Location of centre of resistance and centre of rotation with variatioin in root length by finite element method

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Abstract

Background & Objectives: Patterns of initial displacement of a tooth may be influenced by such anatomic variables as dimension of the tooth, alveolar bone, width of periodontal ligament space, and mechanical properties of the periodontium. Variations in root length modify biomechanical behaviour of a tooth when subjected to orthodontic forces. Thus it is of clinical significance to understand the optimal force considerations for patients with altered crown – to – root ratio. This study is designed to evaluate maxillary central incisor and lateral incisor considering only variation in root length, locating centre of resistance, centre of rotation, and displacement of the tooth.

Methods: Seven two Dimensional element models of an upper central incisor and five two dimensional element model of an upper lateral incisor were designed. The mechanical properties (Poisson's ratio, Young's Modulus) of the PDL, tooth and Alveolar bone were obtained from previous studies. The boundary conditions were defined to simulate how the model was constrained and to prevent it from free body motion. For all the above mentioned models, a force of 100gm was applied to the Labial surface of the tooth crown at each phase of the study at 5.5mm apical in respect to incisal edge (this was presumed to be the location of the bracket). The point of force application was centered mesiodistally.

Result and conclusion: As the root lengthy increased the centre of resistance shifted more cervically and as the root length decreased the centre of resistance shifted more apically.Displacement of the root apex increased with short root length.

Keywords: Centre of Resistance, Centre of Rotation, Finite Element Method.

INTRODUCTION

"There is a far greater need for understanding how orthodontic applications affect their treatment than there is, at this time, for any new treatment methods".

- ROBERT E, MOYERS

In Orthodontics the nature of tooth displacement is of great interest in terms of optimal force application and subsequent tooth movement. Patterns of initial displacement of a tooth may be influenced by such anatomic variables as dimension of the tooth, alveolar bone, width of periodontal ligament space, and mechanical properties of the periodontium. Variations in root length, modify biomechanical behaviour of a tooth when subjected to orthodontic forces. Thus it is of clinical significance to understand the optimal force considerations for patients with altered crown – to – root ratio[1].

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The finite element method (FEM) is a highly precise technique used to analyse structural stress. Its ability to handle material in homogeneity and complex shapes makes the FEM the most suitable method for the analysis of stress in the periodontium[1]. In addition, the FEM provides information about point-wise (nodal) displacements. It is therefore expected that the FEM may be capable of analysing systematically and quantitatively the biomechanical tissue response.[2] Finite element analysis has been used in dentistry to investigate a wide range of topics, such as structure of teeth, biomaterials and restorations, dental implants and root canals.

The force system is currently the major factor that the orthodontist can control to achieve desirable orthodontic tooth movement. It is clinically useful to relate tooth movement with orthodontic force systems generated from various appliances at the bracket on the crown of a tooth, although this force system can be defined at any arbitrary point on the tooth[3]. When we apply mechanics for tooth movements in a biological environment the mechanics involved is termed as "Bio-mechanics". The biological responses to the mechanics in the oral cavity are varied hence this requires a clear understanding of bio-mechanics.

This study was designed to evaluate maxillary central incisor and lateral incisor considering only variation in root length, locating centre of resistance, centre of rotation, and displacement of the tooth. The maxillary central & lateral incisors were chosen because these teeth undergoes the most detailed tooth movement and are at higher risk for root resorption[4].

MATERIALS AND METHODS

Seven two Dimensional element models of an upper central incisor and five two dimensional element model of an upper lateral incisor were designed. A Quadrilateral element was used to evaluate, This Quadrilateral element consisted of 8 Nodes [Quad. 8 Node 183 according to ANSYS].

The average anatomic data for upper central incisor and lateral incisor were based on the Dental Anatomy text book by Wheeler. The height of the central incisor [distance from apex of the root to the incisor edge] was 23.5mm and the mesiodistal and labio palatal width of the crown was 8.5mm and 7mm respectively (Fig 1) the root length was considered to be 13mm. The root length was varied by 1mm from 10mm to 16mm respectively, keeping crown length constant. The height of lateral incisor [distance from apex of the root to the incisor edge] was 22mm and the mesiodistal and labio-palatal width of the crown was 6.5mm and 5mm respectively (Fig. 2). The root length was varied by 1mm from 11mm to 15mm respectively, keeping crown length constant. The PDL was simulated as 0.2mm thick layer around the root. The computer program used for the analysis was ANSYS program. In the present study, all materials were assumed to be isotropic and elastic.

The mechanical properties (Poisson's ratio, Young's Modulus) of the PDL, tooth and Alveolar bone were obtained from previous studies, 5, 6 . The material constants are shown in the Table I. The boundary conditions were defined to simulate how the model was constrained and to prevent it from free body motion.

Fig. 1: Central Incisor measurements

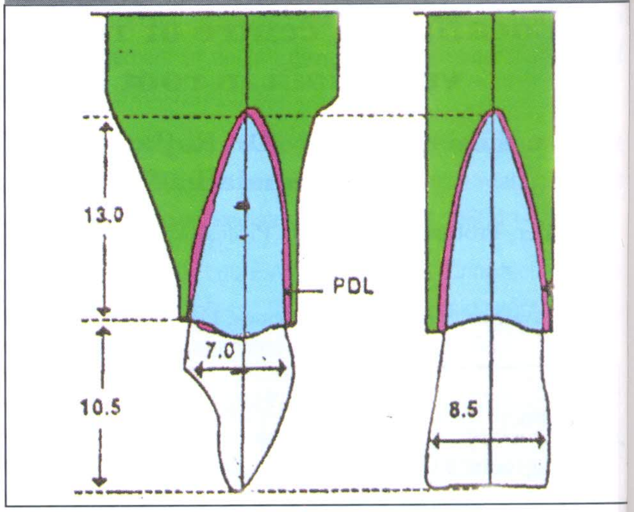


Fig. 2: Lateral Incisor measurements

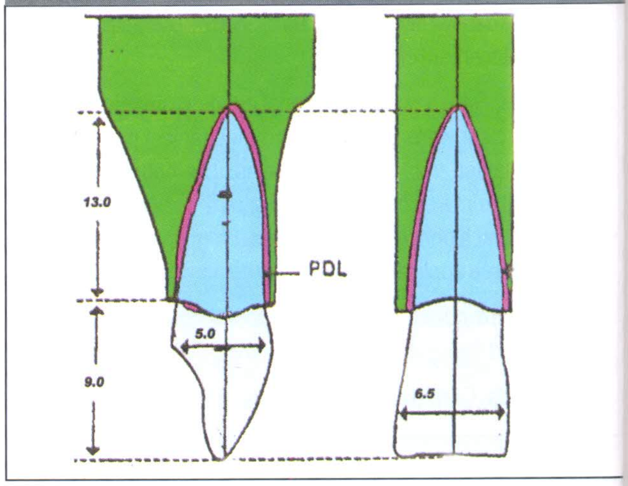


Fig. 3: FEM Models Showing Centre of Resistance and Centre of Rotation Andapical Displacement In Central Incisor Model

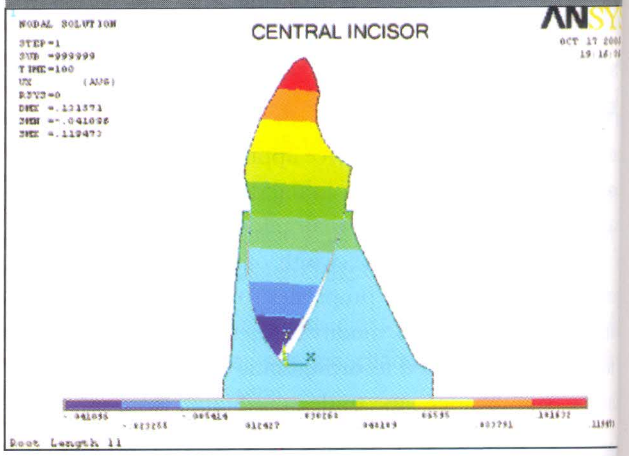


FIG 4: FEM Models Showing Centre of Resistance and Centre of Rotation Andapical Displacement in Lateral Incisor Model

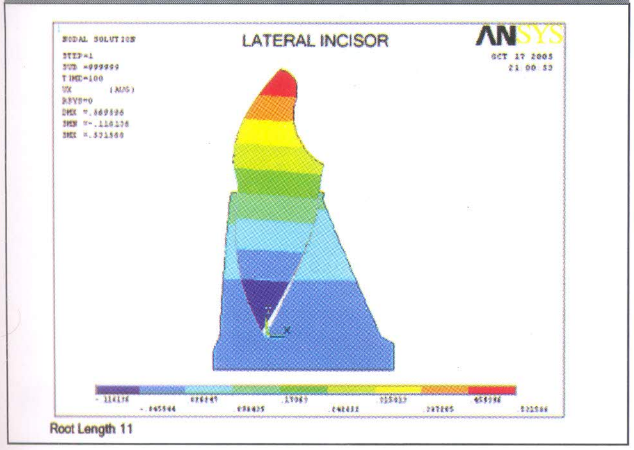


Table 1: Mechanical Properties for the Structural Elements

Material Young's	Modulus (kg/mm^2)	Poisson's Ratio
Tooth	2 x 10	0.30
PDL	6.8 x 10	0.49
Alveolar	1.4 x 10	0.30

RESULTS

As root length was increased from 13mm to 14mm, 15mm and 16 mm thecentre of resistance shifted cervically and was found at a distance of 5.2mm, 6.8mm, 6.9mm from the root apex, respectively. As the root length was decreased from 13mm to 12 mm and 11mm then centre of resistance was located more apically at 2.8mm and 2.0mm respectively. (Table II and IV).

The center of rotation was found at 4.5mm from the apex and showed no significant variations as the root length was increased to 14 mm, 15mm and 16mm. As the root length was decreased to 12mm, 11mm and 10mm. The center of rotation was found at 2.5mm from the apex and showed no significant variation with decrease in the root length. The displacement of tooth apex increased with shorter root length. Basedon the statistical analysis a regression equation was derived to locate the center of resistance and center of rotation as shown in graph 1, 2, 3 and 4 respectively. Using this equation the location of centre of Resistance and centre of Rotation can be calculated with variation in root length (TABLE III).

DISCUSSION

Trying to understand and predict the complexities involved in the response of teeth to forces and moments has always been challenging in orthodontics. There are many techniques to study the effect of force on the dento-alveolar complex such as strain gauge technique, laser holographic technique and photo elastic studies.[7] These techniques involved the inter dependency between the applied force system and initial tooth displacement. These studies were based on planar models and tried to predict the behavior of a tooth by setting up and solving a set of differential equations. However the handicap was that the equations fail to mimic the role of periodontal ligament.

The finite element analysis was selected for this study because it has the following advantages[2].

1. It is a non-invasive technique.
2. The periodontal ligament model can also be generated.
3. The actual physical properties of the materials involved can be simulated. Thus this method is nearest one that could possibly get to simulate the oral environment in-vitro.
4. The actual stress experienced at any given point can be measured.
5. The actual displacement of the tooth can be visualized.
6. Reproducibility does not affect the physical properties of the involved material and the study can be repeated as many times as desired.

Table 2: Characteristics of the Model Used in the Study of Central Incisor

Model	Root Length (mm)	No. of Elements	No. of Models	Center of Resistance (From Apex to Alveolar crest)	Center of Rotation (From Apex to Alveolar crest)
1	10	671	1967	2.5	2.3
2	11	814	2382	2.73	2.5
3	12	916	2589	2.8	2.8
4	13	829	2396	3.4	3.5
5	14	690	1992	5.2	4.2
6	15	902	2272	6.8	4.6
7	16	994	2510	6.9	4.8

Table 4: Characteristics of the Model used in the study of Lateral Incisor					
Model	Root Length (mm)	No. of Elements	No. of Models	Center of Resistance (From Apex to Alveolar crest)	Center of Rotation (From Apex to Alveolar crest)
1	11	811	2299	6.8	5.9
2	12	832	2352	7.0	5.8
3	13	892	2522	8.5	6.0
4	14	919	2587	9.2	6.5
5	15	1047	2951	9.8	6.6

Table 3: Changes in Initial Tooth Displacements Associated with Various Root Lengths							
	10	11	12	13*	14	15	16
APEX	-1.09	-1.06	-1.03	1	-0.98	-0.95	-0.92
CERVIX	1.03	1.02	1.01	1	0.99	0.97	0.94
INCISAL EDGE	1.06	1.04	1.02	1	0.94	0.93	0.87

(Comparative Displacements with an Average Root Length of Central Incisor)
Root Lengths (in mm) *An Average root length from Wheeler

Table 5: Changes in Initial Tooth Displacements associated with various Root Lengths					
	11	12	13*	14	15
APEX	-1.01	-1.03	1	-0.65	-0.75
CERVIX	1.02	1.01	1	0.75	0.80
INCISAL EDGE	1.03	1.02	1	0.85	0.90

(Comparative Displacements with an Average Root Length of Central Incisor)
Root Lengths (in mm) *An Average root length from Wheeler
(Text book of Dental Anatomy, Physiology and Occlusion, 9 th Edition)

Present study showed that there was greater displacement of the apex with decrease in the root length which can probably lead to root resorption and excessive injury to the periodontal ligament.Similarly the study conducted by Tanne et al[7] showed that patients with short embedded roots due to substantial alveolar bone loss, the displacement of the tooth increased 16.5 times with approximately 19%, 38% & 50% alveolar bone loss. This finding was further confirmed by the study conducted by A. Geramy[8] on Maxillary Central Incisor with Various Alveolar Bone Heights, the displacement of the tooth increased from 1.46 to 44.2 times with approximately 8 to 61 % alveolar bone loss.

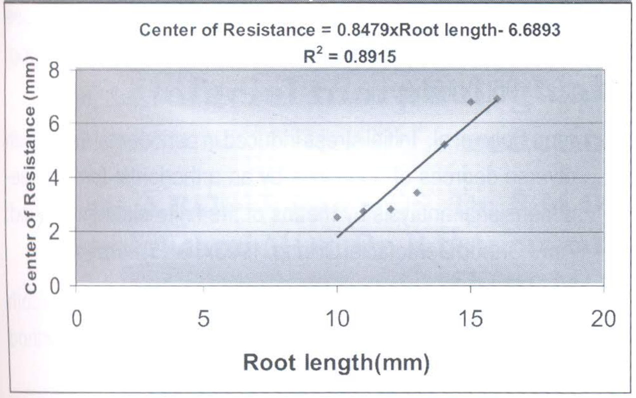
The location of the Centre of Resistance is important because, when there is a decrease in the root length or a variation in the alveolar bone height due to periodontal disease, there is a shift of the Centre of Resistance more to the apical region, making the use of smaller orthodontic force mandatory. As the Centre of Resistance shift apically, a given force will generate a large moment. Anticipating this magnitude of force applied should be manipulated. A clinical study by Boyd R.L reports a slight loss of periodontal attachment in adults or adolescents during treatment wit fixed orthodontic appliances. This results in an increase crown-to-root ratio.[9]

For uncontrolled tipping of a tooth, the center of rotation i located between center of resistance and the root apex. Fo controlled root movement, the center of rotation is at inciso edge. Present study showed that the center of rotation i apically to center of resistance in case of increased roo length. So for a desired tooth movement it is important t predict the location of center of rotation and center o resistance so that undesirable tooth movements can b controlled.

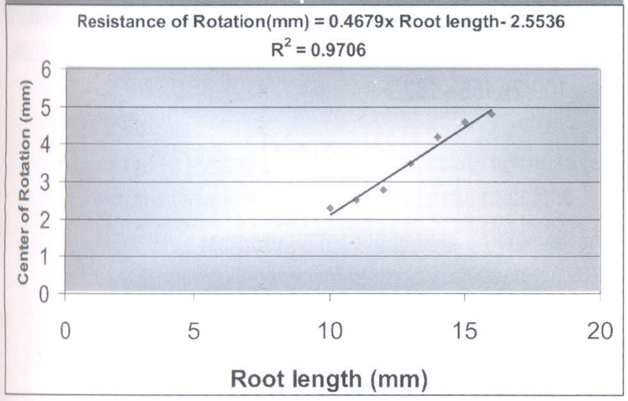
Limitations:

The limitations of our model include approximation in th material behaviour and shapes of the tissues. Similar t previous studies,[1,5,7,10,11] the PDL was modeled as a layer o uniform thickness(0.2mm) and was treated as linear-elasti and isotropic, even though the PDL exhibits anisotropy an nonlinear viscoelastic behavior because of tissue fluid. There are no reliable and adequate data that pertain t anisotropic and nonlinear properties of the PDL. The effe

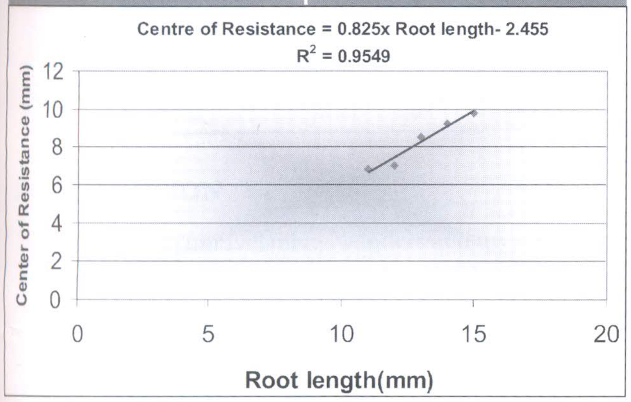
Graph 1



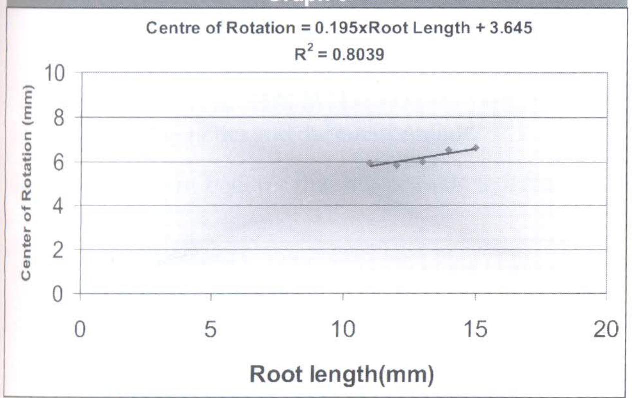
Graph 2



Graph 3



Graph 3



of anisotropy of bone and the PDL on the stress in the periodontium should be examined in further studies. In the periodontally compromised patients, PDL properties may vary significantly with times due to continuous remodeling process. The tooth was simplified as a homogenous body because force transmission to the PDL is not significantly affected by adding the internal structure because of its greater stiffness relative to the PDL. The shape of the tooth described in this study represents the most common morphologic features of a maxillary central incisor and lateral incisor. However, the wide variation in morphologic condition such as shape of the roots, among normal individuals may affect the applicability of the analysis.

Clinical implications:

With increased number of adults seeking orthodontics, the orthodontist need to consider the periodontally compromised status of patients. Reduction in the alveolar bone decreases the embedded root length which in turn leads to the center of resistance shifting more apically thus lighter forces can produce larger moments and large tooth displacements. Hence orthodontics needs modifications in the appliance and the force levels in the treatment mechanics.

CONCLUSION:

1. As the root length increased the Center of Resistance is shifted more cervically.

2. As the root length decreased the Center of Resistance shifted more apically.

3. This study showed that there was no variation in the position of Center of Rotation.

4. The displacement of the tooth apex increased with shorter root length.

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