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Biomechanical study of bone-dental implant interactions using patient-specific approach and multiscale computational modeling

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Dental implants are modern solutions for the cases of lost tooth replacements. Although the application of dental implants is relatively efficient solution, complications and failure of dental implant might occur [3]. This contribution is focused on the mechanical interaction of dental implants with the bone tissue with respect to different types of cancellous bone model. The solution is associated with a broader range of dental-implant-related clinical problems. The effective processing of data from CT and micro-CT devices enables achieving a high level of computational models that include detailed trabecular bone architecture as well as non-homogeneous material property distribution. Using such models allows local biomechanical analyses that are inevitable for better understanding of bone-implant contact (BIC) mechanisms.

Full human mandible was scanned using conventional CT device (pixel size of 0.5 mm) and a mandibular segment was scanned using micro CT scanner (General Electric v tome x L240, Boston, Massachusetts, USA; pixel size of 25 μm). Branemark implant was used in this study (diameter 3.3 mm and length 11.5 mm). Creation of geometry model is described in detail elsewhere [3]. To focus on the BIC in detail and in an effective way, the sub-modelling technique was adopted meaning the coarse model was used to provide boundary conditions for more detailed sub-model, see Fig. 1.

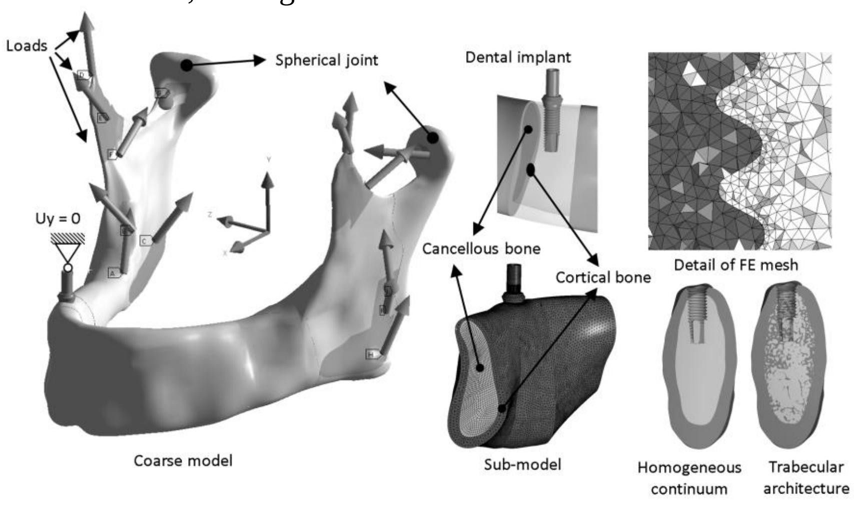

Fig. 1. Coarse model with load, sub-model, detailed mesh, model of cancellous bone

The sub-model consisted of a mandible segment with one implant of an approximate length 50 mm. Sufficiently fine mesh (0.05 mm) was defined around the threaded parts using SOLID187 elements, see Fig.1. All interacting components were connected to each other using contact elements TARGE160 and TARGE174. The total number of nodes was around 250,000 nodes for coarse model and 20 mil nodes for sub-model.

The materials of the implant and the cortical bone were assumed to be linearly elastic, homogeneous and isotropic (E_{imp} = 110000 MPa, μ_{imp} = 0.3; E_{cor} = 15000 MPa, μ_{cor} = 0.3) [3]. Cancellous bone in the sub-model was represented in three ways: 1. Assuming the cancellous bone to be homogeneous continuum with isotropic properties (E = 2840 MPa, μ = 0.3) [2]; 2. Same as 1 except for using orthotropic properties (E_x = 2000 MPa, E_y = 3180 MPa, E_z = 3340 MPa, μ_{xy} = 0.14, μ_{yz} = 0.21, μ_{xz} = 0.19, G_{xy} = 579 MPa, G_{yz} = 515 MPa, G_{xz} = 493 MPa) [2]; 3. Considering trabecular architecture (E_{trab} = 15000 MPa, μ_{trab} = 0.3). In the coarse model, the mandible was loaded by forces mimicking the muscle activity [1].

To investigate the influence of the cancellous bone type on the implant behavior, dental implant was evaluated for von Mises stress and total displacements. The stress and displacement distributions are shown in Fig. 2. The displacements, maximum stresses as well as the stress isolines indicate that the choice of cancellous bone representation has an insigificant effect on the implant results. Therefore, as far as the implant structural behavior is concerned, all investigated cancellous bone model types provide the same results if the stiffnesses of those bone types are equivalent.

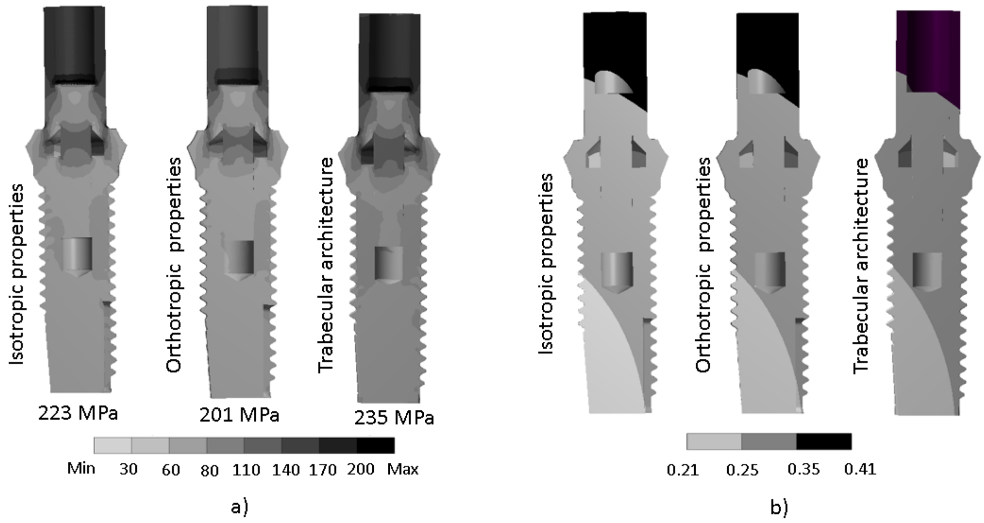

Fig. 2. a) von Mises stress [MPa] in dental implant; b) total displacement [mm]

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