Stress Analysis in the Periodontium of the Maxillary Canine in Translatory Movement with a Three Dimensional Finite Element Method

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Abstract: The aim of this study was to simulate the stress distribution in the periodontium of the maxillary right canine during translatory movement and determination of optimum the moment to force ratio (M/F)for bodily movement by the three dimensional finite element method(FEM).The assumption in this study was that materials behaves linearly elastically. The three dimensional finite element model of canine was constructed on the basis of Wheeler's average of anatomy and morphology and consisted of 89402 element and 101872 nodes .The model was designed to dissect the periodontal . ligament,pulp,dentin, cortical and cancellous bone separately Various distal crown moments were applied with a constant 1 newtone distal force at the center of the labial crown surface of canine to determine the optimum M/F ratio for bodily movement of canine. The pattern and magnitude of stresses in root, PDL and alveolar bone were showed: The optimum M/F ratio for bodily movement was 10/8.7. During bodily movement,the stresses were either tensile or compressive at mesial or distal levels, although stresses varied from cervical to apex. High stress concentration area was observed at the cervical levels not at the apex. The maximum stresses were at the cervical and centre of periodontium and minimum stresses were at apical level. This findings differs from previous studies that have described uniform stress for translation. This difference is arised from the shape of our model which is not uniform. The findings would suggest that even with perfect orthodontic appliances it would be difficult to obtain canine pure bodily movement. It is suggested that the force magnitude which is used should be less than one newtone to decrease stresses and high stress concentration points.

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Key word: Stress Analysis, Canine retraction, Bodily or Translator Movement, Finite Element Method (FEM), Orthodontic Forces

Introduction

To clarify the mechanism of orthodontic tooth movement, many studies have investigated the changes in the periodontal tissue from histologic [(1-2)], histochemical and biochemical [(3),]physiologic and bioelectrical and biomechanical[(3-4)] view points. It is well known that the initiating factor for the biologic change is the stress induced in the periodontal tissue ;therefore, it is important to investigate the stress level from the orthodontic forces in the periodontal tissue .However, because of the complexity of a stress analysis or experimental technique, little information is available on the stress induced in the periodontal tissue when an orthodontic force is applied. The finite element method (FEM), which was introduced as one of the numerical analysis [(5),]has become a useful technique for stress analysis in biologic systems. In the general field of medicine, FEM has been applied mainly to orthodontic research [(6-7)] in which the mechanical responses of bony structures relative to external forces were studies .Furthermore, some research[(8)] has been carried out in order to investigate the soft tissue and skeletal responses to mechanical forces. The application of FEM in dentistry have been found in studies by Thresher and Saito, Konell, Tanne and Sakuda, Cook and Klawitter and etc [(3).] It has been shown in previous studies [(3-6-7-8)] that the finite element method can be applicable to the problem of the strain-stress levels induced in internal structures. This method also has the potential for equivalent mathematic modeling of a real object of complicated shape and different materials. experimental techniques are limited in measuring the internal stress levels of PDL. Strain gauge techniques[(9)] may be useful in measuring tooth displacement; however,they cannot be directly placed in the PDL without producing tissue damage. The photoelastic techniques[(9)]are also limited in determining the internal stress levels because of the crudeness of modeling and interpretation. The force systems that are used on an orthodontic patient can be complicated. The FEM makes it possible to analytically apply various force systems at any point and in any direction. Experimental techniques on patients or animals are usually limited in applying known complex force system. It is very important to keep in mind that the FEM will give the results based upon the nature of the modeling system and, for the reason,the procedure for modeling is most important. In this study only the linear-elastic behaviors of the tooth-periodontal structures are considered. During tooth movement non linear elastic, plastic and viscoelastic phenomen can occur [3-5-8-9-10]. In orthodontics, FEM was used successfully to model the application of forces to single-tooth system .Canine retraction has been modeled by use of FEM .The stress distribution in PDL were quantified during canine retraction in several studies .The purpose of this study was to elucidate the three dimensional distribution of stress in the peridontium when distally directed force are applied for bodily movement.

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Material and Method

Initial stress distribution from the application of an orthodontic force was investigated by the FEM on the maxillary right canine. A three dimensional finite element model was constructed on the basis of Wheeler's average of anatomy and morphology (Table:1) [11]. This model perfectly designed the same as human canine .It is the difference between this study and other studies .Three soft ware program used in the analysis were solid work 2003, Auto CAD and Ansys v.8.0(2004).This model consisted of 89402 isoparametric element and 101872 nodes. The model was designed to dissect the periodontal ligament, pulp, dentine, cortical and cancellous bone separately. The mechanical properties of this model which were based on previous studies are given in (Table .2). The thickness of PDL was simulated as a

2.5 mm layer around the root . Mesiodistally force of 100 g (1 newton) with various moments was applied at the center of the buccal crown surface at the position of bracket to determine the optimum moment-to-force(M/F) ratio for bodily movement and it was 10/8.7. Stresses (kg/mm2) were calculated and present in colorful contour bands; different colors represent different stress level in the deformed state. Positive or negative values in the column of stress spectrum indicated tension or compression, respectively. The stresses were determined at the surface of the root, PDL (normal,principal [s1.s3] and shear stresses),cortical and cancellous bone (principle stress [s1,s3].

Results

Figures (1,2) show principal stresses in root .The maximum and minimum normal stress was in cervical and apical third of distal side of root respectively. The maximum principal stress(s1) was observed on the distal side of the root between cervical and middle third (fig 1).Concentration of principal stress(s3)was observed on the distal side of the root between cervical and middle third and on mesial side it was on cervical (fig 2).Stress distribution in the other points was approximately uniform. Fig(3) showed stress distribution in PDL that it was on mesial side more uniform than distal. The PDL showed tension on the mesial surface and compression on the distal surface. Maximum and minimum principal stress (sx) on the distal side of the PDL was in cervical and apical respectively. Maximum and minimum shear stress in PDL (sxz) was in cervical and middle third respectively (4). Maximum and minimum principal stress (s1,s3) were in cervical and apical of distal side of PDL respectively(5). Figures (6,7,8,9) are shown principal stress (s1,s3) in cortical bone. Stress distribution on mesial side was more uniform than distal side .Figures(10,11) are shown principal stress(s1,s3) in cancellous bone. These result indicated that stress distribution was not uniform on distal side. Orthodontic department, Dental School of Zahedan, Tirandazi Ave, Zahedan, Iran

Table 1. Dimensions of maxillary canine

	Cervico-incisal length of crown	Length Of Root	Mesio-distal Diameter of Crown	Mesio-distal Diameter of Crown at Cervix	Labio-or Bucco-lingual Diameter of Crown	Labio-or Bucco-lingual Diameter at Cervix	Curva-ture of Cervical line-Mesial	Curva-ture of Cervical line-Distal
Dimensions suggested for carving technique(in mm)	10.0	17.0	7.5	5.5	8.0	7.0	2.5	1.5

Table 2.

Material		Youngs Modulus	Poissons Ratio
Tooth	Enamel	8.25×10^3kg/mm^2 (841×10^4N/mm^2)	0.33
	Dentine	1.8×10^3kg/mm^2 (1.83×10^4N/mm^2)	0.31
	Pulp	0.2kg/mm^2 (2.03N/mm^2)	0.45
PDL	PDL	6.8×10^{-2}kg/mm^2 (6.9×10^{-3}N/mm^2)	0.49
Alveolar Bone	Cortical	33.8×10^3kg/mm^2 ($3.433.8\times10^4$N/mm^2)	0.26
	Cancellous	1.35×10^3kg/mm^2 ($1.3733.8\times10^4$N/mm^2)	0.38

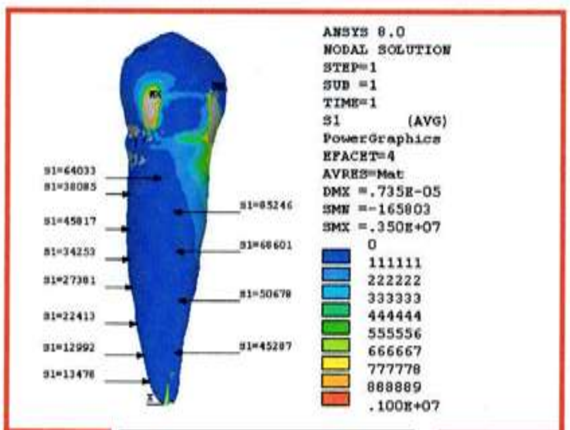

Fig.: 1 stress S_1 from labial view

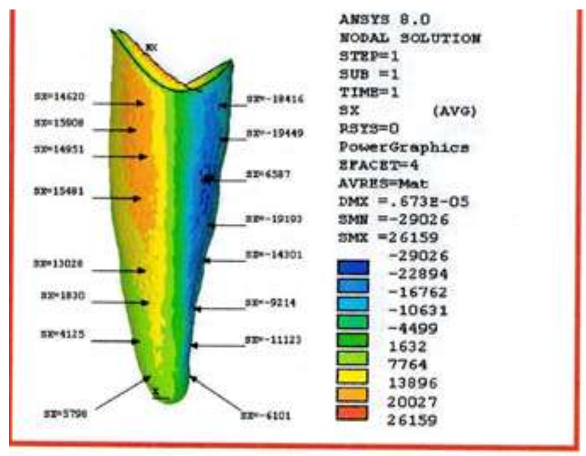

Fig.: 3 stress of S_x in PDL from labial

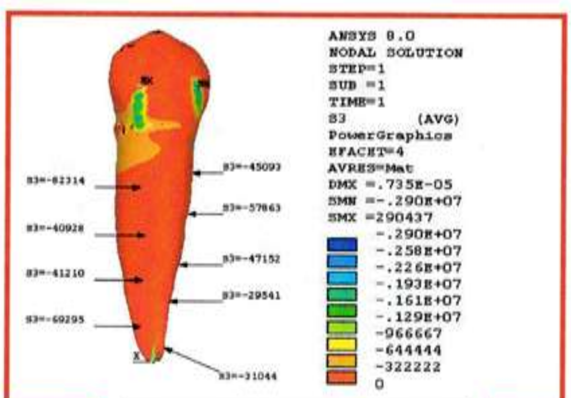

Fig.: 2 stress of S_3 from labial view

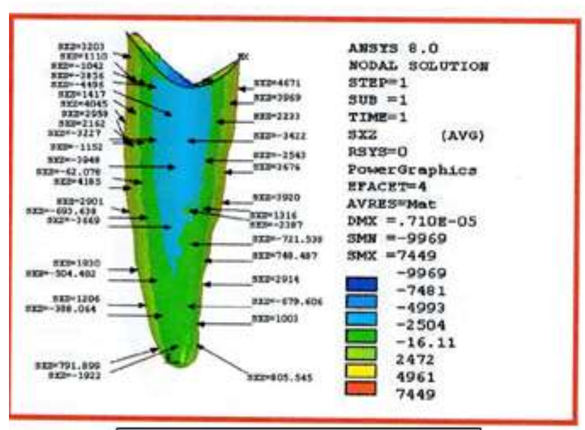

Fig.: 4 stress of S_{xz} in PDL from labial view

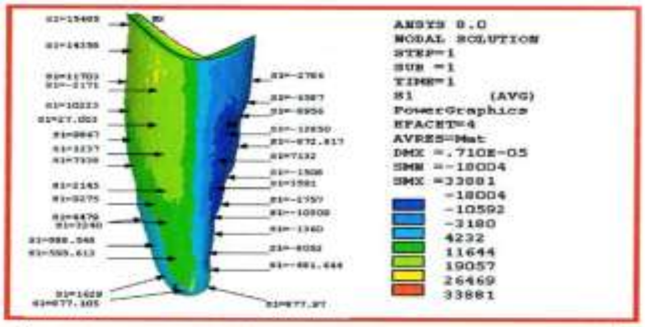

Fig.: 5 stress of S_1 in PDL from labial view

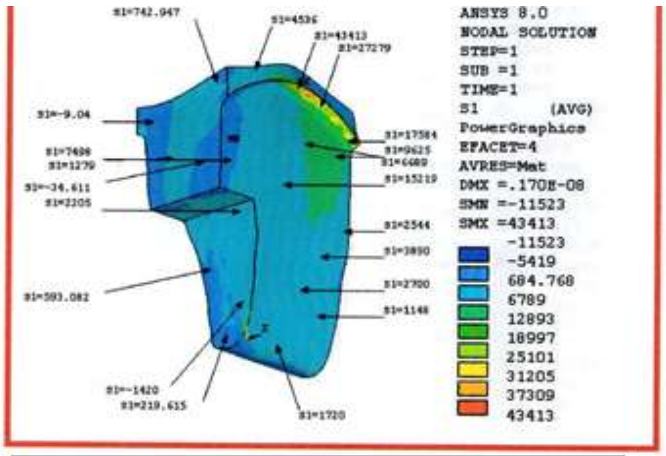

Fig.: 6 stress of S_1 in compact bone from labial and mesial view

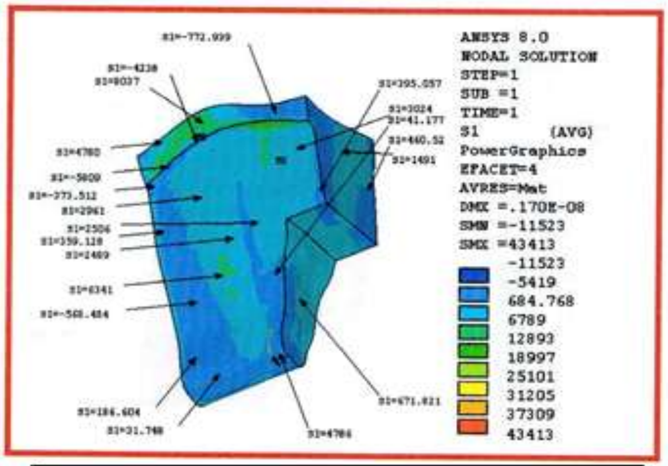

Fig.: 7 stress of S_1 in compact bone from lingual and distal view

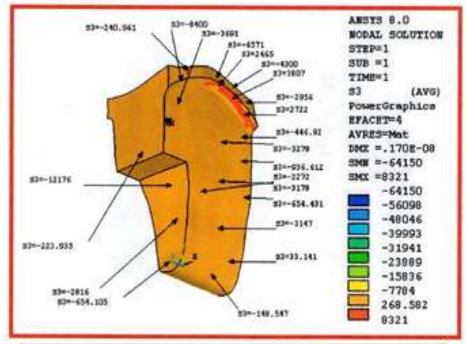

Fig.: 8 stress of S_3 in compact bone from lingual and mesial view

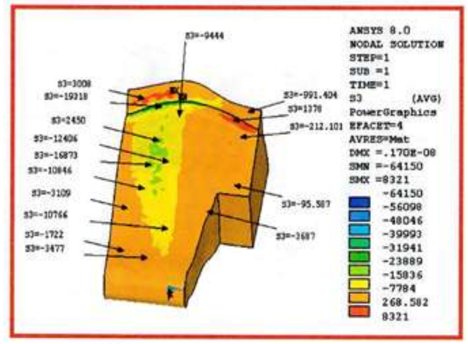

Fig.: 9 stress of S_3 in compact bone from lingual and distal view

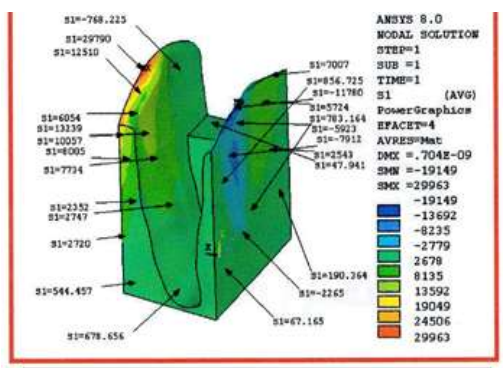

Fig.: 10 stress of S_1 in cancellous bone from labial and distal view

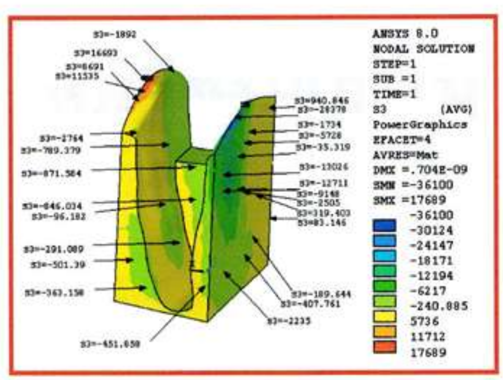

Fig.: 11 stress of S_3 in cancellous bone from labial and distal view

Discusion

Large bending stresses acting at most parallel to the root were found at the surface of root and distal side of cancellous and cortical bone .These stresses on the bone can be related to bodily movement of canine. Stress distribution in mesial side was more uniform than distal because shape of the root on the mesial side was more regular than distal .Although stresses varied from the cervix to apex,they were more constant than in tipping movement .It confirm that bodily movement may be more physiologic, which suggested in the previous histological studies because of the lower and more uniform stress distribution in the periodontium. An important finding is that, although the stress is more uniform in translation in the PDL, it does vary some what, being highest at the center of the root. This finding is similar to Cobo and Tanne's study but it differs from previous studies that have described uniform stress for translation(9-10-12).Stress distribution in Cobo and Tanne's study was more uniform than our study because our model was constructed perfectly same as human teeth whereas their model had conic shape without any curvature and our model consist. Overall, the highest stress were observed on the root, secondary on the alveolar bone, and finally in the PDL, which most likely was caused by the differences in the mechanical properties of these structures. It was similar to Tanne's study(lower first premolar) but it was different from Cobo's study (lower canine)(10-12) ted of 89402 elements and 101872 nodes. The PDL was modeled as a layer of uniform thickness(2.5 mm)and was treated as a linear-elastic and isotropic,even thought the PDL exhibits anisotropic and nonlinear viscoelastic behavior because of tissue fluid (13-14-15-16-17-18). It should be examined in further studies. In our study, stress concentrated more at the alveolar crest that is similar to previous study (19,20,21,22,23) .

Overall, the highest stress were observed on the root, secondary on the alveolar bone, and finally in the PDL, which most likely was caused by the differences in the mechanical properties of these structures. It was similar to Tanne's study(lower first premolar) but it was different from Cobo's and Hemanth’s study that stress value in PDL was less than the other structures (10,12,23) .In bodily movement forces concentrate at the alveolar crest not at the apex for this reason the talent of resorption may be more than other sites.

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Conclusion

1.Stress distribution in PDL, teeth and supporting bone is not uniform because of irregular shape of these structures.

2.It is suggested that the force magnitude which is used should be less than one newtone to decrease stresses and high stress concentration points.

3.In bodily movement maximum stress was at cervical not at the apex.

4.The highest stress were observed on the root, secondary on the bone and finally in PDL.

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