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Original Research Article

Three-dimensional finite element simulation of intrusion of the maxillary central incisor

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ABSTRACT

Purpose: The aim of this study is to generate a global digital model of treatment, analysis of stress distribution and displacements: in a construction of the bracket, in the incisor with bonded bracket, in tissues of the incisor, in a periodontal membrane and in an alveolus.

Methods: An orthodontic therapy was provided with a three-dimensional model of a unique Cannon Ultra bracket. The placement of the bracket to the incisor was provided according to clinical standards. Composite material was placed between the rough surface of the bracket's base and labial incisor surface – which, in a digital model, resulted in contact without displacement. The bracket was loaded. An orthodontic arch wire was free to move in a wing slot of the bracket. For simplification, a force vector was parallel to the longitudinal axis of the incisor. A clamper was set on the surface of the cortical bone of the alveolus. The model was divided into a finite number of tetrahedral elements. To calculate the distribution of stress Ansys Workbench software was used.

Results: The stress values indicate that there were no tissue overloaded areas. The stress distribution was regular in the periodontal ligament. Slight movements were observed with maximal values in the area of apex.

Conclusions: This study simulation proves that tissues surrounding the tooth were influenced mechanically by the force loaded on the bracket. According to the results of the study,

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Abbreviations: CBCT, cone beam computed tomography; FEM, finite element method; PDL, periodontal ligament.

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the simulated treatment should be successful. The bracket transferred the load from the wire to the alveolar ridge.

1. Introduction

Digital simulations employing the finite element method (FEM) used in orthodontics allow to identify the biomechanical indications and predict the effects of treatment [1–7]. In order to be properly carried out, a simulation must meet a number of criteria that reflect the in vivo situation. The article presents a three-dimensional model of intrusion of a maxillary central incisor using the orthodontic Cannon Ultra bracket.

Indications for orthodontic incisor intrusion are dentoalveolar deep bite and gummy smile. Deep bite occurs when overbite is increased and there is incorrect contact on the incisors. Gummy smile – excessive exposure of the upper gingiva when smiling.

Intrusion is an apical tooth/teeth movement (into the alveolus) under action a constant longitudinal force. The level of alveolar bone follows the teeth position.

Diagnostic imaging of the maxilla was made with a cone beam computed tomography (CBCT) [8]. It enabled to assess anatomical structures as well as to perform a pre-treatment analysis within treatment planning.

The aim of the study was to carry out a digital simulation of intrusive load transfer from the orthodontic arch wire to the alveolar process through the bracket.

Stress distribution and resultant displacement within the bracket, bracket–incisor junction, tooth tissue, the periodontal ligament and alveolar structures were recorded. The distribution of stress and displacements should allow to visualize the function of the periodontal membrane and explain the biomechanical effect on the alveolus [9].

The presented study was based on three-dimensional digital simulation derived from a modern diagnostic imaging and modelling taking into account the anatomical structures in a high quality [3,7,10,11].

2. Materials and methods

2.1. Three dimensional modelling

The material for this study was the CBCT scan of the maxilla of a patient with an indication for orthodontic treatment (Fig. 1). The high resolution dicom standard Kodak K9000 CBCT machine (voxel size of 0.076 mm) was used for the diagnostics. The model analysis was performed taking into consideration the Hounsfield scale. 3D Doctor, NE/Nastran Femap Modeler, SolidWorks software was used for the analysis and the segmentation of anatomical structures and the three-dimensional reconstruction.

The modelling included: the reconstruction of the geometrical structure of the maxilla cortical and cancellous bone as well as the incisor with enamel, dentine and pulp (Figs. 2 and 3). A periodontal ligament (PDL) was modelled as a 0.25 mm thick layer surrounding the root. The thickness of PDL was determined on the basis of measurements made on CBCT scans. According to the subject literature data, the value may range between 0.1 mm and 0.4 mm. [12,13]. The tooth with PDL was placed in the model of maxilla. The unique twin-slot Cannon Ultra bracket was used in the study (Fig. 4) [14]. The Cannon Ultra bracket consists of several parts as described in Fig. 4. The base of the bracket has rough surface from the tooth side to achieve high contact surface with the adhesive resin for maximum adhesion to the tooth surface. Three tie wings are seen: one at gingival site – a ''T-bar'' and two shorter ones on the other site of the bracket. There are two slots as shown in Fig. 4 edgewise slot generating high friction and a low friction wing slot. Using a wing slot in Cannon Ultra System makes possible to achieve individual position of the teeth for patients with different skeletal configurations which differs from preadjusted systems which are usually designed for class I patients. One of the advantages of using low friction wing slot in connection with an intrusive wire makes it possible to intrude the incisors in deep bite cases. The edgewise slot corresponds with the shape of most brackets used in the contemporary orthodontics, yet without the possibility of its direct use in the intrusion of the tooth. As for the wing slot, it allows for a low friction movement of an orthodontic arch wire. It can be used for tipping or intrusion of the tooth where the Cannon Ultra bracket was placed. In the study a nickel-titanium straight leg intrusion wire was modelled. The arch was round 0.018″ in diameter.

2.2. Finite element digital modelling

The digital procedure leading to the simulation and the analysis of a global three-dimensional digital model with the use of the ANSYS software involved the solid geometry modelling of the maxilla and the incisor with the PDL and the construction of the bracket and the orthodontic arch wire. Then the elements were divided into finite tetrahedral elements. The bracket was positioned at the labial surface of the enamel of the incisor and the contact with no displacement between the two structures was established. The global model was generated. The material parameters of bone, enamel, dentine, periodontal ligament, composite cement, cementum, bracket, arch wire were introduced to the model (Table 1). The clampers, the maps of tension distribution and tension within the tissues and appliance were set.

The bracket was bonded to the tooth's surface with a composite material so that the bracket was stable. In the digital model contact without displacements between the bracket and the enamel was set (Fig. 5). The boundary