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Comparison of Periodontal Stresses in Maxillary Anterior Teeth by Two Methods of En-Masse Retraction: A 3-D Finite Element Analysis

Dr. Abhishek Jain[1], Dr. Garima Jain[2], Dr. Madhuli Bhide [3], Dr. Manoj Tiwari[4], Dr. S. Vidhya Bharathy[5], Dr. Purvi Kothari[6]

[1]Associate Professor, Department of Orthodontics and Dentofacial Orthopaedics, Mansarovar Dental College, Bhopal MP, India (Corresponding Author)

[2]Associate Professor, Department of Periodontics, Rishiraj College of Dental Sciences and Research Centre, Bhopal MP, India

[3]Resident Orthodontics, Eastman Institute for Oral Health, Rochester NY, USA

[4]Associate Professor, Department of Periodontics, Mansarovar Dental College, Bhopal MP, India

[5]Assistant Professor, Department of Orthodontics and Dentofacial Orthopaedics, Priyadarshini Dental College and Hospital, Thiruvallur, Tamilnadu, India

[6]Post Graduate Resident, Department of Orthodontics and Dentofacial Orthopaedics, Mansarovar Dental College, Bhopal MP, India

Corresponding Author: Dr. Abhishek Jain

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KEYWORDS

Periodontal Stresses, FEM, En-Masse Retraction, Mini-Screw Implant

ABSTRACT:

Introduction: Periodontal ligament, tooth, and alveolar bone react as deformable entities under loads. Stresses in the PDL believed to be the starting factor in tooth movement, and various types of stresses are transmitted to bone through the PDL. Therefore, it is essential to consider these tissues as continuous unit to help in quantitative assessment of stress and strain in periodontium. FEM provides an approximate solution for response of the 3-dimensional (3D) structures to applied external loads under certain boundary conditions.

Materials and Methods: Total of four models were created i.e. two models with retraction by elastomeric chain and two models with retraction by NiTi coil spring with help of implant placed at 3 mm and 5 mm height from alveolar crest. Results were represented in the form of stress diagrams.

Results: En-masse retraction with elastomeric chain showed more periodontal stresses. Increasing the height of mini-screw implant was also associated with increase in periodontal stresses.

Conclusions: For the same height of mini-screw implant, en masse retraction with elastomeric chain demonstrated a higher amount of periodontal stresses as compared to NiTi coil springs. The highest stress throughout the PDL was always present around cervical area in both types of en-masse retraction, indicating that cervical area, apart from apex, bears the most loads and might be considered as susceptible area for potential tissue damage. Increasing height of mini-screw implant more gingivally associated with more amount of periodontal stresses in both types of en-masse retraction.

Introduction

In the past many studies have been conducted to clarify the mechanism of tooth movement under the influence of orthodontic forces, which included the changes in the periodontium from histologic, histochemical and biochemical, physiological and bioelectrical and biomechanical standpoint.[1] In the conventional methods

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for study of biomechanics, the tooth is considered as a free non-deformable body which is separated from the periodontal ligament (PDL) and bone. The periodontal ligament, tooth, and alveolar bone react as deformable entities under loads. Stresses in the PDL believed to be the starting factor in tooth movement, and various types of stresses are transmitted to bone through the PDL. Therefore, it is essential to consider these tissues as a continuous unit to help in quantitative assessment of the stress and strain in the periodontium. The major problem in this advanced approach is the construction of complicated three-dimensional geometries of these tissues with different biomechanical properties. These properties of the periodontium make the finite element method the most useful means of analysis because of its ability to manage various shapes and material nonhomogeneity.[2] It is very difficult to measure stresses accurately in vivo and to achieve an analytical solution for problems involving complicated geometries like the maxilla and the mandible, which are exposed to different kinds of loads. FEM provides an approximate solution for the response of the 3-dimensional (3D) structures to the applied external loads under certain boundary conditions. It appears to be suitable for simulating complex mechanical stress situations in the maxillofacial region.[3] The aim of this study was to compare the stress distribution in periodontal ligament of maxillary anterior teeth with two methods of en-masse retraction i.e. NiTi coil spring and elastomeric chain, with mini-screw implants placed at various heights using finite element analysis.

Materials and Methods

Finite Element Method (FEM) is an advanced electronic tool for stress analysis, having the advantage of being applicable to solids of irregular geometries with heterogeneous material properties. The FEM helps the orthodontist by providing quantitative data which can extend the understanding of physiological reactions which occur within the dento-alveolar complex.[4]

Basic steps involved in carrying out FEM are[4]:

1. Pre-processing.
a. Construction of the geometric model
b. Conversion of the geometric model into a finite element model.
c. Assembly/Material Property data representation.
d. Defining the boundary conditions.
e. Loading Configuration.
2. Processing.
3. Post-processing.

For this FEM study total four finite element models were developed i.e. two models demonstrating en-masse retraction by elastomeric chain with the mini-screw implant placement at 3 mm and 5 mm height respectively from alveolar crest and two models with en-masse retraction by NiTi coil spring with mini-screw implant placement at 3 mm and 5 mm height from alveolar crest. To develop the irregular geometry of the tooth structure, tetrahedron shape was chosen as the finite element. This element is more suitable for meshing irregular geometries. These elements are connected with each other at the nodes. This study includes the total 294124 elements and total no. of nodes were 66448. The different structures involved in this study include periodontal ligament, alveolar bone, teeth, elastomeric chain, nickel titanium coil spring, stainless steel arch wire and hook and titanium mini-screw implant. Each structure comes with a specific material property. These material properties are the average values provided in the literature (Table-1).

Table: Material Properties

Material	**Young' s Modulus N/mm2**	**Poisson's ratio**
Tooth[6]	2.0×10^{3}	0.30
PDL[6]	6.8×10^{-2}	0.49
Alveolar Bone[6]	1.4×10^{3}	0.38
Bracket[6]	21.4×10^{3}	0.30
Arch wire/ hook[6]	21.4×10^{3}	0.30
NiTi coil spring[3]	110×10^{3}	0.35
Mini Implant[3]	110×10^{3}	0.35
Elastomeric Chain[7]	0.025×10^{3}	0.5

After development of four finite element models, a constant en-masse retraction force was applied in each model i.e. 150 grams bilaterally from mini-screw implant to hook (power arm) of 3 mm height placed between the maxillary lateral incisor and canine.[5]

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Results

The result of an analysis is called Post Processing. The stress patterns in periodontal ligament were assessed when retraction force of 150 grams was applied by two methods i.e. NiTi coil spring and elastomeric chain. Stresses (MPa) in the periodontal ligament during en-masse retraction were calculated and presented in the form of stress diagrams; eight different colors represented different stress levels in the deformed state. Red color column of spectrum indicates the maximum principal stress and dark blue color spectrum represent the lowest level of the same.

Periodontal Stresses with Elastomeric Chain

When the retraction was carried out with mini-implant placed at the height of 5 mm the maximum amount of periodontal stresses (0.006 MPa) were seen in the cervical third of root of lateral incisors (figure. 1). The stress values decreased from cervical to apical areas. The stress in the canine was mainly concentrated in cervical third with no or minimal stresses in middle or apical third of the PDL. Central incisors showed no or very minimal stresses (<0.001 MPa). When the retraction was carried out with mini-implant placed at the height of 3 mm (figure. 2) the amount of periodontal stresses decreased significantly with the maximum stress seen in the cervical third of root of canine (0.00002 MPa). There were very minimal stresses in the middle third of the root and no stresses in the apical area. Lateral incisors experienced lesser stress (0.00001 MPa) mainly in the cervical third. No stresses were seen in the central incisors.

Periodontal Stresses with NiTi Coil Spring

When the retraction was carried out with mini-implant placed at the height of 5 mm (figure. 3) the increased periodontal stresses (0.002 MPa) were seen in the cervical third of lateral incisors as compared to that with elastomeric chain. The stress values decreased from cervical to middle thirds. Stresses were more uniformly spread in the middle third of PDL as compared with that from elastomeric chain. Lesser (0.001 MPa) value of periodontal stress was seen in the canines but it was uniformly distributed in the PDL except the middle third where no or minimal stresses were present. Central incisors showed no or very minimal stress. When the retraction was carried out with mini-implant placed at the height of 3 mm (figure. 4) the least amount of periodontal stresses (0.000002 MPa) were seen in the cervical margins of canines and lateral incisors. Most of the PDL showed lesser values of stresses (0.000002 MPa) spread all over the PDL including the remaining cervical areas of lateral incisors and canines as well as whole PDL of central incisors.

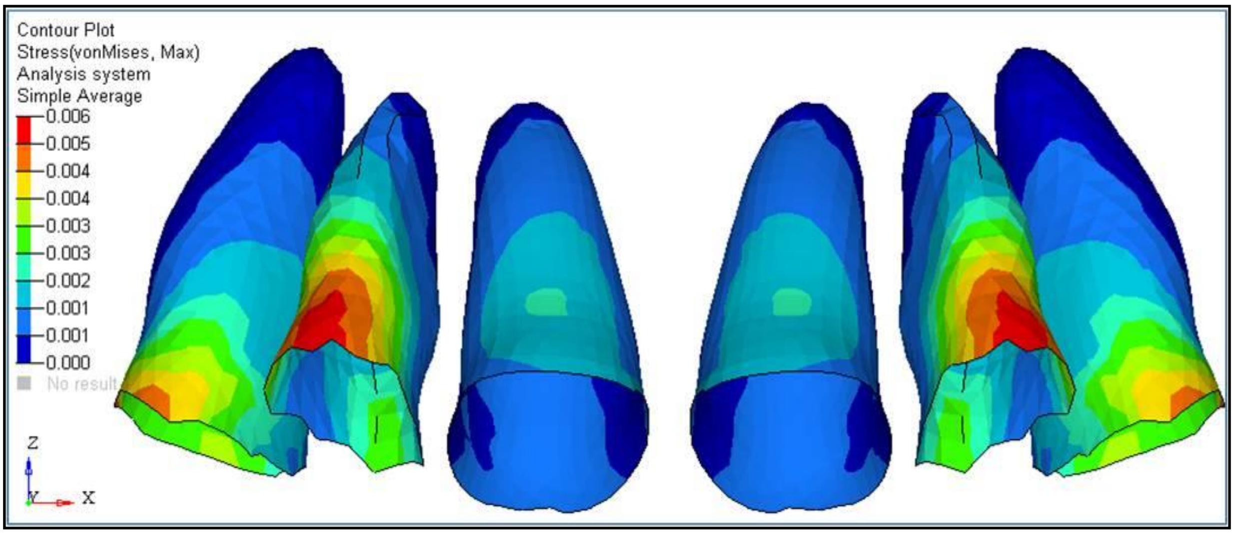

Figure. 1 – En-masse retraction with elastomeric chain with mini-screw implant placement at 5 mm

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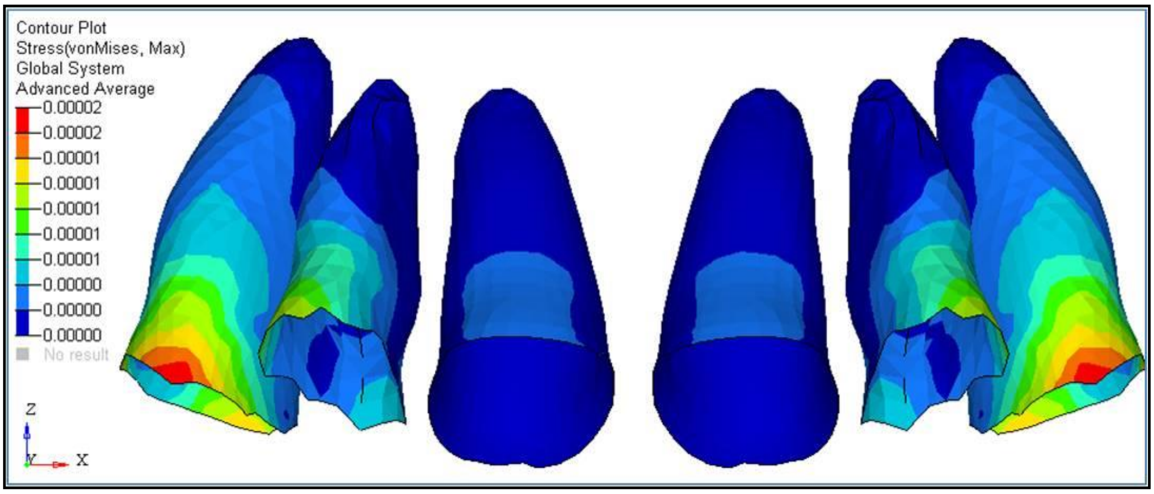

Figure. 2 – En-masse retraction with elastomeric chain with mini-screw implant placement at 3 mm

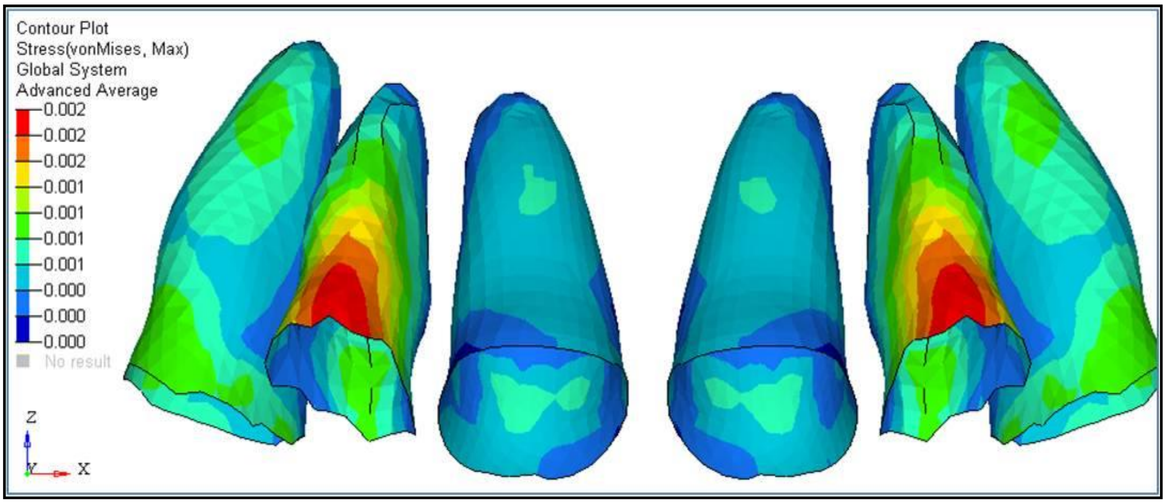

Figure. 3 – En-masse retraction with NiTi coil spring with mini-screw implant placement at 5 mm

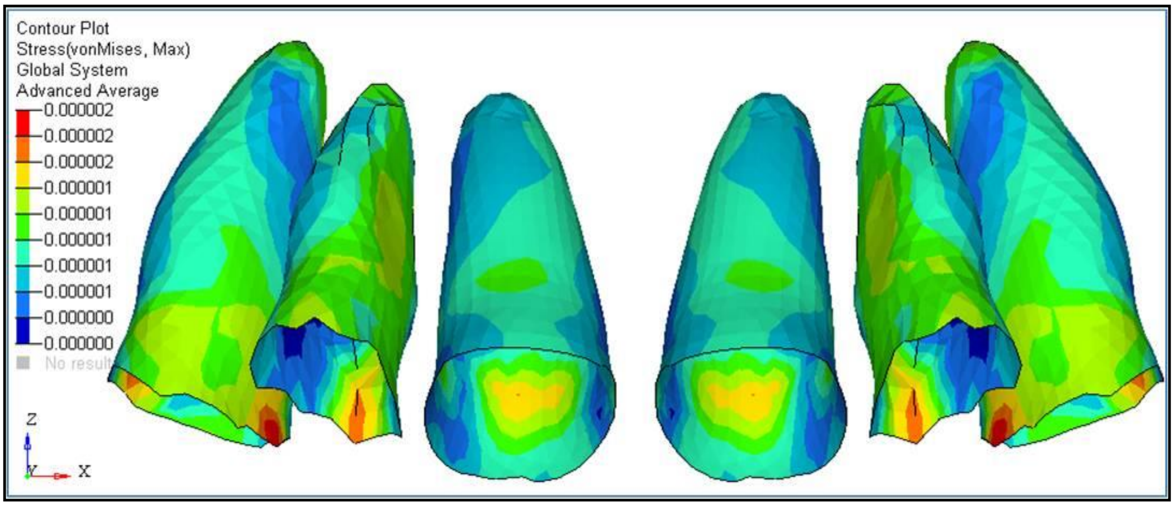

Figure. 4 – En-masse retraction with NiTi coil spring with mini-screw implant placement at 3 mm

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Discussion

Biomechanical considerations play a crucial role in orthodontics. After the application of external force in the oral environment, the development of unwanted stresses is anticipated in the tooth, periodontium and its related structures which may lead to unsuccessful outcomes.[8] When an orthodontic force is applied to dentoalveolar structures consisting mainly the tooth, periodontal ligament and its surrounding bone structures, stresses of differential nature are generated in its vicinity.[9] Area under the compressive stress shows alveolar bone resorption while areas with tensile stress show bone apposition.[10] The stresses generated in the periodontal ligaments of anterior teeth were found to be different with each technique of retraction. The stresses generated during retraction with NiTi coil spring were of lesser value as compared to the stresses generated with the elastomeric chain with the same height of mini-screw implant placement. This could be attributed to the difference in physical properties of elastomeric chain and NiTi coil spring. Also there was difference in the values of stresses when the position of mini-screw implants were changed. As the mini-screw implant was moved more apically, the value of stresses was increased. This difference can be due to change in force vector from horizontal to more vertical. For the same height of mini-screw implant, en-masse retraction with NiTi coil spring showed lower amount of periodontal stresses as compared to elastomeric chain.

In all the study models, the maximum amount of stresses were found to be concentrated at the cervical third area of the PDL which was supported by the studies of Tanne et al[1] and Jing Yan et al[11] who suggested that initial phase of tooth movement is associated with stresses on the PDL mainly on the cervical area which declined towards the apex. According to the Studies by Rudolph et al[12], and Field et al[13], in translation movement, the stress distributed more even throughout the PDL and the root. Darendeliler et al.[14] and Chan et al.[15] studied the root resorption after force application and demonstrated that root resorption occurs more frequently in high-pressure zones. According to them, in the alveolar region root resorption was 2.66 times while apex showed no significant change between the light-force group (25 g) and heavy-force group (225 g). With the combination of these results, it indicates that the cervical region bears greater stresses and can be one of the most susceptible areas for potential tissue damage, especially during tipping type of tooth movement.

Conclusions

1. For the same height of mini-screw implant, en masse retraction with elastomeric chain demonstrated a higher amount of periodontal stresses as compared to NiTi coil springs.
2. The highest stress distribution throughout the PDL was always present around the cervical area in both types of en-masse retraction, indicating that cervical area, apart from apex, bears the most loads and might be considered as a susceptible area for potential tissue damage.
3. Increasing the height of mini-screw implant towards more gingivally is associated with more amount of periodontal stresses in both types of en-masse retraction.

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