Syllabus

ANTH 595: Biomechanics

THE UNIVERSITY OF TENNESSEE – FALL 2020

Course Information

Instructor: Dr. Benjamin M. Auerbach
Office: 416 Strong Hall (Dr. Auerbach will not be available at his office)
Office Hours: Dr. Auerbach is available for individual meetings with limited availability. Individual meetings may be requested via e-mail.
E-mail: auerbach@utk.edu
(Dr. Auerbach typically responds within 24 hours of receiving an e-mail. More urgent matters should be marked as URGENT in the e-mail subject line.)
Course website: Canvas page (utk.instructure.com)

Course Meeting Details

All course meetings will take place exclusively online via Zoom video conferencing. Our course meetings will occur synchronously throughout the semester. Please note that all course meetings will be recorded for those who cannot attend (see the attendance policy section below). Details about course meeting structure may be found on the next page.

Meeting Times: Tuesdays and Thursdays, 8:10 A.M. – 9:25 A.M.
Zoom meeting address: https://tennessee.zoom.us/j/96550683967
The password for the Zoom session will be posted to Canvas.

About the course

Biomechanics is the study of functional morphology. Broadly, in biomechanical studies, we examine the movements and physical behaviors of organisms—from bacteria to trees to vertebrates—and attempt to understand the physical properties that allow them to engage in these behaviors. The literature in this subject is replete with examinations of the material properties of solid materials (e.g., the stiffness of wood, or the strength of bone), both statically or dynamically, as well as the movement of liquids through organisms or of organisms through liquids (including air).

This course, a graduate lecture-based seminar, focuses on the basic concepts of biomechanics and relates them to studies of vertebrates, especially humans. We start the course with a review of basic evolutionary principles and bone biology. Three topics are the focus for the remainder of the course: scaling relationships (allometry) & basic mechanics; statics and bone; and kinematic and energetic studies. You, as a participant in the course, are asked to relate this information to

the areas of research that interest you, and to bring this into the weekly discussions of the seminar. Though this is not an engineering course, some engineering principles are introduced throughout the semester.

Course objectives

By the end of this course, you will:

- develop a firm comprehension of the general areas noted in the course description, especially bone biology, scaling, and basic mechanics;
- appreciate the relationship of these topics to current biological anthropology research, including knowledge of consensus and debate within the field;
- explore the application of theory to practical questions and your own research.

Prerequisite

All students enrolled must have a good understanding of osteology and basic bone biology. Additional backgrounds in evolutionary biology, human and/or comparative anatomy, and some basic math knowledge (basic calculus and geometry) are beneficial but not mandatory.

Course structure

The course is a mixture of lectures and seminar discussions. On Tuesdays, I will present an informal lecture; your thoughts, questions, and input are welcome at any point during class meetings. On Thursdays, we will have a discussion of questions that you submit about the current week's course readings (that is, the subject of the lecture). These questions should be submitted no later than Monday at 8:00, and I will post your questions on Canvas. Each student is expected to submit two questions each week (except the first week), and other students are encouraged to prepare answers to their peers' questions before class.

As about half of the readings for the course are not from peer-reviewed papers, and instead come from edited volumes and textbooks, it is up to you to introduce original research papers to the class. That is, you, as participants, are expected to regularly seek additional publications that are of interest and are relevant to current or past weeks. You must submit to me citations of original research papers relevant to the that week's topic no later than Wednesday at 5:00 so that they may be posted on the course web site. Two or three papers will be added each week to the list of readings to be discussed on the subsequent week (either Tuesday or Thursday). **You must provide a paper to the course a minimum of two times during the semester.**

Finally, **a note about Zoom etiquette**: Since we will be meeting exclusively online this semester, please abide by the following rules:

1) When you log in, please mute your microphone unless you are speaking;
2) Only one person may speak at a time;

3) Dr. Auerbach will moderate all conversations. To help, please click on the hand raise button under the Participants option at the bottom of the Zoom window; you will be called on in order by Dr. Auerbach;
4) Be respectful of all other participants in the course.

For each class meeting

- **You should have read the assigned readings for that week.**
- **You should submit at least two questions that you have about those readings to me on the Monday before class.**
- **In addition, you should be prepared to discuss the additional peer-reviewed papers added the previous week by your peers and you.**

Required texts (Citations for all readings may be found on pages 6–8.)

You should obtain a copy of Vogel's Comparative Biomechanics (available at the University Book Store). There is a wealth of information in Vogel that we will only touch on in this course; for example, I have elected to not include fluid mechanics and dynamics in the course, though the first half of Vogel's textbook covers these topics. Other books are required as well (Martin et al. 2015 and Burr & Allen 2014), but copies of chapters will be provided instead of requiring you to purchase them. Reading beyond the assigned papers is encouraged. All course readings (including Vogel) will be provided weekly as PDFs via Canvas.

In prior years, I have assigned readings from Currey's Bones book (from which I provide select chapters on Canvas), as well as Carter and Beaupré's Skeletal Function and Form. Though more recent sources are now used in the course, these books are still valuable resources and worth picking up if you can find copies. There still is no single volume as well-written and thorough as Currey's work. See the "Course Readings" at the end of the syllabus for the full citations for these and all course readings.

Term paper / term project

In addition to weekly participation in course discussions, as well as providing some additional course readings, you are expected to complete a paper based on literature research. I normally encourage original research projects as well, but this semester this option is only available if you already have data; no novel data collection during the semester will be eligible for a term paper. **Term papers will be due on 7 December**. (However, you are encouraged to submit them at any time prior to this date.) You must choose whether you will complete a literature-based study or conduct and write up a functional anatomy research project. See below for details of each. Also see the "How to Write a Good Term Paper" supplementary document, which may be downloaded on Canvas.

There are three deadlines to know:

1) E-mail Dr. Auerbach with your decision to pursue a literature review or original research project no later than 10 September. You will be scheduled to meet with me after this date to discuss the details of your term paper.
2) Provide a formal proposal (no more than 400 words) detailing your research to me by 8 October via e-mail.
3) Term papers are due on 7 December via e-mail to me. They must be submitted in a MS Word (*.docx) file.

Literature-based term paper

If you choose to perform a literature-based term paper, it should be an argumentative discussion of a biomechanical topic that is of relevance to biological anthropology, functional anatomy, and/or bone biology. As an argumentative paper, you should establish a position and provide thorough evidence both to support at to argue against that position. Good arguments consider their detractions but are able to provide counterevidence to those differing opinions.

This term paper option should be no shorter than 15 pages (double-spaced, 12 point font), and should not exceed 30 pages, excluding the bibliography.

Original research project

If you choose to conduct an original research project, you will need to devise a hypothesis that may be tested using sources of available data. Data that you have previously acquired are eligible, but to use them you should have not utilized them previously to formally analyze your stated hypothesis. (In other words, if you have a publication, a thesis, or a term paper from another course, you **cannot** recycle it for the term paper in this course.) Be aware that the university IRB and human subjects committees must first approve any research that has involved living subjects.

Your research project should be an original research question or may be a reanalysis of a published question. In either case, you will need to justify the hypothesis you are testing via a review of salient literature (as you would do in a peer-reviewed paper). It is not expected that the literature review will be as in depth as in the literature-based term paper, but it must be sufficient to support your research goals. Likewise, the data and analyses should sufficiently address the hypothesis, but need not be extensive or more sophisticated than necessary. In short, set realistic goals for a project that may be completed within the confines of a semester. You will always have future opportunities to revisit your research question and expand it as necessary.

Term papers on original research should be no shorter than 15 pages and no longer than 30 pages (double-spaced, 12 point font), which are the general length requirements for many journals' original research papers (e.g., American Journal of Physical Anthropology, Anatomical Record,

Bone, etc.). This does not include tables, figures, and the bibliography, all of which should be included separately at the end of the paper, but which should be properly cited in the main text.

Proposal Guidelines

Your proposal should be no more than 400 words. In it, you must establish the problem that your term paper will address. For literature-based papers, you should make your argumentative position in the proposal, which in turn justifies the paper. An example thesis statement would be: "Wolff's Law, as originally defined, does not reflect current knowledge of the processes by which bones maintain their shape in response to mechanical loading." For original research projects, you must state the hypothesis you will be testing. A plan for how you will complete the research (either based on the literature or a research project) must be explicitly discussed as well in the proposal. (In the case of the original research, you should cite the sample you will be using and the methods you will be employing.)

Evaluation

Seminar Questions, Additional Papers, and Class Participation (40% of the final grade)

Class attendance, additional paper contributions, submitted seminar questions and active participation in seminar discussions are 40% of the grade for the course. You must submit at least one question concerning the week's readings on the Monday prior to the class meeting (except for the first week). Do not forget that you are responsible as well for finding a minimum of two supplementary peer-reviewed papers, which, for a given topic, you will submit no later than the day after that topic is lectured about in class (i.e. each Wednesday).

While I realize that some students do not like to speak in class, given the small enrollment and discussion-based nature of this course, you should make every effort to verbally contribute to course discussions. The more participation you engage in during the class, the more you will get out of the course! I will give feedback throughout the semester concerning your participation and am available to discuss questions or concerns that you have.

Term Paper (60% of the final grade)

The term paper, as outlined above, along with its proposal, comprises 60% of the grade for the course. Term papers are graded using the point system explained in the "How to Write a Good Term Paper" supplementary document, which may be downloaded from Canvas. I am available to discuss questions that you have about writing approaches, argumentation, and analytical concerns. While I do not have time to read full drafts of papers prior to their submission, you are welcome to send portions (i.e., a section) of your paper to me for feedback before the submission deadline, which is 10 December. LATE TERM PAPERS WILL NOT BE ACCEPTED, BARRING EXTREME CIRCUMSTANCES. (See the excused absence policy, especially in light of COVID-19 infection, below.)

Tips for getting the most out of the course

As a crucial part of this course is keeping up with the reading before class meetings, you need to give ample time to reflect on the perspectives presented in the chapters and papers you read. On average, you are expected to read between 50 and 100 pages a week in assigned chapters and articles. You are strongly encouraged to read broadly, looking into additional sources to help you better develop an understanding of the topics covered. An excellent place to start is always in the references cited within the assigned readings. I am also available by e-mail to point you toward additional resources as specific questions arise. However, you should use this course as an opportunity to develop skills at independently locating and reading relevant sources to supplement those that are assigned.

Students with technological needs

If you do not have access to a stable internet connection, or lack the computing resources necessary to access the materials for this course, you may contact the Office of Information Technology (http://oit.utk.edu) to request a personal hotspot or a loaner laptop for use during the semester. Due to high demand, please contact them well in advance of the semester.

Students with special needs

If you require accommodation because of special needs in learning, please contact the Office of Disability Services at 2227 Dunford Hall (974-6087). Please also contact me immediately via e-mail after you register with the Office of Disability Services. Arrangements will be made to adjust the course to fit your needs.

Make-up policy

If you become sick (with the novel coronavirus, flu, or any other cause), with notice, you will be accommodated. Understandably, if you are sick, I do not expect you to attend lectures, even virtually, though you will need to make up any work missed. Legitimate athletic, religious, legal or medical reasons all qualify for eligibility to make up assignments or request extensions on course deadlines. If you must miss a lecture, or cannot turn in any materials required over the semester, you must contact Dr. Auerbach ***before*** the lecture or deadline.

Course Readings

Books required in the course

Burr DB, & Allen MR (editors). 2019. *Basic and applied bone biology*. Second edition. New York: Academic Press.

Martin RB, Burr DB, Sharkey NA, & Fyhrie DP. 2015. *Skeletal tissue mechanics*. Second edition. New York: Springer.

Vogel S. 2013. *Comparative biomechanics: life's physical world*. Second edition. Princeton: Princeton University Press.

Books provided as additional resources

Carter DR, & Beaupré GS. 2001. *Skeletal function and form: mechanobiology of skeletal development, aging, and regeneration*. Cambridge: Cambridge University Press.

Currey JD. 2002. *Bones: structure and mechanics*. Princeton: Princeton University Press.

McGowan C. 1999. *A practical guide to vertebrate mechanics*. Cambridge: Cambridge University Press.

Schmidt-Nielsen K. 1984. *Scaling: why is animal size so important?* Cambridge: Cambridge University Press.

Wall-Scheffler CM, Kurki HK, & Auerbach BM. 2020. *The Evolutionary Biology of the Human Pelvis*. Cambridge: Cambridge University Press.

Articles used in the course

Agosto ER, & Auerbach BM. 2020. Evolvability and constraint in the primate basicranium, shoulder, and hip and the importance of multi-trait evolution. *Evol Biol*. *In Press*.

Auerbach BM, Gooding AF, Shaw CN, & Sylvester AD. 2017. The relative position of the human fibula to the tibia influences cross-sectional properties of the tibia. *Am J Phys Anthropol* 163:148–157.

Auerbach BM, & Sylvester AD. 2011. Allometry and apparent paradoxes in human limb proportions: implications for scaling factors. *Am J Phys Anthropol* 114:382-391.

Biewener AA. 1989a. Scaling body support in mammals: limb posture and muscle mechanics. *Science* 245:45–48.

Biewener AA. 1989b. Mammalian terrestrial locomotion and size. *BioScience* 39:776–783.

Biewener AA. 1993. Safety factors in bone strength. *Calcif Tissue Int* 53:S68-S74.

Canington SL, Sylvester AD, Burgess ML, Junno J-A, & Ruff CB. 2018. Long bone diaphyseal shape follows different ontogenetic trajectories in captive and wild gorillas. *Am J Phys Anthropol* 167:366-376.

Cosman MN, Britz HM, & Rolian C. 2019. Selection for longer limbs in mice increases bone stiffness and brittleness, but does not alter bending strength. *J Exp Biol* 222:jeb203125.

Dawson RS, Warburton NM, Richards HL, & Milne N. 2015. Walking on five legs: investigating tail use during slow gait in kangaroos and wallabies. *Austral J Zool* 63:192-200.

Diogo R, Molnar JL, Rolian C, & Esteve-Altava B. 2018. First anatomical network analysis of fore- and hindlimb musculoskeletal modularity in bonobos, common chimpanzees, and humans. *Scientific Reports* 8:6885.

Eleazer CD, & Jankauskas R. 2016. Mechanical and metabolic interactions in cortical bone development. *Am J Phys Anthropol* 160:317–333.

Foster AD, Raichlen DA, & Pontzer H. 2013. Muscle force production during bent-knee, bent-hip walking in humans. *J Hum Evol* 65:294-302.

Garland T, Bennett AF, & Rezende EL. 2005. Phylogenetic approaches in comparative physiology. *J Exp Biol* 208:3015–3035.

Gutman AK, & Bertram JEA. 2017. Metabolic cost of human hopping. *J Exp Biol* 220:1654-1662.

Hallgrímsson B, Green RM, Katz DC, Fish JL, Bernier FP, Roseman CC, TOung NM, Cheverud JM, Marcucio RS. 2019. The developmental-genetics of canalization. *Sem Cell Dev Biol* 88:67-79

Hallgrímsson B, Katz DC, Aponte JD, Larson JR, Devine J, Gonzalez PN, Young NM, Roseman CC, Marcucio. 2019. Integration and the developmental genetics of allometry. *Integr Comp Biol* 59:1369-1381.

Harper BM, & Sylvester AD. 2018. Effective mechanical advantage allometry of felid elbow and knee extensors. *Anat Rec* 302:775-784.

Holowka NB, & O'Neill MC. 2013. Three-dimensional moment arms and architecture of chimpanzee (*Pan troglodytes*) leg musculature. *J Anat* 223:610–628.

Kipp S, Grabowski AM, & Kram R. 2018. What determines the metabolic cost of human running across a wide range of velocities. *J Exp Biol* 221:jeb184218.

Klingenberg CP. 2008. Morphological integration and developmental modularity. *Annu Rev Ecol Evol Syst* 39:115–132

Kramer PA. 2012. Brief Communication: Could Kadanuumuu (KSD-VP-1/1) and Lucy (AL 288-1) have walked together comfortably? *Am J Phys Anthropol* 149:616–621.

Kubicka AM, Nowaczewska W, Balzeau A, & Piontek J. 2018. Bilateral asymmetry of the humerus in Neandertals, Australian aborigines and medieval humans. *Am J Phys Anthropol* 167:46-60.

Macintosh AA, Davies TG, Ryan TM, Shaw CN, & Stock JT. 2013. Periosteal versus true cross-sectional geometry: a comparison along humeral, femoral, and tibial diaphyses. *Am J Phys Anthropol* 150:442–452.

Macintosh AA, & Stock JT. 2019. Intensive terrestrial or marine locomotor strategies are associated with inter- and intra-limb bone functional adaptation in living female athletes. *Am J Phys Anthropol* 168:566-581.

O'Neill MC. 2012. Gait-specific metabolic costs and preferred speeds in ring-tailed lemurs (*Lemur catta*), with implications for the scaling of locomotor costs. *Am J Phys Anthropol* 149:356–364.

O'Neill MC, Umberger BR, Holowka NB, Larson SG, & Reiser PJ. 2017. Chimpanzee super strength and human skeletal muscle evolution. *Proc Natl Acad Sci USA* 114:7343–7348.

Polk J. 2004. Influences of limb proportions and body size on locomotor kinematics in terrestrial primates and fossil hominins. *J Hum Evol* 47:237–252.

Püschel TA, & Sellers WI. 2016. Standing on the shoulders of apes: analyzing the form and function of the hominoid scapula using geometric morphometrics and finite element analysis. *Am J Phys Anthropol* 159:325–341.

Rolian C. 2020. Endochondral ossification and the evolution of limb proportions. *WIREs Dev Biol* 9:e373.

Ruff CB, & Hayes WC. 1983. Cross-sectional geometry of Pecos Pueblo femora and tibiae: a biomechanical investigation. I. Method and general patterns of variation. *Am J Phys Anthropol* 60:359–381.

Ruff CB. 2000. Body size, body shape, and long bone strength in modern humans. *J Hum Evol* 38:269–290.

Ruff CB. 2008. Biomechanical analyses of archaeological human remains. In (Katzenberg MA and Saunders SR, editors): Biological Anthropology of the Human Skeleton. John Wiley & Sons, Inc., New York, pp. 183–206.

Ruff CB. 2018. Functional morphology in the pages of the *AJPA*. *Am J Phys Anthropol* 165:688-704.

Ruff CB, Garofalo EM, & Holmes MA. 2013. Interpreting skeletal growth in the past from a functional and physiological perspective. *Am J Phys Anthropol* 150:29–37.

Russo CR, Lauretani F, Bandinelli S, Bartali B, Di Iorio A, Volpato S, Guralnik JM, Harris T, & Ferrucci L. 2003. Aging bone in men and women: beyond changes in bone mineral density. *Osteoporos Int* 14:531-538.

Stock JT, & Shaw CN. 2007. Which measures of diaphyseal robusticity are robust? A comparison of external methods of quantifying the strength of long bone diaphyses to cross-sectional geometric properties. *Am J Phys Anthropol* 134:412–423.

Sylvester AD, Mahfouz MR, & Kramer PA. 2011. The effective mechanical advantage of A.L. 129-1a for knee extension. *Anat Rec* 294:1486–1499.

Terhune CE, Sylvester AD, Scott JE, & Ravosa MJ. 2020. Internal architecture of the mandibular condyle of rabbits is related to dietary resistance during growth. *J Exp Biol* 223:jeb220988.

Yang H, Xu X, Bullock W, & Main RP. 2019. Adaptive changes in micromechanical environments of cancellous and cortical bone in response to in vivo loading disuse. *J Biomech* 89:85-94.

Course Schedule – Fall 2020: Biomechanics (ANTH 595)

Always read Vogel first (when assigned), and then the other readings. In other cases, read papers chronologically.
COMPLETE ALL READINGS BY TUESDAY OF EACH WEEK UNLESS SPECIFIED OTHERWISE.

DATE	TOPIC	MAIN READING	ADDITIONAL READINGS & IMPORTANT DEADLINES
20 August	Introduction to biomechanics	Vogel 2013: Chapter 1 Ruff 2018	
25 & 27 August	Material mechanics	Vogel 2013: Chapters 2, 3 & 15 Wallace 2019*	Currey 2002: Chapter 2
1 & 3 September	Bone, part one: Bone biology	Burr 2019* Bellido et al. 2019* Plotkin et al. 2019* Allen & Burr 2019*	Currey 2002: Chapter 1
8 & 10 September	Bone, part two: Basic bone mechanics	Vogel 2013: Chapters 16 & 17 Robling et al. 2019* Li et al. 2019*	Currey 2002: Chapters 2 & 3 McGowan 1999: Chapters 4-7
15 & 17 September	Bone, part three: beam theory	Vogel 2013: Chapters 18 & 19 Auerbach et al. 2017 Macintosh & Stock 2019	***Declare topic of term paper*** Kubicka et al. 2018
22 & 24 September	Multi-trait evolution and mechanics	Crosman et al. 2019 Klingenberg 2008 (skim) Agosto & Auerbach *in press*	Rolian 2020 Hallgrímsson et al. 2019 (SCDV) Wall-Sheffler, Kurki & Auerbach 2020: Boxes 5.2 & 5.3
29 September	Scaling and body size	Vogel 2013: Chapters 20 & 26 Biewener 1989a & 1989b	Currey 2002: Chapter 10 Auerbach and Sylvester 2011 Hallgrímsson et al. 2019 (ICB)
1 October	Safety factors and effective mechanical advantage	Biewener 1993 Polk 2004 Harper & Sylvester 2019	Foster et al. 2013 Gutman and Bertram 2017

DATE	TOPIC	MAIN READING	ADDITIONAL READINGS & DUE DATES
6 & 8 October	Calculating bone properties	Martin et al. 2015: Chapter 7 Ruff 2008 Macintosh et al. 2013	***Term paper proposals due*** Ruff and Hayes 1983 Yang et al. 2019
13 & 15 October	Ontogeny and bone mechanics	Weaver & Peacock 2019* Eleazer & Jankauskas 2016 Canington et al. 2018 Terhune et al. 2020	Ruff et al. 2013 Stock and Shaw 2007
20 & 22 October	Ageing and bone mechanics	Gallant and Weaver 2019* Phipps et al. 2019* Russo et al. 2003	Hernandez 2019*
27 & 29 October	Joint mechanics	Martin et al. 2015: Chapters 1 & 5 Sylvester & Terhune 2017	Currey 2002: Chapter 8 McGowan 1999: Chapter 8
3 & 5 November	The basics of muscle mechanics	Vogel 2013: Chapters 23 & 24 O'Neill et al. 2017 Bonetto and Bonewald 2019*	McGowan 1999: Chapter 9
10 & 12 November	Moving, mobility, and muscle	Vogel 2013: Chapter 25 Holowka & O'Neill 2013 Dawson et al. 2015	
17 & 19 November	Cost of transport and kinematics	O'Neill 2012 Kramer 2012 Kipp et al. 2018	Wall-Scheffler, Kurki & Auerbach 2020: Chapter 2
24 November	Future directions for biomechanics: Thinking about multiple traits together	Püschel & Sellers 2016 Diogo et al. 2018	Garland et al. 2005 Wall-Scheffler, Kurki & Auerbach 2020: Chapters 4 & 5
7 DEC	**TERM PAPERS DUE BY 8:00 P.M.**		

* Publications marked with an asterisk are from Burr and Allen (2019).