

Introduction



Cite this article: Kramer PA, Berthaume MA.

2021 Introduction to the theme issue

'Biological anthroengineering'. *Interface Focus*

11: 20210058.

<https://doi.org/10.1098/rsfs.2021.0058>

Accepted: 14 July 2021

One contribution of 12 to a theme issue

'Biological anthroengineering'.

Subject Areas:

biomechanics, biometrics, bioengineering

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Introduction to the theme issue 'Biological anthroengineering'

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While using the theoretical foundation and methodological techniques of mechanical engineering to understand living creatures is not unique to biological anthropologists, in 2016, the authors began discussing an integration of anthropology and engineering that is more than simply a borrowing of ideas of one discipline from another. We imagined—and continue to develop—this vision of anthroengineering [1]. But the first step in expanding our ideas beyond our inner circles was to host the world's first symposium on the topic. At the annual meeting of the American Association of Physical Anthropologists (now the American Association of Biological Anthropologists) in the spring of 2019, we brought together a diverse group of biological anthropologists to interrogate this vision. Not only was the symposium well attended (despite its 8.00 start time), but more importantly, the room was filled with lively intellectual discussions about the projects being presented and how engineering and anthropology could be further combined to answer new, exciting research questions.

'What's next?' was a common question of the morning. This collection of 11 articles from the participants is that next step.

Berthaume & Kramer [1] begin the collection by providing a working definition of the field. Beyond simply a description, they demonstrate the continued need for integrating engineering and anthropology, and the subsequent 12 papers are testaments to that perspective. Perhaps more importantly is that Berthaume & Kramer [1] establish that the foundational principles of anthropology—such as human variability and ethnography as a data collection tool—are important to engineering in a globally connected, culturally diverse world. Anthroengineering is imagined not as simply cross- or trans-disciplinary work, but rather as its own field. Finally, having the disciplinary examples of dubious inclusivity from anthropology and engineering allows them to make explicit a fundamental goal for anthroengineering: to be truly inclusive from the inception of the field.

The first four studies focus on different aspects of locomotor biomechanics in humans. Hammerberg & Kramer [2] analysed centre of pressure (CoP) in the foot during the braking and propulsive phases of walking. Applying cluster analyses from spatial statistics, they assessed the consistency of the location of the CoP across contiguous steps during human walking trials. They found CoP during propulsion was consistently located in the forefoot, while CoP during braking was spread across the fore-, mid- and hindfoot. Their results stress the importance of incorporating several steps in biomechanical locomotor analyses as the location of the CoP during braking can vary widely between steps.

Sylvester *et al.* [3] use a technique employed by both biological anthropologists and biomechanical engineers—musculoskeletal modelling—to demonstrate the importance to each group to the other. Biological anthropologists can seek more realistic representations by understanding the underlying mechanical principles (such as mechanical strength variation due to muscle fibre type (Holmes *et al.* [4])) while a deeper appreciation of human morphological variation would enable engineers to design applications for 'humans' that are appropriate for,

and more representative of, more of them. Anthroengineering, then, provides real opportunities for an improved understanding of human biomechanics.

Hatala *et al.* [5] describe a new method for quantifying and analysing track ontogeny during locomotion. By combining physical experiments (i.e. motion capture, biplanar X-ray) with digital simulations (i.e. the Discrete Element Method) and three-dimensional 3D visualization, they were able to create validated simulations of footprint formation. Using these simulations, they investigated the patterns of substrate flow under the foot during footprint formation, allowing aspects of track morphology to be directly correlated with hidden aspects of track formation. This new tool will eventually allow researchers to test hypotheses about how foot morphology and locomotion (e.g. kinematics and kinetics) relate to substrates and track formation, ultimately allowing for more accurate interpretations of fossilized tracks. The results of this study additionally have clear implications not only to scientific fields like paleoanthropology, but also to engineering disciplines like robotics.

Stamos & Berthaume [6] examine a previously proposed hypothesis [7] that the bumpy metaphyseal surface observed in climbing-adapted hominoids—as distinguished from the smoother metaphyseal surface of bipeds—exists to resist shear stresses by ‘locking’ the metaphysis and epiphysis together. Using a parametric finite-element (FE) model, morphologically informed chimpanzee-like and human-like models were constructed and loads were applied to simulate climbing and walking forces. As the hypothesis predicted, growth plates for the bumpier, chimpanzee-like models experienced lower von Mises stresses during climbing compared to growth plates for the flatter, human-like models. Further, both models resisted the stresses of bipedal walking similarly. These results support the relationship between metaphyseal morphology and locomotor repertoire in mammals, suggesting that metaphyseal shape may be a useful method for reconstructing the locomotor habits of extinct mammals.

Switching from locomotor to masticatory studies, the following three studies investigate masticatory biomechanics from a tooth/food item perspective. Berthaume & Kupczik [8] examined differences in molar biting biomechanics between two South African hominin species, *Australopithecus africanus* and *Paranthropus robustus*. *P. robustus*—which is believed to have consumed more biomechanically challenging foods—was found to require more force and energy to fracture a proxy food item than *A. africanus* (although there were large levels of overlap in biomechanical performance). They interpreted their results in the context of other dietary reconstructions and hypothesized three possible evolutionary scenarios concerning the dietary ecology of these hominins. Importantly, they stress the importance of taking a holistic approach to reconstructing hominin dietary ecology, instead of analysing characters in isolation.

Borrero-Lopez *et al.* [9] use materials engineering to review the mechanisms that can cause dental enamel to mechanically fail. Dental enamel has many unique micro- and macroscopic features that make it highly resistant to fracture and mechanical wear. They explain how aspects of enamel structure and properties, like elastic modulus gradients, can help protect enamel from failure by, for example, redirecting microcracks. By leveraging concepts from indentation mechanics, they develop a fundamental physical, ‘anthroengineering’ basis for exploring aspects of the evolutionary biomechanics of tooth function.

While understanding how teeth function is an important part of masticatory biomechanics, so is understanding how food items break down, as this is how forces are transmitted from the teeth to the skeleton. Traff & Daegling [10] use a novel testing rig to investigate biomechanical differences between more compliant, young and more mechanically challenging demanding, mature, leaves during simulated chewing. They found that mature leaves require more total force to break down, and that they break down into smaller pieces. This is presumably because their higher fibre content provides them increased strength but makes them more brittle. They discuss the ‘tough/brittle’ dichotomy often used to describe mechanically challenging foods and suggest this dichotomy may not be appropriate for describing differences between young and mature leaves.

The final studies continue the theme of masticatory biomechanics, but from the perspective of the soft and hard tissues in the skull. Holmes *et al.* [4] extend previous research on chewing muscle mechanics by combining muscle physiological cross-sectional area (PCSA) with muscle fibre type data to examine estimates for muscle force production. From an anthroengineering perspective, accurate estimates of muscle force are critical for the accuracy of biomechanical models (Sylvester *et al.* [3]). Previous methods for estimating muscle force often assume homogeneity of muscle fibre type within a muscle: that is to say, all muscle fibres are assumed to have the same force production capabilities. By accounting for heterogeneity in muscle fibre type, Holmes *et al.* show that muscle force production for the masseter and temporalis in a chimpanzee were significantly overestimated in previous studies, and bite force was overestimated by as much as 63%.

The last papers deal with hard tissue in the skull. Cook *et al.* [11] constructed a cranial FE model of the type specimen *Homo floresiensis* (LB1) to test hypotheses about its dietary ecology. They found *H. floresiensis* generally experienced higher strains than the australopithecines and similar strain magnitudes to humans. The strain patterns in the zygomatic bodies and arches, however, were more similar to those of chimpanzees than to those of humans. *Homo floresiensis* appeared efficient at transmitting bite force but experienced high strains that might have risked TMJ subluxation or dislocation during powerful molar biting. Contrary to findings from a biomechanical analysis of the mandible, the cranium of *H. floresiensis* was found to be nearly as weak or weaker than that of modern humans, suggesting that *H. floresiensis* was poorly suited for feeding on objects that required high bite force or highly repetitive chewing.

In Smith *et al.* [12], an FE model of a *Pan* mandible was compared to that of a *Macaca* mandible to determine if the two genera experience similar deformation regimes. The loads and strains experienced by a *Macaca* mandible are often thought to be representative of anthropoids and thus are used to interpret the mechanics of mandibular morphology of extinct hominins. While the overall deformation regime (i.e. how the mandible deforms) is similar between *Pan* and *Macaca*, differences in loading and strain regimes were apparent, implying differences in morphology cause the forces to be transmitted differently in the mandible. Consequently, strain patterns were unique in each species. An important result of their study is that—due to the omission of balancing (i.e. non-biting) side muscle forces—two-dimensional FE models do not produce accurate estimates of mandibular biomechanics. This inaccuracy of two-dimensional models is

particularly true of the strains adjacent to the mandibular symphysis.

While this collection of articles is tangible evidence of the intellectual products of anthroengineering—from musculoskeletal and FE modelling to heterogeneity in properties—we ask the same question that we did after the 2019 symposium: What is next for anthroengineering? Although the travel restrictions associated with the pandemic have prevented many of us from meeting since the 2019 symposium, we remain virtually connected and even more excited about

the opportunities for finding ways to probe the most salient questions of our time with an integrated approach. Join us.

Data accessibility. This article has no additional data.

Competing interests. We declare we have no competing interests.

Funding. We received no funding for this article, but are grateful to the then American Association of Physical Anthropologists (now American Association of Biological Anthropologists) for funding for the initial symposium in 2019 from which this volume derives.

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