Biomechanics

ANTHROPOLOGY 595
THE UNIVERSITY OF TENNESSEE – FALL 2018

Course Information

Instructor: Dr. Benjamin M. Auerbach
Office: 416 Strong Hall
Office Hours: 12:30 – 1:30 P.M., Tuesdays and Thursdays, or by appointment
E-mail: auerbach@utk.edu

Class Time: Tuesdays, 5:00 – 6:30 P.M.; Thursdays, 5:00 – 6:00 P.M.
Class Location: 514 Strong Hall
Course Materials may be found on the Canvas page (**utk.instructure.com**)

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.

So, for each class meeting, you are expected to do the following:

1) **You should have read the assigned readings for that week.**
2) **You should submit at least two questions that you have about those readings to me on the Monday before class.**
3) **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 or an original project. **These will be due on 10 December, the week after the final course meeting**. (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 11 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 9 October via e-mail.
3) Term papers are due on 10 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 counter-evidence 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 the skeletal samples available on campus or other 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. Should you have access to kinematic research equipment (*i.e.* force plates, motion capture, and VO_2 measuring devices), these are also eligible. Be aware that the university IRB and human subjects committees must first approve any research that involves living subjects.

There are extensive skeletal collections available on campus for research. The Small Primate Osteological Collection, which I curate, consists of thousands of pedigreed tamarins and marmosets. Likewise, thousands of archaeological modern human skeletons are available via both the Department of Anthropology and the McClung Museum. The Bass Donated Skeletal Collection has hundreds of individuals whose deaths date to the latter 20th and early 21st centuries. I am available to discuss methods for accessing these collections with you.

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.

<u>Proposal Guidelines</u>

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.**

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 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 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.

Course Readings

Books required in the course

Burr DB, & Allen MR (editors). 2014. *Basic and applied bone biology*. 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.

Articles used in the course

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.

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.

Crosman MN, Sparrow LM, & Rolian C. 2016. Changes in shape and cross-sectional geometry in the tibia of mice selectively bred for increases in relative bone length. *J Anat* 228:940–951.

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.

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

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

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.

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.

Marchini M, & Rolian C. 2018. Artificial selection sheds light on developmental mechanisms of limb elongation. *Evolution* 72:825–837.

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. 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.

Rathkey JK, & Wall-Scheffler CM. 2017. People choose to run at their optimal speed. *Am J Phys Anthropol* 163:85–93.

Rolian C. 2009. Integration and evolvability in primate hands and feet. *Evol Biol* 36:100–117.

Rolian C, Lieberman DE, Hamill J, Scott JW, & Werbel W. Walking, running and the evolution of short toes in humans. *J Exp Biol* 212:713–721.

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. 2006. Gracilization of the modern human skeleton: the latent strength in our slender bones teaches lessons about human lives, current and past. *Am Sci* 94:508–514.

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

Ruff CB, Holt B, Trinkaus E. 2006. Who's afraid of the big bad Wolff? 'Wolff is law' and bone functional adaptation. *Am J Phys Anthropol* 129:484–498.

Savell KRR, Auerbach BM, & Roseman CC. 2016. Constraint, natural selection, and the evolution of human body form. *Proc Natl Acad Sci USA* 113:9492–9497.

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.

Sylvester AD, & Terhune CE. 2017. Trabecular mapping: Leveraging geometric morphometrics for analyses of trabecular structure. *Am J Phys Anthropol* 163:553–569.

Course Schedule – Fall 2018: Biomechanics (ANTH 595)

Always read Vogel first (when assigned), and then the other readings. In other cases, read papers chronologically.

DATE	TOPIC	MAIN READING	ADDITIONAL READINGS & DUE DATES
23 August	Introduction to biomechanics	Vogel 2013: Chapter 1 Ruff et al. 2006	
28 & 30 August	Multi-trait evolution and mechanics	Crosman et al. 2016 Klingenberg 2008 (skim) Savell et al. 2016	Rolian et al. 2009 Rolian 2009
4 & 6 September	Material mechanics	Vogel 2013: Chapters 2, 3 & 15	Currey 2002: Chapter 2
11 & 13 September	Bone, part one: Bone biology	Burr & Akkus 2014* Bellido et al. 2014* Allen & Burr 2014*	***Declare topic of term paper*** Currey 2002: Chapter 1
18 & 20 September	Bone, part two: Basic bone mechanics	Vogel 2013: Chapter 17 Robling et al. 2014* Li & Stocum 2014*	Currey 2002: Chapters 2 & 3 McGowan 1999: Chapters 4 & 5
25 & 27 September	Bone, part three: beam theory	Vogel 2013: Chapters 18 & 19 Auerbach et al. 2017	McGowan 1999: Chapters 6 & 7
2 October	Scaling and body size	Vogel 2013: Chapter 20 Biewener 1989a & 1989b	
9 & 11 October	Calculating bone properties	Allen & Krohn 2014* Martin et al. 2015: Chapter 7	***Term paper proposals due*** Ruff and Hayes 1983
16 & 18 October	Practicum: How to calculate bone cross-sectional properties	Ruff 2000 Ruff 2008	Stock and Shaw 2007 Macintosh *et al.* 2013
23 & 25 October	Ontogeny and bone mechanics	Weaver & Fuchs 2014* Eleazer & Jankauskas 2016 Marchini & Rolian 2018	Ruff et al. 2013

DATE	TOPIC	MAIN READING	ADDITIONAL READINGS & DUE DATES
30 October & 1 November	Joint mechanics	Martin et al. 2015: Chapters 1 & 5 Sylvester & Terhune 2017	Currey 2002: Chapter 8 McGowan 1999: Chapter 8
6 & 8 November	The basics of muscle mechanics	Vogel 2013: Chapters 23 & 24 O'Neill et al. 2017	McGowan 1999: Chapter 9
13 & 15 November	Moving, mobility, and muscle	Vogel 2013: Chapter 25 Holowka & O'Neill 2013	
20 November	Safety factors and effective mechanical advantage	Vogel 2013: Chapter 26 Polk 2004 Sylvester et al. 2011	Currey 2002: Chapter 10
27 & 29 November	Cost of transport and kinematics	O'Neill 2012 Kramer 2012 Rathkey & Wall-Scheffler 2017	
4 December	Future directions for biomechanics: Thinking about multiple traits together	Püschel & Sellers 2016 Diogo et al. 2018	Garland et al. 2005
10 DEC	**TERM PAPERS DUE BY 8:00 P.M.**		

* Publications marked with an asterisk are from Burr and Allen (2014).