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The effects of modeling simplifications on craniofacial finite element models: The alveoli (tooth sockets) and periodontal ligaments

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Several finite element models of a primate cranium were used to investigate the biomechanical effects of the tooth sockets and the material behavior of the periodontal ligament (PDL) on stress and strain patterns associated with feeding. For examining the effect of tooth sockets, the unloaded sockets were modeled as devoid of teeth and PDL, filled with teeth and PDLs, or simply filled with cortical bone. The third premolar on the left side of the cranium was loaded and the PDL was treated as an isotropic, linear elastic material using published values for Young's modulus and Poisson's ratio. The remaining models, along with one of the socket models, were used to determine the effect of the PDL's material behavior on stress and strain distributions under static premolar biting and dynamic tooth loading conditions. Two models (one static and the other dynamic) treated the PDL as cortical bone. The other two models treated it as a ligament with isotropic, linear elastic material properties. Two models treated the PDL as a ligament with hyperelastic properties, and the other two as a ligament with viscoelastic properties. Both behaviors were defined using published stress–strain data obtained from *in vitro* experiments on porcine ligament specimens. Von Mises stress and strain contour plots indicate that the effects of the sockets and PDL material behavior are local. Results from this study suggest that modeling the sockets and the PDL in finite element analyses of skulls is project dependent and can be ignored if values of stress and strain within the alveolar region are not required.

1. Introduction

Due to the strong selection pressures associated with feeding (Herrel et al., 2008), a biomechanical system commonly studied using finite element analysis (FEA) is that part of the craniofacial apparatus that is routinely subjected to masticatory forces and constraints (Dumont et al., 2005; Farke, 2008; Kupczik et al., 2007, 2009; McHenry et al., 2007; Rayfield, 2005a, 2005b, 2004, 2007; Rayfield et al., 2001, 2007; Richmond et al., 2005; Ross et al., 2005; Strait et al., 2005, 2010, 2007, 2008, 2009; Wroe et al., 2007, 2008; Wroe, 2008; Wroe et al., 2010). The level of anatomical detail required in such finite element models (FEMs) depends extensively on the objective of the analysis and the performance variables of interest. For example, if accurate prediction or comparison of the distribution of stresses and strains in teeth are not the focus of the analysis, then it may be possible to model the teeth, periodontal ligaments (PDLs), and alveolar margins quite crudely. However, due to uncertainty regarding the effect of various anatomical simplifications on the performance variable of interest, biologists are often reluctant to make these modeling simplifications. The results are often FEMs of biological structures involving millions of elements and nodes that are computationally expensive to analyze. On the other hand, sometimes modeling simplifications are made in order to realize a tractable model, and an obvious issue to address is whether or not such modeling simplifications are appropriate given the objectives of the analysis.

In this paper we examine the effect of various modeling simplifications related to craniofacial FEMs on stress and strain distributions due to feeding biomechanics and dynamic tooth loads. Results from this paper will help determine if the alveoli and PDL have an effect on stress and strain patterns and whether or not they need to be modeled in future FE skull model analyses.

The first portion of this study examines the effect of the alveoli on the stress and strain distributions for a cranium under static biting conditions to address the following hypothesis: failure to properly model the tooth sockets (i.e., by treating the tooth roots as if they were fused with the alveolar bone) leads to an FEM whose alveolar process is overstiffened, producing strong local effects near the sockets as well as strong global effects in craniofacial regions far away from the alveoli.

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