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INTRODUCTION

Craniofacial biomechanics: *in vivo* to *in silico*

Central to craniofacial biomechanics is an understanding of the relationship between structure and function during both development and evolution. Craniofacial biomechanics has traditionally been approached using a combination of *in vivo* experimentation and constitutive modelling. Recent advances in the availability of 3D imaging and computing power mean that the engineering tools of finite element analysis (FEA) have become increasing popular and are allowing morphologists to address new questions. For example, FEA provides the opportunity to carry out highly controlled *in silico* experiments, such as assessing the mechanical effect of the presence or absence of particular structures or comparison of the performance of structures that differ between species. Biologically meaningful finite element modelling of the craniofacial skeleton, however, requires not only a diverse array of information ranging from *in vivo* EMG and kinematics to the material properties of foods and craniofacial tissues, but also validation and sensitivity tests to assess whether the models adequately approximate reality. This special issue of *Journal of Anatomy* contains contributions which arose from a workshop and symposium entitled 'Craniofacial biomechanics: *in vivo* to *in silico*', generously sponsored by the Anatomical Society and the Hull York Medical School and held in York, UK in July 2009. The aim of the special issue is to bring together an international group of experts to demonstrate the current state of research in the diverse range of topics necessary to model the biomechanics of the craniofacial skeleton.

The issue starts with two review papers. The first review by O'Higgins and colleagues proposes the combination of virtual biomechanics tools with the tools of geometric morphometrics to the assessment of form-function relationships. This synthesis of methods provides the means with which to generate models of hypothetical forms, take account of variations in morphology, and analyse mechanical performance, all within a statistical framework. The statistical biomechanics of form as set out in this review have potentially far-reaching applications. The second review by Curtis introduces multibody dynamics analysis (MDA), a relatively uncommon method in craniofacial biomechanics. MDA models the movements and forces between structures such as the mandible and cranium and can predict muscle activity during feeding, model jaw motion and investigate the function of muscle parameters such as fibre length and muscle tension.

Knowledge of the material properties of bone is fundamental to an understanding of the basic biology of bone adaptation to specific functions and to improving the accuracy of finite element (FE) models of the craniofacial skeleton; however, studies of variations in material properties across different regions of the craniofacial skeleton and the skeleton in general are not common. In the first of the research papers, Chung and Dechow use an ultrasonic method (off-axial ultrasonic velocity) to analyse the variation in elastic properties of human cortical bone across the cranium, mandible and femur. Tsafnat and Wroe then present a novel approach to combining FE model validation and material properties testing of bone using a material testing stage fitted inside a microCT scanner.

Validation in FEA is essential in order to assess how closely modelling results reflect reality. The next three papers present validation studies on a variety of taxa and tissues. Rayfield presents a validation of specimen specific FE models of ostrich mandibles (*Struthio camelus*). Ostriches provide a valuable extant reference for models of extinct non-avian theropod dinosaurs; in fact, validation studies on non-mammalian taxa are extremely limited so this study provides much-needed data. Reed and colleagues also add to the non-mammalian FE validation studies, in particular by investigating the functional effects of varying stiffness in the bone and sutures in the alligator mandible (*Alligator mississippiensis*). In the third of these validation studies, Panagiotopoulou, Kupczik and Cobb assess FE model sensitivity to variation in the material properties and thickness of the periodontal ligament in *Macaca fascicularis*.

Lev-Tov Chattah and colleagues investigate the functional implications of the shape of the enamel cap of mandibular incisors in *Macaca mulatta*. The findings indicate that the shape of the enamel cap and variation in enamel thickness across the crown provide an important role in directing the tooth deformation during incisal loading. Few studies currently address the influence of mechanics during development, Cobb and Panagiotopoulou present a study investigating the relationship between bone and teeth during development and the mechanical effects in *M. fascicularis*. The authors show, by using FEA, that the presence of the developing incisors during growth reduces the volume of trabecular bone and increases strain; they propose that this constrains the mechanical adaptation of the mandibular symphysis. Ross and colleagues test mechanical hypotheses concerning the region where the facial skeleton is hafted onto the neurocranium. This region contains many of the defining features of higher primates and so has far-reaching implications for our understanding of primate evolution. Focusing on the postorbital septum portion of the craniofacial haft, Nakashige, Smith and Strait use FEA of *M. fascicularis* to assess the mechanical impact of the presence of the septum in anthropoid primates during biting. Their findings show that the postorbital septum has no substantive mechanical role molar biting and suggest either that the septum evolved for non-mechanical reasons or that the original mechanical role has subsequently been lost. Finally, Dumont and colleagues use FEA to investigate functional feeding specializations between two closely related marmosets that are plant exudate feeders: one has a large gape and feeds exclusively on tree sap by gouging the bark with its incisors, while the other does not gouge but opportunistically feeds on exudates. The study demonstrates that while the tree-gouging marmoset may have traded a large gape for the ability to produce high bite forces, it has not come at the expense of performance during molar biting.

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