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ANALYSIS OF STRESS IN THE PERIODONTIUM (PDL) OF MANDIBULAR SECOND PREMOLAR WITH A THREE – DIMENSIONAL FINITE ELEMENT MODEL

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1. Introduction

The special area of dentistry – orthodontics concerned with the correction of anormalus tooth position. Orthodontic tooth movement results from the application of forces to teeth. These forces are produced by the appliances (wires, brackets, elastics, etc.) inserted and activated by the clinician. The teeth and their associated support structures respond to these forces with a complex biologic reaction that ultimately results in the tooth movement through bone. When a force is applied to a tooth, areas of pressure and tension are created in the the attachment apparatus – periodontium. In areas of pressure created in the direction of the applied force, bone is resorbed; and in oposite direction at tension sites, bone is formed. The cells of the periodontium, which respond to the applied forces are unaware of the appliances design – their activity is based solely on the stresses and strain occuring in their enviroment [1]. In order to achieve a precise biologic response, one would have to apply precise mechanical stimuli. Minimizing or eliminating the unknown factors related to the delivery of forces in periodontium can reduce the variability in treatment response.

The aim of this study was to simulate the stress response in the periodontium of mandibular second premolar to different orthodontics load by means of the finite element method.

2. 3D FE model of mandibular second premolar

The FE model of mandibular second premolar was designed to dissect the periodontal ligament, tooth, and alveoral bone separately (Fig. 1). The PDL, tooth and alveoral bone are all deformable entities under loads. Stress in the PDL is believed to be the initiating factor in tooth movement, and a range of stresses are transmitted to the alveoral bone through the PDL.

3D geometries constructing of mandibular second premolar is complicated by its shape. The geometrical model of a tooth was created by using

MicroStation Modeler software, and based on the dimensions of sample tooth of mandibular second premolar [2]. The height of the tooth was 22.5 mm, mesiodistal and buccopalatal width of the crown were 7mm and 8mm respectively. The root length was 14.5mm. The periodontal membrane (Fig. 1) was simulated as 0.2 mm thick layer around the root [3].

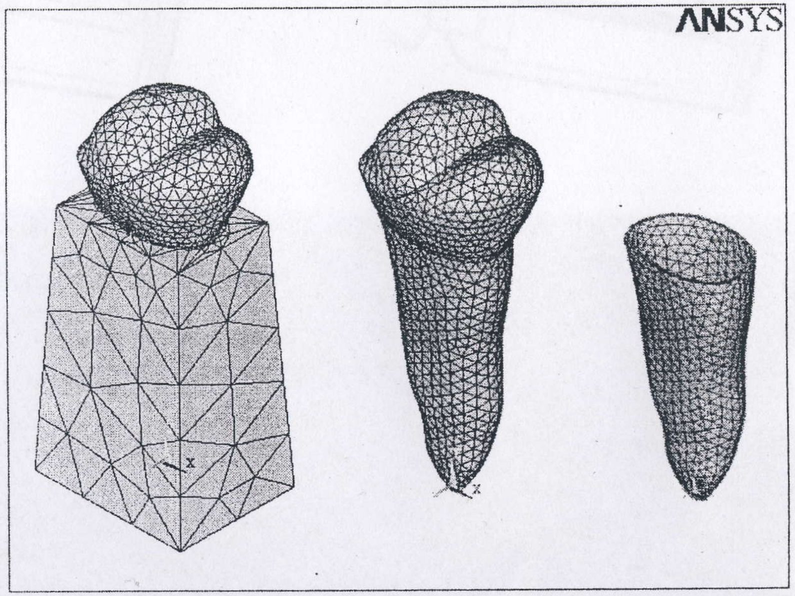

Fig. 1 3D FE model of mandibular second premolar: alveolar bone, tooth, PDL

The 3D FE model (Fig. 1), comprising a mandibular second premolar, PDL, and alveoral bone, consisted of 19989 nodes and 28162 isoparametric tetrahedral structural solid elements (Solid 92) (Fig. 2). The element is defined by ten nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions [4]. The software ANSYS 5.6 for WINDOWS was used on a Pentium II.

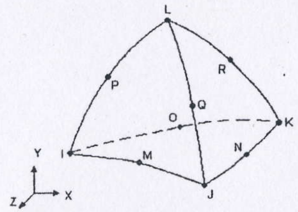

Fig. 2 Finite element (Solid 92)

The boundary conditions were defined to prevent the model from free body motion. The nodes on the bottom boundary surface of the bone were fixed (no degrees of freedom). The orthodontic force applied at the center of the buccal surface of the crown. Three different types of loads realizing orthodontics force were used (Fig. 3). In the first case the load of 30g single force was applied perpendicular to bucal surface to tip the tooth linqually, in the second – the same amount of force was applied vertically to extrude the tooth, and in the third case – the tooth was rotated by 75.3 g·mm force couple. In this study, the maximum principal stress, which is the maximum normal stress without a shear-stress component, was used to describe the pattern because it is best to represent the compressive state of stress.

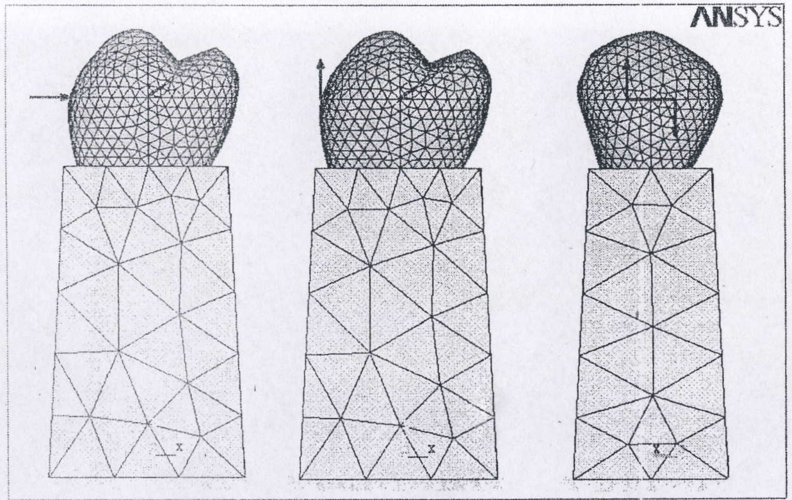

Fig. 3 Three different types of loads

The mechanical properties of the periodontal ligament, tooth, and alveoral bone based on previous studies [5] are shown in Table.

Table

Mechanical properties

Material	Young's modulus E, [Pa]	Poisson's ratio, ν
Tooth	$2\cdot10^{10}$	0,15
PDL	$1,8\cdot10^{6}$	0,49
Alveoral bone	$1,4\cdot10^{10}$	0,15

The limitation of this model involve approximation in the material behaviors and geometries of the tissue. The stress-strain relationship of the tissues were assumed linear-elastic and isotropic. The viscous nature of the PDL comes from the tissue fluid, and the elastic behavior from fibers. The anisotropy from the orientation of the fibers. Studies have been done to examine viscoelastic behavior of the PDL which is characterized by time-dependent strain [4]. In this model, the tooth was simplified as homogeneous, because force transmission to the PDL is not significantly changed by the internal design of the tooth due to its much high stiffness relative to the PDL. Another limitation comes from the approximation of root geometries. Variations in root morphology and the PDL thickness may affect stress value and distribution.

3. Results

Figs. 4 through 6 show the changes in stress paterns in the periodontium in response to different load types.

In the first case of load the tooth rotates about its centre of rotation. The high concentration of tension (σ_1=27357 Pa) is observed at the bucal side servical region. The high concentration of compression (σ_1=17232 Pa) is at the reverse side (Fig. 4).

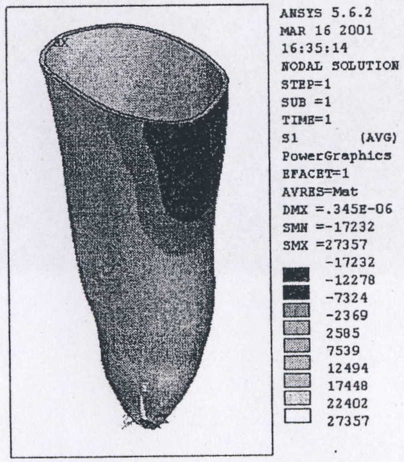

Fig. 4 Stress distribution in PDL under force (F=30 g) turn to lingual direction

In the second case of load the tooth extrudes and rotates about centre of rotation. The high concentration of tension (σ_1=34596 Pa) is observed at the root apex region. The high concentration of compression (σ_1=5935 Pa) is observed at the mesial side servical region (Fig. 5).

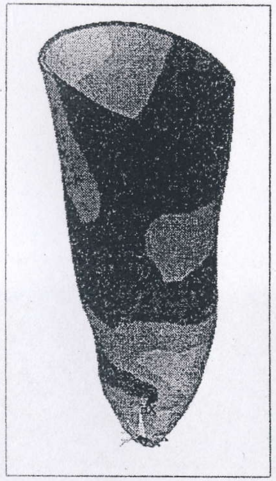

Fig. 5 Stress distribution in PDL under force (F=30 g) turn to occlusal direction

Then the tooth was acting by couple force it rotates about long axis. The high concentration of tension (σ_1=4854 Pa) and compression (σ_1=5181 Pa) is observed at the mesiodistal surface (Fig. 6).

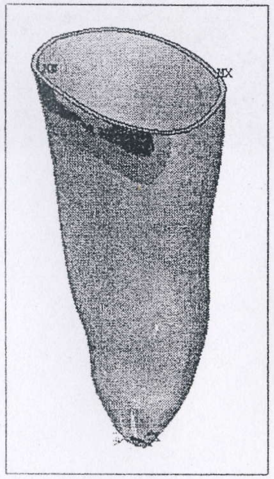

Fig. 6 Stress distribution in PDL under force couple (M=75.3 g·mm)

4. Conclusions

1. The presentation of stress contours in the PDL of mandibular second premolar show, that the location of tension and compression in the PDL was dependent on the load type.
2. The shape of the root influence the stress distribution significantly with different loads.
3. FEM can be a powerful computational tool with great flexibility in modelling geometries and mechanical behaviours of biological tissues.
4. Knowledge of the stress-strain principles in the periodontium is necessary for the improving orthodontic mechanotherapy in order to avoid side effects generated during the treatment.

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Summary

The stress distribution in the periodontium of mandibular second premolar was analysed with 3D FE model. The FE model of mandibular second premolar was designed to dissect the periodontal ligament, tooth, and alveolar bone separately. The software ANSYS 5.6 for WINDOWS was used.

The bottom boundary surface of the bone was fixed. Three different types of loads realizing orthodontic force were used. Maximum principal stress contours in the PDL of mandibular second premolar are presented.

Key words: Finite Element tooth model, orthodontic force, periodontium stress analysis.