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RESEARCH ARTICLE

PATTERNS OF STRESS DISTRIBUTION IN DIFFERENT ROOT MORPHOLOGIES ON TIPPING – A 3D FINITE ELEMENT STUDY

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ABSTRACT

Background And Objective: The objective of this study was to access the stress patterns in the periodontal ligament of a central incisor with different root morphologies on different orthodontic loads, using the linear, non-linear and viscoelastic finite element analysis and to quantify the optimal force levels for roots with different root morphologies.

Materials and Method: A finite element model of a maxillary central incisor with different root morphologies was taken and 60g of tipping forces were applied. The stress patterns and magnitude in the periodontal ligament was observed for linear, non-linear and viscoelastic properties of the PDL and were compared with the optimal stress range (0.012-0.020 MPa).

Results: It was observed that, the stress patterns produced in the PDL on tipping were similar for linear, nonlinear and viscoelastic properties of the PDL. The magnitude of stress, varied for all three analyses. For 60gms of tipping forces, it was seen that, the stress produced were least in linear and highest in viscoelastic analyses. The force applied was decreased in increments of 0.1 gms by iteration, to obtain an minimal stress in the periodontal ligament (0.012 Mpa). It was observed that the force levels had to drop down by two fold in viscoelastic analysis in tooth with different root morphologies.

Conclusion: From the results obtained, it was observed that the force levels required to produce the same amount of stresses in the PDL of a upper incisor, were the least in viscoelastic analysis, followed by non linear and the maximum in linear analysis. The optimal force levels recommended for tipping in central incisor with normal root morphology is in accordance with the normal values given by Profitt, but optimal force levels varies in tooth with different root morphologies. Considering that the viscoelastic properties depicts a more realistic behaviour of the PDL, the force levels have to be closely monitored when teeth with different root morphologies is encountered.

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INTRODUCTION

Orthodontic tooth movement is a complex procedure based on force-induced remodelling of periodontal ligament and alveolar bone. An optimal orthodontic force is one that enables maximum movement of teeth with minimum damage to tooth and supporting structures (Schwarz, 1932). However, some studies have reported that orthodontic forces are never distributed equally throughout the periodontal ligament (PDL) (Remington et al., 1989; Brezniak et al., 2002). The optimal force for tooth movement may thus differ for each tooth morphologies, for each individual patient and for different types of tooth movement. Forces beyond optimal threshold can cause pain, increased mobility, pulp devitality, and root resorption (Schwarz, 1932; Remington et al., 1989; Brezniak et al., 2002; Brudvik, 1994; Henry, 1951).

Root resorption commonly affects the maxillary laterals, maxillary centrals as they travel a longer distance (Brudvik, 1994). Teeth with abnormal root morphologies (Mirabella, 1995; Parker, 1998; Ngan et al., 2004) frequently shows external root resorption, compared to normal root morphology because stress is concentrated at a particular region of the root. Root resorption have been investigated ranging from 2-D to 3-D techniques which provide measurements with inherent[11-13] Finite element method is a highly precise technique to analyze structural stress (Brudvik, 1994) in the roots, PDL, and trabecular bone upon application of different loads (Brudvik, 1994). The method can incorporate linear, nonlinear and visco elastic properties to better understand the mechanical behaviour of thePDL (Oyama et al., 2007). Till date no biomechanical study has been done that documents the influence of different orthodontic forces (tipping) on various root morphologies (normal, short, blunt, dilacerated and pipette) during orthodontic force application.

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Thus, the present study aims to analyse the effects of tipping on central incisor with different types root morphologies using FEM model.

MATERIALS AND METHODS

Computational facilities used for the study

Hardware specification

- RAM: 128GB
- Disk Space: 4TB
- PROCESSOR: INTEL ® XEON ® e5-26090 @2.40GHz

Software specification- Abaqus Explicit 6.14

- **For finite element modelling:** The design program used is 3-D modeling software, SOLIDWORKS release 2012.
- **For finite element analysis:** For calculating stress in finite element analysis ANSYS workbench R 14.5 version

Steps involved in the generation of finite element model

Construction of the geometric model

The analytical model incorporating maxillary central incisor along with periodontal ligament, cortical and compact bone were developed. Data required for the study was obtained from preexisting CBCT scans (high resolution DICOM) (Sameshima, 2001). Periodontal ligament was simulated as a 0.2mm thick ring around the model of the tooth and cortical bone at 0.5mm thick (Mirabella et al., 1995). With software SOLIDWORKS surfaces were generated and this data was exported in IGES format to ABAQUS workbench (Fig 1,2).

Conversion of geometric model to finite element model

This geometric model in IGES format was imported for creating a finite element model consisting of nodes and elements using discretization technique. The basic theme was to make calculations at only limited (finite) number of points and then interpolate the results for the entire domain (surface or volume). Hence in FEM the infinite degree of freedom was reduced to finite with the help of MAC meshing. (fig 3,4)

Number of nodes: 11, 47, 343 nodes

Number if elements: 2, 82, 372 elements

Type of elements: Tetrahedral

Boundary conditions: Cortical bone was fixed in all degrees of freedom

Force applied in X and Y direction on Enamel

Material property date representation

The mesh is programmed to contain the material and structural properties (elastic modulus, Poisson's ration and yield strength) which define how the structure will react to certain loading conditions. The different structures in the finite element model are tooth, periodontal ligament, cortical bone and cancellous bone was then assigned a specific material property. The analysis was performed as linear, non- linear and viscoelastic analysis depending on the allocation of appropriate physical characteristics to the different parts of the tooth. The material properties used have been taken from finite element studies previously conducted (Owman, 1996; Kamble, 2012) (Table 2 , 3, 4)

Defining the boundary condition

The boundary condition, in the finite element model was defined at all the peripheral nodes of the bone with no degree of movement in all directions. Boundary conditions were assigned to the nodes surrounding the outer most layers of the tooth, roots and alveolar bone.

Application of forces

The loading configuration was designed to simulate conventional orthodontic tooth movement. Tipping force was appliedwithin the range of optimum forces as proposed by Profit (Fig 5) and (Table 1).

Solving the system of algebraic equations

The sequential application of the above steps leads to a system of simultaneous algebraic equations which had to be solved using linear, non linear and visco elastic properties.

RESULTS

Orthodontic force application on tooth produces areas of compression and tension in the PDL. In this study, the stress levels within the PDL on application of tipping type of orthodontic force were calculated in terms of Von Mises. The Von Mises stress is used to check if a structure will withstand a particular load and were assigned a positive value. The patterns of stress distribution were compared between linear, nonlinear and viscoelastic material properties of the periodontal ligament for all the root morphologies (normal, short, blunt, dilacerated and pipette shaped) during tipping movements. 60 grams of tipping force (maximum force in the range 35-60 grams by Profitt) were applied to the tooth with different root morphologies. Table 5 shows the Patterns of stress distribution in teeth with different root morphologies during tipping force

DISCUSSION

Normal root morphology

Pattern of stress distribution in the pdl

For model A, (normal root shape) when forces were applied, no significant stress concentration was observed at the root.

Tipping

The table VI shows the comparison of von mises stress when tipping force of 60gms was applied and optimal force for the three analyses in a normal tooth. As stated by Lee et al. (1995) the optimal stress values ranges from 0.012- 0.020 Mpa. In our study, the stresses produced on application of 60 gms of tipping forces suggested by Profitt were in accordance to optimal stress in linear analysis and increased in non linear and visco elastic analysis.

Table 1. Loading configuration designed to simulate conventional orthodontic tooth

S.NO	TYPE OF LOADING	MAGNITUDE AND DIRECTION
1	TIPPING	35-60 grams of horizontal force in lingual direction perpendicular to long axis of the tooth at mid point

Table 2. Linear material properties of periodontal ligament in Finite Element Analysis

PART	DENSITY	YOUNG'S MODULUS	POISSON'S RATIO
PERIODONTAL LIGAMENT	1.5E-09 (TONNES/mm³)	0.69 MPa(LINEAR) 0.032MPa(NON LINEAR)	0.33
ENAMEL	2.99E-09 (TONNES/mm³)	84100 MPa	0.3
CORTICAL BONE	2.99E-09 (TONNES/mm³)	345 MPa	0.3

Table 3. Continuous nonlinear material properties of periodontal ligament in Finite Element Analysis

	Yield Stress	Plastic Strain
1	1E-005	0
2	0.0008	0.025
3	0.0008676559083	0.0251
4	0.001617539833	0.046
5	0.00254749844	0.073
6	0.003338719812	0.095
7	0.004172148662	0.119
8	0.004970709101	0.142
9	0.005760363011	0.165
10	0.006038330001	0.173
11	0.006529689287	0.187

Table 4. Viscoelastic material properties of periodontal ligamnet in Finite Element Analysis

Viscoelastic

Domain: Time

Time: Frequency data

Type: Isotropic Traction

Preload: None Uniaxial Volumetric Uniaxial and Volumetric

Maximum number of terms in the Prony series: 13

Allowable average root-mean-square error: 0.001

Test Data

Suboptions

Data

	Omega g* real	Omega g* imag	Omega k* real	Omega k* imag	Frequency
1	1.7548039E-005	-1.98034E-010	0	0	1E-005
2	0.00017548038	-1.98034E-008	0	0	0.0001
3	0.0017547991	-1.98032E-006	0	0	0.001

Table 5. Pattern of Stress Distribution In The Pdl

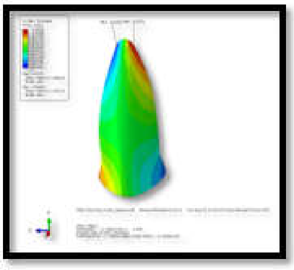
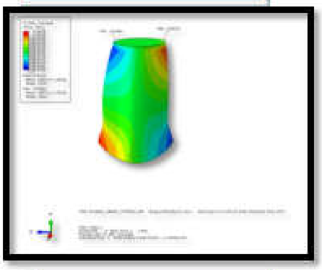
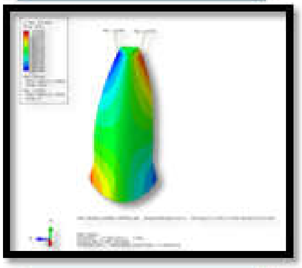
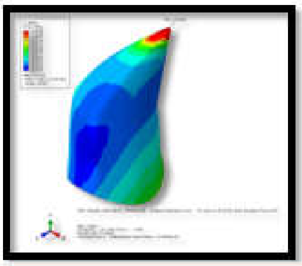
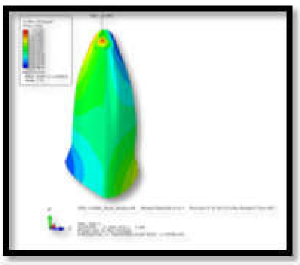
TIPPING	STRESS DISTRIBUTION
 NORMAL ROOT	No significant stress concentrations was observed on the root
 SHORT ROOT	Significant stress was concentrated at the neck of the root.
 BLUNT ROOT	Stress level at theroot apex was decreased
 DILACERATED ROOT	Stress was concentrated at the middle and apical regions of theroot
 PIPETTE SHAPED ROOT	Stress was concentrated at the apex of the root

Table 6. Shows the comparison of von mises stress when tipping force of 60gms was applied and optimal force for the three analyses in a normal tooth

NORMAL ROOT	FORCE APPLIED	STRESS	OPTIMAL STRESS (Lowest value in the range was considered)	FORCE REQUIRED
Linear properties	60 grams	0.012 Mpa	0.012 Mpa	60 grams
Nonlinear properties	60 grams	0.017 Mpa	0.012 Mpa	43 grams
Viscoelastic properties	60 grams	0.020 Mpa	0.012 Mpa	35 grams

Table 7. shows the comparison of von mises stress when tipping force of 60gms was applied and optimal force for the three analyses in a short root tooth

SHORT ROOT	FORCE APPLIED	STRESS	OPTIMAL STRESS (Lowest value in the range was considered)	FORCE REQUIRED
Linear properties	60 grams	0.019 Mpa	0.012 Mpa	42 grams
Nonlinear properties	60 grams	0.021 Mpa	0.012 Mpa	36 grams
Viscoelastic properties	60 grams	0.024 Mpa	0.012 Mpa	32 grams

Table 8. shows the comparison of von mises stress when tipping force of 60gms was applied and optimal force for the three analyses in a blunt root tooth

BLUNT ROOT	FORCE APPLIED	STRESS	OPTIMAL STRESS (Lowest value in the range was considered)	FORCE REQUIRED
Linear properties	60 grams	0.014 Mpa	0.012 Mpa	54 grams
Nonlinear properties	60 grams	0.018 Mpa	0.012 Mpa	42 grams
Viscoelastic properties	60 grams	0.023 Mpa	0.012 Mpa	33 grams

Table 9. shows the comparison of von mises stress when tipping force of 60gms was applied and optimal force for the three analyses in a dilacerated root tooth

DILACERATED ROOT	FORCE APPLIED	STRESS	OPTIMAL STRESS (Lowest value in the range was considered)	FORCE REQUIRED
Linear properties	60 grams	0.020 Mpa	0.012 Mpa	36 grams
Nonlinear properties	60 grams	0.028 Mpa	0.012 Mpa	25 grams
Viscoelastic properties	60 grams	0.034 Mpa	0.012 Mpa	21grams

Table10. Shows the comparison of von mises stress when tipping force of 60gms was applied and optimal force for the three analyses in a pipette shaped root tooth

PIPETTE SHAPED ROOT	FORCE APPLIED	STRESS	OPTIMAL STRESS (Lowest value in the range was considered)	FORCE REQUIRED
Linear properties	60 grams	0.017 Mpa	0.012 Mpa	44 grams
Nonlinear properties	60 grams	0.020 Mpa	0.012 Mpa	37 grams
Viscoelastic properties	60 grams	0.023 Mpa	0.012 Mpa	33 grams

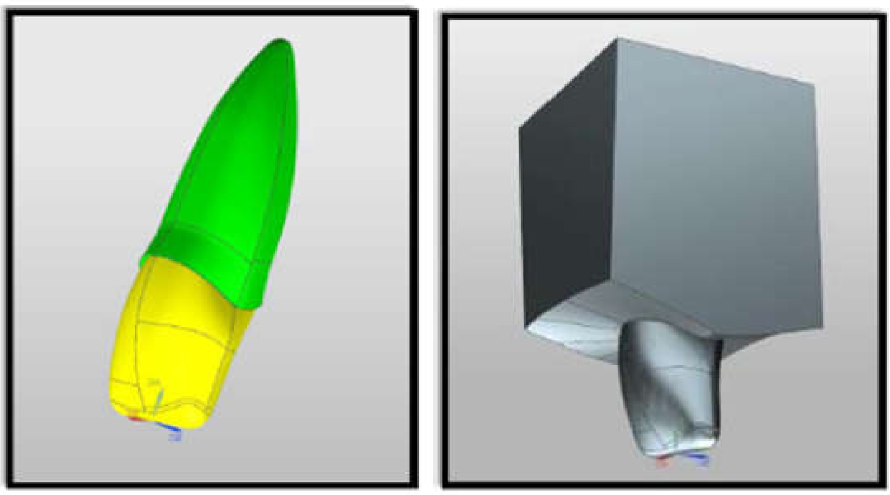


Fig. 1 Geometric model showing maxillary incisor, periodontal ligament and the bone

With the application of non linear material properties the magnitude of stresses increased (0.017 Mpa) and were beyond the lowest value in the optimal range of stresses given by Lee, (1995) ((0.012 – 0.020 Mpa). When the force applied was decreased in increments of 0.1 gms by iteration, it was observed that a force of 43 gms innon linear analysis and 35 grams in visco elastic analysis was required for the stresses in the PDL to be within the optimal stress range.

Short root morphology

Pattern of stress distribution in the pdl

In model B (short root), significant stress was concentrated at the neck of the root. This finding is related to the alteration of the crown-root ratio. A decrease in the ratio of the root to the crown is thought to enhance loading on the root, resulting in significant stress.

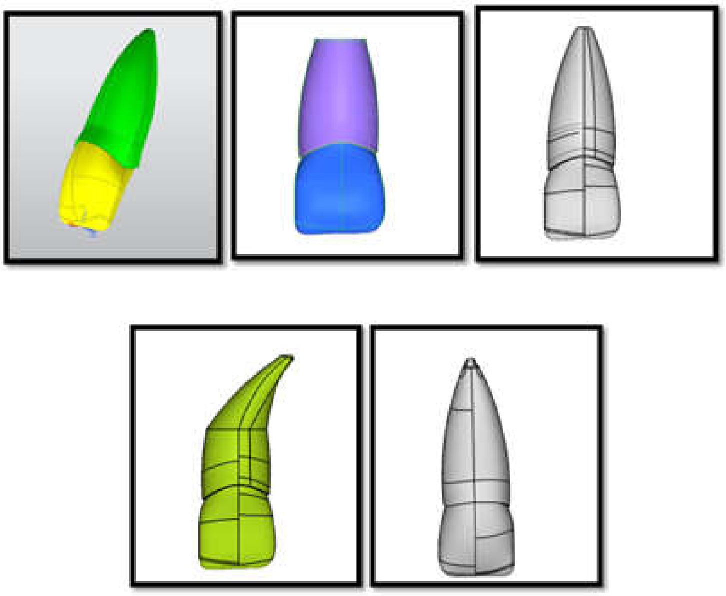


Fig. 2. Geometric model showing maxillary incisor with different root morphologies

Fig. 3 Finite element Model of the maxillary incisor with its surrounding structures

Fig. 3a Finite element model of the tooth

Fig. 3b Finite element model of the tooth

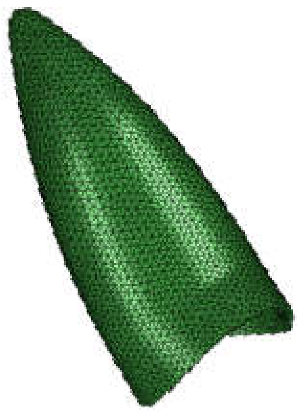


Fig. 3c. Finite element model of the periodontal ligament

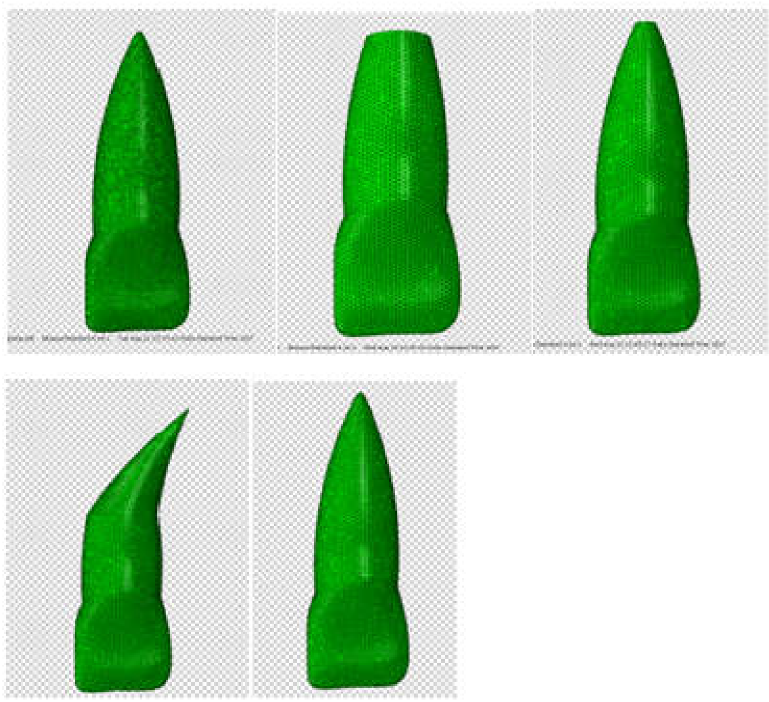


Fig 4. Finite element model of maxillary incisor with different root morphologies

LOADING CONDITIONS

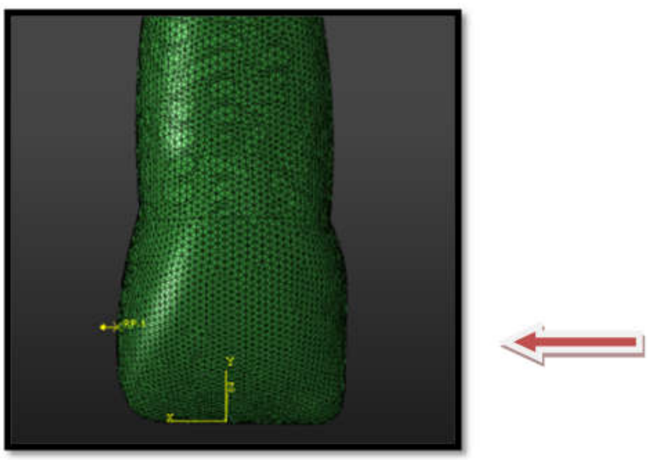


Fig 5. Tipping -60 gms of force directed in the horizontal direction, perpendicular to the long axis of the tooth

Taithongchai et al. David Rudolph et al. (2001) Kamble et al. (2012) Koji Oyama et al. (2007) and Thongudomporn and Freer, (1988) reported that roots with a short apex are at high risk of rootresorption, which supports the findings of the present study.

Tipping

The table VII shows the comparison of von mises stress when tipping force of 60gms was applied and optimal force for the three analyses in a short root tooth. In our study, the stresses produced on application of 60 gms of tipping forces, were increased in linear, non linear and visco elastic analysis. When the force applied was decreased in increments of 0.1 gms by iteration, it was observed that a force of 42 gms in linear analysis, 36 grams in non linear analysis and 35 grams in visco elastic analysis was required for the stresses in the PDL to be within the optimal stress range.

Blunt root morphology

Pattern of stress distribution in the pdl

Model C (blunt-shaped root) showed no significant stress concentration at the root. The stress level at the root apex was decreased during tipping and translation compared with model A. These findings are partly in accordance with the results of Thongudomporn and Freer, David Rudolph et al. (2001) Kamble et al. (2012) Koji Oyama et al. (2017) and Levander and Malmgren et al. (1988). In their radiographic studies they reported that blunt-shaped roots frequently showed rootresorption when compared with normal roots. The reason for this difference may be related to genetic or other predispositions. Newman, (1995) reported that a congenital blunt shaped root results from physical defects and genetic factors during the root formation stage.

Tipping

The table VIII shows the comparison of von mises stress when tipping force of 60gms was applied and optimal force for the three analyses in a blunt root tootIn our study, the stresses produced on application of 60 gms of tipping forces, were increased in linear, non linear and visco elastic analysis. When the force applied was decreased in increments of 0.1 gms by iteration, it was observed that a force of 54 gms in linear analysis, 42 grams in non linear analysis and 33 grams in visco elastic analysis was required for the stresses in the PDL to be within the optimal stress range.

Dilacerated root morphology

Pattern of stress distribution in the pdl

In model D (dilacerated root apex), stress was concentrated at the middle and apical regions of the root during tipping, and translative force application. The results concerning stress distribution on the dilacerated root shape are in agreement with the findings of Levander and Malmgrenet al. (1988) David Rudolph et al. (2001) Kamble et al. (2012) Koji Oyama et al. (2007) and Mirabella and Artun, (1995) who reported that a bent shape have high chances of root resorption.

Tipping

The table IX shows the comparison of von mises stress when tipping force of 60gms was applied and optimal force for the three analyses in a dilacerated root tooth. In our study, the stresses produced on application of 60 gms of tipping forces, were increased in linear, non linear and visco elastic analysis. When the force applied was decreased in increments of 0.1 gms by iteration, it was observed that a force of 36 gms in linear analysis, 25 grams in non linear analysis and 21 grams in visco elastic analysis was required for the stresses in the PDL to be within the optimal stress range.

Pipette shaped root morphology

Pattern of stress distribution in the pdl

For model E (pipette shape), regardless of the direction of force application, stress was concentrated at the apex of the root. In their radiographic studies, Thongudomporn and Freer et al. (1988) David Rudolph et al. (2001) Kamble et al. (2012) Koji Oyama et al. (2007) and Sameshima and Sinclair (2001) described that teeth with a pipette-shaped root apex enhanced root resorption.

Tipping

The table X shows the comparison of von mises stress when tipping force of 60gms was applied and optimal force for the three analyses in a pipette shaped root tooth. In our study, the stresses produced on application of 60 gms of tipping forces, were increased in linear, non linear and visco elastic analysis. When the force applied was decreased in increments of 0.1 gms by iteration, it was observed that a force of 44 gms in linear analysis, 37 grams in non linear analysis and 33 grams in visco elastic analysis was required for the stresses in the PDL to be within the optimal stress range.

Conclusion

- It was observed that the force levels required to produce the optimal amount of stresses in the PDL of a upper incisor, were the least in viscoelastic analysis, followed by non linear and the maximum in linear analysis.
- Thus, the force levels have to be reduced by almost half in the viscoelastic analysis to produce the same amount of stresses as seen in the linear analysis.
- Considering that the viscoelastic properties depicts a more realistic behaviour of the PDL, the force levels have to be closely monitored when dealing with deviated root morphologies and cautioned not to exceed the recommended optimal value, to prevent iatrogenic damage.
- When tooth with different root morphologies are encountered, optimal force values for tipping forces given by profit has to be modified.

REFERENCES

Brezniak N, Wasserstein A, Brezniak N, Wasserstein A. 2002. Orthodontically induced inflammatory root resorption. Part I: The basic science aspects. *Angle Orthod.,* 72(2):175-9.

Brudvik P, Rygh P. 1994. Multi-nucleated cells remove the main hyalinized tissue and start resorption of adjacent root surfaces. *Eur J Orthod.,* 16(2):265-73.

Chan E, Darendeliler MA. 2005. Physical properties of root cementum: part 5. Volumetric analysis of root resorption craters after application of light and heavy orthodontic forces. *Am J Orthod Dentofacial Orthop*.127(2):186-95.

Engstrom C, Granstrom G, Thilander B. 1988. Effect of orthodontic force on periodontal tissue metabolism. A histologic and biochemical study in normal and hypocalcemic young rats. *Am J Orthod Dentofacial Orthop*. 93(6):486-95.

Henry JL, Weinmann JP. 1951. The pattern of resorption and repair of human cementum. *J Am Dent Assoc.,* 42(3):270-90.

Kamble. R H 2012. Stress distribution pattern in a root of maxillary central incisor having various root morphologies A finite element study. *Angle Orthod.,* 82(5):799-805.

Levander E, Malmgren O. 1988. Evaluation of the risk of root resorption during orthodontic treatment: a study of upper incisors. *Eur J Orthod.,*10(1):30-8.

Linge L, Linge BO. 1991. Patient characteristics and treatment variables associated with apical root resorption during orthodontic treatment. *Am J Orthod Dentofacial Orthop.* ;99(1):35-43.

Mc Nab S, Battistutta D, Taverne A, Symons AL. 1999. External apical root resorption of posterior teeth in asthmatics after orthodontic treatment. *Am J Orthod Dentofacial Orthop.* 116(5):545-51.

Mirabella AD, Artun J. 1995. Prevalence and severity of apical root resorption of maxillary anterior teeth in adult orthodontic patients. *Eur J Orthod*. 17(2):93-9.

Mirabella AD, Artun J. 1995. Risk factors for apical root resorption of maxillary anterior teeth in adult orthodontic patients *Am J Orthod Dentofacial Orthop.* 1995;108(1):48-55.

Ngan DC, Kharbanda OP, Byloff FK, Darendeliler MA, Ngan DCS, Kharbanda OPl. 2004. The genetic contribution to orthodontic root resorption: a retrospective twin study. *Aust Orthod J.* 20(1):1-9.

Owman-Moll P, Kurol J, Lundgren D 1996. The effects of a four fold increased orthodontic force magnitude on tooth movement and root resorptions. An intra-individual study in adolescents. *Eur J Orthod.* 18(3):287-94

Oyama K, Motoyoshi M, Hirabayashi M, Hosoi K, Shimizu N, Oyama K. 2007. Effects of root morphology on stress distribution at the root apex. *Eur J Orthod.* 29(2):113-7.

Parker RJ, Harris EF. 1998. Directions of orthodontic tooth movements associated with external apical root resorption of the maxillary central incisor. *Am J Orthod Dentofacial Orthop1.,* 14(6):677-83.

Remington DN, Joondeph DR, Artun J, Riedel RA, Chapko MK. 1989. Long-term evaluation of root resorption occurring during orthodontic treatment. *Am J Orthod Dentofacial Orthop*. 96(1):43-6.

Rudolph DJ, Willes MG, Sameshima GT. 2001. A finite element model of apical force distribution from orthodontic tooth movement. *Angle Orthod.,* 71(2):127-31.

Sameshima GT, Sinclair PM. 2001. Predicting and preventing root resorption: Part I. Diagnostic factors. *Am J Orthod Dentofacial Orthop.* 119(5):505-10.

Schwarz A M. 1932. Tissue Changes incident to orthodontic tooth movement. *International journal of Orthodontia, Oral Surgery and Radiograph.* 18(4): 331–52.

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