an increase in the proportion of the supraspinatus muscle and a decrease in the proportions of the infraspinatus and teres minor muscles in pronograde primates. These differences could be related to the important role of the supraspinatus as a postural muscle in pronograde primates and to the important role of the infraspinatus and teres minor as stabilizers of the glenohumeral joint in knuckle-walkers gorillas and chimpanzees and in vertical climbers and arm-swingers orangutans. Also, within the pronograde primates, we observed a particular pattern in vertical clingers, with a major proportion of the subscapularis mass, with respect to the arboreal quadrupeds or semiterrestrial pronograde primates.

P-031
GUENONS VS GREAT APES: THREE-DIMENSIONAL KINEMATIC ANALYSIS OF THE PATELLA DURING MOTION
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Quantifying the kinematics of the patella is essential for understanding the role of the knee joint in locomotion, but also a challenge due to the complexity of function of the muscles and ligaments around the joint. Previous studies focusing on the human knee have postulated two different biomechanical models for the patella, the short-beam and the pulley models. However, little attention has been paid to the knee functioning in non-human primates. Based on 3D scan data of Gorilla and Cercopithecus patellae, these two hypotheses are evaluated using Finite Element Analysis (FEA). Deformation and von Mises stress have been analyzed under different loading conditions and considering muscles and ligaments, in order to test how these patellae respond to dynamic loading (i.e., during knee flexion). Results show that stresses are more widely distributed through the FE model of Cercopithecus, and it also carries greater deformations. Interestingly, this primate displays a distal structure in the patella, the apex, which apparently favors the dissipation of stress. By contrast, a non-stressed anterior area is observed in the patella of Gorila, while stress and deformation are mainly concentrated in its posterior side. Remarkably, the patella of Gorila does not present a distal apex. Thereby, differences observed between the two patellae are probably due to their different external geometry and the diverse positional behaviors of these two primates, assuming that the
Patella of the gorilla reflects a broader range of positions and that the guenon’s knee relies on extreme flexion positions with a higher frequency. Although further validations are needed, our preliminary results are consistent with the hypothesis of a short-beam model for the patellae of both taxa. Results from this research evidence the potential of FEA as an efficient tool in reconstructing the primary function of the patella during motion.

P-032
FORM AND FUNCTION OF THE FOOT AND HALLUX IN THEROPOD DINOSAURS
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The presence of an opposed hallux (hindlimb digit I) in the theropod lineage is regarded as an important indicator of increasing perching ability. However, the function of the foot of non-avian theropods, with its non-reversed hallux, is poorly understood. To clarify foot function in non-avian theropods, principal component (PC) analyses were conducted on four datasets of linear measurement values of all non-ungual pedal phalanges in extant birds; these were then compared to similar datasets from non-avian theropods. One of these analyses successfully differentiated the plot distributions among extant birds in different functional categories of foot, and plots of non-avian theropod dinosaurs in morphospace distributed close to the convex hull of ground-foraging bird plots. Additionally, detailed observation was done for the purpose of unraveling halluxal functions. According to the form of articulation, the movement axis of the hallucal metatarsal-phalangeal joint in general theropods was more restricted to vertical motion than in extant ground-foraging birds. This might indicate a mechanical function of the hallux, such as prey holding. In three specimens of Velociraptor (Dromaeosauridae), the attachment of MT I on MT II varied from the medial to the plantar side, and was accompanied by the lateral and posterior directions, respectively, of the distal articular facet of MT I and associated digits. A similar condition of MT I was seen in three troodontid specimens, and the proximal articular facets of MT I of both dromaeosaurid and troodontid specimens were convex like that of extant birds, rather than having the concave facet of more basal theropods. These characters mean the mobility of the intermetatarsal joint between MT I and II was increased in Paraves, and the range of halluxal movement extended, a feature presumably correlated with acquisition of the perch-grasping function in basal birds.

P-033
A GEOMETRIC MORPHOMETRIC ANALYSIS OF THE FEMUR OF HOPPING MARSUPIALS
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Kangaroos and wallabies (Macropus) are the largest mammals to use bipedal hopping for fast locomotion. This study examines variation in the shape of the marsupial femur in relation to hopping locomotion. Thirty eight homologous 3D landmarks on 47 femurs of Australian marsupials were digitised. The species included 20 hopping marsupials from the family Macropodidae, and 20 other species including those with arboreal, fossorial and quadrupedal terrestrial habits. The data were analysed using geometric morphometric techniques in morphologika and the EVAN toolbox. The results show that hopping marsupials have characteristic femoral features including a greater trochanter that extends far more proximally than the femoral head, the femoral shaft is more robust and convex anteriorly, and there is a dramatic change in the relative sizes of the hip and knee. Hopping marsupials have a larger knee and a smaller, more cylindrical femoral head, while in non-hopping marsupials the reverse is true. Among the hopping marsupials, the macropod species are the largest and fastest, and have the greatest crural and smallest intermembral indices. Their femora have the features described above in their most exaggerated form. The significance of the hopping adaptations is unclear. The high greater trochanter may be related to powerful hip extension. The relatively small femoral head may be related to the flexed posture at the hip, which may reduce the forces transmitted through the hip joint and make the muscles around the hip transmit most of the impact. The large knee joint may be a reflection of the large bone to bone forces transmitted there. The increased diameter and curvature of the femoral shaft maybe an adaptation for resisting femoral bending stresses.

P-034
IN VIVO FEMORAL STRAINS IN SWIMMING TURTLES: THE INFLUENCE OF LOCOMOTOR MEDIUM ON LIMB BONE LOADING
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Many terrestrial vertebrate lineages have members that have returned to aquatic habitats. Such taxa often show characteristic changes in limb bone shape, such as flattening of the shaft. The basis for evolutionary modifications in skeletal structure is often assumed to relate to changes in the loads that bones experience. Shifting to aquatic habitats would be expected to alter the loads to which limbs are exposed, lowering body support demands but retaining muscle forces from cyclic activity. No experimental data are available to evaluate such predictions, however, or to specify changes in load magnitude or regime between habitats. We tested how limb bone loading changes between use in terrestrial and aquatic habitats by recording in vivo strains from the femur of swimming slider turtles (Trachemys scripta) and comparing these data to bone strain recordings from turtle femora during terrestrial walking. We predicted that peak load magnitudes would be lower during swimming than walking, but that nearly equal load peaks, indicating bending in opposite directions, might occur during each of the thrust and recovery phases of the limb cycle. Preliminary data indicate that our first prediction was met, with average peak strains in swimming less than half the magnitude of those during walking. However, magnitudes of individual peak strains during swimming can reach values that are twice average values. Loading regimes were consistent between swimming and walking, with compressive axial strains experienced on the dorsal surface of the femur. Thus, our second prediction was not met, as single peaks of loading were consistently experienced during the thrust phase, whereas loads during recovery were more variable and typically much lower in magnitude than the strains recorded during thrust. These results indicate the strong role that limb muscles play in producing bone loads even after the reduction of environmental forces.

P-035
GAIT TRANSITIONS AND MODULAR ORGANIZATION OF MAMMAL LOCOMOTION
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Quadrupedal locomotion is the result of complex interactions between biomechanical and neural systems. During steady gaits both systems are in stable states. When an animal changes its speed, transitions between gaits can occur and different coordination parameters are dissociated. Consequently, transitions are the periods where it is possible to detect and identify those parameters involved in the mechanical or neural control of locomotion. The analysis of the inter-limb coordination modifications and of each footfall parameter during the transition between all possible gaits in dogs showed that mechanics drive the stance phase whereas the coordination is controlled during the swing phase. Furthermore, the comparison of the transition patterns between all possible gaits reveals a morpho-functional modular organization of locomotion: a pectoral module coordinates the two fore limbs, a pelvic module coordinates the two hind limbs, and an axial module coordinates the two pairs and the trunk motion. The three modules cooperate to give rise to a template of stable inter-limb coordination pattern, such as the walk, the trot, or the gallop. The modular organization of mammalian locomotion can be followed during tetrapod evolution and provides a template for the interpretation of the main patterns of body plan organization.

P-036
AQUATIC BURST LOCOMOTION BY HYDROPLANING AND RUNNING IN FEMALE COMMON EIDERS (SOMATERIA MOLLISIMA)
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We studied water-surface burst locomotion in female Common Eiders (Somateria mollissima), which are coastal sea-ducks. Surface-swimming animals can overcome the speed limitations of self-generated waves by performing rapid behaviors that generate dynamic lift (hydroplaning). Eiders have high wing loadings that are near the accepted threshold for flightlessness in birds. Therefore, any increase in mass from a heavy meal or egg formation in females can cause flight to be energetically expensive or impossible. We obtained high-speed videos (210 fps) of female Common Eiders around the Isles of Shoals in the Gulf of Maine. The videos showed two distinct hydroplaning behaviors: (1) “steaming”, which involved rapid paddling with the wings to propel the duck along the surface of the water and (2) “wing-assisted running,” during which the ducks lifted themselves completely out of the water and paddled along the surface while flapping their wings. When steaming, the wings made substantial contact with the water, but during running, only the feet made contact with the water, with a gait using alternating contralateral hind limbs. The mean wingbeat frequency of steaming (4.57 ± 0.44 Hz) was significantly slower than wingbeat frequency of wing-assisted running (8.69 ± 0.65 Hz) (t=19.16, p<0.0001). Both prolonged steaming and running resulted in either diving underwater or a return to floating on the water surface, but not flight. When burst locomotion by Eiders is necessary, hydroplaning and running are likely energetically economical and rapid alternatives to diving or flight for these heavy marine ducks.
P-038
CONVERGENT PYGOSTYLE MORPHOLOGY IN UNDERWATER FORAGING BIRDS
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Understanding the processes that generate morphological diversity is an important goal in evolutionary biology. Adaptation is considered a major driver of phenotypic evolution. Convergence, the evolution of a similar feature in distantly related organisms from nonhomologous ancestral states, is considered strong evidence for adaptive phenotypic evolution. This study explores the morphology of the pygostyle, the terminal element of the avian caudal skeleton. The avian tail is used for multiple functions (e.g., locomotion, display), with tail morphology exhibiting considerable variability among species. The pygostyle is a site of attachment for several muscles and serves to anchor the rectrices. I examine the hypothesis that variation in pygostyle morphology results as a response to variation in the functional demands of different flight styles (e.g., flap, soar) or foraging styles (e.g., sit-and-wait, plunge dive, pursuit dive). Elliptical Fourier Analysis, a geometric morphometric method used for analyzing variation in structures with few clearly delineated homologous landmarks, was used to quantify pygostyle shape in 50 species of waterbirds and shorebirds. Permutation tests show that phylogeny has a significant effect on pygostyle shape. A phylogenetic principal components analysis reveals that penguins, murres, sulids, and tropicbirds are characterized by an elongate pygostyle distinct from the short, rounded pygostyle of their closely related sister taxa. These birds share underwater foraging behaviors; penguins and murres utilize wing-propelled pursuit diving; sulids and tropicbirds are plunge divers. The tail can be used as a control surface for underwater turning. This suggests that an elongate pygostyle may be adaptive for these birds, perhaps by providing a larger attachment for the calami of the rectrices, thereby anchoring them more firmly. Convergent evolution of an elongate pygostyle in multiple lineages with common foraging behaviors strongly suggests that the phenotypic diversity in the avian tail is indeed shaped by adaptive evolution in response to functional demands.

P-040
CT ANALYSIS OF SEA OTTER HIP JOINT RELATED TO SWIMMING LOCATION
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The Sea otter Enhydra lutris does not possess the ligament of the head of the femur ligamentum teres, differing from other lutrinae. These morphological characteristics are well known in pinnipeds and have been suggested to contribute to aquatic adaptation in mammalian evolutionary history. In this study, first, the range of adduction-abduction movement of femur of E. lutris was quantitatively estimated by CT scan analysis. Secondly, the hindlimb skeleton and muscles of E. lutris were morphologically compared with those of Eurasian river otter Lutra lutra. The hindlimb muscles of both species were weighed. In the CT estimations of hindlimb of E. lutris, the femur abducted at maximum angle of 104 degree from the sagittal plane. In the macroscopic observations, the muscles of the hip joint Musculus gluteus superficialis, M. tensor fasciae latae and M. caudofemoralis, were more developed in E. lutris than L. lutra. The origins of these three muscles were fused in E. lutris. The weight ratios of these three muscles were much higher in E. lutris than those of L. lutra. In E. lutris, since M. gluteus superficialis, M. tensor fascia lata and M. caudofemoralis are fused, we point out that the three muscles act as a single abductor of femur. As a result, the hip abductor muscles of E. lutris are relatively huge than those of L. lutra. In E. lutris, the articular capsule of hip joint prevents the femur from a dislocation when the femur abducted maximally. In contrast, lig. teres strongly restricts the abduction of femur of L. lutra. During the terrestrial locomotion, a stability of hip joint adapts to running behavior. The Sea otter possesses a unique swimming locomotion using powerful lateral side movement of femur, whereas E. lutris reduce an advantage of running on the land.

P-041
MORPHOMETRICS AND GAIT ON DIFFERENT SUBSTRATES IN THE LONG-TAILED LIZARD (TAKYDROMUS SEXLINEATUS): EXPERIMENTS AND MODELS
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Takydromus sexlineatus is a specialised lacertid lizard with an extremely long tail used for “grass swimming”, but the animals can also locomote in various other substrates. We tested animals in mimicked grass, on three terrestrial substrates with different friction (smooth, sand, pebble stones) and slope, and in water. We collected kinematic (250-500 fps, 23 normal subjects and a morphosed subject with an accidentally lost tail) data at voluntary speeds, morphometric data, and calculated dynamic coefficient of friction of the ventral tail on the substrates. A backwards travelling bending wave (with large amplitude, especially in the tail) is used in concert with limbed gait (except during swimming, where limbs are adducted). The observed gait is
typically a trot, although this is very variable in grass. Speed is increased by a combination of stride frequency and stride length, with similar relationships in all non-preferred habitats, and relatively large strides in grass. Tail tip amplitude differs between substrates, being higher in water, grass and on a smooth surface, and lower on pebble stones and sand. Average body mass was 3.80 g and total body length 304 mm (of which, on average, 82% tail). Tail and trunk mass are similar and together constitute more than 80% of total body mass. Segment inertial data and substrate properties were fed into a simulation model of a long-tailed lizard. The model (using particle swarm optimisation) successfully mimicked all essential aspects of the animal’s locomotion, and confirmed some kinematic key differences of the morphosed individual, e.g. lower spinal amplitude, smaller stride length and greater hip height. Combined, the findings suggest that the effects of morphology (esp. tail length and mass) are important in determining gait kinematics.

P-042
DISSECTING A KANGAROO’S FIFTH LIMB
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The kangaroo is best known for its fast, efficient, bipedal hopping. The tail of the kangaroo is likely to act as a counterbalance to the forward pitching of the kangaroo’s body during bipedal hopping. At slow speeds kangaroo’s utilise an entirely novel gait known as pentapedal locomotion in which the tail is employed together with the forelimbs to support the body weight while the hind limbs are simultaneously lifted and drawn forward. The tail, then, has functionally significant roles in both fast and slow locomotion. In light of this, the caudal musculature of the western grey kangaroo (Macropus fuliginosus) was dissected and described in this study. Three key features were noted. 1. In the sacral region the dorsal extensors, mm. sacrocaudalis dorsalis lateralis, were very large and extensive, spanning the lumbar, sacral and proximal caudal regions. These thick bellied muscles reflect the active engagement of the tail as a counterbalance during fast bipedal hopping and in stiffening the tail during the tail support phase of pentapedal locomotion. 2. In the proximal region of the tail the mm. coccygeus, a lateral flexor/abductor of the tail, is relatively large and fleshy. The relative size, orientation and arrangement of fibres of the mm. coccygeus points to a significant role in stabilising the pelvis and proximal tail while the tail is supporting the body weight during pentapedal locomotion. 3. The significance of flexion in the proximal region is further highlighted by the predominance of the relatively large ventral flexor, the mm. pubococygeus in this region. Flexion of the tail is likely to play a significant role in drawing the tail under the body and stabilising the tail during the support phase of pentapedal locomotion. Further studies will investigate the functional significance of the caudal musculature in relation to locomotor strategies within the Macropodidae family.

P-043
PELVIC MUSCLE ARCHITECTURE AND FIBER COMPOSITION IN TERRESTRIAL FROGS
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Recent work on a large sample of frog taxa shows that bones of the frog pelvis are more variable than hindlimb and forelimb length across terrestrial and arboreal locomotor modes. Moreover, sacral width, diaphyseal expansion, and pelvic length show a high degree of phylogenetic signal across frog locomotor modes. Current thinking posits at least three pelvic types based on degree of sacral diaphyseal expansion, type of ligamentous connection of the ilium to the sacrum, and spatial planes in which the ilium moves under the sacrum during locomotor behaviors. Despite a widespread scientific interest in the mechanics of the frog jump, little is known about variation within pelvic musculature of frogs, and even less of pelvic movements that occur during locomotor behaviors across locomotor modes. Is variation within muscles that move or stabilize the pelvis concordant with the differences observed in sacral and pelvic morphology across locomotor modes? Herein, architectural and fiber-composition are described for several pelvic muscles (coccygeolliacus; coccygeosacralis; longissimus dorsi; iliolumbaris) in Ascaphus montanus, Bombina orientalis, Anaxyrus terrestris, and Lithobates sphenocephala. Variation in pelvic muscle architecture and fiber composition are presented and discussed in relation to pelvic type and hypotheses of pelvic movement across locomotor modes in the above taxa.

P-044
PROTECTIVE BUTTRESSING OF THE HUMAN HAND: METACARPAL STRAIN IN BUTTRESSED AND UNBUTTRESSED FISTS
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The derived proportions of the human hand may provide supportive buttressing that protects the hand from injury when striking with a fist. Flexion of digits 2-5 results in buttressing of the pads of the distal phalanges against the central palm and the palmar pads of the proximal phalanges. Additionally, adduction of the thenar eminence to abut the dorsal surface of the distal phalanges of digits 2 and 3 locks these digits into a solid configuration that may allow a transfer of energy through the thenar eminence to the wrist. To test the hypothesis of protective buttressing, we measured strain on the dorsal surface of the 2nd metacarpal with a rosette strain gage during striking with buttressed and unbuttressed fists. Human cadaver arms were mounted on a pendulum that was swung so that the fist struck an 8 kg mass instrumented with an accelerometer. Lines tied to the tendons of the muscle of the wrist and digits allowed us to vary the posture of the hand. On impact, the dorsal surface of the second metacarpal was strained in long-axis tension in both the buttressed and unbuttressed strikes. Peak principle strains were approximately 50% greater at the highest striking forces in the unbuttressed posture than in the buttressed posture. These results are consistent with the hypothesis that the proportions of the human hand provide protective buttressing when striking with a fist.

P-045
FATIGUE EFFECTS ON GAIT PATTERNS IN DEGU
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The use of lateral-sequence and diagonal-sequence gaits in small- to medium-sized quadrupedal mammals is often discussed for counteracting some level of locomotor instability. Non-substrate related factors for a decrease in locomotor stability comprise muscle weakness, exhaustion and reduced neuromuscular response during fatiguing exercise. In order to test if extended exercise results in changes in gait patterns, we examined fatigue effects on selected gait parameters in degus. Five individuals were filmed with a normal light high-speed camera during level locomotion on a motor-driven treadmill. Metric gait parameters of the left forelimb and hindlimb were calculated for the first 30 seconds and during the last 30 seconds of a 6 min capture period at a constant speed. Metabolic fatigue was determined using an open-flow respirometry system. First preliminary results show that degus use predominantly lateral-sequence gaits with a tendency towards lower limb phase values with time. The decrease in limb phase indicates a reduction in limb synchronization that supports the idea of increased locomotor instability during fatiguing exercise.

P-046
THE MECHANICAL AND ENERGETIC ADVANTAGES OF FOOTFALL TIMINGS IN QUADRUPEDAL WALKING
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One of the simplest and most readily available measurements from video of quadrupedal locomotion is that of footfall pattern and timing, making it an ideal approach for field studies. Previous analyses of the factors influencing footfall timings and gait selection have focused separately on the mechanical and energetic cost implications for animals moving on relatively simple substrates. We combine and build upon these factors to present a novel and holistic model of the functional constraints acting on the footfall timings of quadrupeds during walking, one that allows us to predict the environmental contexts in which animals will select footfall timings that maximize energetic efficiency, minimize rolling and pitching moments, or balance the two. We hypothesise that quadrupeds will prioritise energy recovery on broader, flatter substrates, while resisting pitch and roll will play a larger role on narrower and more complex supports. The highly flexible gait patterning of the squirrel monkey (Saimiri sciureus) makes an ideal study model with which to test some of these functional constraints. Here we do so using three rigid substrates – a flat surface, straight pole and side-branched pole – designed, respectively, to provide simple roll-reducing, simple roll-inducing and complex roll-reducing environments. Walking steps on the flat surface tended towards timings consistent with optimizing energy exchange, while both poles tended towards those that reduced rolling and pitching moments. These data expand our understanding of the influence of substrate type on footfall pattern timings and provide insight into the competing pressures that may influence footfall timing choices in quadrupedal mammals with energetic efficiency being a priority on the ground, and safety being a competing priority in the trees. By using data gained under controlled conditions, we anticipate that this simple measure of gait properties will be useful to understanding wild animal locomotion, particularly on arboreal substrates.
P-047
PALEOECOLOGY OF MIOCENE KANGAROOS: INFERENCES FROM CRANIODENTAL AND POSTCRANIAL DATA
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Multivariate analyses (Principle Components Analysis and Canonical Variates Analysis) of 14 craniodental measurements from 43 species of extant macropodoids (kangaroos and rat kangaroos) show excellent discrimination (98% correct classification) between dietary categories (omnivore, browser, mixed feeder, grazer). Tropical forest browsers (species of Dendrolagus and Dorcopsis) cluster separately from the other browsers, which clustered closer to the mixed feeders. Analyses were also conducted with only five measurements (four dental and one mandibular) in order to include more extinct taxa, providing similar results (with 76% correct classification). Twenty five specimens of extinct kangaroos (including three complete skulls), from deposits ranging from late Oligocene to late Miocene (Etadunna and Riversleigh deposits), mainly cluster with the tropical forest browsers and the regular browsers, with one species falling within the mixed feeders. Similar multivariate analyses were performed on the calcaneum (25 variables) of 49 extant macropodoids (41 species). Excellent discrimination (93% correct classification) was achieved between the locomotor habits of “non-hopping or rare hoppers” (mainly tree kangaroos, Dendrolagus spp.), “specialized hoppers” (Macropus spp.), and “regular hoppers” (other species). Nine Miocene kangaroos grouped mainly with the non-hoppers in the PCA; two species grouped with the regular hoppers, and one, Rhizosthenurus, the largest taxon and youngest (10 Ma) extinct taxon, grouped with the Macropus species. Several species of the primitive extinct family Balbaridae clustered with the tree kangaroos in the CVA. We conclude that Miocene kangaroos were predominantly browsers, without specialized hopping abilities until the late Miocene, and some primitive forms (species of Balbaroo) may have been at least partially arboreal. This supports the hypothesis of a closed forested environment in the early to middle Miocene of Australia, and shows the potential for data from fossil kangaroos to aid in the interpretation of regional and temporal environmental change in the Australian Cenozoic.

P-048
FUNCTIONAL ANALYSIS OF THE FEEDING APPARATUS OF THE EARLY ORNITHISCHIAN DINOSAUR LESOTHOSAURUS DIAGNOSTICUS
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Neornithischian dinosaurs constituted a flourishing group of herbivores in Jurassic and Cretaceous times. The evolution of their feeding apparatus had a long and ‘creative’ history and the southern African Early Jurassic species Lesothosaurus diagnosticus is in a good position to feature the condition from which the more advanced jaw mechanisms of later neornithischian dinosaurs could be derived. I conducted a functional analysis of the feeding apparatus of L. diagnosticus. The occlusion pattern involves an irregular interlocking of the maxillary and dentary teeth that indicates an essentially orthal tooth-to-tooth shearing motion of the lower jaw during the power stroke. There is no compelling arthrological evidence of effective intracraniial mobility in L. diagnosticus, as in non-avian dinosaurs in general. As is virtually the case in all ornithischians, no moveable joint is evidenced within the mandibular rami of L. diagnosticus either (although, the predentary-dentary joint certainly did not form a tight synarthrosis). Examination of the skull of L. diagnosticus reveals that the m. adductor mandibulae externus profundus and, maybe to a lesser degree, the m. pseudotemporalis superficialis, formed the dominant jaw adductors. A two-dimensional model of the skull of L. diagnosticus predicts that 46 % of the force exerted by these muscles was applied at the middle of the dental row (at least in juveniles). This value falls within the range of those calculated for the extant agamid lizard Uromastix spp., which is able to eat tough plants. The functional morphology of the skull of L. diagnosticus overall advocates for a diet including mechanically resistant plants, which is consistent with an arid biotope, be it seasonal or not.

P-049
THE RELATIONSHIP BETWEEN MANDIBULAR SYMPHYSEAL PERFORMANCE AND JAW-MUSCLE ACTIVITY DURING CHEWING IN PRIMATES
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A long-standing hypothesis in studies of primate feeding functional morphology argues that mandibular symphyseal fusion in anthropoid primates relates to the activity and timing of the balancing-side deep masseter (BDM) during chewing. This hypothesis receives support from correlations linking symphyseal fusion, and to a lesser extent symphyseal shape, to specific jaw-muscle activity patterns during chewing across primates. We do not know, however, whether symphyseal load resisting performance shares similar associations with jaw-muscle activity across primates. Because symphyseal fusion and shape are used as proxies for symphyseal strength in testing this relationship, this hypothesis predicts that symphyseal strength is correlated with patterns of fusion and symphyseal morphology across primates. We loaded cadaveric jaws of humans, five groups of monkeys (baboons, macaques, callithrichids, capuchins and owl monkeys), four groups of strepsirrhines (bamboo lemurs, galagos, ring-tailed lemurs, sifakas) and tree shrews (outgroup) in simulated wishboning to ultimate failure using a UTM. We compared relative in vitro strength estimates to electromyographic data from primates in the Feeding Experiments End-user Database to assess whether symphyseal strength is related to BDM activity. Our preliminary results support the assertion that primates with fused symphyses exhibit increased loads at failure relative to symphyseal size (F=10.4; p=0.012). Given that the ratio of working-to-balancing side recruitment levels for the deep masseter and relative timing of the BDM show similar significant shifts between primates with fused versus unfused symphyses, we argue that the results for relative symphyseal strength support the hypothesis linking symphyseal fusion to BDM muscle activity. Despite a trend for increased relative recruitment of the BDM to be associated with relative symphyseal strength (R=−0.6; p=0.09), we do not see a significant relationship across primates. Albeit preliminary, we interpret this finding to indicate that symphyseal strength is modulated by additional functional influences among anthropoids and strepsirrhines, respectively.

P-050
FUNCTIONAL MORPHOLOGY OF THE INCISORS IN SUBTERRANEAN RODENTS
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Subterranean rodents are restricted to a life underground, with excursions above ground a rarity. Due to these limitations, such rodents have evolved a very specialized morphology as selective pressures in a subterranean environment are very different to those above ground. This investigation specifically highlights the specialization of the digging apparatus for burrow construction, with an emphasis on blesmols (African mole-rats, Bathyergidae). The specimen sample is divided between non-tooth-digging and tooth-digging rodents. Included is the non-tooth-digging mole-rat Bathyergus suillus, which primarily uses a scratch mode of digging involving soil being broken and removed by forelimbs. This is in contrast to the chisel tooth digger Cryptomys hottentotus, which primarily uses its incisors for burrowing. We tested the hypothesis that the angle of curvature of the incisors in the sample of subterranean rodents would be significantly different between tooth-digging and non-tooth-digging species. Using standard mathematical calculations alongside more sophisticated geometric morphometric techniques, the curvature of the lower and upper incisors was measured in all specimens. The non-tooth-digging rodent species have smaller angles of curvature than the blesmols with regard to the upper incisors. However, within the blesmols family, the angle of curvature in both the tooth-digger Bathyergus suillus and tooth-digger Cryptomys hottentotus are markedly similar, although the position of the upper incisor within the skull varies widely between these two species. This result suggests that upper incisor curvature is phylogenetically constrained in bathyergids, but that different functions (digging/feeding) may be achieved by repositioning the teeth. A separate analysis was conducted on the lower incisors of the sample specimens. The lower incisors grouped differently to upper incisors, with no clear separation between tooth diggers and non-tooth diggers, which may indicate that selection pressures on the upper and lower incisors are different.

P-051
AGE-RELATED TOOTH WEAR IN MANDRILLS AND BABOONS
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Tooth wear in primates is caused primarily by dietary and aging factors. However, there is limited information on the effect of ecology and feeding behavior on tooth-use wear. Here, we developed an approach using dentine exposure of molar teeth in two in vivo African papionin species to test if diet and age affect age related tooth-wear. Mandibular and maxillary tooth molds (M1 and M2 teeth) were obtained in forest-dwelling mandrills (Mandrillus sphinx; n=38) from Gabon, and from savanna-living yellow baboons from living yellow baboons.
(Papio cynocephalus; n=95) from Kenya. Occlusal digital images were obtained from positive high-resolution replicas and the percentage of dentine exposure (PDE) recorded. Uni- and multivariate statistics (P<0.05) were used to examine PDE interaction on age and sex. Results show no sex-related differences, and no differences between captive and wild animals. Moreover, when tooth wear on age was compared, we found that mandrills exhibited significantly higher PDE than baboons in M1. Our findings support the hypothesis that differences in diet and in the number of extrinsic abrasive particles cause differences in tooth wear. Although baboons ingest large amounts of underground storage organs with adherent abrasive grit particles, mandrills mainly feed on fruits that present hard shells and seeds. Moreover, they also live in an environment that has a much higher proportion of extrinsic abrasive particles, including those from quartz, which cause higher tooth wear rates.

P-052
TOOTH SHAPE DIFFERENCES BETWEEN UNTUFTED AND TUFTED CAPUCHINS: POSSIBLE IMPLICATIONS FOR THE TAXONOMY OF CEBINAE
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Several studies based on molecular, morphological, ecological, biogeographic and behavioral data have found differences among capuchins monkeys, suggesting a change at the genus-level of the Cebus lineage in two separate clades: Cebus (untufted or gracile capuchins) and Sapajus (tufted or robust capuchins). In the present study, a comparative dental morphology perspective was used to corroborate the existence of the two capuchin morphotypes. The analyses included first and second molars from 7 species (Cebus albifrons, C. olivaceus, Sapajus apella, S. robustus, S. libidinosus, S. neglectus and S. xanthosternos). In order to quantify dental morphological variation of lower molars, two-dimensional (2D) and three-dimensional (3D) Geometric Morphometric (GM) methods were employed. We also examined which technique is more accurate in providing taxonomic information. Photographs obtained from occlusal surfaces and 12 landmarks were chosen in 2D GM; while 11 landmarks in the surface and 6 in the sidewalls were defined in 3D scanned models for 3D GM. The procustes coordinates were employed as shape variables in Discriminant Function Analyses (DFA). The results showed different molar shapes between tufted and untufted capuchins. Moreover, Sapajus species were grouped according to a biogeographical criteria. When 2D and 3D GM methods were compared, the 2D method showed better results, possibly because 2D analysis takes into account the cusp position and the occlusal shape, but not the cusp height. Although 3D analysis presented a high power of classification, it did not discriminate accurately the groups, as cusp height is related to adaptive foraging ecology, which may be a homoplastic trait in capuchins.

P-053
EFFECT OF ROBERTSONIAN TRANSLocations ON COVARIANCE STRUCTURE AND MODULAR ORGANIZATION OF THE MOUSE MANDIBLE
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Modularity and integration are complementary concepts directly linked to the degree of covariation among the constituent parts of complex morphological structures. Both features are conditioned by genetic covariance among traits, which can be due to pleiotropic effects of single loci and to genetic linkage between loci. The alteration of meiotic recombination induced by chromosomal reorganizations could modify linkage groups and consequently affect the patterns of genetic covariance, integration and modularity. With the aim of revealing the effect of Robertsonian translocations on such patterns, phenotypic and ontogenetic covariance patterns of mandibular shape were analyzed in populations of the western European house mouse (Mus musculus domesticus) from the Spanish Robertsonian system. The mouse mandible is known to be generated by the coordinated action of six morphogenetic units and is suggested to consist of two modules: the alveolar region and the ascending ramus. Results highlighted that Robertsonian translocations do not alter the organization of the mandible into these two phenotypic and developmental modules. However, the increasing number of metacentrics contributes to a higher and higher degree of developmental modularity. Despite not altering the two-module organization of the mouse mandible, Robertsonian translocations do distort its patterns of covariance and integration. Chromosomal groups being close with regard to their diploid number showed the highest correlation values for phenotypic covariance, while no obvious trend was observed for ontogenetic covariance. Phenotypic covariance is increasingly due to direct interactions between developmental pathways as the number of metacentrics increases, and is greatly conditioned by allometry. Robertsonian translocations are therefore suggested to increase intramodular genetic covariance by fostering linkage groups that promote intramodular integration, and at the same time...
are believed to affect intramodular integration by disrupting genetic coadaptation when they are newly acquired.

P-054
DENTAL SHAPE MODULARITY AND PHENOTYPIC VARIATION IN HUMAN POPULATIONSTorrijo, Stéphanie (1); Romero, Alejandro (1); Galbany, Jordi (2); Gamarra, Beatriz (2); De Juan, Joaquin (1); Pérez-Pérez, Alejandro (3)
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Dental morphology is highly variable between human populations. Early reports showed that phenotypic variability in Sino- and Sundadonty is mainly determined by genetic factors. Although nonmetric trait frequencies have been identified among dental complexes, the analysis of metameric shape variation and the integration affecting these variants have not yet been developed. Here, we focused on the geometric shape and covariation of upper P3-M2 in individuals of two different populations of Sino-American Eskimos (n=41) from Alaska, and Sunda-Pacific Javanese (n=35) from Southeast Asia, to test whether variation in dental morphology is associated with modular integration. Dental shape was extracted from landmark configuration, located at occlusal surface on digital images from high-resolution replicas, using generalized least-square Procrustes superimposition. Two-block partial least-squares analysis and vector correlation (Rv) coefficient were used to quantify morphological integration through cross-covariance between subsets of landmarks corresponding to the major cusp components within each tooth and population. Results showed that teeth displayed high levels of crown shape complexity among populations. We found significant covariation in cusp shapes (Rv = 0.2-0.3; P<0.001) when premolar and molar teeth were compared, and this supports a dual-structure model of phenotypic trait expressions and morphogenetic interdependence between dental characters. Moreover, when covariation shape patterns between adjacent teeth were examined, only a strong integration within M1-M2 was found in Native American populations (Rv= 0.48, P<0.001). This major direction of phenotypic variance corresponds to a reduction in the expression of the hypocone cusp in M2. Our finding provides an example of the pleiotropic effects on tooth morphology linked to EDAR (ectodysplasin A receptor) polymorphism as a genetic determinant in dental phenotypic dichotomy between Asian and Asia-derived populations.

P-055
HISTOLOGICAL CHANGES DURING THE POSTNATAL DEVELOPMENT OF THE HOUSE MOUSE MANDIBLE
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The house mouse mandible is a model structure in mammalian biological research for the study of the development and evolution of complex morphological systems. Genetic, embryological and functional anatomical studies have provided an extensive background on mechanisms underlying phenotypic variation. Nevertheless, the growth mechanisms involved in the morphogenesis of the mandible are poorly known. We analysed the postnatal growth dynamics in a control sample of Mus musculus using fluorescence labelling, histological analysis and a non-destructive method, which is applied for the first time in a non-primate mammal. This method involves the metallization of the bone surface and its analysis with a reflected light microscope to identify the histological features of the cellular activities related to the bone growth mechanism. The bone formation and resorption fields were mapped to obtain the bone modelling map. Results show changes in the growth dynamics during postnatal development. Maps from the first two weeks display resorption fields in the lingual side of the alveolar region, in the buccal coronoid and the lingual angular regions of the ascending ramus. The cross-sections show woven bone tissue and high growth rates in the buccal side of the alveolar region and different growth rates in the ramus. These data indicate lateral growth of the alveolar region and complex dynamics in the ramus, which grows posteriorly as it adopts a vertical configuration. From the fourth postnatal week, the mandible shows histological changes. Bone resorption fields are found only in the gonial and coronoid regions of the ramus, while parallel-fibered bone tissue is observed in the alveolar region and the growth rates decrease. The complex growth dynamics of the ramus could indicate the influence of mechanical factors once the increase in size ceases in late ontogeny. Dietary changes after weaning could be leading this change in the growth dynamics.
CANINE EVOLUTION IN SABRETOOTHED CARNIVORES: NATURAL SELECTION OR SEXUAL SELECTION?
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The remarkable elongated upper canines of extinct sabretoothed carnivorous mammals have been the subject of considerable speculation on their adaptive function, but the absence of living analogues prevents any direct inference about their evolution. We analysed scaling relationships of the upper canines of 20 sabretoothed feliform carnivores (Nimravidae, Barbourofelidae, Machairodontinae), and 33 non-sabretoothed felids, in relation to body size. Our aim was to characterize and identify the evolutionary processes driving their development, using the scaling relationships of carnassial teeth in both groups as a control. Carnassials display isometric allometry in both sabretooths and non-sabretooths, supporting their close relationship with meat-slicing, whereas the upper canines of both groups display positive allometry with body size. The stronger positive allometry of upper canine height in sabretooths compared to non-sabretooths reveals that different processes drove canine evolution in these groups. Although sabretoothed canines must still have been effective for prey capture and processing by hypercarnivorous predators, canine morphology in these extinct carnivores was likely to have been driven to a greater extent by sexual selection than in non-sabretooths. Scaling relationships therefore indicate the probable importance of sexual selection in the evolution of the hypertrophied sabretooth anterior dentition.

P-057
PHYLOGENETIC SIGNAL OF DENTAL SHAPE IN EXTANT AND FOSSIL CATARRHINE PRIMATES: A GEOMETRIC MORPHOMETRIC ANALYSIS OF MOLAR CROWN
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Morphology has been widely used for inferring phylogenetic affinities between different primate species. The improvement of phylogenetic reconstructions in recent times has shown incongruence between morphological and molecular phylogenies and, consequently, the reliability of morphological analyses has been questioned when analyzing phylogenetic affinities. Detecting phylogenetic signal in anatomical features, especially when fossil specimens are considered, is therefore of great relevance. Teeth constitute the fossil evidence most used in paleontological research because of their durability and abundance on the fossil record. We have analyzed molar crown shapes, through Geometric Morphometrics, in a large sample of both extant and fossil catarrhine primates to detect their phylogenetic signal and usefulness for finding affinities of fossil specimens with extant taxa. Our results show that molar shape carries a strong phylogenetic signal, principally at superfamily and, to some extent, family levels. The fossil specimens of Pliohippotheria, Cercopithecoidae and Hominidea superfamilies, are clearly classified according to the expected taxonomic affinities with the extant groups, although some discrepancies have been found depending on the tooth considered. The results obtained suggest that although molar crown shape can be used as a reliable proxy for establishing taxonomic affinities of catarrhine fossil primates with extant groups, a significant amount of interspecific variability can be detected, indicative of derived adaptations at the genus or species levels.

P-058
THE RADIAL SESAMOID OF INDARCTOS ARCTOIDES, THE FIRST EVIDENCE OF A FEEDING RELATED FALSE THUMB
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Bataliones-3 is one of the nine Late Miocene (Late Vallesian) fossil vertebrate localities that conform the faunistic area of Cerro de los Batalones (Madrid Basin, Spain). The recovery of a very complete collection of remains of the bear Indarctos arctoides Depéret has allowed us to describe, for the first time, the radial sesamoid of this species. With a total of 12 specimens of this bone belonging to, at least, 10 individuals, we have been able to perform a detailed comparison with the homologues of other extant and extinct carnivore species. The genus Indarctos has been recently included inside the subfamily Ailuropodinae, but separated from the giant panda’s closest lineage. Among several cranial, mandibular and dentitional characters, Indarctos arctoides shares the presence of a developed radial sesamoid with
**Ailuropoda melanoleuca.** The functional importance of this bone depends, to great extent, on its relative size, degree of development compared to the rest of the wrist bones and individual movement relative to the metapodials. Moreover, its use as an opposable false thumb is only possible in animals, such as *I. arctoides*, which possess a relatively enlarged radial sesamoid, with more or less independent degree of movement. Therefore, with our anatomical research of the hand of *I. arctoides* we describe the first evidence of a feeding-related development of the false thumb in the fossil record.

P-059
**DENTAL WEAR PATTERN IN RHIZOMYS (RODENTIA, SPALACIDAE)**
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*Rhizomys* is a derived genus within the tribe Rhizomyini that comprises three species. A detailed description of the morphology and dental wear pattern of the cheek teeth of this taxon is provided based on the examination of 41 skulls. For the first lower and upper molars, six stages of wear (0–5) are recognized. The second lower and upper molars show five stages of wear (0–4), whereas the third ones have four (0–3).

Wear stage 0 of the first lower and upper molars, in which the second molars are still in their crypts, is that of new-born individuals. Wear stage 0 of the second lower and upper molars (wear stage 1 of the first ones) corresponds to infants, in which the third molars have not yet erupted through the jaw bone. Wear stage 0 of the third lower and upper molars (wear stages 2 and 1 of the first and second ones, respectively), corresponds to juvenile individuals. Finally, wear stages 3–5 of the first molars (2–4 of the second molars and 1–3 of the third ones) are found in adult individuals. *Brachyrhizomys shansius* (Pliocene) is the sister taxon of the crown group of the tribe Rhizomyini. Its dental wear pattern is comparable to that of *Rhizomys*. Nevertheless, *B. shansius* shows stronger difference in upper molar wear than *Rhizomys* spp. as M1 and M2 of the former are more worn than those of the latter at the same wear stage. By determining the relative age of the individuals, the study of dental wear patterns allows estimation of the age-class structure of the fossil sample to which they belong. Besides, this kind of study allows comparing hypsodonty in teeth of individuals belonging to different species (provided the teeth of the specimens are at the same wear stage).

P-060
**MECHANISMS AND TIMING OF REPLACEMENT DENTAL LAMA REGRESSION**
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The individual tooth anlagen of the functional dentition are initiated from the dental lamina. In monophyodont species, the dental lamina connecting the tooth anlagen to the oral epithelium is short. Furthermore, the successional lamina is only rudimentary and reduced in size during development. On the other hand, species with successional dentitions develop a dental lamina that grows deep into the mesenchyme. Here, we focus on the differences in dental lamina morphology and development in monophyodont (mouse), diphodont (pig) and polyphyodont (Burmes python) species. We aim to compare the timing of the initiation and regression of the successional lamina with focus on the mechanism of lamina regression. The successional dental lamina of polyphyodont species (python) is formed as the primary dentition reaches the cap stage and is not interrupted during development. In the diphodont pig, the replacement lamina forms after the primary dentition has reached the late bell stage. At the same stage, the dental lamina connecting the primary tooth to the oral epithelium becomes disconnected and fragments into several pieces. Lamina regression starts with the loss of the basement membrane, allowing the epithelial cells to break away from the lamina and migrate into the surrounding mesenchyme. Similar mechanism of the dental stalk regression was observed in the monophyodont mouse, where a disruption of the basement membrane was observed by transmission electron microscopy. Fibroblasts form long cytoplasmatic processes and produce extracellular matrix around the disrupted basement membrane during postnatal stages. The epithelial cells of the dental lamina generate long cytoplasmatic processes towards the mesenchyme. Only few apoptotic cells were observed in the dental lamina during regression. Therefore, apoptosis does not seem to be the main process involved in mouse lamina regression, similar to that previously described in the pig. This work is supported by IGA UVPS (61/2013/FVL) and ASCR (M200451201).
P-061
FUNCTIONAL MECHANICS OF ORNITHOMIMOSAURS
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Ornithomimosaurs are a rather enigmatic group of theropods due to the edentulous nature of derived members. Their possession of keratinous rhamphotheca, large orbits, lightweight skulls and elongate necks and legs has led to comparisons with ostriches and other extant palaeognaths. Understanding the evolution of this group has implications for that of theropods in general and dietary shifts from carnivory to herbivory. The skulls of three ornithomimosaurs (Garudimimus and the ornithomimids Struthionimus and Ornithomimus) were digitally reconstructed using CT scan data. Virtual muscles were recreated using osteological correlates, from which bite forces were calculated. Hypothetical beaks that cover the rostrum were created based on known fossils and modern birds to study their effects. Finite element models were run using the muscle loads to compare the more primitive Garudimimus to the derived ornithomimids. Further work on postcranial material involved a reanalysis of limb elements from most of the ornithomimosaurs to study modular evolution of fore- and hindlimbs with respect to the crania. The limb elements were measured traditionally (e.g. length, proportions, mid-shaft diameters) and using functional measures (e.g. muscle scar sizes, distance between muscle insertion and origination, moment arms). The individual modules were used to produce phylogenies, with each of these being compared to the overall phylogeny to see which characters affected it most. Results show that the crania strain similarly to each other, but the ornithomimids are more similar to each other than to the more primitive Garudimimus. This trend is also followed with the limb elements (both traditional and biomechanically), with more primitive ornithomimosaurs performing more variably. This may be linked to their changes in diet and a shift in ecospace.

P-062
INTERSPECIFIC DIFFERENCES IN MYOSIN EXPRESSION CHARACTERIZE CYPRINIFORM JAW ADDUCTORS
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Myosin heavy chain isoforms largely determine muscle fiber contractile speed and force, thus differential expression of myosin isoforms underlies the specific contractile properties of whole muscles. Teleost fishes have twice the number of myosin isoforms as tetrapods and thus provide an unusually rich canvas with which to study variation in myosin isoform expression and concomitant whole muscle performance consequences. Cypriniformes (e.g. carps, minnows, suckers, algae eaters, and loaches) includes such scientifically relevant model species as goldfish and zebrafish and make up more than 25% of all freshwater species with nearly 4000 species worldwide. This spectacular diversity of fishes, supported by an ever-growing phylogeny, provides us with an exceptional framework for exploring the evolution of myosin isoforms within the jaw adductors. Jaw adductors are derived from precursor cells within the first pharyngeal arch and are associated with movements of the mandible (during scraping/manipulation and respiration) and the maxilla (during powerful suction feeding). This formerly undifferentiated mass has become secondarily divided giving rise to three discrete divisions (adductor mandibulae A1, A2, &A3) and concomitant functions (A1-explosive protrusile movements, A2-scaping and manipulative movements, A3-cyclic respiratory movements). Since myosin isoforms comprise a continuum befitting their function we here test the hypothesis that divisions of the adductor mandibulae display patterns of myosin expression correlated with their functional diversity. Given these differences we hypothesized that A1 would show the greatest variation in myosin heavy chains, while A3 would show the least diversity. Indeed A1 showed the greatest variation in myosin expression patterns. However A3, with a much more conserved respiratory function, still showed variation in myosin isoforms expressed.

P-063
EFFECT OF LINGUAL SENSORY LOSS ON OROMOTOR FUNCTION IN PIGS
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The mammalian tongue is uniquely designed to produce complex movements during feeding. Its ability to change shape is critical for food handling, including ingestion and positioning of the bolus on the teeth during mastication. It also helps move the bolus through the oral cavity during swallowing. During all of these behaviors, tongue movements must be coordinated with jaw movements during the gape cycle. Given the dynamic nature of feeding and the ever-changing physical and mechanical properties of the food being consumed, sensory input from the tongue may be essential to oral function, especially jaw-tongue...
coordinated. Here, we investigate the functional consequences of unilateral and bilateral lingual sensory loss on jaw and tongue movements during chewing in pigs (Sus scrofa) using X-ray Reconstruction of Moving Morphology. Radiopaque markers were implanted in the jaw and skull to quantify jaw movements in 3 dimensions from biplanar high speed fluoroscopy movies of pigs feeding on various foods before and after unilateral and bilateral lingual nerve transections. Our results show that loss of sensation from the anterior part of the tongue affects the timing and kinematics of oral movements. Chewing cycles are shorter with complete lingual sensory loss but longer with unilateral sensory loss. The power stroke is significantly shorter with bilateral sensory loss. Maximum gape is significantly greater after unilateral transection. The impact of lingual sensory loss on tongue movements is less pronounced but there is a trend towards increased protrusion and retraction during chewing. Without sensory information from the tongue, we propose that pigs are unable to precisely locate the bolus within the oral cavity and place it on the teeth. Longer gape cycles after sensory loss also suggest that pigs may be more careful in their feeding movements to avoid injury.

P-065
THE FRONTAL SINUSES OF SIMOCYON BATALLERI (CARNIVORA, AILURIDAE) FROM THE LATE MIOCENE OF BATAHONES-1 (TORREJÓN DE VELASCO, MADRID)
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The Ailuridae includes one living and up to 6 fossil genera of carnivorans, and few aspects of their intracranial anatomy are known. Simocyon batalleri is the best-known fossil species, thanks to the material from Batallones-1 (Late Miocene), including 2 skulls. Previous studies revealed S. batalleri as a puma-sized animal, with a generalised dentition and arboreally adapted skeleton possessing a false-thumb, previously known only in the extant ailurid Ailurus fulgens and the ursid Ailuropoda melanoleuca. This works intends to describe the frontal sinuses of S. batalleri, comparing them with those of A. fulgens. Several hypotheses have been proposed to explain the function of these cavities: increasing the surface of the olfactory epithelium, protecting the brain, increasing the humidification and heating of inhaled air, dissipating stress during mastication, etc. We performed CT Scans of skulls of A. fulgens, and of S. batalleri from Batallones-1 (B-3458). The imagery reveals dorso-ventral crushing of the rostral half in the skull of S. batalleri, and the breakage of the nasal cavity and related structures. The frontal area shows brittle deformation, producing the breakage of the walls of the frontal sinus. A Puzzle Reconstruction was used for restoring the sinus original shape, and a 3D model of it was obtained through a virtual filling of the cavity. The relative length of the frontal sinuses of S. batalleri is similar to those of A. fulgens, but those of S. batalleri are more caudally expanded, and are relatively wider than those of A. fulgens, also exhibiting a much higher number of struts reinforcing the cavity. There is no widely accepted explanation of the function of frontal sinuses, but given the strong differences in size, dental adaptation and skull shape of both ailurids, the similarities in their frontal sinuses might reflect phylogenetic relationships rather than similar biomechanical or physiological requirements.

P-066
USING MICROCT AND FINITE ELEMENT ANALYSIS TO COMPARE DEVELOPING ORGANISMS, A 3D-ILEMMA
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Finite element analysis (FEA) combined with computed tomography (CT) creates a powerful technique for understanding the mechanics of a biological system which are otherwise too complex to accurately model. Currently, the predominant use of FEA in biological studies has been constrained to fully developed organisms. This is due to difficulties using structures comprised of multiple tissues as they transition between types during development, as well as the lack of tissue specific x-ray opaque stains. The resulting dilemma is that unstained specimens show incomplete structures consisting of disconnected parts, while in stained specimens it is not possible to differentiate the various tissues in a structure, making it impossible to correctly assign material properties. Here we describe a solution to performing FEA on developing organisms by using images of the same specimen from both pre- and post staining. The process involves replacing sections of the stained images with structures visible in the unstained images. This maintains tissue specificity while incorporating all elements of the developing structure into the model. The model can then be compared to successive developmental stages within the same species or across species. Alternatively, the model can be altered before the FEA. This allows for comparisons of the existing organism to hypothetical morphologies and developmental trajectories. We illustrate this technique on the pharyngeal jaw apparatus of two species of fish, Haplochromis elegans and Labrus bergylta.
P-067
FUNCTIONAL MORPHOLOGY OF THE FEEDING BEHAVIOR IN T. DOBROGICUS, KIRITZESCU 1903 (URODELA, SALAMANDRIdae)
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The crested newt Triturus dobrogicus (Kiritszescu, 1903), that occurs from the Austrian Danube Floodplains up to the Danube Delta, is considered near threatened. Populations of this species are increasingly isolated, due to loss of habitats like small temporary water bodies. Natural environments, like side branches of the Danube with low velocity, are disappearing gradually due to river regulations. The phylogenetic position of the genus Triturus within the Salamandridae has not yet been completely resolved and is therefore an aspect of in herpeto-taxonomy that has been discussed extensively. Triturus has the highest number of species among all other salamandrid taxa, but recent molecular data suggest that this genus is polyphyletic, not monophyletic. Since the monophyly of the genus Triturus is based on homologous morphological and behavioral characters, the aim of this study is to investigate the functional morphology of the feeding behavior of Triturus dobrogicus. Using high-speed videography we have investigated various kinematic variables like maximum gape of the jaw, maximum lowering of the hyoid, speed and acceleration of prey when sucked into the buccal cavity. In addition, micro tomographic recordings and histological methods were used to examine the anatomy of skull and hyoid apparatus the main propulsive element for the typical aquatic feeding behavior. The branchial ossicles, tongue and associated cervical muscle were inspected, concerning their function during suction feeding. Despite the merely descriptive character of this study, newly generated data may contribute, as a morphological approach, to the unclear status of the genus Triturus in herpetological taxonomy.

Allometry/Modularity
P-069
EVIDENCE FOR DIFFERENTIAL ALLOMETRIC EFFECT ON CARNIVORAN SCAPULAR SHAPE
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The effect of size on shape was tested in 213 scapulas from 101 carnivoran species, digitizing 34 3D-landmarks and using geometric morphometric methods. The sampled species spanned the whole size range of the order, and also covered all currently recognized families and all locomotor patterns and habitat preferences in Carnivora. As expected, a regression of shape on log-transformed centroid size revealed a significant allometric effect (size explained 17.2% of scapular shape variation). Furthermore, since significant evidences of phylogenetic signal in both the size and shape of the carnivoran scapula were found, the effect of size on shape was again tested after correcting for phylogenetic relatedness using phylogenetically independent contrasts. In this case, the allometric effect, although still significant, only explained 5.3% of shape variation, indicating that most of the allometric shape differences were related to size changes along phyletic lines. Finally, we tested whether the magnitude of the allometric effect varied among different subgroups within Carnivora. Indeed, the percentage of scapular shape variation explained by size varied among the different carnivoran families and among different locomotor types and habitat preferences, ranging from no significant effect on some subgroups to 50.0% in semifossorial carnivorans. Overall, the allometric effect found in ecological subgroups (locomotor type, habitat) exceeded the allometric effect found for the different families. However, after correcting for phylogenetic relatedness, the allometric effect was only significant in scansorial carnivorans and in those living in forest, mosaic and variable habitats. Furthermore, a reduction of its magnitude was observed in all cases. Thus, the results of the present study suggest that most of the allometric shape differences found in the carnivoran scapula are related to size changes occurred during carnivoran evolution.

P-070
DELIMITING THE BODY MASS RANGE OF ANCIENT AVIAN FLYERS
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A huge amount of empirical evidence indicates that an animal's body mass (BM) correlates with a number of physiological variables, with ecologically relevant characteristics and with larger-scale patterns in community structure, biogeography and evolution. In the case of flying birds, BM poses biomechanical constraints on aerial locomotion. Therefore, a first step before reconstructing any biological aspect of an extinct bird should be the obtaining of an accurate estimate of BM based on the information yielded by the fossil skeleton. Up to date, most mass estimates for extinct birds were obtained by allometric equations derived by simple
regression from isolated skeletal measurements. Here we try to find the best BM estimates for fossils using multiple regressions and taking into account the effects of both phylogenetic constraints and taphonomic bias. The database includes fore and hind limb measurements from 495 flying Neognathae, 43 Mesozoic birds and four Deinonychosaurus. Specific regressions were derived for each fossil taxa (i.e., Deinonychosauria, Archaeopterygidae, Jeholornithidae, Sapeornithidae, Confuciusornithidae, Enantiornithes and basal Ornithuromorpha) by selecting those variables that showed a similar behavior between extinct and extant taxa. As result, a total of 15 multiple regressions were achieved for calculating BM in fossils. The coefficients of determination of these regressions were high (R² from 0.972 to 0.981) and the values of Mean Prediction Error (MPE = |BMobserved - BMpredicted| / BMobserved) were lower than 20%. Furthermore, the difference between the mass estimated from the best regression and the average of estimated masses was of only 6.7%. Compared to the two best simple regressions previously published (R² = 0.941, MPE = 33.4% and difference between estimates = 47.8 %), our results are notably more accurate for estimating BM in fossils. The accuracy of these obtained regressions will allow us to get deep into the flight skills of some volant Mesozoic paravians.

P-071
THE NATURE OF SHAPE VARIATION IN THE SKULL AND HORNS OF THE TAPAJA CLADE OF HORNED LIZARDS (PHRYNOSOMA), BASED UPON CRANIAL GEOMETRIC MORPHOMETRICS OF THE GREATER SHORT-HORNED LIZARD (P. HERNANDESI)

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The phrynosomatid genus Phrynosoma (the horned lizards) displays variation in cranial structure associated with phylogeny. We use geometric morphometric analysis to explore shape change in the skull of the Greater Short-horned lizard, Phrynosoma hernandesi, as a basis for a more comprehensive study of the evolution of cranial disparity among the species of the Tapaja clade of this genus. Three-dimensional reconstructions of the skulls of a sample covering the ontogenetic size ranges of both sexes of this species were recovered from μ-CT scans. A suite of landmarks, covering the dorsal and occipital aspects of the cranium and the bases and tips of the squamosal, parietal and supraocular horns, were applied to the reconstruction sample. After Procrustes fit, landmark data were subjected to multivariate regression against log centroid size and the regression residuals used in principal components analysis and discriminant analysis in order to test for sexual shape dimorphism in cranial features. Sexual shape dimorphism in horn development and skull shape are not supported. Positive allometry relative to log centroid size is displayed for most cranial and horn features. Ontogenetic changes in landmark coordinates indicate that the squamosal and parietal horns typical of Phrynosoma display some developmental independence from the bones bearing them. These findings suggest that heterochrony among cranial modules in the Tapaja clade is important in producing the morphological disparity of the cranium and horns displayed by this lineage. We extend these results to a phylogenetic analysis of cranial shape change among the species of Tapaja.

P-072
RELATIVE GROWTH AND MORPHOLOGICAL VARIATION IN THE SKULL ROOF OF AELUROGNATHUS (THERAPSIDA, GORGONOPSIA)

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Gorgonopsia represent a group of specialised carnivorous therapsids that filled the role of apex predator during the Late Permian of Gondwana. Skull size in the Gorgonopsia ranges from that of a domestic cat, to larger than any extant, terrestrial predator. Despite this degree of size variation, the observed morphological variation in the gorgonopsian skull is relatively conservative. This study set out to better understand the extent of size and morphological variation among the six species attributed to the South African genus, Aelurognathus. All available specimens were studied, and morphological differences at both the intraspecific and interspecific levels noted. Observed variations in the skull roof morphology allowed for six previously recognised species to be divided into three morphotaxa, based predominantly on the character state of the preparietal, and the extent of the contribution of the frontal to the supraorbital margin. Similar variation in the skull roof has been demonstrated to occur within populations of extant taxa. This suggests that the degree of morphological variation observed in Aelurognathus represents individual variation. The hypothesis that all specimens of Aelurognathus represent a single taxon, exhibiting a high degree of morphological variation, was tested using bivariate allometry. Linear measurements of the skull were selected, such that variation in skull size and shape was accounted for in all dimensions. Results of the allometric analyses showed a high level of correlation with the plotted fitted lines, providing support for the single taxon hypothesis. While
Aelurognathus has previously been divided into six species, based upon variation of morphological characters, this study has shown that certain characters used in the past have been unreliable. As such it is proposed that all species currently attributed to Aelurognathus be synonymised with the type, Aelurognathus tigriceps.

General Morphology

P-073
COMPARATIVE MORPHOLOGY AND HOMOLOGY OF THE PARASPHENOID BONE IN VERTEBRATES
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The parasphenoid is a small, unpaired, dermal bone that is located in the cranium of some vertebrates. The parasphenoid is not present in more derived vertebrates (e.g. mammals). Instead, mammals have a vomer, which is also an unpaired, dermal bone located in the cranium. The parasphenoid and the vomer are considered homologous by some early twentieth century researchers; however, more current research into whether or not these two bones represent true homology has not been conducted. To determine if the parasphenoid is indeed homologous to the vomer found in mammals, we reviewed literature on the morphology and developmental origins of these bones in vertebrates (placoderms, teleosts, amphibians, reptiles, and mammals). We found that the parasphenoid’s morphology is simpler in derived vertebrates (e.g. reptiles). When compared to less derived vertebrates (e.g. teleosts and amphibians), the parasphenoid in more derived vertebrates is a site of fewer muscle attachments and makes up portions of fewer structures in the cranium. Additionally, the parasphenoid has neural crest developmental origins in amphibians and reptiles, but does not in teleost fish. The mammalian vomer also has neural crest origins. We conclude that the parasphenoid and vomer cannot be considered homologous because vomers are also present in the other vertebrates examined. Therefore, the vomer and parasphenoid fail Patterson’s conjunction tests. Furthermore, the parasphenoid in vertebrates may not be homologous between groups because of their differing developmental origins. We hope that this research will help to resolve important questions surrounding homology in the vertebrate cranium.

P-074
THE BULBUS ARTERIOSUS OF THE HOLOCEPHALAN HEART
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Previous work has shown that the outflow tract of the elasmobranch heart, namely the cardiac portion intercalated between the ventricle and the ventral aorta, does not consist of a single component, the conus arteriosus, as has classically been assumed, but two, the myocardial conus arteriosus and the non-myocardial bulbus arteriosus. From the evolutionary perspective, knowledge of the anatomy of the cardiac outflow tract of the holocephali is important, as they are the sister group of elasmobranchs. Our aim is to describe the cardiac outflow tract of four holocephalan species, two of them, Chimaera monstrosa and Hydrologus affinis of the family Chimaeridae, and the other two, Harriotta raleighana and Rhinichimaera atlantica, of the family Rhinocidae. The cardiac outflow tract of the four species consisted of a myocardial conus arteriosus, furnished with valves, and a bulbus arteriosus devoid of cardiac muscle. Both the bulbus and conus are tubular in shape. The length of the bulbus relative to the total length of the outflow tract is somewhat smaller in the rhinocidae (15%-19%) than in the chimaerids (19%-23%). The bulbus is covered by epicardium and is crossed by the main coronary artery trunks. Histologically, the bulbus is mainly composed of elastin and collagen, and, to a lesser extent, by smooth muscle. This suggests that in holocephalians, the bulbus actively helps to protect the gill vasculature from exposure to high-pressure pulses of blood. Our results prove that the bulbus arteriosus is common to chondrichthysans. In addition, they support the hypothesis that the cardiac outflow tract consisted of a conus arteriosus and a bulbus arteriosus from the beginning of the jawed vertebrate radiation, contributing to our understanding of the morphological changes that have occurred at the arterial pole of the heart in both actinopterygians and sarcopterygians.

P-075
MYOCARDIAL STRUCTURE AND VASCULARIZATION OF THE HEART VENTRICLE IN HOLOCEPHALI: IMPLICATIONS FOR HEART EVOLUTION
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It has been classically assumed that the ventricle of the primitive vertebrate heart is composed of spongy myocardium, supplied exclusively by oxygen-poor, luminal blood. This idea is on two facts: (1) extant agnathans have a spongy ventricular myocardium, and (2) in avian and mammalian embryos, the formation of trabeculated myocardium precedes the appearance of compact myocardium. Recently, it has been proposed that, like elasmobranchs, the early gnathostomes possess a fully vascularised ventricle composed of mixed myocardium. We tested this idea by studying the structure and vascularisation of the ventricular myocardium in four holocephalan species of the families Chimaeridae and Rhinocirhinaidae. *Chimaera monstrosa*, *Hidrologus affinis* and Harriott *raleighana* have a spongy myocardium covered by a thin layer of cardiac muscle. In *H. raleighana*, the compacta is reduced to an extremely fine rim. In all three species there is a well-developed coronary artery system consisting of subepicardial vessels which give off branches that penetrate the myocardial trabeculae. *Rhinocirhina atlantica* has no compacta and its ventricular coronary artery system is reduced to subepicardial vessels that do not enter the spongy layer. This report is the first to show that in wild living vertebrates, a coronary artery system supplying the whole myocardium exists in the absence of a well-developed compacta, which supports experimental work that shows that myocardial cell proliferation and coronary vascular growth rely on genetically separated programs. We conclude that the mixed ventricular myocardium is primitive for chondrichthyans, and that the lack of compacta in some holocephalans is a derived character. Moreover our results support the hypotheses that the mixed myocardium is the primitive condition in gnathostomes, and that the absence of a compacta in different actinopterygian taxa is the result of its repeated loss during evolution.

P-076

**DISTRIBUTION OF PIGMENT CELLS IN THE HEART OF THE RABBITFISH, CHIMAERA MONSTROSA (CONDORCHTHYSES: HOLOCEPHALI)**

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The study of extracutaneous cells producing and storing melanin is of interest because it may provide valuable information about the presence of neural crest elements in internal organs and tissues. Here we report, for the first time, the presence and distribution of melanophores in the heart of a chondrichthyan species, the rabbitfish, *Chimaera monstrosa*. Pigment cells were found in all of 20 hearts examined. Pigment cells occur mainly in the cardiac outflow tract, which consists of two anatomical components, the proximal, myocardial conus arteriosus and the distal, non-myocardial bulbous arteriosus. A few groups of dark pigmented cells were found in the apex of the ventricle of one specimen and in the atrium of two specimens. In all instances, the melanophores were located in the subepicardial space, where they could be well recognized in both unstained and stained histological sections. The distribution and intensity of the pigmentation in the cardiac outflow tract varies markedly between individuals. In all cases, however, the pigmented area is larger on the dorsal than on the ventral surface. Dorsally, the size of the pigmented area ranges from a fringe that includes the bulbus and the distal part of the conus to the whole surface of the outflow tract. Ventrally, the pigmented area does not cover the entire conus arteriosus. The intensity of the pigmentation also varies widely: in general, it is highest at the distal portion of the conus. There is no relationship between the distribution and intensity of the pigmentation and the sex and age of the animals. The functional role of the pigmented cells is unknown. If the melanophores in the heart of *C. monstrosa* are indeed of neural crest origin, it would suggest a notable contribution of the neural crest cells to the cardiac outflow tract in holocephalans.

P-077

**THE ANATOMICAL COMPONENTS OF THE CARDIAC OUTFLOW TRACT OF THE BICHIR, POLYPETERUS SENEGALUS: EVOLUTIONARY SIGNIFICANCE**

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In chondrichthyans and actinopterygians, the outflow tract of the heart, namely, the cardiac portion intercalated between the ventricle and the ventral aorta, consists of two anatomical components: the conus arteriosus and bulbous arteriosus. In chondrichthyans and extant representatives of phylogenetically ancient actinopterygian groups, the conus and bulbus are well-developed in size, whereas in most teleosts, the bulbus is markedly larger than the conus. Current knowledge about the cardiac outflow tract of the polypteroforms is scarce and highly contradictory, a fact that contrasts with their crucial phylogenetic position at the source of the actinopterygian lineage. In fact, it remains uncertain whether they have a bulbus at the arterial pole of the heart. We aimed to elucidate the anatomical arrangement of the cardiac outflow tract of the bichir, *Polypterus senegalus*, in an attempt to improve our understanding of the evolution of the vertebrate heart. We examined the hearts from 12 bichirs using histochemical and immunohistochemical
techniques. The outflow tract of the bichir consists of two components, a long conus arteriosus, largely composed of myocardial tissue and furnished with a variable number of valves at its luminal side, and a very short, elastin rich bulbus arteriosus, devoid of myocardium. The bulbus has an arterial-like histological composition, but it differs from the aorta because it has a thicker wall, shows a different arrangement of the histological elements, is covered by the epicardium and is crossed by coronary arteries. Our observations are consistent with the hypothesis that the conus arteriosus and the bulbus arteriosus have coexisted from the beginning of the jawed vertebrate radiation, which is of particular interest because there is evidence that the bulbus arteriosus, a second heart field derived structure, is homologous with the intrapericardial portions of the aorta and pulmonary artery of birds and mammals.

P-078
PIGMENTATION OF THE HEART IN THE BICHIR, POLYPTERUS SENEGALUS
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The presence of melanin-containing cells in the heart has been documented in tetrapods, but not in fish. It has even been suggested that dark pigmented cells are exclusively associated with hearts having two atria and two ventricles. Our aim is to determine the occurrence of pigment cells in the heart of the bichir, Polypterus senegalus, an extant representative of the polypteriformes, an ancient ray-finned fish lineage that split from the stem of the actinopterygians soon after their divergence from the sarcopterygians. The bichir heart is composed of sinus venosus, atrium, ventricle, conus arteriosus and bulbus arteriosus arranged sequentially within the pericardial cavity. Dendritic-shaped cells containing melanosomes were found in the five cardiac components of all 12 bichirs in this study. Numerous melanophores are distributed regularly over the surface of all segments having myocardium in their walls, thus resulting in marked pigmentation of the whole heart. The bulbus arteriosus, which in the bichir is reduced in size, shows an even more intense pigmentation. In all instances, the melanophores are localized in the subepicardial space. Pigment cells also occur in the pericardium and ventral aorta. The functional role of melanocytes in the tetrapod heart remains unknown, but anti-inflammatory activity, cytoprotection and effects on the viscoelastic properties of the cardiac tissue are possible functions. The role of pigment cells in the bichir heart constitutes a new open question. Interestingly, however, the only cells that form melanin-containing cells in the heart are derive from the neural crest. If the melanophores of the bichir heart are of neural crest origin, it would suggest a much more extensive contribution and persistence of elements from the neural crest in the primitive heart of jawed vertebrates than assumed so far in other studies of vertebrate heart embryology.

P-079
GOING THROUGH CHANGES: REORGANIZATION OF THE OLFACTORY SYSTEM OF FIRE-BELLIED TOADS DURING METAMORPHOSIS
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The nasal cavity of adult Fire-Bellied toads (Bombina orientalis, Anura: Amphibia) contains three different olfactory subsystems: the main olfactory organ, the vomeronasal organ and a structure called the recessus olfactorius. This recessus olfactorius is a small area of sensory epithelium localized on the ventral floor of the anterior part of the main nasal cavity that develops during metamorphosis in other anurans. Interestingly, a fourth olfactory structure, the lateral appendix (also called “Bawden'sches Divertikel”), is present in larval stages of some anuran species. The lateral appendix consists of a distinct diverticulum formed by the dorsolateral wall of the main nasal cavity, lined with sensory epithelium, and is lost at the onset of metamorphosis. Both the recessus olfactorius and the lateral appendix have scarcely been investigated and their respective functions remain unknown. The ontogenetic development of the recessus olfactorius of the genus Bombina has not been described and the existence of a larval lateral appendix is still unconfirmed. We used histological cross sections of the nasal region at different developmental stages of Bombina orientalis (Discoglossidae) to study the recessus olfactorius and lateral appendix. Furthermore, we used vital staining to determine the onset of aerial breathing during ontogeny. Our results clearly show that Bombina orientalis develops a lateral appendix during its larval period. The structure occurs just before hatching of the larvae and disappears during the onset of metamorphosis, synchronously with the incipient development of the recessus olfactorius. Shortly afterwards, and before the actual transition from water to land, the animals begin aerial breathing.

P-080
CRANIAL OSTEOLOGY OF THE BRIDLED SKINK, TRACHYLEPIS VITTATA (OLIVIER, 1804), AND ITS COMPARISON WITH TRACHYLEPIS AURATA TRANSCAUCASICA (CHERNOV, 1926) (SAURIA: SCINCIDAE)
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In spite of high diversity of the Iranian Plateau herpetofauna, especially the lizards, and numerous studies done on the morphometric characters of lizards, information on the detailed characters of their skeleton remains insufficient. We described for the first time the adult cranial osteology of the bridled skink, Trachylepis vittata (Olivier, 1804) based on cleared and double-stained skeletal elements and compared it with Trachylepis aurata transcaucasica (Chernov, 1926). We focused on characters of the skull and mandibular elements. There are slight differences between the two studied species according to bone and skull characters. The skull of both species, as typical representatives of the Scincidae, bear teeth on the premaxilla, maxilla, and pterygoids. The mandibular teeth are present on the dentaries. Obvious differences include: different number of pleurodont maxillary teeth, narrower tip of the nasal processes of the premaxilla in T. vittata, different ornamentation of the nasal processes of the frontals, degree of serration on the posterior margin of the frontals, differences in form, size and special manner of articulation in bones such as: the lacrimals, prefrontals, postfrontals, palatines, pterygoids, dentary and prearticular.

P-081
OSTEOPATHOLOGY IN THE FEET OF RHINOCEROSES: LESION TYPE AND DISTRIBUTION
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There has been little published data on the skeletal anatomy of the foot and distal limb of rhinoceroses, despite their prominence in captivity worldwide and similar knowledge on other large mammalian herbivores (e.g. horses, elephants). We examined the normal skeletal anatomy of rhinoceros feet, noting features that the different species share, and investigating some of the common morphological changes in bones resulting from use and/or disease. The bones of 81 feet from 27 rhinoceroses (of various species) were examined: visually in the case of mounted osteological specimens (67 feet) or via Computed Tomography for cadaveric specimens (14 feet). Unlike related species or other large terrestrial mammals (e.g. horses, elephants) the distal limb bones of rhinoceroses typically have many small holes or channels (lucencies on CT) in the surface bone focused over metaphyseal regions. Additionally, six types of pathological bony change were observed: enthesiopathy, osteoarthritis, pathological bone remodelling, osteitis/osteomyelitis, fracture, and subluxation. Generally, these changes occurred with similar frequency in the fore- and hindfoot, although some did occur more often at certain bony sites: enthesiopathy most commonly on the proximal phalanges, and osteoarthritis in the distal interphalangeal joints of the outermost digits. Some of these osteopathologies have been previously unrecognised in rhinoceroses (e.g. enthesiophyte formation, pathological remodelling), and others are possibly more common than might have been formerly thought (e.g. osteitis/osteomyelitis). This is the first detailed study cataloguing common bony changes to rhinoceros feet, and includes the use of advanced imaging modalities to analyse specimens from multiple collections. Our findings reveal new data on both normal and pathological bony features in the rhinoceros distal limb, which we hope will lead to positive practical applications in the husbandry and care of captive rhinoceroses.

P-082
SPECIES DIVERSITY OF NOS GENE IN SPINAL CORD IN RESPONSE TO NERVE ROOT AVULSION
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Background: In order to study the mechanism of the spinal root-avulsion-induced spinal motoneurons death, the diversity of the nNOS gene expression and the response to the root-avulsion injury of the spinal motoneurons were compared among different laboratory rodents. Methods: Sprague-Dawley rats, hamsters and BALb/c mice were chosen as the experimental animals. All of the right C5, C6, C7, C8 and T1 spinal roots of the brachial plexus were avulsed. After surviving for 3 and 14 days, the spinal cords of all the animals were taken and prepared for RT-PCR, Western blot of nNOS genes, and NADPH histochemistry plus neutral red staining. Results: Following avulsion injury, the levels of the nNOS mRNA in ipsilateral spinal cords decreased in hamsters and mice, while it increased in rats. The nNOS mRNA levels were higher in the ipsilateral than that in the contralateral spinal cords in all studied species; however this difference disappeared for mice at 14 days postinjury. The nNOS proteins in the ipsilateral spinal cords were dramatically increased for rats and hamsters but declined for mice following avulsion. The NOS protein levels were higher in the ipsilateral than that in the contralateral spinal cords in the rats and hamsters but not
in mice at 14 days. Avulsion induced positive NADPH reactions inside the spinal motoneurons both in rats and hamsters at 14 days but not in mice. At 14 days post injury the number of surviving motoneurons at the ipsilateral C7 spinal segments was only 35.64% in mice, 53.29% in hamsters, and 79.57% in rats. 

Conclusions: Our present data showed evidence of the species diversity of nNOS gene expression in the spinal cords in laboratory rodents in response to the root avulsion injury. It suggests that the nNOS gene might be essential for spinal motoneurons to survive root-avulsion injury.

P-083 PARALLELISM BETWEEN ONTOGENY AND PHYLOGENY? A CASE STUDY IN AMPHIBIANS
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Ernst Haeckel's idea of "ontogeny is a fast recapitulation of adult phylogenetic stages" has been discussed extensively since its publication in 1866. In the nearly 150 years since then, the recapitulation idea has been refuted; authors such as Stephen Jay Gould have re-defined a theory that stresses that there is a parallelism between ontogeny and phylogeny, but no ontogenetic recapitulation of ancestral adult stages. To test this theory, we studied amphibian cranial muscle development by undertaking dissections, using whole-mount antibody staining, and serial sectioning. We found that the order in which muscles appear during amphibian ontogeny is effectively similar, in general, with the order the muscles appear in phylogeny. However, there are some heterochronic events that could be related to the particular lifestyle of specific taxa. Also, we found that contrary to the commonly accepted view that ontogeny tends to lead to the differentiation of new muscles, several amphibian larval cranial muscles actually become indistinct during metamorphosis. This can lead to a confusion about the homology of several cranial muscles in salamanders, frogs and other vertebrates, which should be resolved in order to understand vertebrate evolutionary history. Furthermore, we found general patterns in cranial muscle development, e.g. the differentiation of muscles from anterior to posterior, from lateral to medial, and from origin to insertion.

P-084 THE ROLE OF ANGIOGENESIS DURING REGENERATION: AN INVESTIGATION USING THE LEOPARD GECKO (EUBLEPHARIS MACULARIUS)
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The ability to regenerate lost appendages including the tail has evolved in many vertebrates, including various teleost fish, urodeles, and lizards. Appendage regeneration involves the formation of a mass of proliferating cells—a blastema—accompanied by the formation of new blood vessels. The primary mechanism of blood vessel formation during appendage regeneration involves outgrowth from preexisting vascular networks, a process known as angiogenesis. It is predicted that angiogenesis is required for the tissue differentiation and tail outgrowth phases, but not for the initiation of blastema formation. To date, however, the exact role of angiogenesis during regeneration remains unclear. We investigated the role of angiogenesis during regeneration using a naturally-evolved regeneration-competent lizard species, the leopard gecko (Eublepharis macularius). We hypothesize that following tail loss, the formation of new blood vessels via angiogenesis is required for regenerative outgrowth and tissue differentiation. As evidenced by immunohistochemical staining for von Willebrand factor and α-smooth muscle actin, we find that blood vessels first appear during the cell proliferation phase of tail regeneration, prior to tissue differentiation. Although both original and regenerate tails demonstrate a hierarchy of vessel sizes, details of the angioarchitecture differ, suggesting that replication of original vessel organization is not required for regeneration. Using a peptide mimetic of the endogenous anti-angiogenic protein thrombospondin−1 (TSP-1), we demonstrate that angiogenesis is required for appendage regeneration. More specifically, injection of the TSP-1 mimetic impairs tissue differentiation and outgrowth, but does not prevent the initial formation of a blastema. These results provide evidence that reformation of blood vessels is a key requirement for successful regeneration.

P-085 EYE, NOSE, HAIR AND THROAT: EXTERNAL ANATOMY OF THE HEAD OF A NEONATE GRAY WHALE (CETACEA, MYSTICETI, ESCHRICHTIIDAE)
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Information is scarce on gray whale (Eschrichtius robustus) external anatomy and that of mysticetes in general. A recent dissection of the head of a neonate female gray whale calf revealed novel anatomical
details. Gray whales have eyeballs positioned laterally and external to the bony orbit. The gray whale eyeball is nearly twice as long as that of a similar sized right whale calf. The external nares have paired elongate, narrow blowhole openings that converge anteriorly, separated by two folds with a shallow median groove. Between the blowholes, the paired nasal cartilages are secured by fibrous connective tissue and the mesorostral cartilage anteriorly and a single blowhole ligament posteriorly. A small, fleshy protuberance near the palate’s rostral tip is associated with the vomeronasal organ, previously undescribed in gray whales. Two slits leading to blind vomeronasal pits were identified. The vomeronasal organ, like most olfactory structures, appears better developed in neonates than in adults. Many elongated, stiff hairs occur on the rostrum from the ventral tip to the blowhole and on the lower jaw. These hairs are concentrated on the chin, and those on the lower jaw are arranged in a V-shaped pattern. Each hair emerges from a circular depression and is rooted deep within the hypodermis. We confirm the presence of two primary, anteriorly converging throat grooves, confined to the throat region. A third, shorter groove occurs lateral to the left primary groove. The grooves are similar to those of ziphiid odontocetes although they extend farther posteriorly in gray whales. Also, as in ziphiids, the reduced throat grooves in the gray whale have been implicated in gular expansion during suction feeding. The genioglossus muscle has a novel position and unique fiber direction compared to other mammals. Dissection of the tongue confirmed the presence of countercurrent vascular retia and taste buds.

P-086
MORPHOLOGICAL EFFECTS OF CAPTIVITY: A GEOMETRIC MORPHOMETRIC ANALYSIS OF THE DORSAL SIDE OF THE SCAPULA IN CAPTIVE-BRED AND WILD-CAUGHT HOMINOIDEA
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Osteological collections from captive animals are especially important in the case of endangered species, but it is not known whether the differences in habitat and lifestyle have a direct impact upon the bone morphology of captive-bred and wild-caught animals. In the extant apes, locomotor and postural behaviors could be affected by restrictions related to the nature of their environments (substrates, space in the enclosures). Consequently, the use of the remains of captive animals in morphological studies is often rejected, as they are not considered to be representative of the wild morphology. We employed landmark-based geometric morphometrics to compare the shape of the dorsal side of the scapula of wild and captive hominoids to clarify the effect of captivity the scapular morphology of extant apes. At least in the case of the scapula, captive conditions do not have a direct impact in the bone morphology i.e., it is impossible to distinguish the scapulae from a wild-caught and captive-bred apes. Therefore, scapulae from captive specimens can be used in morphological analyses as they will be representative of normal wild specimens.

P-087
VARIATION IN AVIAN BRAIN SHAPE: RELATIONSHIP WITH SIZE AND ORBITAL SHAPE
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There is wide variation in brain shape among birds. Differences in brain dimensions reflects species-specific sensory capacities and behavioral repertoires that are shaped by environmental and biological factors during evolution. Most previous studies aimed at defining factors impacting brain shape have used volumetric or linear measurements. However, few have explored the quantitative indices of three-dimensional (3D) brain geometry that are absolutely imperative to understanding avian evolutionary history. This study aimed to (1) reveal mosaic changes across brain regions of different avian species, (2) explore the relationship between brain shape and overall brain size, and (3) assess the relationship between brain shape and orbital shape. Avian brain endocasts were reconstructed from computed tomography images and analyzed using 3D geometric morphometrics. Principal component analysis revealed dominant regional variations in avian brain shape and shape correlations between the telencephalon and cerebellum, between the cerebellum and myelencephalon, and between the diencephalon and optic tectum. Brain shape changes relative to total brain size were determined by multivariate regression analysis. Larger brain size is associated with a relatively slender telencephalon and differences in brain orientation. The correlation between brain shape and orbital shape was assessed by two-block partial least-squares analysis. Relatively round brains with a ventrally flexed brain base are associated with rounder orbits, while narrower brains with a flat brain base are associated with more elongated orbits. The shapes of functionally associated avian brain regions are correlated, and orbital size and shape are dominant factors influencing the overall shape of the avian brain.
P-088
SEXUAL DIMORPHISM IN THE YASSUJIAN LIZARD, APATHYA YASSUJICA (NILSON ET AL, 2003) (Sauria: Lacertidae) FROM IRAN

Sexual size dimorphism occurs when the sexes of a species or a population differ in morphometric characters and in the body size. So far, sexual size dimorphism in the Yassujian lizard (endemic for Iran), Apathya yassujiica (Nilson et al 2003), is undocumented. In this study 35 (20 males and 15 females) adult specimens were collected from Kohguiluyeh Va Boyer Ahmad Province in southwestern regions of the Iranian Plateau during field work in September 2012. The uni- and multivariate analyses performed on the morphometric data demonstrate that males are larger than females. The results of the Principal Component Analysis (PCA) for metric characters show that the first three axes collectively represent 74.16% of the total variation. In Apathya yassujiica sexual size dimorphism occurs in general body size and several body parts, with males being significantly larger than females in 20 out of 30 studied characters.

P-089
IS THE BULBUS ARTERIOSUS OF FISH HOMOLOGOUS TO THE MAMMALIAN INTRAPERICARDIAL THORACIC ARTERIES?

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Two major findings have significantly improved our understanding of the embryology and evolution of the arterial pole of the vertebrate heart (APVH): 1) a new embryonic presumptive cardiac tissue, the second heart field (SHF), forms the myocardium of the outflow tract, and the walls of the ascending aorta (AA) and the pulmonary trunk (PT) in mammals and birds; 2) the bulbus arteriosus (BA), previously thought to be an actinopterygian apomorphy, is present in all basal vertebrates, and probably derives from the SHF. We hypothesized that the intrapericardial portions of the AA and the PT of mammals are homologous to the BA of basal vertebrates. To test this, we performed 1) a literature review of the anatomy and embryology of the APVH; 2) novel anatomical, histomorphological, and embryological analyses of the APVH, comparing basal (Galeus atlanticus), with advanced (Mus musculus and Mesocricetus auratus) vertebrates. Evidence obtained: 1) Anatomically, BA, AA, and PT are muscular tubes in the pericardial cavity, which connect the distal myocardial outflow tracts with the aortic arch system. Coronary arteries run through or originate in these anatomical structures; 2) Histologically, BA, AA, and PT show an inner layer of endothelium covered by circumferentially oriented smooth muscle cells, collagen fibers, and lamellar elastin. The histomorphological differences between the BA and the ventral aorta parallel those between intrapericardial and extrapericardial great arteries; 3) Embryologically, BA, AA, and PT are composed of smooth muscle cells derived from the SHF. They show a similar mechanism of development: incorporation of SHF-derived cells into the pericardial cavity, and distal-to-proximal differentiation into an elasticotic cell lineage. In conclusion, anatomical, histological and embryological evidence supports the hypothesis that SHF is a developmental unit responsible for the formation of the APVH. The BA and the intrapericardial portions of the great arteries must be considered homologous structures.

P-090
FUNCTIONAL MORPHOLOGY OF SKULL AND MANDIBLES OF THE LATE MIOCENE GIANT MUSTELID EOMELLIVORA PIVETEAUI FROM CERRO DE LOS BATALLONES (MADRID, SPAIN)

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We describe the functional morphology of both the skull and mandible of the giant mustelid Eomellivora piveteau from the Late Miocene (MN10) of Cerro de los Batallones (Madrid Basin, Spain). This material is remarkable due to the fact that it includes complete cranial and postcranial remains. These have an interesting mixture of features that help us to interpret the feeding habits of this species. We describe possible hypercarnivorous adaptations that emphasize and increase the shearing function based on: (1) straight dental series, (2) loss of the metaconid and a trenchant hypoconid placed centrally in the m1, (3) m1 and m2 with labiolingually compressed cuspids in line with the dental series, and (4) a conspicuous development of the muscular attachments of M. masseter pars superficialis and M. masseter pars profunda.
We also suggest that besides hunting small to medium size prey, *E. piveteaui* could have taken down larger prey, based on: (1) shape and robustness of the muzzle, mandible and mandibular symphysis, (2) reinforced temporomandibular joint through large and robust muscular attachments of *M. digastricus* and *M. zygomaticomandibularis articularis*, and (3) some musculoskeletal adaptations that would have allowed more effective skull movements in all directions, to support the struggle with the larger preys. Therefore, *E. piveteaui* could be described as one of the more hypercarnivorous mustelids, even more than the extant relatives *Gulo* and *Mellivora*, and the fossil relatives *E. wimani*, *E. ursogulo* and *E. hungarica*. Nevertheless, *E. piveteaui* also possessed several important adaptations to carcass processing. Consequently *E. piveteaui* can be considered as an alternative trajectory for hypercarnivorous specialization that leads not to a cat-like condition but towards a more hyena-like animal, as we can observe in other species of *Eomellivora*.

P-091
QUANTIFYING PERIPHERAL NERVE REGENERATION IN THE LIZARD TAIL
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In response to a traumatic injury, vertebrates undergo one of two reparative programs: scar formation or tissue regeneration. Among mammals, the most common wound healing response is scar formation. Although scars act to restore tissue homeostasis, they also inhibit the re-establishment of peripheral nerves thus compromising tissue functionality. In contrast, among various teleost fish, urodeles (newts and salamanders) and lizards, lost or damaged tissues can spontaneously regenerate. Tissue regeneration includes the re-establishment of peripheral nerves. With this in mind, we investigated axonogenesis in a regeneration-competent amniote, the leopard gecko (*Eublepharis macularius*). To quantify peripheral nerve regeneration in gecko tails we used RT-97, a well-documented neurofilament marker of axons. Cross sections were used to compare the peripheral nerve densities of original and regenerated tails. The peripheral nerve density in the regenerated tail was significantly (p<0.05) greater than that of the original tail. We also show that nerves initiate regrowth from the dorsal root ganglia adjacent to the site of tail loss. Following a brief period of nerve degeneration, axonogenesis is initiated early during tail regeneration. Based on these findings, we conclude that although the regenerated tail is more heavily innervated, the mode of axonogenesis is conserved. We demonstrate that this difference in nerve density is related in part to an increase in the overall amount of muscle tissue present in the regenerate tail.

P-092
INFERENCE OF HORMONE LEVELS FROM CRANIAL MORPHOLOGY IN GREAT APES AND ITS APPLICATION TO RECONSTRUCTING SOCIAL BEHAVIOR IN EXTINCT HOMININS
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A new method of inferring androgen levels, and thus mating behavior, in fossil species is described. We review evidence of cranial dimensions affected by testosterone (T) level in humans and investigate whether those landmarks are similarly T-sensitive in non-human primates, and thus fossil humans. The results indicate that certain mandibular and anterior-facial measurements closely mirror androgen profiles in ape species. This relationship is strongest in the great apes, proving that it is phylogenetically deep enough to predict T levels in the extinct hominins. Baseline androgen levels in primate species, as well as dimorphism between the sexes within species, are highly predictive of social systems. In particular, it has been observed that increased T accompanies heightened intergroup aggression. Androgen levels vary greatly between the sexes in chimpanzees, whereas the difference is insignificant in bonobos. The low variation in T between bonobo males and females is interpreted to reflect decreased aggression and sexual competition in that species compared to chimpanzees. Relative facial and mandibular measures are found to be significantly different between male and female chimpanzees but not so in bonobos, further supporting the use of craniofacial landmarks as predictors of T. Craniofacial measurements from hominin casts suggest high levels of male-male competition and by inference highly promiscuous mating systems in *Australopithecus afarensis* and *Homo erectus*. Early *H. sapiens* and *H. neanderthalensis* are also interpreted to have been subject to slightly elevated levels of male-male competition and thus a higher incidence of polygyny compared to modern humans. We present a method of obtaining direct insight into the T levels of any single individual, rather than relying on large sample sizes to understand sexual dimorphism and, by proxy, the mating systems of extinct species.

P-093
USING BIPLANAR CINEFLUOROSCOPY TO GUIDE RADIOPAQUE VASCULAR INJECTIONS: A NEW METHOD FOR VASCULAR IMAGING
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Studying vascular anatomy, especially in the context of relationships with hard tissues, is of great interest to morphologists and paleontologists alike. Vascular injections of resin or latex have been standard techniques for decades. Recently, there has been a surge in popularity of radiopaque latex vascular injection followed by CT scanning and digital "dissection." This technique best displays both blood vessels and bone, and allows injections to be performed on cadaveric specimens. Vascular injection is risky, however, because it is not possible to view the perfusion of injection medium throughout the vascular system of interest. Data, and difficult to obtain specimens, can therefore be lost due to poor or excessive perfusion. Here, we use biplanar cinefluoroscopy as a technique to guide craniovascular radiopaque latex injection. Cadaveric domestic pigs (Sus scrofa) and white-tailed deer (Odocoileus virginianus) were cannulated and injected with a 40% barium/latex solution. Injections were monitored and recorded in coronal and sagittal planes. Following injection, specimens were CT scanned and digitally dissected in Avizo (VSG v. 7.0). Perfusion patterns were analyzed from videographic data using Qualisys Track Manager. This method was found to enable adjustments, in real time, to the rate and pressure at which latex is injected in order to avoid data loss. In addition to visualizing the injection process, this technique can be used to determine flow patterns, and has permitted development of standardized markers for complete perfusion. In 100% of injections, complete unilateral perfusion and bilateral perfusion of large vessels was achieved when effluent flow of latex began through the contralateral internal carotid artery.

P-094
THE DOWNWARD BENDING MECHANISM OF GIRAFFE NECK
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The giraffe (Giraffa camelopardalis) is the tallest extant terrestrial animal. Whereas a long neck and limbs allow the giraffe to hold the head up to a high position, they make it difficult to lower the head to the ground. Head-lowering is essential for drinking water, thus one would expect the giraffe to have a mechanism for accomplishing this movement. The aim of this study is to clarify the downward-bending mechanism of the giraffe neck by focusing on its musculature. We dissected four giraffes and described the origin and insertion of the cervical muscles. For identifying patterns of musculature specific to the giraffe, we made similar analyses of the neck muscles in the okapi, the other extant giraffid with a shorter neck, and compared them with those of the giraffe. The infants of the giraffe and okapi were subjected to a CT maximum dorsal extension and ventral flexion, and then the movement range of the cervical and thoracic vertebrae was examined. The dissection revealed that the major tendons of the longus colli muscle, which pull down the root of neck, inserted onto the inferior transverse process of C7 in the giraffe, but on the ventral lamella of C6 in the okapi. CT images suggest that eight vertebrae from C1 to T1 showed larger movement range than the other thoracic vertebrae during the vertical neck movement in the giraffe. Contrary to this, the seven vertebrae from C1 to C7 moved in a larger range in the okapi. This study suggests that the posterior end of the ventral neck-bending system in the giraffe shifts posteriorly relative to the okapi, allowing the giraffe to move more than seven vertebrae to lower the head.

P-095
THE VERTEBRATE-SPECIFIC STRUCTURES THE NEURAL CREST AND THE PLACODE ARISE FROM THE NEURAL PLATE BORDER: DEVELOPMENT OF A NEW CULTURE METHOD FOR A POSSIBLE PRECURSOR OF EXTERIOR EPITHELIUM OF THE NEURAL PLATE
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Previous studies have shown that the neural crest is induced in the neural plate—the embryonic ectoderm border by the action of BMP4, which is derived from the embryonic ectoderm, and that the neural plate explant is likewise transformed to the neural crest cells by BMP4. We described a new culture method we developed and used to find that the additive effects of BMP4 and FGF2 on the neural plate explant results in morphological change to the simple squamous epithelium, which characteristically expresses Dlx5, which is a neural plate border specifier that positions the neural crest and future epidermis. We then examined the effect of Dlx5 downstream genes that are expressed in the neural plate and its border region on the induced epithelium. The expression levels of epidermis specific markers GATA3/keratin19 and neural crest markers Slug/Msx1 in the induced epithelium were increased at the expense of the expression of neural plate marker Sox2. The pre-placodal ectoderm or ridge (PPE or PPR) arises in the anterior border of the neural plate in the form of an inverted-U shape and is regarded as a presumptive placode area at the late neurula—early pharyngula stage. The expression levels of the PPE-specific genes Six1/Eya2 known as the direct downstream genes of Dlx5, and of some placode-specific markers were also increased, albeit only slightly.
This study thus suggests that the neural plate cells have a latent ability to be transformed into exterior epithelium of the neural plate, such as the neural crest, the PPE, and the embryonic ectoderm through the action of BMP4 and FGF2. The induced epithelium might be a precursor of all exterior epithelium of the neural plate. We are now investigating molecular cascades and cell differentiation in both the epithelium induced by the explant culture and the neural plate border in the embryo.

P-096
EXPLORING THE PATTERNS OF CRANIAL AND MANDIBULAR CO-VARIATION WITHIN THE ORDER RODENTIA
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Morphological co-variation is the occurrence of correlated variation between two anatomical modules, units or discrete structures. The potential for variation results from phylogenetic and developmental processes, but patterns of co-variation may be also be constrained by functional selection pressures. In Rodentia, the incisor-dominated cranial and mandibular morphology has successfully adapted to a wide array of ecological traits, including diet. The versatility of rodent morphology and the developmental plasticity shown in laboratory studies suggest that patterns of co-variation in Rodentia may be capable of rapid evolution and therefore exhibit variability. Geometric morphometrics (GMM) encapsulates detailed 3D shape information using landmarks, enabling complex quantitative analysis. GMM analysis using anatomically homologous fixed landmarks was used to compare the shape variation and co-variation of 28 rodent species from 24 families, sampling across the majority of the order. Principal component analysis was used to describe the variation within the skull and mandible independently. Two-block partial least squares analysis was used to describe and statistically analyse the co-variation between the skull and mandible across the entire sample. As well as raw geometric data, phylogenetically-corrected data was also analysed to test for significant phylogenetically-independent effects. The largest variations in shape were described, and the distributions of phylogenetic and functional groups were compared. There was a clear phylogenetic pattern in respect to relative size of braincase and rostrum, orbit placement, length of the coronoid process and robustness of molar alveolar region. Possible dietary effects were seen in the angle of the mandibular ramus, zygomatic robustness and a flat versus globular cranium. The phylogenetically-independent co-variation is significant, however the dominant constraint in this sample appears to be phylogeny. Phylogenetically-independent effects appear to be complex and require a study sample with detailed ecological comparisons.

P-097
FIRST AMPHISBAENIAN SKULL FROM THE EUROPEAN FOSSIL RECORD: A MILESTONE IN THE EVOLUTION OF BLANIDAE
Bolet, Arnau (1); Dellino, Massimo (2); Fortuny, Josep (1); Almécija, Sergio (3); Robles, Josep M. (4); Carmona, Raül (5); Rotgers, Cheyenn (2); Alba, David M. (2)

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Amphisbaenians are a group of squamates (Reptilia, Lepidosauria) strongly adapted for a fossorial lifestyle. Fossil remains of the genus Blanus, the single extant European amphisbaenian, have been reported for many Neogene and Quaternary localities of Europe. Nevertheless, researchers encounter difficulties regarding the taxonomic referral of the specimens because of the fragmentary nature of the material, almost exclusively represented by isolated and incomplete bones. Moreover, the most commonly found elements are vertebrae, which lack diagnostic characters even at the genus level, as well as tooth-bearing bones, which display a great intra-specific variability among modern forms. This situation has favoured the erection of several genera and species clearly related to Blanus, whose taxonomic status and phylogenetic relationships are difficult to elucidate. We report here the first European fossil amphisbaenian skull, from locality ACM/C8-A4 (11.6 Ma, Middle Miocene) of the local stratigraphic series of Abocador de Can Mata (Vallès-Penedès Basin, Catalonia, Spain). As revealed by a CT-scan reconstruction, this specimen shows a cranial morphology approaching that of the extant Blanus, although subtle morphological differences suggest it is not conspecific with either B. cinereus from the Iberian Peninsula or B. strauchi from the Middle East. The lack of knowledge on the osteology of the other extant species (B. mettetali and B. tingitanus...
from Morocco, and the cryptic B. mariae from Iberia), together with the limited information available for fossil blanid species, hamper a taxonomic identification of the specimen at the species level. Nonetheless, this skull represents an unprecedented opportunity for tracking the paths and timing of some key cranial characters during blanid evolution. This work has been supported by the Spanish Ministerio de Economía y Competitividad (CGL2011-28681, CGL2011-30069-C02-01, RYC-2009-04533 to D.M.A and BES-2009-026731 to A.B.) and the Generalitat de Catalunya (2009 SGR 754 GRC).

P-098
MESOPODIAL MORPHOLOGY IN TWO BASAL CTENOHYSTRID RODENTS, CTENODACTYLUS GUNDI AND LAONASTES AEINGAMUS
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Carpal and tarsal bones provide valuable data on ecology, behaviour and locomotion, as well as phylogenetic information. All these aspects are barely studied in Laonastes aenigmamus, a rodent from Laos and Vietnam, firstly described in 2005. We compare 3D-models of the carpal and tarsal regions in Laonastes, reconstructed from µCT-data, with its proposed sister-taxon within the Ctenohystricidae, Ctenodactylus gundi. Based on a large comparative work on rodent carpals, we interpret the morphology of these two basal ctenohystricid rodents, discuss lifestyle and locomotion and make suggestions for the systematic position of Laonastes. Carpals of ctenohystricid rodents are diverse. Some changes in size, shape and arrangement are adaptations for subterranean lifestyles; others can be interpreted in a phylogenetical context. All hystrocognathi studied to date (except for Erethizon) have a newly-described bone in the carpal region. This Os posthamatum is a putative synapomorphy of the Hystriognathi. We found that Laonastes also possesses this bone, but Ctenodactylus, the proposed sister-taxon within the ctenohystricids, does not. The tarsal bones of both species are close to the rodent ‘groundplan’; however, Ctenodactylus shows some reduction in the first digit. Further reduction of toes within the Ctenohystrica commonly occurs in association with cursorial lifestyle.

P-099
MODELLING STRESS IN THE SKULL OF SALAMANDERS (AMPHIBIA: CAUDATA)
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Different feeding systems are known for salamanders. Aquatic feeding is widespread among this group using suction to capture the prey while terrestrial feeding involves typically the tongue. When prey is small, the jaws and dentition do not contact the prey but larger taxa feeding on larger prey usually used jaws and probably experience important levels of stress in the feeding apparatus. Here, we used 3D Finite Element Analysis (FEA) to investigate stress distribution in two skulls of large living salamanders (Cryptobranchidae and Dicamptodontidae) with clearly different feeding systems in aquatic and terrestrial habitats. We generated 3D models from CT scans of adult animals and applied simplified boundary conditions to test the role of the adductor musculature complex. Our results show that the adductor musculature complex cause important stresses in the central area of the frontals in both taxa, but reveal different stress distribution in the palate. The cryptobranchid taxon presents higher stresses along the parasphenoid. The dicamptodontid taxon stresses are reduced in the parasphenoid, being only present in the posterior part, but present higher stress values in the central part of the pterygoid. These stress differences in the palate are probably caused by the different role of the hyobranchial skeleton and associated musculature; these play a key role in the cryptobranchid taxon during suction and jaw prehension and a minor role in the dicamptodontid taxon.

P-100
FROM CUÉNOT’S “preadaptation” to GOULD’S “exaptation”: A REVIEW OF THE CONCEPT(S)
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In 1983 Gould and Vrba proposed the term “exaptation” for features non adapted but available for cooptation in the descendants. They argued that it was a missing term to explain some evolutionary phenomena. It was a supposed conceptual alternative to the idea of preadaptation. But in fact they overlooked most of the history behind the concept of preadaptation. This is especially evident regarding the ideas of the French biologist Lucien Cuénot (1866-1951), who was probably the first biologist to introduce the concept of preadaptation as early as 1914. Cuénot developed the concept in various contributions during his career. According to him, preadaptative characters would have their origin in the heterozygosis of populations
occupying an environment where those characters would have had only some potential properties. These properties would completely develop when individuals from the population displaying them migrate to a new and empty habitat. The occupation of these new habitats would have been an important evolutionary mechanism, permitting to the emigrants to avoid the competition with individuals from other ecotypes existing in the ancestral population. The mechanism would be in the origin of the morphotypes resulting from the early Palaeozoic radiation (currently, the Cambrian explosion). Similar ideas about preadaptation, linked to genetic variability and habitat migration, are also found in other authors including Goldschmidt and Schmalhausen. In this situation, we can wonder whether exaptation is really a new concept and contributes actually to clarify the debate about adaptation and its origin.

Cuénot, L. (1921). La genèse des espèces animales.
Goldschmidt, R. (1940). The material basis of evolution.

P-101
DIVERSITY OF MITOCHONDRIAL STRUCTURES IN MICE
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Mitochondria are dynamic intracellular organelles consisting of a smooth outer membrane, an inner membrane, and a protein-rich matrix. The inner membrane folds into invaginations (cristae) that cause an enlargement of the reactive surface. All cristae are connected to the inner mitochondrial membrane by cristae junctions. The enzymes of the respiratory chain, especially oxidative phosphorylation, are located on the inner mitochondrial membrane and the in mitochondrial matrix. Thus, the area of the membrane and the volume of the matrix determine the mitochondrions’ capacity for oxidative phosphorylation. However, mitochondria of different tissues vary in size, shape and inner structure. A systematic comparison of the mitochondria of different tissues within and among species has not been made yet. We are currently preparing an atlas of mitochondrial diversity for different tissues of 40 Swiss-Webster mice. After cervical dislocation, tissue samples were collected from skeletal muscles, heart, lung, liver, intestine and kidney. These samples were embedded in epoxy resin, sectioned and stained for transmission electron microscopy following standard protocols. Transmission electron micrographs were analyzed for shape and size differences, crista organization and crista junctions. The differences between mitochondria in size and shape among different organ systems of the mouse are striking. In particular, mitochondria of skeletal and heart muscle form an extensive network that extends through the entire muscle cell / fiber. Mitochondria of liver and kidney are characterized by size and difference in the matrix composition. The results of this comprehensive ultrastructural survey present an atlas of structural diversity; while this is primarily a descriptive tool, it offers the opportunity to develop and test more explicit hypotheses about differences in shape and size, within tissues and among tissues. Without that knowledge, the dynamics of shape changes of the mitochondria remain enigmatic and prone to misinterpretations.

P-102
MORPHOLOGICAL VARIATION OF SYNANTHROPIC MICRO-MAMMAL SPECIES IN WESTERN EUROPE THROUGHOUT THE HOLOCENE
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The ecology of the micro-mammals in Western Europe has been altered due to anthropogenic activity, potentially affecting their morphological evolution. Throughout the Holocene the landscape and ecology have been dramatically changed, primarily through the introduction of agriculture 7500 – 7000 ya. The flora has altered from mostly open woodland to fields, and agricultural methods have intensified over time. Archaeological assemblages have shown changes in the biodiversity of micro-mammals, including the orders Rodentia and Eulipotyphyla. The selection pressures on micro-mammal ecology, such as foraging, will also have altered. The mandibular morphology of rodents and shrews has been shown to be highly evolutionarily responsive to functional and ecological changes. The variation of mandibular morphology over time will therefore be a good indicator of evolutionary responses to functional selection pressures in these taxa. Geometric morphometrics (GMM) will be used to analyse the variation in mandibular shape of synanthropic species. Archaeological specimens will cover a geographical and temporal range in Western Europe, from the late Palaeolithic and early Holocene prior to the introduction of agriculture, until the modern era. Biomechanical models using modern specimens will be developed in order to test the functional implications of any historic morphological variation. Three species representing ecological diversity have been chosen to observe anthropogenic effects on multiple niches. The species chosen are Eliomys...
the frontal, maxilla, sphenoid, and ethmoid to produce air conservation. In addition, this epithelium may invade the bones surrounding the nasal chamber, including

The nasal cavity of mammals is lined by epithelium that functions in olfaction and heat and water conservation. In addition, this epithelium may invade the bones surrounding the nasal chamber, including the frontal, maxilla, sphenoid, and ethmoid to produce air-filled cavities called paranasal sinuses. Paranasal

P-103 MORPHOLOGY AND SYSTEMATIC VALUE OF THE UNUSUAL HEAD APPENDAGES IN FOUR SPECIES OF LIMNONECTES (ANURA: DICROGLOSSIDAE)

Lambertz, Markus (1); Hartmann, Timo (2); Walsh, Shannon (3); Geissler, Peter (2); McLeod, David S. (3)

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Most of the 55 currently recognized species of Limnonectes (Ranoidea: Dicroglossidae) are rather unremarkable, medium-sized brown frogs. The males of four species (L. dabanus, L. gyldenstolpei, L. macrognathus, and L. plicatellus), however, possess a conspicuous dorsal ornamentation of their heads. To date, no study has examined this structure in detail. The goals of this study were to address the systematics of the flap-headed species and assess the functional and evolutionary significance of this feature. Morphological analyses of these structures (via gross anatomical, histological, and radiographic means) in all four species revealed great differences in external characteristics such as shape and extent. Histological architecture, however, was nearly identical in all species, suggesting that the appendages indeed could have a common evolutionary origin. Additionally, we found that all four species have a concave lateral curvature of the anterior ramus of the pterygoid bone, which is convex in all other Limnonectes. Results of molecular phylogenetic analyses of the 12S–16S mtDNA gene region provided well-supported evidence for the monophyly of this group. Based on these two independent lines of evidence, we conclude that these four species represent a monophylum and that the head appendage is a reliable diagnostic feature of this group.

P-104 CLADISTIC ANALYSIS OF THE EUROPEAN PAROMOMYIDAE (PRIMATES, MAMMALIA)

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Plesiadapiforms represent the first adaptive radiation of Primates, appearing near the Cretaceous–Paleogene boundary. Eleven families of plesiadapiforms are recognized, including the Paromomyidae, which are known from North America, Europe, and Asia. Four species of Paromomyidae, all belonging to the genus Arcius, have been reported from Europe: A. fuscus, A. lapparenti, and A. rougieri from France, and A. zbyszewskii from Portugal. Arcius sp. is also known from the Masia de l’Hereuet fossil site in northeastern Spain, and a specimen identified as A. lapparenti has been described from the Abbey Wood site in England. A comprehensive cladistic analysis of the European paromomyids has never previously been performed. Existing conceptions of the relationships between the various species of Arcius suggest that A. rougieri represents a more primitive stage than A. fuscus and A. lapparenti. Arcius zbyszewskii was suggested to be the most primitive species of the European paromomyids, closely related to A. rougieri. The Spanish specimens were suggested to be closely related to A. lapparenti, but not part of the same species. A total of 157 dental characters were analyzed for the four species of Arcius and the Arcius sp. specimens from Spain. The single specimen from England is analysed separately from the French A. lapparenti. Parsimony based cladistic analysis using TNT yielded a single-most parsimonious cladogram rooted with Paromomys maturus. The results agree with A. zbyszewskii being the most primitive species. However, A. fuscus is positioned as the sister taxon of A. rougieri and A. lapparenti, and the Spanish material seems to pertain to a quite primitive lineage, instead of being closely related to A. lapparenti. These results contrast with the conclusions based on more restrictive comparisons, which demonstrates the potential power of the simultaneous consideration of all morphological data in a cladistic analysis.

P-105 [Affiliated with Symposium 14 – Inside the Vertebrate Nose] BEYOND THE SNIFER: A THREE-DIMENSIONAL STUDY OF PARANASAL SINUSES IN CARNIVORA

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The nasal cavity of mammals is lined by epithelium that functions in olfaction and heat and water conservation. In addition, this epithelium may invade the bones surrounding the nasal chamber, including the frontal, maxilla, sphenoid, and ethmoid to produce air-filled cavities called paranasal sinuses. Paranasal
sinuses are widespread among mammals, but few studies have quantified sinus morphology, and their function is still unknown. Previous studies were limited by the fact that paranasal sinuses are hidden within skulls and inaccessible without using destructive methods. We conducted the first quantitative study of frontal sinus morphology for the mammalian order Carnivora using non-destructive CT technology that included 64 individuals representing 38 species of hyaenids, canids, and felids. Carnivores offered an excellent comparative sample because they span a range of skull size and shape disparity, and have evolved and lost sinuses multiple times. We focused on frontal sinuses because they vary greatly among species compared to the other paranasal sinuses. We constructed volumetric models of frontal sinuses from CT scans using specialized visualization software and applied a novel shape quantification technique called spherical harmonics (SPHARM) to characterize three-dimensional shape disparity among species. Skull size and shape were quantified using three-dimensional geometric morphometrics. We examined the relationship between sinus size and shape and skull size and shape within a phylogenetic context to test the hypothesis that sinuses form where bone is mechanically unnecessary. Results indicate that sinus volume scales similarly with skull size and sinus shape shows convergence in that distantly related species with similarly shaped skulls have comparably shaped sinuses. Our results suggest that sinuses develop where bone is not mechanically necessary, and allow for expansion of the feeding apparatus while using minimal materials.

P-106 [Affiliated with Symposium 14 – Inside the Vertebrate Nose]
LED BY THE NOSE: TRACING THE PATHS OF HUMAN EVOLUTION BY EXPLORING THE NASAL COMPLEX OF LIVING PRIMATES AND EXTINCT ANCESTORS
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As air-breathing mammals, humans possess a nasal complex – nose, nasal cavity, nasopharynx, sinuses, and connecting pathways – that serves as the key entry portal to other components of the upper, and eventually lower, respiratory tracts. Although the respiratory system is vital for survival its evolutionary changes have been explored far less frequently than other systems such as the musculoskeletal or dentognathic. Indeed, its osseous boundaries are seldom studied relative to portions of the skeletal system that are more commonly preserved during the fossilization process. This taphonomic effect has hindered the tracking of evolutionary changes in nasal morphology, leaving great gaps in the human fossil record. This report will trace our studies on the comparative biology and function of the primate nasal complex through anatomical dissections and imaging visualizations. Cranial material was studied from a range of extant primates encompassing strepsirhines, New and Old world monkeys, apes, humans and fossil hominids. Comparative osteometric analyses were performed using a range of techniques such as geomorphometrics and CT and MR imaging of human and nonhuman primate material. Results from our studies show that the morphology of the nasal complex in nonhuman primates is heavily interactive with, and dependent upon, climatic variables. For example, one extinct human species – the Neanderthals – may have exhibited autapomorphic features that give insight into both the function of their respiratory systems and their evolutionary relationships with early modern humans. The nasal components of the upper respiratory tract remain a critical but poorly understood area within paleoanthropology that may yet offer novel insight into the course of human evolution.

P-107 [Affiliated with Symposium 14 – Inside the Vertebrate Nose]
COMPLEXITY OF THE ETHMOID REGION IN CARNIVOROUS AND INSECTIVOROUS BATS
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Recently, the carnivorous bat Megaderma lyra was shown to possess a larger number of ethmoturbinals than described for any microchiropteran to date. Here, we investigate whether morphology of the ethmoidal region in bats could be linked to dietary preference. As a preliminary study, serially sectioned heads of two carnivorous bats, M. lyra and Nycteris thebaica, were compared to two insectivor species, Myotis lucifugus and Mystacina tuberculata. Surface area (SA) of ethmoidal turbinals (e.g., ethmoturbinals, frontoturbinals, interturbinals) was measured using Image J software. Turbinal complexity was expressed as a percentage: turbinal SA/total nasal SA x 100. Results indicate that the two carnivorous species do not have greater turbinal complexity than the insectivor species. In our sample, Nycteris has the least complex ethmoidal region, whereas Megaderma and the highly insectivor Mystacina possess the most elaborate ethmoidal region. The four bats were highly variable with respect to turbinal types, as denoted by their position. In the two insectivor species and Megaderma, most of the turbinal SA represents turbinals that occur near the midline. In Nycteris, most of the turbinal SA was distributed away from the midline. Megaderma, which was previously shown to lack any frontoturbinals, possesses a numerous small turbinals between the ethmoturbinals, which constitute ~25% of turbinal SA. Both Myotis and Nycteris possess
frontoturbinals. *Mystacina* is distinguished by having an especially large “ectoturbinal” that parallels the medial row, and is not clearly located within a paranasal recess. These results confirm osteological studies that show the ethmoturbinal region to be highly variable in microchiropterans. However, no link between relative turbinal complexity and diet can be discerned based on our small sample. Since turbinals have multiple functions (air-conditioning, olfaction, and direction of air currents), correlates to dietary function could be subtle or even obscured by adaptations to more than one function.

P-108 [Affiliated with Symposium 14 — Inside the Vertebrate Nose]
RECONSTRUCTION AND MORPHOMETRIC ANALYSIS OF THE NASAL CAVITY OF THE WHITE-TAILED DEER (*ODOCOILEUS VIRGINIANUS*) AND IMPLICATIONS REGARDING RESPIRATORY AND OLFACTORY AIRFLOW
Craven, Brent (1); Ranslow, Allison (1); Quigley, Andrew (1); Richter, Joseph (1); Rumple, Christopher (1); Neuberger, Thomas (1); Pang, Benison (2); Ryan, Timothy (1); Stecko, Timothy (1); Van Valkenburgh, Blaire (2)
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The ungulate nasal cavity is a complex multi-purpose organ, having many functional roles. The nasal turbinals provide a tortuous airflow path and a large surface area for respiratory air conditioning, filtering of inspired contaminants, and olfaction. The objective of this study is to quantitatively investigate the anatomy and functional morphology of the nasal cavity of the white-tailed deer (*Odocoileus virginianus*) using high-resolution X-ray micro-computed tomography (micro-CT) and magnetic resonance imaging (MRI), combined with state-of-the-art anatomical reconstruction and morphometric analysis techniques. Specifically, we combine micro-CT and MRI scans to produce a multimodal data set that is used to reconstruct the three-dimensional anatomy of the turbinal bones and the convoluted nasal airways. The white-tailed deer is shown to possess an extensive double-scroll maxilloturbinal, which occupies much of its long snout, and an extremely complex arrangement of ethmoturbinals in the olfactory region. A detailed morphometric analysis is presented that includes regional distributions of airway size and shape (e.g., perimeter, cross-sectional area, surface area), and a comparison of these measures with available data in other species. Finally, the functional implications regarding respiration and olfaction are considered, based on non-dimensional analyses that incorporate airway morphometry and respiratory physiology data.

P-109 [Affiliated with Symposium 14 — Inside the Vertebrate Nose]
EVOLUTION OF THE OLFACTORY SYSTEM IN MONOTREMES
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The origin of crown Mammalia was the culmination of several pulses of increased encephalization that were tied primarily to elaboration of the olfactory system. Evidence from the fossil record generated by high-resolution computed tomography revealed that expansion of the olfactory bulbs and pyriform cortex accounted for most of the increase in relative brain size. Mammals have an order of magnitude more olfactory genes than most other vertebrates, and current estimates suggest that approximately 1000 olfactory genes were present and active in mammals ancestrally. The origin of an ossified ethmoid skeleton accompanied the onset of expression of these genes in basal mammals, as it expanded surface area for olfactory epithelium by an order of magnitude. The basal split between monotreme and therian mammals was followed by further episodes of olfactory elaboration as well as episodes of reduction in olfactory function. Monotremes show both trends. The ancestor of living monotremes inherited a well-developed olfactory system designed for receiving airborne odorant molecules, and it evolved a unique electroreception system arrayed over its snout. Skeletal and behavioral evidence indicates that it was a terrestrial scratch-digger. The platypus clade subsequently became aquatic, and the fossil record indicates a trend toward progressive reduction of its olfactory functionality, while its electroreception system elaborated enormously. In contrast, the echidna clade maintained a comparatively insensitive electroreceptive system but further elaborated its olfactory system, as is revealed by increased complexity of its ethmoid skeleton. Our results predict that echidnas may have among the largest functional olfactory genomes in living mammals. Additionally, our data reject recent allegations that Monotremata was aquatic ancestrally and that echidnas are secondarily terrestrial.

P-110
AGE AND SEX VARIATION IN BODY MEASUREMENTS IN *WIEDOMYS PYRRHORHINOS* (RODENTIA, SIGMODOONTINAE) FROM NORTHEASTERN BRAZIL
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Age determination is an essential step in morphological studies, since ontogenetic variation can mislead interpretation of patterns and differences among groups of distinct ages. For wild animals, age estimation is generally assessed by the observation of age related characters, such as molar wear. This study focuses on the relative age estimation of a single rodent population, and on the analysis of variation in body measurements among samples separated by age and sex classes. The specimens comprised skulls of 1048 females and 901 males of *Wiedomys pyrrhorhinos*, collected between 1951 and 1955 by the National Plague Service in Caruaru, Pernambuco, Brazil. Standard body measurements were recovered from original voucher cards. Specimens were sorted into six age classes determined on the basis of molar wear and eruption. Monthly frequency distributions revealed an age structured population, with subsequent peaks of occurrence for consecutive age classes, being separated by 1 to 2 months from each other. Life span was estimated around one and a half year, since specimens of younger classes (1 and 2) were captured only in the second semester of each year (July – December) and individuals of the eldest class (6) were recorded from January to October. One-way ANOVAs for all body measurements and weight revealed highly significant differences among means of age classes (p<0.001), whereas Student’s t-test detected significant differences (p<0.01) between males and females for the total sample (all ages pooled), indicating secondary sexual dimorphism. However, when analyzed by age class, secondary sexual dimorphism was significant only for age classes 3 to 5. Reaching senescence, males and females presented similar means for body measurements, although males were heavier. Secondary sexual dimorphism coincided with puberty (class 3 on) and might be related to differences between sexes in energy allocation toward reproduction over growth.

P-111
ANALYTICAL AND MODELING APPROACHES FOR THE DIGITAL RESTORATION OF DINOSAUR HEAD FUNCTIONAL ANATOMY WITHIN THE VISIBLE INTERACTIVE DINOSAUR PROJECT
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The Visible Interactive Dinosaur (VID) project restores dinosaur head anatomy by reconstructing soft-tissue systems within a 3D digital environment, allowing functional hypotheses to be tested by running virtual simulations. CT scanning brings the anatomy into the digital realm where 3D analytical and modeling software allows restoration of dinosaur skulls. The goal is to restore each skull to the form actually used by the living animal so that artifacts of fossilization do not compromise subsequent analyses. Plastic and brittle deformation is corrected, and missing elements are constructed or mirrored using modeling software, all in a hypothesis-driven, specimen-oriented manner. Hypotheses regarding dinosaur soft tissues (e.g., jaw, ocular, and neck muscles; brain and sense organs; airways and sinuses; vasculature) are tested by reference to extant sister groups (birds, crocodilians, squamates), drawing on the osteological correlates (OCs) of soft tissues (e.g., muscle scars, neurovascular grooves) that can be surveyed in the fossils. The restored dinosaur skulls are then “fleshed out” in a testable manner based on objective criteria, such as OCs, phyllogenetics, and packing constraints. Packing constraints—getting the soft tissues to fit and function within the confined space of the head—emerge as a key test of restored anatomy. For example, each jaw muscle, as well as adjacent structures such as the middle ear and orbital contents, all must fit and so provide reciprocal tests for size and conformation. Initial dinosaur study taxa—sauropod *Diplodocus*, theropods *Majungasaurus* and *Allosaurus*, pachycephalosaur *Stegoceras*—show the utility of VID restorations to test higher-order functional hypotheses pertaining to thermal physiology, nasal airflow, and feeding biomechanics. For example: (1) VID revisions of jaw muscles in *Diplodocus* indicate bite force was only 25% that of previous estimates; (2) restored airflow and vascular patterns reveal potential brain-cooling mechanisms in sauropods; and (3) restored cervicocephalic anatomy in *Allosaurus* reveals novel feeding behaviors.

P-112
GEOMETRIC MORPHOMETRIC ANALYSIS OF THE BREAST-SHOULDER APPARATUS OF LIZARDS: A TEST CASE USING JAMAICAN ANOLES (SQUAMATA: DACTYLOIDAE)
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The breast-shoulder apparatus (BSA) is a structurally and kinematically complex region of lizards that consists of a sector of the vertebral column and associated sternal ribs, sternum, scapulocoracoid, interclavicle and clavicle. Compared to the pelvic region, the BSA has received scant attention from a functional perspective although its morphological variation is extensive. The complex nature of the BSA has been difficult to explore as a composite entity. Here we apply geometric morphometric techniques to the analysis of the BSA to determine the efficacy of such an approach, and to attempt to more fully understand...
its configuration in relation to function. We explore this by investigating the Jamaican radiation of anoline lizards (genus Norops) as a tractable, small monophyletic assemblage represented by distinctive ecomorphs. We hypothesized that the different species (and, thus, ecomorphs) would exhibit differences in the configuration of the BSA and that these would be associable with behavioral and kinematic differences (yet to be investigated). The alternate hypothesis is that in this radiation the structure of the BSA will be conservative and will not differ appreciably between species (and ecomorphs). Our findings indicate that there are consistent differences in the configuration of the component parts of the BSA (subdivided into the vertebral column; clavicle; sternum-interclavicle moiety; and scapulocoracoid) between these species. Each component shows distinctive patterns. The differences that are evident are generally subtle, except in the case of Norops valencienni. This species is highly divergent in the configuration of its BSA. Such differences are consistent with behavioural differences that characterize that species. The outcomes of this study are promising as an approach that will more readily allow the association of the morphology of the BSA with ecological specialization. We are encouraged that this approach will enable us to further our understanding of the adaptive responses of the BSA.

P-113
IS THE ABBREVIATED SPINAL CORD A COMMON FEATURE IN TETRAODONTIFORM FISHES?
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It has been well known that the spinal cord (SC) in the sunfish (Molidae) is very short and exclusively located within the skull. Our previous study (1986) shows that in two species of the families Monacanthidae and Tetraodontidae, the SC is greatly reduced in length and located within a few rostral vertebrae. In this study we aimed to observe comprehensively the SC in the Tetraodontiformes and elucidated the spatial relationship of the SC proper to the vertebral column. 19 species of seven families except for Triacanthidae and Triodontidae were used in this study. According to Yamanoue et al. (2008), the order Tetraodontiformes consists of nine families. The tetraodontiform fishes were divided into four groups in the spatial relationship of the SP proper to the vertebral column; (A) Tetraodontidae and Diodontidae, (B) Monacanthidae and Balistidae, (C) Molidae and Ostraciidae; and (D) Triacanthoidae. In group A, the SC flattens suddenly within the first vertebra and transform to the flattened filum terminale (FT). The dorsal and ventral root bundles were located dorsally and ventrally to the FT, respectively. The root bundles decrease caudally in number. In the last vertebra with the vertebral foramen, the FT was cylindrical. In group B, the SC decreases in thickness caudally and then flattens. The dorsal and ventral root bundles surround the SC. The change from the SC to the FT is gradual. In group C, the SC changes drastically to the thin FT within the cranium or the first vertebra. The FT is cylindrical throughout its entire length. A large number of dorsal and ventral root bundles surrounded the FT. In group D, the SC is cylindrical throughout the entire length. Actually, the SC is not abbreviated in this group. Thus, the SC was abbreviated in six out of seven families of the Tetraodontiformes.

P-114
RESEGMENTATION DURING DEVELOPMENT OF THE VERTEBRAL COLUMN
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The vertebral column is the defining feature of the clade to which we belong. It is crucial for support and locomotion, and has long been the focus of developmental, functional, evolutionary, and phylogenetic studies. Nonetheless, many basic features of vertebral development and homology remain contested. To move the spine, a single muscle must attach to two successive vertebrae thereby positioning these structures half a segment out of phase with one another. However, upon formation in the embryo, the compartments of the somite from which these structures derive, the dermomyotome and sclerotome, sit within the same segment. Therefore, there must be some process whereby the sclerotome is re-positioned with respect to the dermomyotome during development. In 1855, Remak proposed the theory of “resegmentation” in which the anterior and posterior half-sclerotomes dissociate with one another and re-join with those of the neighbouring somite. This theory has been supported by quail-chick grafting experiments. However, this approach can give ambiguous results, as it requires somite orientation to be controlled very precisely during grafting. Thus, some controversy remains concerning the contribution of a single sclerotome to the vertebral column. Using the fluorescent dyes DiI and DiO, we have developed an in ovo method for tracing cells of a single somite (or the equivalent somite on each side of the embryo) into the vertebral column in the chicken. In the cervical region, we find that a single somite gives rise to the annulus fibrosus of the intervertebral disc and a proportion of the centrum on either side, thus providing new evidence for Remak’s resegmentation. We also use Optical Projection Tomography to visualise the three-dimensional morphology of the migrating sclerotome in labelled embryos.
P-115
ENDOCRANIAL MORPHOLOGY OF GAVIALIS GANGETICUS USING CT SCANS: BRAIN, INNER EAR, AND PNEUMATICITY
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The skull of an adult specimen of Gavialis gangeticus was CT scanned and 3D models of the brain, inner ear, and pneumatic cavities were made. The cranial endocast is sub-horizontal, with cephalic and pontine flexures poorly marked, and a midbrain relatively more elongated than in Caiman and Crocodylus. The cerebral hemispheres are laterally rounded and the dorsal surface shows small vascular impressions indicating the presence of thin dorsal venous sinuses. There are small orbitocerebral and dorsal head veins. Behind the dorsum sellae, a small passage for the basilar artery communicates with the posterior section of the pituitary fossa. Cranial Nerve (CN) XII has a single root on the endocast but two external openings lateral to the occipital condyle. Another two foraminal lateral to the occipital condyle correspond to the metotic foramen and the internal carotid artery. A branch from the metotic passage, the two branches of CN VII and the CN V2 have connection with the middle ear cavity. In the inner ear the angle formed between the anterior and posterior semicircular canals is approximately 90° and the lagena is extremely short. The anterior semicircular canal is larger than the posterior, which is similar in size to the lateral canal. The paratympanic system has three interconnected regions: the dorsal intartympanic recess (affecting the supraoccipital and the parietal), the lateral cavum tympanicum proper (connected through the siphonium with the foramen aereum posteriorly) and the ventral pharyngotympanic system (median and lateral Eustachian tubes). Compared with Alligator, the intartympanic recess is larger and more anteriorly developed, the siphonion is straight and shorter and the pharyngotympanic system is posteroventrally projected.

P-116
EVOLUTION OF REGULATORY MECHANISMS IN HYPAXIAL MUSCLE DEVELOPMENT
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Trunk skeletal muscles of the jawed vertebrates are categorized into epaxial and hypaxial groups, according primarily to the pattern of motor innervation (dorsal vs. ventral rami of spinal nerves). During development, the hypaxial muscles undergo two distinct modes of differentiation as they emerge from the embryonic somites. One is the direct ventral extension of the somitic muscle plate. The other is the particularly elaborate developmental pathway that involves the delamination and extensive distal migration of mesenchymal myoblasts. These precursor myoblasts give rise to the limb-associated muscles, the diaphragm and the tongue muscles. In this study, we compared the morphology and molecular characteristics of the hypaxial muscles between vertebrate species. In the cyclostome lamprey, which lacks paired fins, the hypobranchial muscle emerges as a stream of myoblasts originated from the anterior somites. The hypobranchial myoblasts express Pax3/7 and Lbx genes as they migrate ventrally into the pharyngeal region. This migration pathway and gene expression pattern are similar to that found in the tongue muscles of the jawed vertebrates. A similar behavior of myoblasts was observed in the teleost medaka, in which the anterior somites give rise to the pectoral fin muscles and so-called posterior hypaxial muscles. In the amphibian Xenopus embryos, Pax3- and Lbx-positive myoblasts give rise to so-called rectus abdominus that ventrally covers the yolk sac and anteriorly connects to the cervical region. We speculate that this muscle is not the developmental homologue of the amniote rectus abdominus, which develops as the direct ventral extension of the somitic muscle plate. These insights suggest that the migratory mode of myogenesis was established in the early jawless ancestor of vertebrates, and contributed to the evolution of complex muscle morphology by being recruited in multiple distal parts of the body.

Reproductive Biology
P-117
ULTRASTRUCTURE OF THE PLACENTAL MEMBRANES IN VIVIPAROUS WATER SNAKES (COLUMBIDAE: NE Rodia)
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In viviparous snakes, pregnant females maintain their developing embryos by means of placentas that transfer nutrients and respiratory gases. Morphological specializations for placental function are subtle and best studied by means of electron microscopy (EM). However, ultrastructural techniques have seldom been
anastomosis is from the right into the left aorta. With the occurrence of bypass, not by its extent. Without pulmonary bypass, flow through the Foramen Panizzae and the aortic anastomosis is determined by the existence of pulmonary bypass. Fill level and perfusion of the digestive tract increases with increasing pulmonary bypass, whereas fill level and perfusion of the lung and the anterior and posterior body decrease. Flow direction through the Foramen Panizzae and the aortic anastomosis is determined by the existence of pulmonary bypass, not by its extent. Without pulmonary bypass, flow through the Foramen Panizzae and the aortic anastomosis is from the right into the left aorta. With the occurrence of pulmonary bypass, flow direction is inverted. The extent of pulmonary bypass has a quantitative impact on blood flow through these structures.

P-118
EMBRYONIC DEVELOPMENT OF GOLDFISH (CARASSIUS AURATUS): A MODEL FOR THE STUDY OF MORPHOLOGICAL EVOLUTION BY ARTIFICIAL SELECTION
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Recent studies in morphologically divergent domesticated vertebrates (e.g., dogs and pigeons) contribute to our understanding of how genomes and genes have been selected by breeders and fanciers. This research prompted us to ask how developmental mechanisms have evolved under the artificial selection for morphological characters. To address this question, we sought a model domesticated organism that is suitable for embryological observations. The ornamental domesticated goldfish (Carassius auratus), is ideal because of its morphological variation among different strains and phylogenetic closeness with zebrafish; thus the well-established zebrafish molecular techniques should apply to the investigation of developmental process of the goldfish morphological varieties. To establish goldfish as the model organism, we describe the embryological development of the Wakin strain which represents the ancestral morphology of goldfish. We succeeded in categorizing the fertilized eggs, embryos, and larvae of goldfish into seven periods containing 34 stages, applying previously reported staging indices of this species and zebrafish. Although several differences between these two teleost species were found in their yolk size, process of epiboly, pigmentation patterns, and developmental rate, the early to late embryonic features of goldfish are directly comparable with those of zebrafish. Moreover, we conducted embryological comparison between several zebrafish mutants and bifurcated caudal fin goldfish strains whose caudal skeletons are largely diverged from the Wakin strain. The dorsoventral patterning in the early developmental stages has been evolutionarily modified in the lineage of the bifurcated caudal fin goldfish strains and conclude that an early developmental mechanism has been modified through the selection of the adult morphology in the lineage of the goldfish.

Respiration
P-119
MODELING OF BLOOD VOLUME SHIFTS DURING PULMONARY BYPASS IN CROCODILES
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The anatomy of the crocodilian heart and its outflow tract allows blood volumes to bypass the pulmonary circulation. The right ventricle can redirect blood volumes into the systemic circulation via the left aorta. Tissue nodes at the basis of the pulmonary artery allow quantitative regulation of pulmonary bypass. Because they emerge from different ventricles, both aortae receive blood with different blood gas compositions. Blood exchange between the left and right aorta is, possible through the Foramen Panizzae and the aortic anastomosis. Based on the vascular arrangement of the cardiac outflow tract, four areas of the crocodilian body are distinguished that receive blood with different blood gas compositions: The capillary beds of the lung, the digestive tract, the anterior body and posterior body. We developed a computational multi-compartment model for the simulation of blood volume shifts caused by pulmonary bypass. It calculates fill levels and input/output flows (representing blood perfusion) of these capillary beds as a function of pulmonary bypass. Additionally, the effect of varying opening of the Foramen Panizzae and the aortic anastomosis was tested. Results from the simulation show that pulmonary bypass has a much larger impact on the perfusion of the capillary beds than flow through the Foramen Panizzae and the aortic anastomosis. Fill level and perfusion of the digestive tract increases with increasing pulmonary bypass, whereas fill level and perfusion of the lung and the anterior and posterior body decrease. Flow direction through the Foramen Panizzae and the aortic anastomosis is determined by the existence of pulmonary bypass, not by its extent. Without pulmonary bypass, flow through the Foramen Panizzae and the aortic anastomosis is from the right into the left aorta. With the occurrence of pulmonary bypass, flow direction is inverted. The extent of pulmonary bypass has a quantitative impact on blood flow through these structures.
P-120
DETAILED MORPHOLOGY OF PULMONARY BYPASS RELATED STRUCTURES IN THE CROCODILIAN HEART AND OUTFLOW TRACT
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The anatomy of the heart and outflow tract of crocodiles plays an important role for blood supply, oxygen delivery and carbon dioxide disposal to and from different supply areas/organ systems of the crocodilian body. Two structures at the root of the outflow vessels are especially important in the context of pulmonary bypass: the ‘cog-teethed valves’ and the Foramen Panizzae. The ‘cog-teethed valves’ are tissue nodules at the basis of the pulmonary artery. It has repeatedly been described that these tissue nodules can be pressed together, thus increasing pulmonary vascular resistance and regulating pulmonary bypass quantitatively. The Foramen Panizzae, a window-like opening between the adjacent aortae at their roots, allows exchange of blood between the aortae, both emerging from different ventricles. The Foramen Panizzae is overlapped by the aortic valves. The degree to which the aortic valves obstruct blood flow through the Foramen Panizzae depends on their length and position. We used virtual 3D reconstructions from histological serial sections and magnetic resonance imaging (MRI) of the crocodile heart to examine and illustrate the detailed morphology of the ‘cog-teethed valves’, the Foramen Panizzae, and related structures. We use alcohol-stored hearts of Crocodylus porosus and C. niloticus. Results of the 3D reconstruction show that the cranial part of the myocardium surrounding the pulmonary artery is arranged as a constrictor-like muscle. Shape, position and orientation of the fibers suggest that it functions as a compressor muscle for the ‘cog-teethed valves’. Based on MRI scans and histological slides we demonstrate that the flaps of the aortic valves must overlap the Foramen Panizzae during systole. This makes blood flow through the Foramen Panizzae very improbable during ventricular systole. The Foramen Panizzae is surrounded by a multipart cartilage clasp, apparently stabilizing the aortic vascular wall close to the Foramen Panizzae.

P-121 [Affiliated with Symposium 10 – Next Steps: Dynamic Simulations in Paleobiology]
A COMPUTATIONAL FLUID DYNAMICS (CFD) MODEL FOR ESTIMATING HEAT EXCHANGE IN THE TRACHEA OF LONG-NECKED ANIMALS
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Sauropod dinosaurs are equally well known for their gigantic body size and extremely long necks. Much controversy exists regarding the metabolic rate of sauropods. The gigantothermy hypothesis holds that animals exceeding 10 tons cannot have had a high metabolic rate because the heat produced could not be adequately dissipated. We applied finite element analyses to create two computational fluid dynamics models for estimating the evaporative cooling and heat export in the trachea based upon available respiratory physiological and histological data for the domestic fowl (Gallus domesticus) and compared the results of our models with published experimental data for this species and the free-living chukar (Alectoris chukar). Our two-dimensional (2D) model consists of a straight trachea and a single air sac, which changes area by oscillation of a moving terminal wall. The more realistic three-dimensional (3D) model has an S-shaped trachea, two bronchi and two air sacs that change volume by lateral expansion, and is calculated in 3D space. Both models yield realistic data that show significant evaporative cooling during inspiration and heat export during expiration but the 3D model produces more plausible pressure values during the respiratory cycle. However, the 2D model remains attractive because it easily can be modified to apply to dinosaurs of different neck length and body mass.

P-122
EXPERIMENTAL EMBRYOLOGY IN SENEGAL BICHIR PROVIDES INSIGHTS INTO A POSSIBILITY THAT EXTERNAL GILLS MIGHT CONTRIBUTE TO EVOLUTION OF THE BRANCHIAL SKELETON IN VERTEBRATES
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The respiratory organ has undergone substantial modification through vertebrate evolution; fish use gills for respiration, whereas terrestrial vertebrates use lungs. Osteichthyes (bony fishes) is divided into two groups: Sarcopterygii (lobe-finned fishes and tetrapods) and Actinopterygii (ray-finned fishes). Bony fishes have the swim bladder, but it is found as the lung not only in the lungfish of lobe-finned fishes and in tetrapods, but also in some ancestral lineages of ray-finned fishes. Evolutionary modification of the respiratory organ in tetrapods has been accompanied by modification of the hyobranchial skeleton including reduction in the...
number of pharyngeal arches and origin of the larynx, while the number of seven pharyngeal arches (a mandibular, a hyoid, and five branchial arches), has been highly conserved in Teleostei of ray-finned fishes. External gills, which protrude from outside of the pharyngeal region, are encountered in the development of lungfish and amphibians. These three facts could lead us to hypothesize that external gills might play an important role in remodeling development of the pharyngeal skeleton during evolution of the vertebrate respiratory organs. Bichirs are phylogenetically positioned as the earliest diverging lineage of ray-finned fishes. They have several unique characteristics that provide the only opportunity to investigate this hypothesis since they possess a pair of primitive lungs, a pair of external gills in young, four branchial arches, and capability to spawn in the lab. We will present some results of experimental embryology on the external gills in Senegal bichir, *Polypterus senegalus*, which show that a small area of the surface ectoderm regulates not only development of the external gills but also formation of branchial skeleton via pouching of the pharyngeal endoderm.