

CAROLYN M. ENG

CURRICULUM VITAE

Yale University
 Mechanical Engineering & Materials Science
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ACADEMIC POSITIONS

Associate Research Scientist, Yale University, Venkadesan Lab	2019-present
Postdoctoral Research Associate, Yale University, Venkadesan Lab	2018-2019
Postdoctoral Research Fellow, Brown University, Roberts Lab	2015-2018
Postdoctoral Research Associate, Harvard University, Biewener Lab	2014-2015
Staff Research Associate II, University of California, San Diego, Lieber Lab	2005-2007

EDUCATION

Harvard University	
PhD, Human Evolutionary Biology & Organismic and Evolutionary Biology	2014
MA, Human Evolutionary Biology	2009
Advisors: Daniel E. Lieberman and Andrew A. Biewener	
Duke University	2005
BS (<i>Cum Laude</i>), Biological Anthropology and Anatomy (Minors: Biology and Psychology)	

GRANTS & FELLOWSHIPS

National Institute of Health, Ruth Kirchstein National Research Service Award (Eng, "Direct Determination of the role of aponeurosis in modulating muscle mechanics"; \$162,642)	2015-2018
Wenner-Gren Dissertation Fieldwork Grant (Eng & Lieberman, "Exploring the function of the human iliotibial band and the implications for human locomotor economy"; \$12,661)	2013-2014
Harvard University Dissertation Completion Fellowship	2013-2014
Alan and Barbara Washkowitz Graduate Student Dissertation Fellowship	2013-2014
Cora DuBois Fellowship	2013
Harvard University Graduate Student Council Conference Grant	2012
Harvard Graduate School of Arts and Sciences Merit Fellowship	2012
Harvard Chapman Fellowship	2009, 2011
National Science Foundation Harvard Biomechanics IGERT Fellowship	2007-2009
Duke University Howard Hughes Undergraduate Research Fellowship	2005
Duke University Undergraduate Research Support Travel Grant	2005
Sigma-Xi Grant-in-Aid of Research	2004
North Carolina Academy of Science Yarbrough Research Grant	2004
Duke University Undergraduate Research Support Grant	2004

PEER-REVIEWED PUBLICATIONS

Venkadesan M, Yawar A, **Eng CM**, Dias MA, Singh DK, Tommasini SM, Haims AH, Bandi MM, Mandre S. Stiffness of the human foot and the evolution of the transverse arch. *Nature* 2020, in press.

Eng CM, Konow N, Tijs C, Holt NC, Biewener AA. In vivo force-length and activation dynamics of two distal rat hindlimb muscles in relation to gait and grade. *Journal of Experimental Biology* 2019; 222: 1-13.

Roberts TJ, **Eng CM**, Sleboda DS, Holt NC, Brainerd E, Stover KS, Marsh RL, Azizi E. The multi-scale, three-dimensional nature of skeletal muscle contraction. *Physiology* 2019; 34(6): 402-408.

Eng CM, Azizi E, Roberts TJ. Structural determinants of muscle gearing during dynamic contractions. *Integrative and Comparative Biology* 2018; 52(2): 207-218.

Eng CM, Roberts TJ. Aponeurosis influences the relationship between muscle gearing and force. *Journal of Applied Physiology* 2018; 125: 513-519.

Eng CM, Arnold AS, Lieberman DE, Biewener AA. The capacity of the human iliotibial band to store elastic energy during running. *Journal of Biomechanics* 2015a; 48: 3341-3348.

Eng CM, Arnold AS, Biewener AA, Lieberman DE. The human iliotibial band is specialized for elastic energy storage compared with the chimp fascia lata. *Journal of Experimental Biology* 2015b; 218:2382-2393.

Eng CM, Pancheri FQ, Lieberman DE, Biewener AA, Dorfmann L. Directional differences in the biaxial material properties of fascia lata and the implications for fascia function. *Annals of Biomedical Engineering* 2014; 42(6): 1224-1237.

Pancheri FQ, **Eng CM**, Lieberman DE, Biewener AA, Dorfmann L. A constitutive description of the anisotropic response of the fascia lata. *Journal of the Mechanical Behavior of Biomedical Materials* 2014; 30: 306-323.

Mathewson MA, Kwan A, **Eng CM**, Lieber RL, Ward SR. Comparison of rotator cuff muscle architecture among humans and selected vertebrate species. *Journal of Experimental Biology* 2014; 217:261-273.

Eng CM, Lieberman DE, Zink KD, Peters MA. Bite force and occlusal stress production in hominin evolution. *American Journal of Physical Anthropology* 2013; 151: 544-557.

Ward SR, Sarver JJ, **Eng CM**, Kwan A, Wuergler-Hauri CC, Perry SM, Williams GR, Soslowsky LJ, Lieber RL. Plasticity of muscle architecture after supraspinatus tears. *Journal of Orthopaedic & Sports Physical Therapy* 2010; 40(11): 729-735.

Eng CM, Ward SR, Vinyard CJ, Taylor AB. The morphology of the masticatory apparatus facilitates muscle force production at wide jaw gapes in tree-gouging common marmosets (*Callithrix jacchus*). *Journal of Experimental Biology* 2009; 212: 4040-4055.

Taylor AB, **Eng CM**, Anapol F, Vinyard CJ. The functional correlates of jaw-muscle fiber architecture in tree-gouging and nongouging callitrichid monkeys. *American Journal of Physical Anthropology* 2009; 139(3): 353-367.

Ward S.R., **Eng CM**, Smallwood LR, Lieber RL. Are current measurements of lower extremity muscle architecture accurate? *Clinical Orthopaedics and Related Research* 2009; 467: 1074-1082.

Ward SR, Kim CW, **Eng CM**, Gottschalk LJ, Tomiya A, Garfin SR, Lieber RL. Architectural analysis and intraoperative measurements demonstrate the multifidus' unique design for lumbar spine stability. *Journal of Bone and Joint Surgery* 2009; 91: 176-185.

Eng CM, Smallwood LH, Rainiero MP, Lahey M, Ward SR, Lieber RL. Scaling of muscle architecture and fiber types in the rat hindlimb. *Journal of Experimental Biology*, 2008; 211: 2336-2345.

Eng CM, Abrams GD, Smallwood LH, Lieber RL, Ward SR. Muscle geometry affects accuracy of forearm volume determination by magnetic resonance imaging (MRI). *Journal of Biomechanics* 2007; 40: 3261-3266.

BOOK CHAPTERS

Taylor AB, Anapol FC, **Eng CM**, Vinyard CJ. The functional significance of jaw-muscle fiber architecture in tree-gouging callitrichids. In *The Smallest Anthropoids: The Marmoset/Callimico Radiation*. Davis LC, Ford SM, Porter LM (Eds.), New York: Springer, 2009.

Taylor AB, Anapol F, **Eng CM**, Vinyard CJ. The relationship between jaw-muscle fiber architecture and feeding behavior in primates: Tree-gouging and nongouging gummivorous callitrichids as a natural experiment. In *Primate Craniofacial Function and Biology*. Vinyard CJ, Ravosa MJ, Wall CE (Eds.), New York: Springer, 2008.

TEACHING EXPERIENCE AND TRAINING

Teaching Certificate 1, Brown University, Sheridan Center for Teaching and Learning (Fall 2016) — I pursued formalized training in designing active learning experiences, creating an inclusive and respectful learning environment, supporting students with diverse backgrounds and learning styles, and critically reflecting on my own teaching and learning practices.

Human Evolutionary Anatomy and Physiology (*Life Sciences 2*), Harvard University (Fall 2010-2012) — Graduate teaching fellow in charge of anatomy and physiology labs covering development; biomechanics; skeletal, muscular, and internal anatomy; and muscle, respiratory and cardiac physiology. I began each lab with a short presentation to review material from lecture and introduce topics explored in each week's lab and then led students through lab activities. I also wrote exam questions and graded exams and weekly lab assignments. In Fall 2012, I served as the head teaching fellow (TF) for this course and in this role, I performed additional responsibilities including helping the preceptor lead weekly TF meetings, overseeing TF activities during labs, and serving as a mediator between the preceptor and other TFs.

Human Anatomy and Physiology (*Biological Sciences E-65C & E-65D*), Harvard University Extension School for Continuing Education (Fall 2012, Spring 2013, Fall 2014) — Graduate teaching fellow leading anatomy and physiology labs exploring histology, respiration and blood typing, blood pressure and exercise, axial and appendicular anatomy, and brain and spinal cord anatomy. I started lab with a presentation reviewing topics covered in lecture that were relevant to the day's lab and then led students through lab activities.

Evolution of Vertebrates (*Organismic and Evolutionary Biology 139*), Harvard University (Fall 2009) — Graduate teaching fellow in charge of labs where students examined and touched fossil and wet vertebrate specimens to answer questions regarding the specimens' function and ecology. The goal of the labs was to encourage students to appreciate the morphological diversity of vertebrates, compare fossils to assess their evolutionary history, or draw and comment on particular anatomical features of fossil specimens. Prior to lab, I went through the collections to select specimens and I revised lab handouts used in

previous years so they better reflected material covered in lecture and served as an enhanced guide to lead the students through the activities.

Human Evolutionary Anatomy (*Human Evolutionary Biology 1420*), Harvard University (Spring 2010) — Graduate teaching fellow leading labs exploring skeletal, muscular, and internal anatomy. In previous years, this lab only included a classroom component utilizing diagrams and anatomical models. I worked with the professor to include a new lab-based component where the students could inspect and touch a prosected human cadaver. I also wrote and graded exams, lab practicals, and assignments.

SYMPOSIA AND INVITED TALKS

Stretch your imagination: Exploring non-tendinous sources of elastic energy storage in the musculoskeletal system at the 6th International Autumn School on Movement Science at the Berlin School of Movement Science in Berlin, Germany, October 2019.

Can intramuscular springs cycle energy like tendon? Muscle and tendon—a complicated friendship symposium at American Society of Biomechanics in Rochester, MN, August 2018.

The battle of the bulge: structural determinants of muscle gearing during dynamic contractions. Spatial scale and structural heterogeneity in skeletal muscle performance symposium at Society for Integrative and Comparative Biology in San Francisco, CA, January 2018.

Comparison of elastic energy storage in the human iliotibial band and chimp fascia lata during locomotion. Elastic mechanisms symposium at the World Congress of Biomechanics meeting in Boston, MA, July 2014.

Biaxial material properties of fascia lata and the functional implications for movement. Muscle-tendon biomechanics symposium at the Society for Experimental Biology annual meeting in Valencia, Spain, July 2013.

SELECTED SCIENTIFIC PRESENTATIONS

A new role for intramuscular springs in energy cycling during locomotion. Society for Integrative and Comparative Biology (SICB) annual meeting, Tampa, FL, January 2019.

Does aponeurosis influence the relationship between muscle gearing and force? Society for Integrative and Comparative Biology (SICB) annual meeting, Portland, OR, January 2016.

Estimating fascial strain and elastic energy storage in the human iliotibial band. Fascia Research Congress, Washington, DC, September 2015.

Bipedally trained rats have an increased hindlimb muscle force-generating capacity compared to quadrupedally trained rats. Experimental Biology annual meeting, Boston, MA, March 2015.

Length changes of the human iliotibial band with motions of the hip and knee. SICB annual meeting, Austin, TX, January 2014.

Directional differences in the biaxial material properties of goat fascia lata. American Society of Biomechanics annual meeting, Omaha, NE, September 2013.

Swing phase energy storage in the goat fascia lata has implications for the function of the human iliotibial band. American Association of Physical Anthropologists (AAPA) annual meeting, Portland, OR, April 2012.

In vivo strain patterns indicate different functions in the proximal and distal fascia lata of the goat. SICB annual meeting, Charleston, SC, January 2012.

Bite force scaling and food mechanical properties. AAPA annual meeting, Chicago, IL. April 2009.

Muscle fiber length operating ranges reflect disparate functions between muscles. SICB annual meeting, Boston, MA. January 2009.

Mechanics of the masticatory apparatus favor muscle force production at wide jaw gapes in tree-gouging marmosets. AAPA annual meeting, Philadelphia, PA. April 2007.

Complete Muscle Architecture of the Rat Hindlimb. American College of Sports Medicine annual meeting, Denver, CO. June 2006.

Forearm muscle volumes can be accurately obtained from high resolution MRI. University of California, San Diego Orthopaedic Surgery Seminar, San Diego, CA. November 2006.

Stretching the limits: Jaw-muscle fiber architecture in tree-gouging and nongouging callitrichid monkeys. AAPA annual meeting, Milwaukee, WI. April 2005.

HONORS, AWARDS, & CERTIFICATES

Derek Bok Distinction in Teaching Award, Harvard University	2011
Course: Human Evolutionary Anatomy and Physiology	
Dean's List, Duke University	2001, 2004-05
Dean's List with Distinction, Duke University	2003

PROFESSIONAL ACTIVITIES AND MEMBERSHIPS

Professional memberships: Society for Experimental Biology, American Association of Anatomists, American Society of Biomechanics, Association for Women in Science, American Association of Physical Anthropologists, Society for Integrative and Comparative Biologists

Peer review: Journal of Experimental Biology, Journal of Biomechanics, Journal of Applied Physiology, Bioinspiration & Biomimetics, American Journal of Physical Anthropology, Journal of Anatomy, Zoology, International Journal of Computer Assisted Radiology and Surgery, Journal of Neuroengineering and Rehabilitation, Royal Society Open Science, Journal of the Mechanical Behavior of Biomedical Materials

SERVICE ACTIVITIES

1000 Girls, 1000 Futures mentor	2018-present
Harvard Graduate Women in Science and Engineering (HGWISE) Mentoring Program Co-chair	2010-2012
HGWISE Department Representative	2008-2013
Science Club for Girls Mentor Scientist	2008-2013
Harvard Graduate Student Council Department Representative	2008-2009
Kids at Heart Tutoring Tutor	2005-2007

RESEARCH EXPERIENCE

2018-present: Yale University; Postdoctoral research — Currently performing experiments to explore the role of curvature in human feet and fish fins in stiffness and stability.
Supervisor: Madhusudhan Venkadesan

2015-2018: Brown University; Postdoctoral research — Conducted experiments to explore the influence of aponeurosis on muscle function using a turkey model.
Supervisor: Thomas J. Roberts

2014-2015: Harvard University; Postdoctoral research — Performed experiments on rats to obtain *in vivo* measures of muscle function, which can be used to validate musculoskeletal models predictions.

Supervisor: Andrew A. Biewener

2007-2014: Harvard University; PhD dissertation — An anatomical and biomechanical study of the human iliotibial band's role in elastic energy storage.

Advisors: Andrew A. Biewener and Daniel E. Lieberman

2013-2014: Used a musculoskeletal model informed by measurements of human lower limb muscle architecture and ITB anatomy and mechanics to estimate the human iliotibial band's potential to store and recover elastic energy.

2011-2012: Performed biaxial materials testing on goat fascia lata samples to explore the tissue's ability to stabilize limbs, transmit muscle forces, and store and recover elastic energy. Used histology and SEM to correlate material properties with structural features.

2009-2011: Examined elastic energy storage in the goat fascia lata during locomotion.

2005-2007: University of California, San Diego; Staff research associate II — dissected human cadaveric limbs to create a database of muscle architectural data from which more accurate musculoskeletal models of human movement have been created; dissected muscles from MR imaged forearms to validate methods of quantifying muscle volume using MRI; revisited undergraduate thesis and combined skull and muscle architectural features with laser imaging techniques and a computer model to model the operating range of monkey jaw muscles during the tree-gouging behavior.

Supervisor: Samuel R. Ward

2003-2005: Duke University; Undergraduate honors thesis — A comparative analysis of temporalis fiber architecture in tree-gouging (*Callithrix jacchus*) and nongouging (*Saguinus oedipus*) callitrichids.

Advisor: Andrea B. Taylor