On the periodontal ligament representation in 3D finite element analysis for orthodontic tooth movement models.

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For the past few years, 3D finite element (FE) models based on computer tomography (CT) scans are increasingly used in the field of orthodontics. However, clinical CT resolution allows only for differentiation of bone (both cortical and alveolar) and teeth. Specially, the surface geometry of the periodontal ligament (PDL) cannot be directly derived from CT images. In most recent studies [1], the PDL is thus generated using scaling and/or Boolean operations on the teeth and bone interfaces in order to obtain a thin enclosure. This approximation is performed despite the fact that most authors agree on the importance of geometrical and material properties of the PDL in the achievement of orthodontic tooth movement. The aim of this study is therefore to propose alternative methods to account for the mechanical role of the PDL without geometrically representing its thickness.

A patient-specific finite element mesh of the human mandible was obtained as follows. First, cortical bone, alveolar bone and teeth were segmented using different labels in a CT-scan of a human mandible. From this image, a multiple-material surface mesh was constructed in a two steps procedure: first a surface reconstruction method is used to extract a smooth representation of the boundaries in the discrete data and avoid tedious smoothing of the mesh in post-processing steps ; then, the mesh is extracted using an enhanced Marching Tetrahedra procedure. The algorithm generated two identical surfaces at the bone/teeth interface while a single triangular surface was extracted between cortical and trabecular bone. From the obtained multiple-material surface mesh, composed of a set of closed triangulations, a tetrahedral volume mesh was easily obtained using TetGen. From the surface meshes, three FE models were derived to represent the PDL. The first one (reference model) includes an enclosure between the teeth and bone interface, allowing the inclusion of prismatic elements for a linear elastic PDL of user-controlled width. A second one includes (non-)linear springs between corresponding nodes of the interface. A third one represents the PDL mechanical behavior by bilateral frictionless contact conditions between the two boundary meshes. As boundary conditions for the FE analysis, a rigid tipping rotation of a tooth was applied and the basal line of the mandibular bone was considered fixed. FE computations were performed using Metafor, a in-house object-oriented non-linear finite element code (http://metafor.ltas.ulg.ac.be). The stress distribution in the bone along the root for all models shows that models with springs or bilateral contact can both ensure the transfer of the pressure through the ligament with the same intensity as for the reference model. However, only the contact model can represent a shear intensity in the bone equivalent to the one obtained with the presence of an elastic PDL.

This study therefore shows the potential of using customized contact conditions on the bone/teeth interface to represent the PDL, as both the hydrostatic and shear stress in the bone could be represented while reducing the preprocessing of the model.

References

[1] F. Gröning, M.J. Fagan, and P. O'Higgins. The effects of the periodontal ligament on mandibular stiffness: a study combining finite element analysis and geometric morphometrics. *Journal of Biomechanics*, 44(7):1304 – 1312, 2011.