Research Article

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Evaluation of Apical Stress Distribution in Maxillary Lateral Incisor with Different Root Morphologies on Application of Vertical Forces: A 3D Finite Element Study

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ABSTRACT

Background: To investigate stress distribution patterns at the root apex of maxillary lateral incisor having various types of root morphologies with regard to application of orthodontic forces in the vertical plane using the finite element method.

Materials and Methods: Finite element models of maxillary lateral incisor with different root morphologies (normal, short, long, blunt, dilacerated and pipette) were constructed and orthodontic forces in vertical direction (Intrusion & Extrusion) were applied to the tooth axis at the bracket level.

Result: On application of extrusive force, significantly increased stress pattern was seen at the root apex with pipette, dilacerated and long shaped root morphology respectively and maxillary lateral incisor with blunt and short root morphology shows increased stress distribution pattern at the root apex during intrusion.

Conclusion: The current study concluded that the maxillary lateral incisor with deviated root morphology are at higher risk of root resorption due to increased stresses at the root apex.

Keywords: Root morphology; Maxillary lateral incisor; Finite element model.

INTRODUCTION

Orthodontics has evolved over the years from an empirical art to a definitive science. The goal of orthodontic treatment is to improve patient's life adjustment through enhancement of dentofacial functions and esthetics.[1] Orthodontically induced inflammatory root resorption is a pathologic consequence of orthodontic treatment. Its occurrence may be of little significance when mild, fortunately severe root resorption is relatively rare.[2] Apical root form, short roots and signs of previous root resorption are risk factors for root resorption.[3]

According to Butler, the theory predicts that the third molars and the maxillary lateral incisors show the highest amount of variability in size and shape.[4] Studies have shown that an association between apical stresses and movement of the root apex may be expected during orthodontic tooth movement.[3] Maxillary lateral incisors are often missing,

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misshaped or small. Particular shapes that recur have been identified (e.g. peg and barrel) and systems have been established so that dental anthropologists can nominally categorize misshaped teeth[5].

Oppenheim explained that the increased tendency to root resorption of the maxillary lateral incisors is because the extent of movement by these teeth which is usually greater than other teeth. Their root structure and relation to bone and periodontal membrane tend to transfer the forces mainly to the root apices.[6] Weekes and Wong observed that root resorption occurred at the interproximal region of the cervical third part of the root after extrusion, demonstrating that orthodontic extrusion is not without risk. The lack of data on this subject indicates that further research on root resorption in relation to extrusion is still required.[7]

One analytical approach to studying stress during tooth movement, one that allows for reasonable approximation of the biological tissues, is the finite element model (FEM). With finite element analysis (FEA), valuable information can be obtained, since various orthodontic clinical conditions can be simulated, and stress distribution in the individual constituents of the periodontium can be evaluated qualitatively and quantitatively. Thus, the purpose of the current study is to investigate the stress distribution patterns at the root apex of maxillary lateral incisor having various types of root morphologies with regard to application of orthodontic forces in the vertical plane using the finite element method.

MATERIALS AND METHODS

MATERIALS

1.Typhodont model having a maxillary lateral incisor.

2.Altair Hyper Mesh software used in Windows operating system.

3.Digitized Fixed orthodontic appliance: Pre adjusted edgewise appliance. (MBT prescription 0.022 slot), stainless-steel ligature and archwires.

METHOD

1. Preparation of Finite Element Model

Three-dimensional finite element model systems of permanent maxillary lateral incisor having a crown length of 9mm and root length of 13mm based on the data derived from Wheelers Dental Anatomy, Physiology and Occlusion[8] and their variations in root morphology as classified by Levander and Malmgren[9] were prepared using the Altair Hyper Mesh software version.

Table 1: Description of the various models prepared using the Finite element method.

Finite Element Models	Root shapes
Model A	Normal root (13mm)
Model B	Short root (10mm)
Model C	Long root (16mm)
Model D	Blunt root
Model E	Dilacerated root (13mm with a bend at apex)
Model F	Pipette shaped root

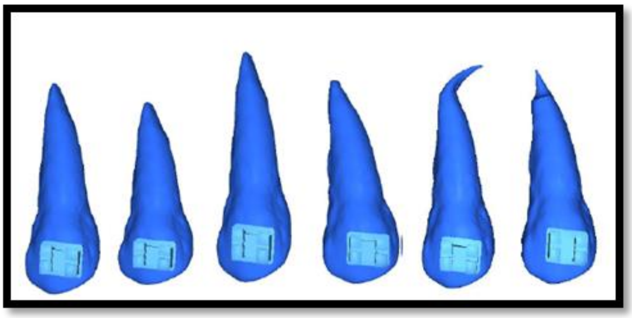

Fig 1: Finite element models of maxillary lateral incisor used in this study.

2. Material Properties

Each structure of the maxillary lateral incisor (i.e. the enamel, dentin and pulp, periodontal ligament and cancellous bone) was meshed using an auto-meshing routine in the finite element analysis program .The material properties of enamel, dentin, PDL and bone used in this study have been experimentally determined. The material properties used are the average values reported in the literature (Table no II).

Table 2: Material properties used in FEM study.

	YOUNG'S MODULUS	POISSON'S RATIO
ENAMEL	8.41×10^4	0.33
DENTIN	1.83×10^4	0.30
PDL	6.90×10^{-1}	0.45
BONE	1.37×10^4	0.30

3. Boundary conditions and solution

Computer aided designed (CAD) model of the maxillary lateral incisor was converted into finite element model. This process is called Meshing or Mesh generation. Tetrahedron elements were created on this CAD model and Mesh was generated using Altair Hyper Mesh software.

The number of nodes and elements used in generating the finite element model are described in the table below (Table III).

Table 3: Number of nodes and elements used in this study.

Tooth model	Number of Nodes	Number of elements
Normal	10486	42754
Short	8058	36472
Long	12357	49260
Blunt	9836	41553
Dilacerated	14641	63365
Pipette	16281	45529
Bracket	3057	12818

Experimental orthodontic forces in the vertical plane were applied to the surface, assuming a bracket base, on the labial crown surface, which are normally applied in clinical practice[10] (Table IV).

Table 4: Description of orthodontic forces used in this study.

Force type	Force magnitude	Direction
Intrusion	15g	Force acting parallel to the long axis and towards the apex of tooth from center of crown.
Extrusion	50g	Force acting parallel to long axis and towards the incisal edge of tooth from center of the crown.

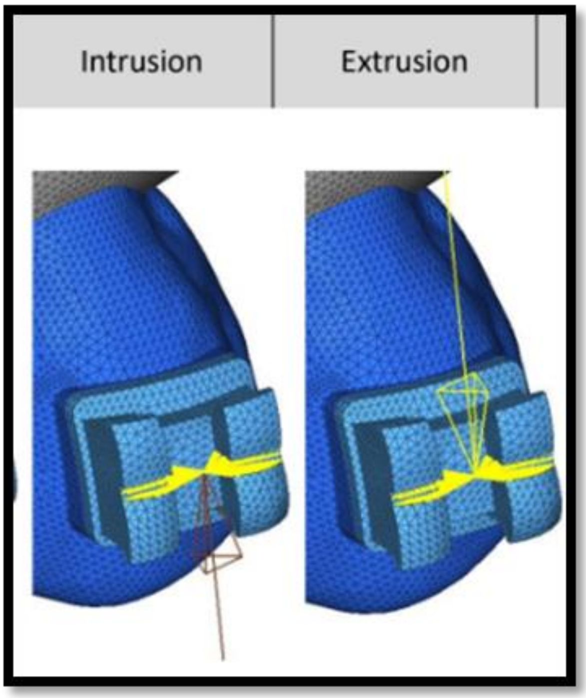

Fig 2: Various orthodontic forces applied within the boundary conditions of FEM.

RESULTS

This three-dimensional finite element study was based on the stresses generated at the root apex of the maxillary lateral incisor having various root morphology by application of orthodontic forces and evaluation of stress patterns in each of the finite element model. The von Mises stresses generated at the root apex are graded by severity with respect to different orthodontic tooth movements as follows (Table V).

Table 5. Severity of apical stress graded as per different orthodontic tooth movements.

Type of tooth movement	Levels of stress pattern (MPa)		
	Mild	Moderate	Severe
Extrusion	0.00-0.07	0.07-0.14	0.14-0.21
Intrusion	0.01-0.02	0.02-0.04	0.04-0.06

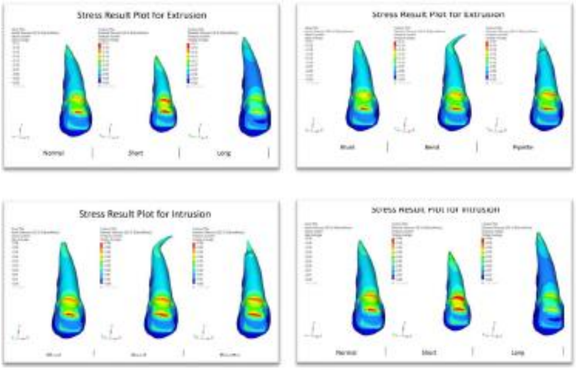

Fig 3: The pattern of computed von Mises stress distribution in the various root models at the root apex during extrusion and intrusion.

Table 6: Comparison of magnitude of von Mises stresses in various root morphologies during different force application.

	Normal	Short	Long	Blunt	Dilacerated	Pipette
Extrusion	0.023	0.034	0.057	0.021	0.044	0.084
Intrusion	0.077	0.092	0.017	0.102	0.013	0.025

DISCUSSION

In this current experimental study, orthodontic forces were applied to six FEM's of maxillary lateral incisor with various root shapes and their stress distribution pattern at the root apex was evaluated. The forces were applied to the labial crown surface assuming a bracket base for intrusive and extrusive tooth movements that are normally used in clinical practice.

In Model A with normal root morphology, mild stress levels are seen at the root apex during extrusion and moderate stress levels during intrusion. In Model B with short root morphology, mild stress levels are seen during extrusion and severe stress levels are seen during intrusion. This finding can be related to the alteration in the crown/root ratio, where a decrease in the ratio of the root to the crown is thought to enhance loading of the root, resulting in a significant amount of stress at the root apex.

In Model C with long root morphology, mild stress patterns were observed during intrusion and extrusion. As per Mirabella and Artun[3], a positive but weak co-relation was found between initial tooth length and the amount of root resorption, thus, a longer root was more likely to be resorbed than a shorter root.

In Model D with blunt root morphology, mild stresses were observed during extrusion while intrusive tooth movements showed severe stress levels at the root apex. In a review conducted by Dindaroglu & Dogan[11] they concluded that the geometrical forms of roots can affect the distribution of the forces through the alveolar bone and root. The forces are more concentrated on localized areas in trigonal sharp apices than in roots with a normal shape and increased resorption was seen in blunt root shapes, especially in a maxillary lateral incisor.

In Model E with a dilacerated root morphology, mild stress levels were observed during intrusive & extrusive tooth movements. Nanekrungsan et al[12] stated that dilacerated or pointed roots were highly significant risk factors for EARR. There are possible explanations for why dilacerated and pointed roots have more EARR. Dilacerated roots are more likely to be resorbed than normal roots, since more force is orthodontically applied to move or torque dilacerated roots.

In Model F having pipette shaped root morphology, moderate stresses at the root apex were seen during intrusion and extrusion. This finding is in accordance to the study conducted by Taithongchai et al[13] which concluded that a significant inverse relationship was shown for the size of the root and the amount of apical root shortening where, smaller roots suffered a greater amount of apical root shortening.

Several authors has shown that roots with abnormal shape have a higher susceptibility to root resorption. As per Nigul and Jagomagi[14], dilacerated and pipette shaped root have more root resorption than normal and blunt roots. This finding has been confirmed in a study conducted by Oyama et al.[15]An increased or decreased risk of root resorption might be associated with an interplay of mechanical and biological factors. Mechanical factors such as extensive tooth movement, root torque and intrusive forces, type of tooth movement, duration and type of force and biological factors such as genetic susceptibility, systemic disease and medication intake has been demonstrated to influence root resorption. Thus, root resorption cannot be considered through one parameter as it is supposed to have multifactorial etiology.

The three-dimensional finite element method used in this study provides the liberty to simulate orthodontic force systems applied clinically and allows analysis of the response of the dentition to the orthodontic loads in three-dimensional space. The point of force application, magnitude and direction of force may easily be varied to simulate the clinical situation. The results of this study were obtained from a simulated model, from which biological variabilities may occur. The resultant values found in the current study should be interpreted only as a reference to help in clinical judgment

CONCLUSION

The results of this study using three-dimensional finite element model of maxillary lateral incisor with various root morphologies during different orthodontic tooth movements shows varied stress distribution patterns at the root apex in each of them. There are no significant stress levels in normal and long root morphology. Maxillary lateral incisor with short root morphology shows increased stress distribution at the root apex during intrusion. Blunt, short and pipette shaped roots are seen to be the most affected root morphologies, followed by dilacerated root.

CONFLICTS OF INTEREST

The authors declare they have no potential conflict of interests regarding this article.

REFERENCES

1. Ong MM, Wang HL. Periodontics and orthodontic treatment in adults. American Journal of Orthodontics and Dentofacial Orthopedics. 2002 Oct 1;122(4):420-8.

2. Nigul K, Jagomagi T. Factors related to apical root resorption of maxillary incisors in orthodontic patients. Stomatologija. 2006;8(3):76-9.

3. Mirabella AD, Artun J. Risk factors for apical root resorption of maxillary anterior teeth in adult orthodontic patients. Am J Orthod Dentofacial Orthop. 1995;108:48–55.

4. Butler P. M. Studies of the mammalian dentition. Differentiation of the post-canine cheek dentition. Journal of Zoology ,1939,109B, 1}36.

5. Yoon Ah Kook, Soher Park, Glenn Sameshima (2003), Peg-shaped and small lateral incisors not at higher risk for root resorption, American Journal of Orthodontics and Dentofacial Orthopedics, Volume 123, Number 3.

6. Costopoulos G, Nanda R. An evaluation of root resorption incident to orthodontic intrusion. American Journal of Orthodontics and Dentofacial Orthopedics. 1996 May 1;109(5):543-8.

7. Middleton J, Jones M, Wilson A. The role of the periodontal ligament in bone modeling: the initial development of a time dependent finite element model. Am J Orthod Dentofacial Orthop. 1996;109:155–162.

8. Ash M, Stanley NJ, Nelson J. Wheeler's Dental Anatomy, Physiology and Occlusion, 8th ed. St Louis, MO: Saunders Publishers; 2004.

9. Levander E, Malmgren O. Evaluation of the risk of root resorption during orthodontic treatment: a study of upper incisors. The European Journal of Orthodontics. 1988 Feb 1;10(1):30-8.

10. Linge, B.O. and Linge, L. (1983) Apical root resorption in upper anterior teeth. European Journal of Orthodontics, 5, 173–183. 20.

11. Dindaroğlu F, Doğan S. Root resorption in orthodontics. Turkish journal of orthodontics. 2016 Dec;29(4):103.

12. Nanekrungsan K, Patanaporn V, Janhom A, Korwanich N. External apical root resorption in maxillary incisors in orthodontic patients: associated factors and radiographic evaluation. Imaging science in dentistry. 2012 Sep 1;42(3):147-54.

13. Taithongchai R, Sookkorn K, Killiany DM. Facial and dentoalveolar structure and the prediction of apical root shortening. American journal of orthodontics and dentofacial orthopedics. 1996 Sep 1;110(3):296-302.

14. Nigul K, Jagomagi T. Factors related to apical root resorption of maxillary incisors in orthodontic patients. Stomatologija. 2006;8(3):76-9.

15. Oyama K, Motoyoshi M, Hirabayashi M, Hosoi K, Shimizu N. Effects of root morphology on stress distribution at the root apex. The European Journal of Orthodontics. 2007 Apr 1;29(2):113-7.