BEHAVIOR OF THE PERIODONTIUM UNDER LOADING USING A KINETIC MODEL OF THE MASTICATORY SYSTEM

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1. Introduction

The periodontal ligament (PDL) is a binding tissue that attaches the teeth to the alveolar bone and governs short-term tooth mobility. It is composed of bundles of connective tissue fibers, specific cells, vasculature, nerves and ground substance [2]. Occlusal forces are absorbed by the oblique fibers, which cover most of the surface of the tooth. The vasculature of the PDL has an essential role with respect to its functional properties. As the teeth are loaded, fluids inside in the PDL (blood vessels and ground substance) will flow to the alveolar bone (the rich vascular supply of the PDL penetrates the alveolar bone), granting the tissue dissipation properties. Once fluid flow can no longer take place, the PDL becomes essentially incompressible, and hydraulic pressure distribution occurs [4].

Currently, discrepancies found in the literature relating to the mechanical properties of the PDL complicate the interpretation of results obtained with simplified numerical models [3]. Additionally, unrealistic loading conditions of the masticatory system with forces not reproducing realistic chewing forces are often employed.

In this work, the behavior of the PDL is compared between two different material models, which are —though also simplified— able to reproduce the results from experimental tests [5], during realistic kinetic chewing tasks. Loading on the teeth and subsequently in the PDL are determined during common motor tasks of incisive biting and unilateral molar biting. These tasks are simulated under kinetic conditions by means of a complete model of the masticatory system which encompasses all essential components of the masticatory system, i.e. the mandible, maxilla, temporomandibular joints (TMJ), periodontal ligament, muscles and the teeth (Figure 1).

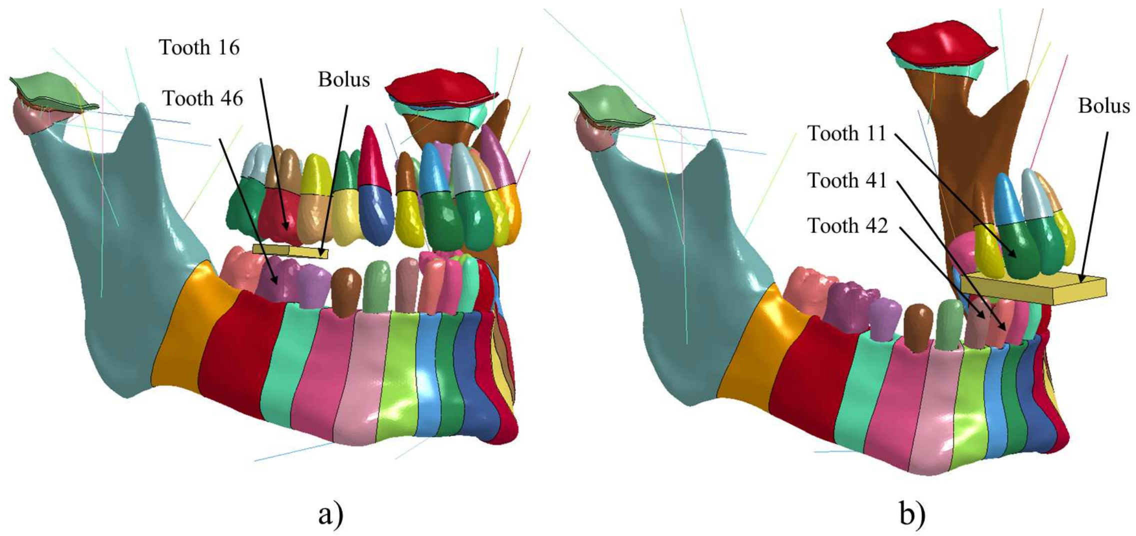

Figure 1: A finite element model that encompasses the majority of the components of the masticatory system is employed to recreate a unilateral molar biting task (a), and an incisive biting task (b)

2. Materials and Methods

A finite element (FE) model comprising all essential components of the stomatognathic system was employed to load the teeth by biting on a deformable bolus. The model is explained in detail in a previous work [1]. Two hyperelastic material models are used for the PDL, a first order Ogden model and a model in polynomial form that follows the work of Su et al. [6]. The strain energy function for the Ogden material model is defined as

$$W = \sum_{i=1}^{3} \sum_{j=1}^{n} \frac{\mu_j}{\alpha_j} (\lambda_i^{\alpha_i} - 1) + K(J-1)^2 . \tag{1}$$

where W is the strain energy potential, λ_i the deviatoric principal stretches, μ_j and α_j material parameters, J the determinant of the elastic deformation gradient, and K the bulk modulus. The employed material parameters can be found in Martinez et al. [1]. On the other hand, the strain energy function in polynomial form proposed by Su et al. [6] is given by

$$W = C_{10}(\bar{I}_1 - 3) + C_{20}(\bar{I}_1 - 3)^2 + C_{30}(\bar{I}_1 - 3)^3 + \frac{1}{D_1}(J-1)^2 + \frac{1}{D_2}(J-1)^4 + \frac{1}{D_3}(J-1)^6 \tag{2}$$

where $C_{10}, C_{20}, C_{30}, D_1, D_2, D_3$ are material parameters, $\bar{I}_1$ the first invariant of the right Cauchy strain tensor with the volumetric component removed, and J the determinant of the deformation gradient. The used material parameters are identical with those proposed in [6] for the volumetric finite strain viscoelastic model.

3. Results

Displacements occurring in the teeth, as well as stresses in the PDL estimated by the two material models are presented and compared during different biting tasks. Both material models are able to reproduce displacements of the teeth that are inside the range observed in experimental tests. However, in the case of very small forces, displacements are smaller than those in the experimental range. The material parameters could be modified to produce better results at this range, but with a significant increase of computational effort, as the non-linear behavior of the material model would increase as well. Stresses predicted by the materials are significantly different from each other, with the polynomial form showing predominantly compressive stresses to handle the loads on the teeth. In both material models, significant stress concentration is observed due to their exponential response to strain. The magnitude and orientation of the resulting forces on the teeth, as well as their respective application points are shown, which can be employed in simplified models where only the teeth and the PDL are modeled.

References

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