Finite Element Simulation of the Human Mandible: The Influence of the PDL on its Structural Behaviour

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Introduction

This paper refers to a detailed research project concerning the structural mechanics of a human mandible dedicated to a stepwise refinement of the simulation model towards the anatomical reality. For its common pathological condition, the partially edentuluous mandible of the female Visible Human [8], characterized by beginning atrophy of the alveolar ridge, was chosen as simulation example. The "periodontal ligament" (PDL) is a thin fibrous connective tissue of a thickness of about 0.2 mm present at the interface between teeth and the mandibular corpus (Figure 1). It surrounds the root of a tooth, separating it from and attaching it to the alveolar bone.
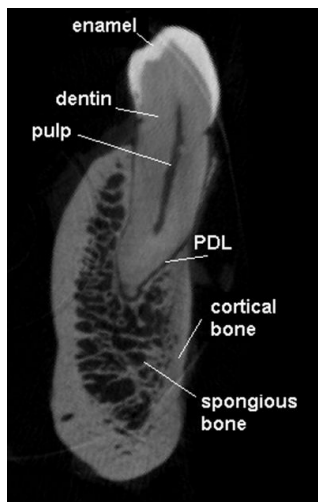
Micro-CT slice of a human premolar in vitro, resolution 160 μm x 160 μm x 320 μm [7].
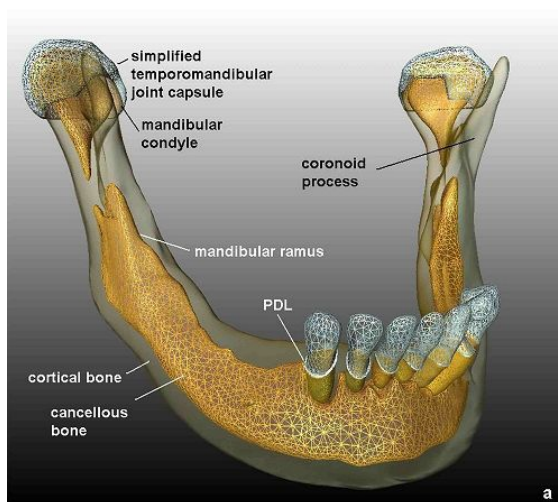
FEA Model with integrated PDL and simplifid temporomandibular joint capsules, transparent rendering of the cortical bone, altogether about 400.000 tetrahdra.

Objectives

The article is dedicated to an analysis of the influence of the PDL on the structural behaviour of human jaw bone by means of finite element simulation of an entire mandibular model (Figure 2).

Material and Methods

In general, the preprocessing of the simulation consists in reconstruction of the individual anatomy, implementation of the inhomogeneous and anisotropic material law of bone, and realization of the load case due to teeth, muscle and joint forces (Figure 3). For the sake of the stepwise refinement towards anatomical reality being a key feature of the project, the mandible was modelled as inhomogeneous and anisotropic [4]. Further, individual muscular lines of action and simplified TMJ capsules were introduced [5,6].

Due to strongly varying dimensions, the PDL was reconstructed by a special semiautomatic procedure. As regards its adaptive viscoelastic material properties, during static biting, a reference to the higher Young's modulus within a "bilinear material approach" was chosen [2].

In order to guarantee reliability and efficiency of the simulation we applied the adaptive Finite Element code KASKADE [3,10]. The geometry reconstruction from 3D image data and all visualizations were performed with Amira 4.1. [1,9].
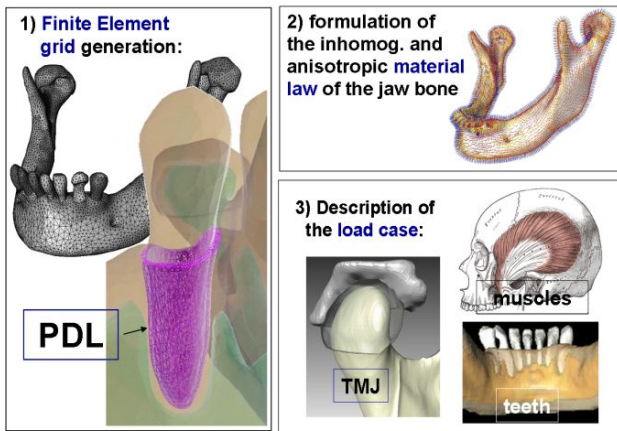

Prerequisites of the simulation.

Results

The simulation results proved remarkable force absorption due to the PDL (Figure 4) as well as qualitative changes of the stress/strain profiles of the alveolar ridge.

Concerning the simulation without PDL, observed high compressive strain at the adjacent bone were in agreement with regions of frequent implant failure (Figure 5).
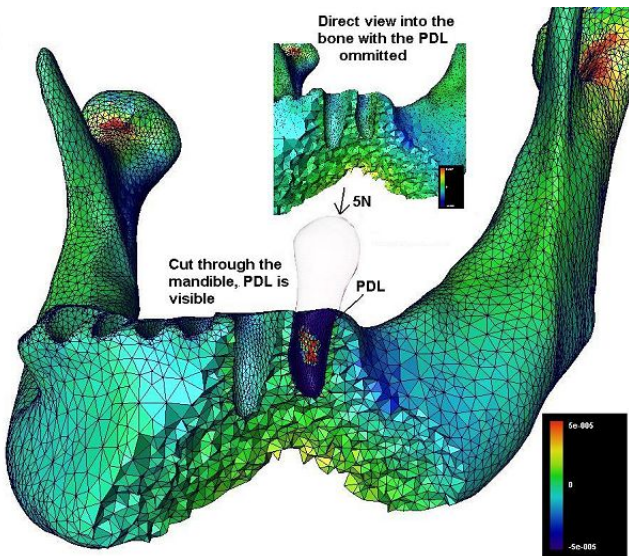
Simulated volumetric strain due to an intrusion on the leftmost premolar (force: 5N), remarkable force absoption on behalf of the PDL can be stated.
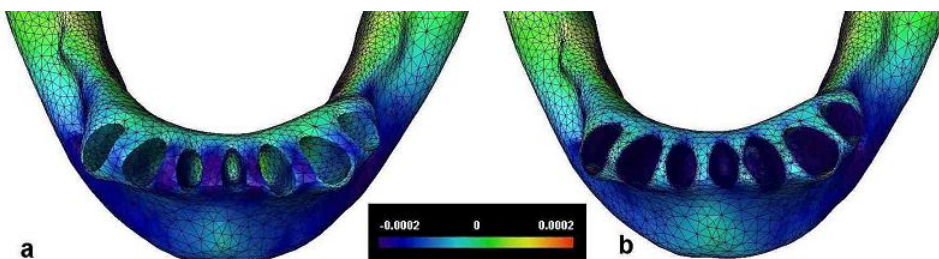
Volumetric strain due to a bite on all teeth (a) without integrated PDL (b) with integrated PDL, view into the alveolar bone, teeth omitted.

Conclusions

The simulation results confirmed that the PDL is essential for the structural behaviour of the human mandible. Based on the mechanical adaptation of bone, the comparison of the simulation with and without PDL provides special insight to the changes due to dental implants, in particular implant loss and bone resorption. Finally, the simulation will serve as virtual platform for evaluation (a) of implant design (b) of implant placement.

Literature

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Finite Element Simulation of the Human Mandible: The Influence of the PDL on its Structural Behaviour

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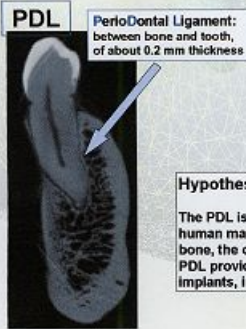
PDL

PerioDontal Ligament: between bone and tooth, of about 0.2 mm thickness

Introduction:

The article is dedicated to the study of the influence of the PDL on the structural behaviour of human jaw bone by means of finite element simulation of an entire mandibular model, see Figure 1.

Hypothesis:

The PDL is essential for the structural behaviour of the human mandible. Based on the mechanical adaptation of bone, the comparison of the simulation with and without PDL provides special insight to the changes due to dental implants, in particular implant loss and bone resorption.

Figure 1: FEA Model with integrated PDL and simplified temporomandibular joint capsules, transparent rendering of the cortical bone, altogether about 400.000 tetrahedra.

Materials and Methods:

Aimed at a stepwise refinement towards anatomical reality, the mandible was modelled as inhomogeneous and anisotropic. Further, individual muscular lines of action and simplified TMJ capsules were introduced.

Due to strongly varying dimensions within the mandible, the PDL was reconstructed by a special semiautomatic procedure. As regards its material law, during static biting, a reference to the higher Young's modulus within a bilinear material approach was chosen [1].

Adaptive Finite Element Simulation: KASKADE, see www.zib.de/Numerik/numsoft/kaskade, Geometry reconstruction and visualization: Amira 3.1.1., see www.amiravis.de [2]

Prerequisites of the simulation

1) Finite Element grid generation:

2) formulation of the inhomog. and anisotropic material law of the jaw bone

3) Description of the load case:

muscles

TMJ

teeth

PDL

Results and Conclusion:

The simulation results proved remarkable force absorption due to the PDL, see Figure 2, as well as qualitative changes of the stress/strain profiles of the alveolar ridge.

Concerning the simulation without PDL, observed high compressive strain at the adjacent bone were in agreement with regions of frequent implant failure, see Figure 3.

The simulation results confirmed the aforementioned hypothesis. Finally, the simulation will serve as virtual platform for evaluation (a) of implant design and (b) of implant placement.
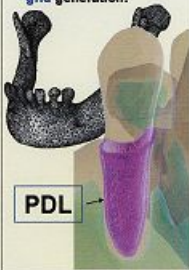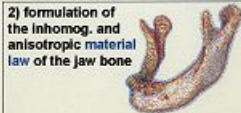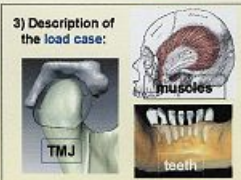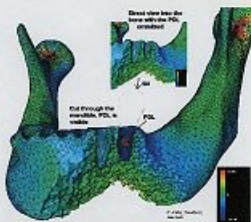
Fig.2: Simulatd volumetric strain due to an intrusion on the leftmost premolar (force: 5N), remarkable force absoption on behalf of the PDL can be stated.
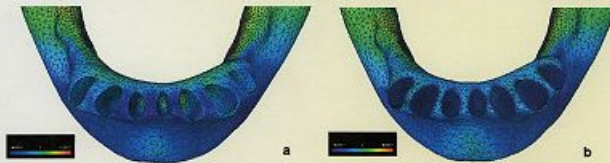
Figure 3: volumetric strain due to a bite on all teeth (a) without integrated PDL (b) with integrated PDL, view into the alveolar bone, teeth omitted

References:
[1] Dorow C., Krstin N., Sander F.-G., "Determination of the Mechanical Properties of the Periodontal Ligament in a Uniaxial Tensional Experiment", Orofac Orthop, 64, 2003, pp. 100-7

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