Integrating geometric morphometrics and biomechanics

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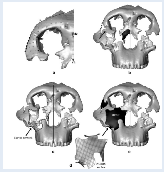
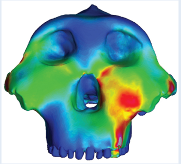
INTRODUCTION: Geometric morphometrics (GMM) can be a useful tool in functional morphology if the functional significance of the anatomical system in question cannot be described using simple measurements. Similarly, finite element analysis (FEA) can be useful if the geometry of an object (i.e., a skull) is too complex to be analyzed mechanically using free body diagrams of simple shapes. Both methods rely on 3D coordinate data as basic input, so there is an opportunity to integrate these approaches. This poster reviews applications of GMM to FEA using examples from the recent literature. We then identify a major challenge facing further integration.

APPLICATION #1: Virtually reconstructing fossil specimens to serve as the basis of a finite element model (FEM)[1,2].

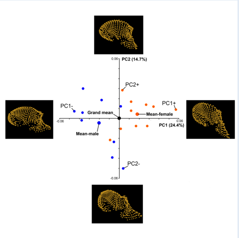


Alignment and joining of upper and lower facial sections. Figure from Benazzi *et al.*[1].

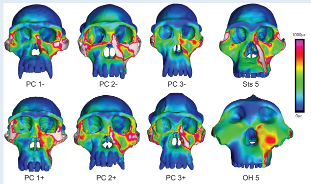


Von Mises strain recorded in the OH 5 FEA during simulated premolar biting[2].

APPLICATION #2: Use GMM to select individuals for FEA that represent the extremes of variation, thereby allowing an assessment of the mechanical consequences of intraspecific variation[2].

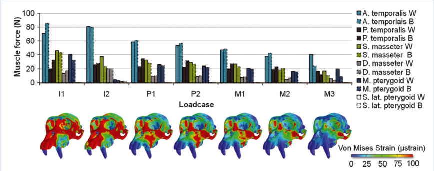


PCA of shape coordinates after GPA of 709 landmarks and semilandmarks recorded on 19 chimpanzees[2].

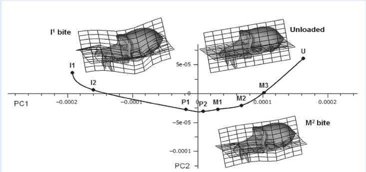


The chimpanzees that load most strongly on the positive and negative poles of the first three PCs were selected for FEA. Color mapping indicates von Mises strain recorded during premolar biting in the chimps and two fossil hominins (OH 5 and Sts 5)[2]. Chimpanzee strains contextualize strains in fossil hominins.

APPLICATION #3: Use GMM to describe deformations in a single FEM after altering model inputs[3].

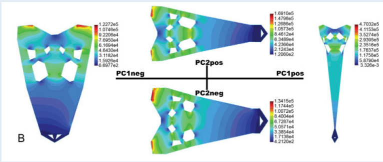


Seven FEAs were performed in which a 100N bite force was generated on each of seven teeth using muscle forces determined by multibody dynamic analysis. Figure from Fitton *et al.*[3].



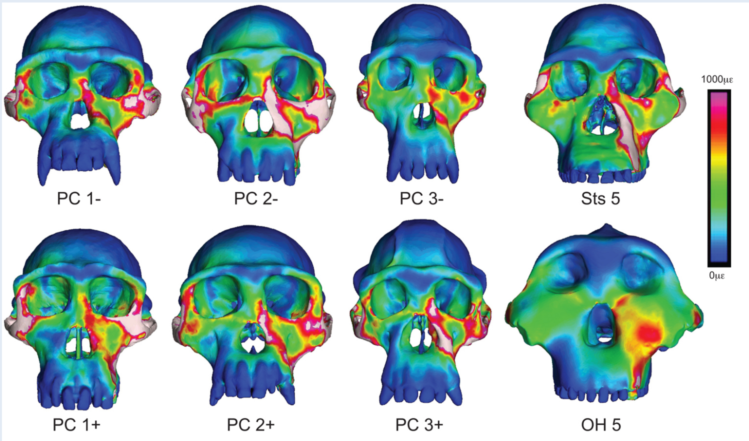
PCA of 70 Procrustes coordinates following deformation by loads on different teeth in FEA, relative to the unloaded model (U). PC1 describes 91% of the total variance, and PC2 describes 7%. Figures from Fitton *et al.*[3].

APPLICATION #4: Use GMM to warp specimens into new shapes, which are then subjected to FEA.



Von Mises stress found in FEA of 2D models of the extreme crocodilian shapes found in PCA, simulating unilateral bites. Differences in stress reflect the mechanical consequences of variation along independent axes of shape. Figure from Pierce *et al.*[4].

CHALLENGE: Each FEM generates a huge amount of data (minimally, 9 types of stress , 9 types of strain, displacements in three directions, and strain energy density at each of hundreds of thousands (or millions) of elements and/or nodes). How can we use these data effectively? Consider the models to the right. Can we answer the following questions in a statistically rigorous way: Are stresses and strains in these models similar or different? In what ways are they similar? In what ways are they different? Currently, we lack the statstical tools to answer these questions. Does GMM point towards a solution, or do we need entirely new statistics? On a logistical level, how do we identify homologous locations on these models, given that we lack precise control over the meshing process?



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