Journal of Positive School Psychology http://journalppw.com
2022, Vol. 6, No. 4, 6089 – 6102

FINITE ELEMENT ANALYSIS TO DETERMINE CENTRE OF RESISTANCE AND CENTRE OF ROTATION WITH VARIATION IN ROOT LENGTH FOR SINGLE ROOTED AND MULTIROOTED TEETH

[1]Pradeep Elango P, [2]Siva Oli M, [3]Chandrakumar. A, [4]Syed Abuthagir. A, [5]Ravivarman. C, [6]Senthilkumaran. M

[1]*Designation: Lecturer, Department of orthodontics and dentofacial orthopedics, Dhanalakshmi Srinivasan dental college, Siruvachur, Perambalur.*
[2]*Private Practioner*
[3]*Private Practioner*
[4]*Private Practioner*
[5]*Reader, Department of conservative dentistry and Endodontics, Dhanalakshmi Srinivasan Dental College, Siruvachur, Perambalur.*
[6]*Reader, Department of periodontology, Dhanalakshmi Srinivasan Dental College, Siruvachur, Perambalur*

Abstract

The finite element method (FEM) is a highly precise technique used to analyze structural stress.The aim of this study was to locate centre of resistance at varying root length,to locate centre of rotation at varying root length and to analyse the changes in tooth displacement associated with various root lengths.ANSYS program was used for the analysis.Displacement of tooth increased with short root length for maxillary central incisor, lateral incisor, canine, and 1st molar. Whereas displacement of tooth did not increase with shorter root length for 1st pre molar and 2nd pre molar.

Keywords: Tooth displacement, ANSYS, Finite element method.

INTRODUCTION

Dental movement has been widely studied histologically, histochemically, physiologically, and biomechanically in both man and animals. Force when carefully executed will bring about desired tooth movement. Hence,in Orthodontics the varied biological responses to the mechanics in the oral cavity including the nature of tooth displacement is of great interest in terms of optimal force application and subsequent 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.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 ratio1,2.

The finite element method (FEM) is a highly precise technique used to analyze structural stress. Used in engineering for years, FEM is a powerful computational tool for solving stress-strain problems; its ability to handle material in homogeneity and complex shapes makes the

FEM the most suitable method for the analysis of stress in the periodontium1. In addition, the FEM provides information about point-wise (nodal) displacements. It is therefore expected that the FEM may be capable of analyzing systematically and quantitatively the biomechanical tissue response. 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 canals3.

The application of the finite element method (FEM) in dental investigation began in the seventies by using two and three-dimensional models. This method provides us with useful method, using it with a 2-dimensional (2-D) model.

The aim of this study was to locate centre of resistance at varying root length,to locate centre of rotation at varying root length and to analyse the changes in tooth displacement associated with various root lengths.

MATERIALS AND METHODS

Five two dimensional models of upper central incisors, lateral incisors, canine, 1st premolar, 2nd premolar and 1st molar were designed. A quadrilateral element has been used to evaluate. This quadrilateral element consists of 8 nodes [quad 8nodes 183 according to ANSYS].

The average anatomic data of maxillary teeth was based on Dental Anatomy text book by WHEELER. The root length was varied by 1mm 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 studies6,7. The material constants are shown in the Table 1. The boundary conditions were defined to simulate how the model was constrained and to prevent it from free body motion.

The system configuration used to run the ANSYS program for simulation of the models were:

- Intel pentium corei3
- 2.5GHZ
- 2Gb RAM
- Windows 7
- Windows compatible mouse

For all above mentioned models, a force of 100gms was applied to the labial surface of the tooth crown at each phase of the study at presumable bracket position. The point of force application was centredmesiodistally.

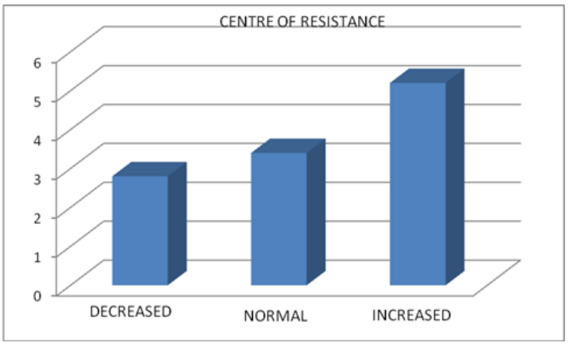
TABLE 1 *MECHANICAL PROPERTIES FOR THE STRUCTURAL ELEMENTS*

Material	Young’s Modulus (kg/mm^2)	Poisson’s Ratio
Tooth	2x10	0.30
PDL	6.8x10	0.49
Alveolar bone	1.4x10	0.30

TABLE 2: *CHARACTERISTICS OF THE MODEL USED IN THE STUDY OF CENTRAL INCISOR*

MODEL	ROOT LENGTH	No of ELEMENTS	No of MODES	CENTRE of RESISTANCE (from apex to alveolar crest)	CENTRE of ROTATION (from apex to alveolar crest)
1	11	814	2382	2.73	2.5
2	12	916	2589	2.8	2.8
3	13	829	2396	3.4	3.5
4	14	690	1992	5.2	4.2
5	15	902	2272	6.8	4.6

GRAPH 1: *CENTRE OF RESISTANCE: CENTRAL INCISOR*



GRAPH 2: *CENTRE OF ROTATION: CENTRAL INCISOR*

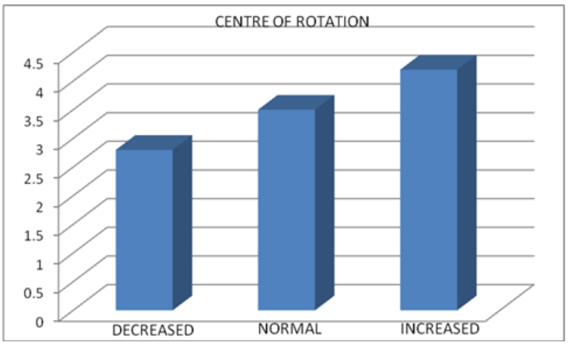
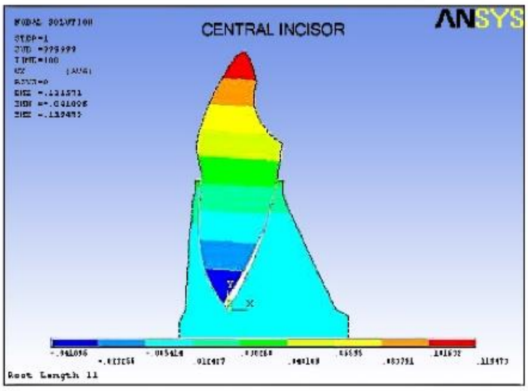
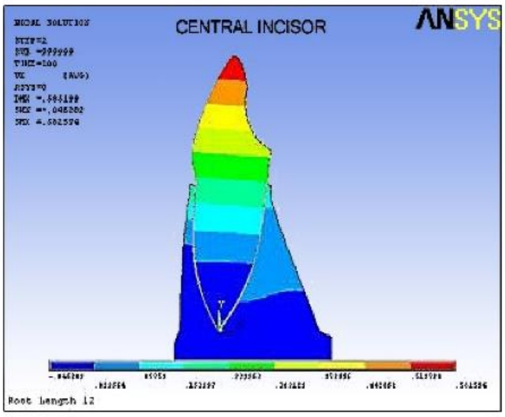
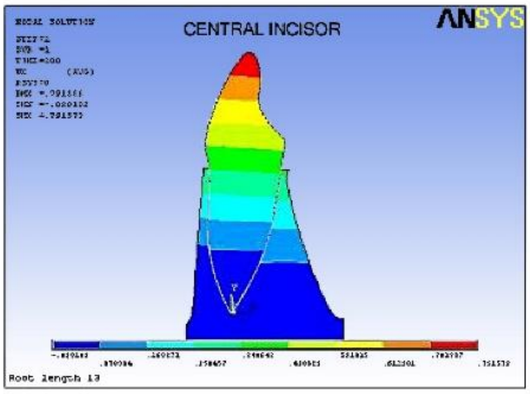
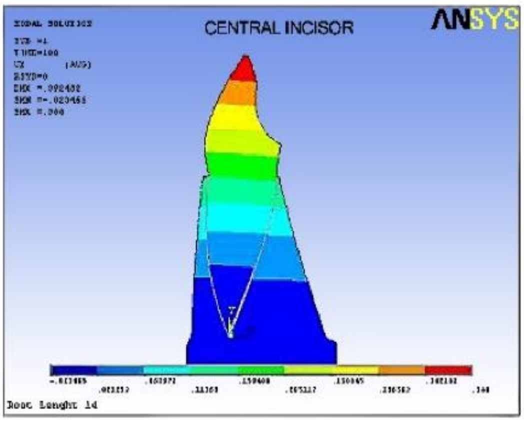


FIGURE 1: *CENTRAL INCISOR*









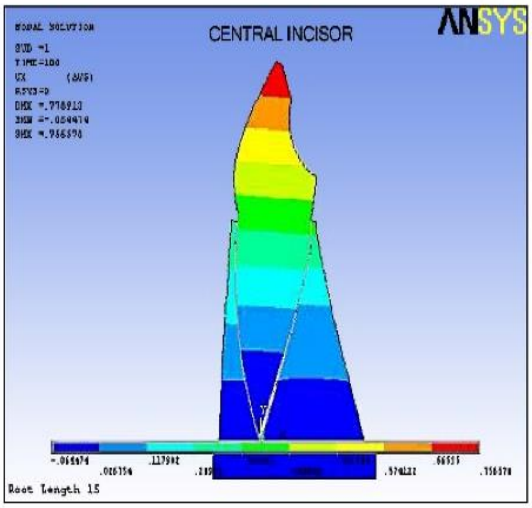
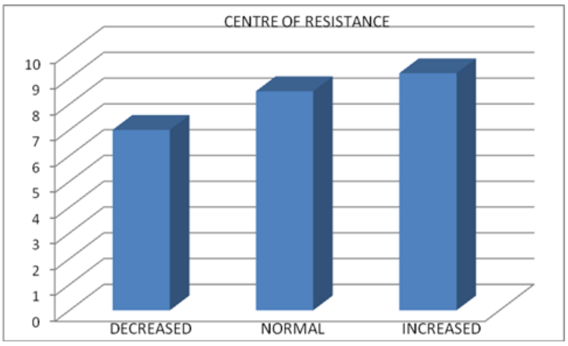


TABLE 3: *CHARACTERISTICS OF THE MODEL USED IN THE STUDY OF LATERAL INCISOR*

MODEL	**ROOT LENGTH**	**No of ELEMENTS**	**No of NODES**	**CENTRE of RESISTANCE (from apex to alveolar crest)**	**CENTRE 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

GRAPH 3: *CENTRE OF RESISTANCE: LATERAL INCISOR*



GRAPH 4: *CENTRE OF ROTATION: LATERAL INCISOR*

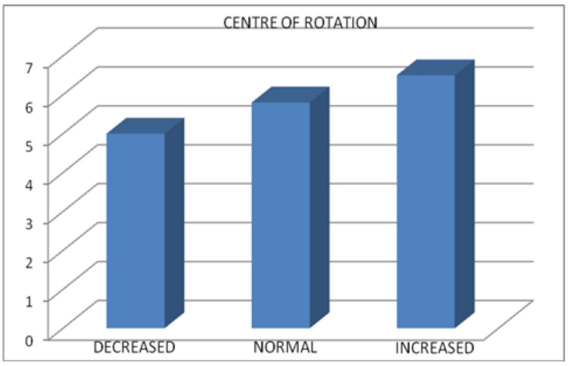
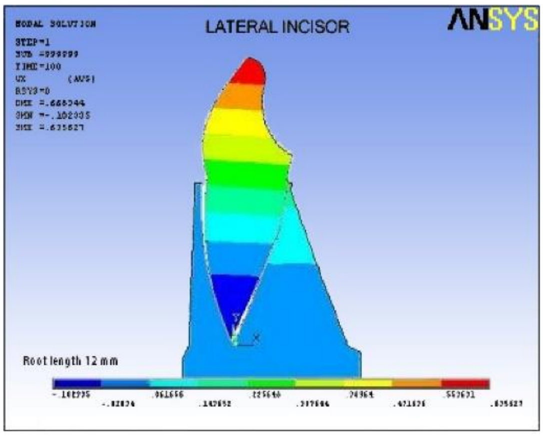
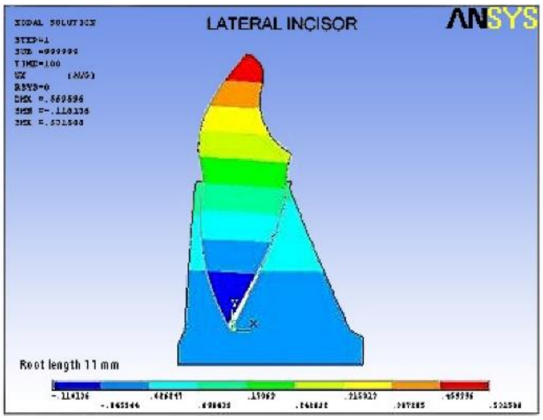
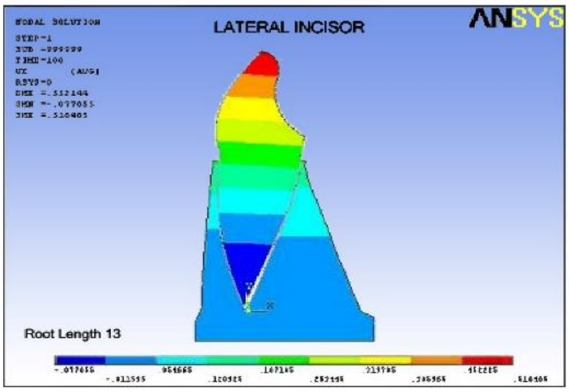
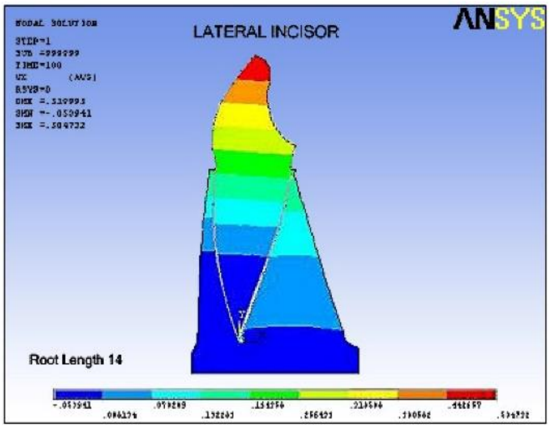


FIGURE 2: *LATERAL INCISOR*









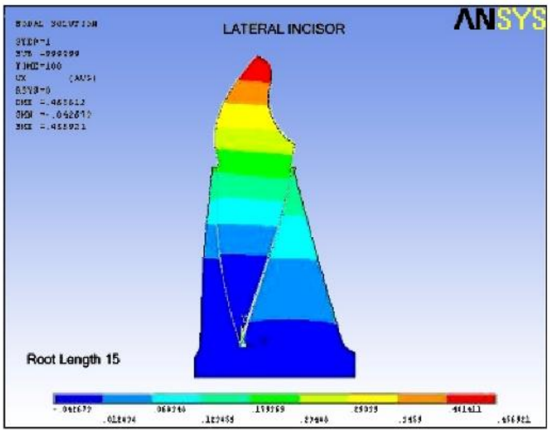
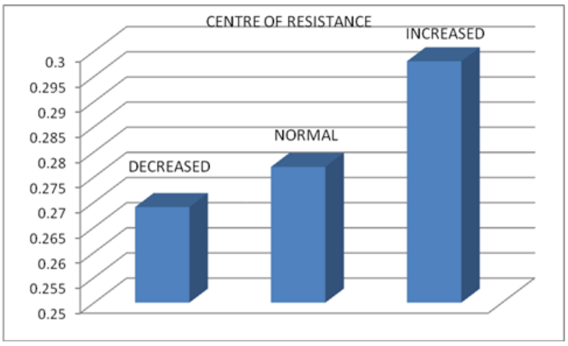


TABLE 4: *CHARACTERISTICS OF THE MODEL USED IN THE STUDY OF CANINE*

MODEL	ROOT LENGTH	NO of ELEMENTS	No of NODES	CENTRE of RESISTANCE (from apex to alveolar crest)	CENTRE of ROTATION (from apex to alveolar crest)
1	15	14793	3967	0.268	0.24
2	16	15231	4108	0.269	0.23
3	17	15231	4228	0.277	0.27
4	18	4525	1349	0.298	0.26
5	19	44231	11993	0.299	0.24

GRAPH 5: *CENTRE OF RSISTANCE: CANINE*



GRAPH 6: *CENTRE OF ROATATION: CANINE*

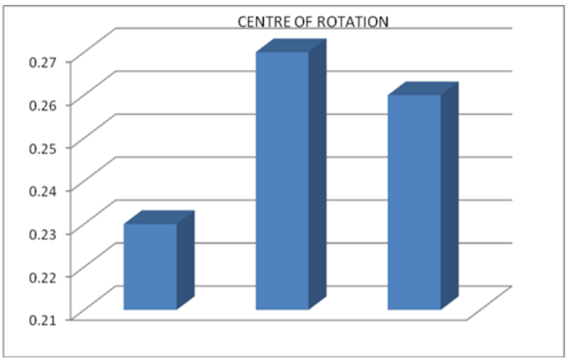
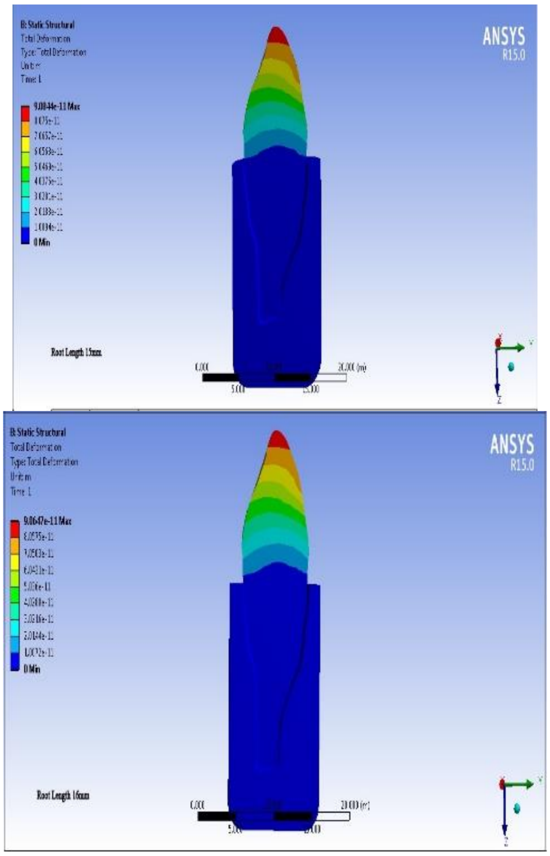
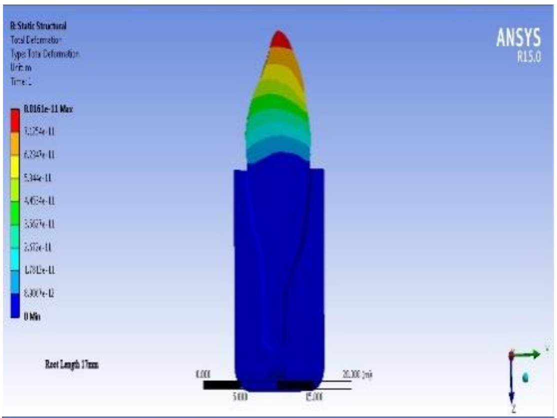
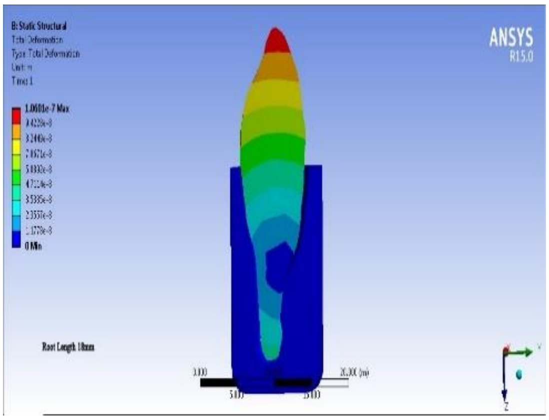


FIGURE 3: *CANINE*







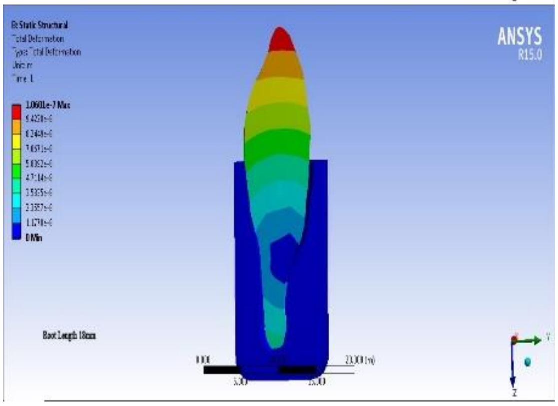
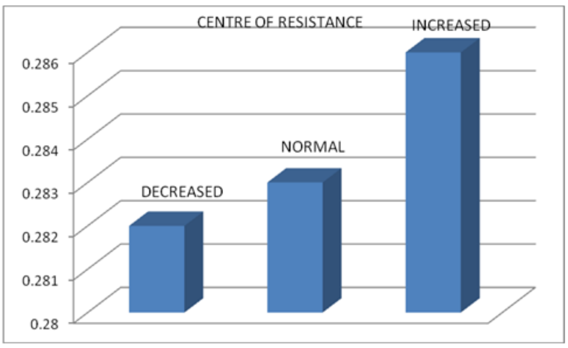


TABLE 5: *CHARACTERISTICS OF THE MODEL USED IN THE STUDY OF 1st PRE MOLAR*

MODEL	ROOT LENGTH	No of ELEMENTS	No of MODES	CENTRE of RESISTANCE (from apex to alveolar crest)	CENTRE of ROTATION (from apex to alveolar crest)
1	12	13992	3969	0.281	0.26
2	13	14340	4102	0.282	0.25
3	14	14823	4209	0.283	0.28
4	15	15318	4389	0.286	0.27
5	16	16224	4604	0.283	0.23

GRAPH 7: *CENTRE OF RESISTANCE: 1ST PRE MOLAR*



GRAPH 8: *CENTRE OF ROTATION: 1ST PRE MOLAR*

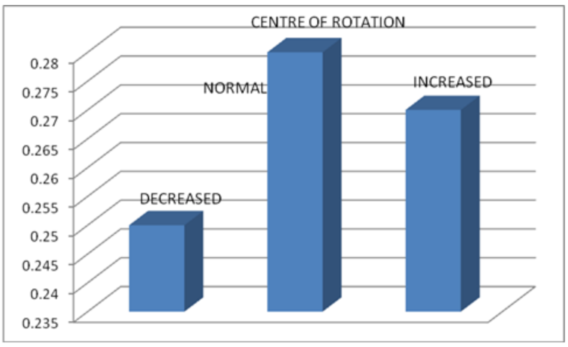
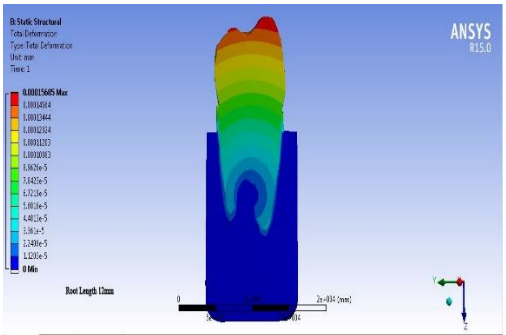
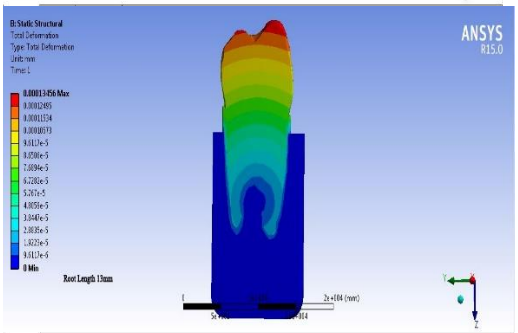
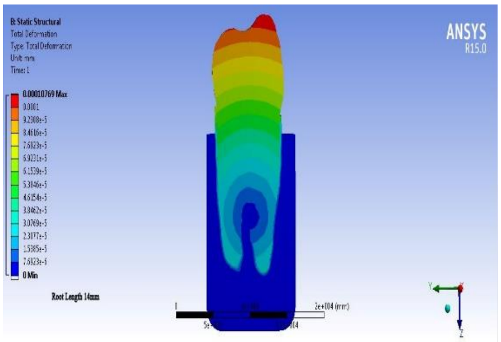
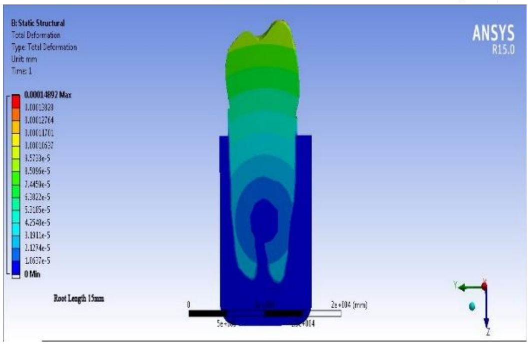


FIGURE 4: *1ST PRE MOLAR*









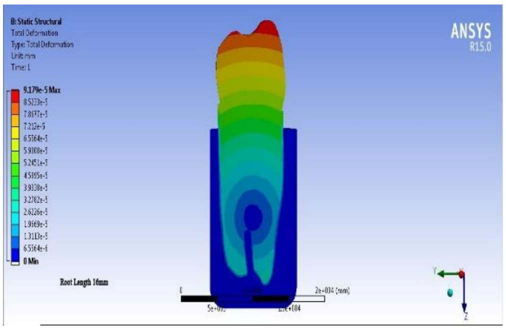
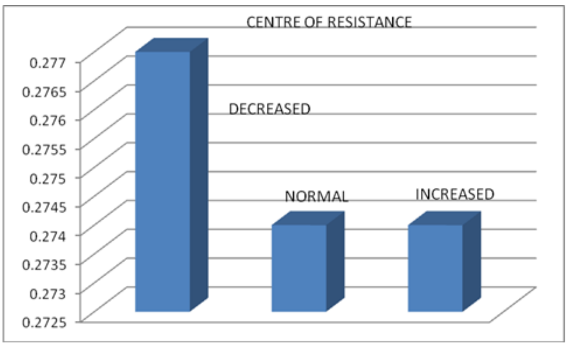


TABLE 6: *CHARACTERISTICS OF MODEL USED FOR THE STUDY OF 2nd PRE MOLAR*

MODEL	ROOT LENGTH	NO of ELEMENENTS	No of MODES	CENTRE OF RESISTANCE (from apex to alveolar crest)	CENTRE of ROTATION (from apex to alveolar crest)
1	12	11275	3141	0.278	0.25
2	13	11746	3256	0.277	0.24
3	14	12267	3372	0.274	0.27
4	15	12564	3449	0.274	0.26
5	16	12936	3613	0.279	0.23

GRAPH 9: *CENTRE OF RESISTANCE: 2ND PRE MOLAR*



GRAPH 10: *CENTRE OF ROTATION: 2ND PRE MOLAR*

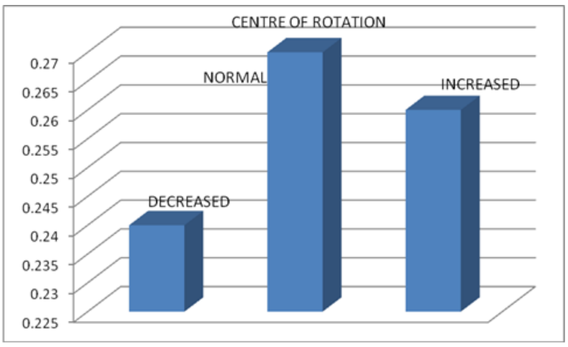
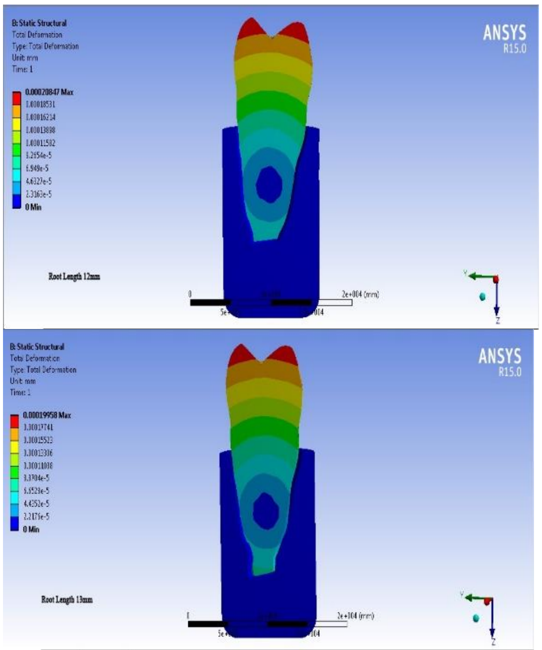
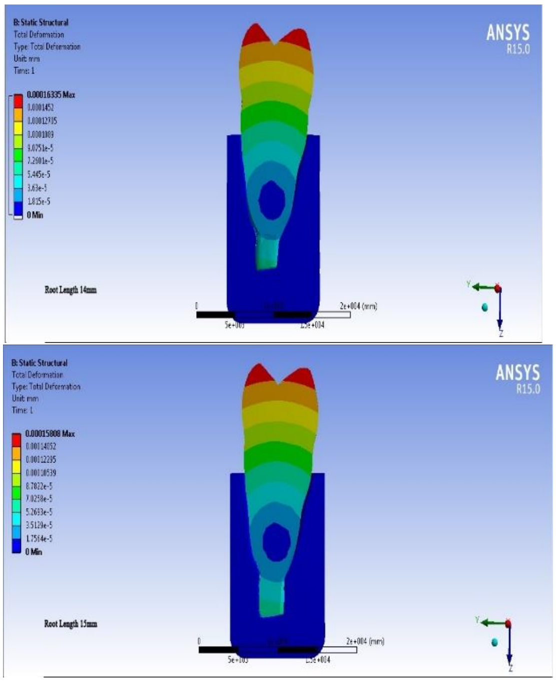


FIGURE 5: *2ND PRE MOLAR*





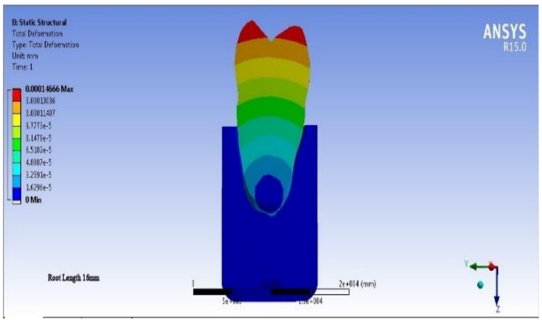
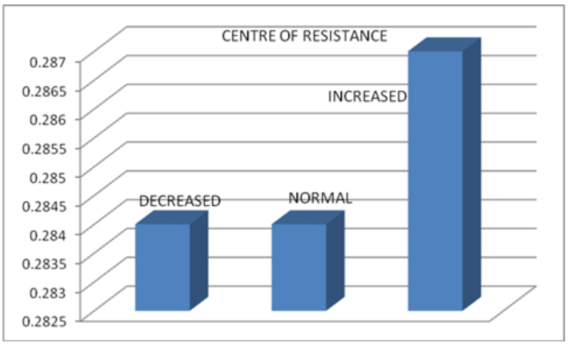


TABLE 7: *CHARACTERISTICS OF MODEL USED IN THE STUDY OF 1st MOLAR*

MODEL	ROOT LENGTH	No of ELEMENTS	No of NODES	CENTRE of RESISTANCE (from apex to alveolar crest)	CENTRE of ROTATION (from apex to alveolar crest)
1	11	17530	5001	0.285	0.26
2	12	18200	5174	0.284	0.25
3	13	18858	5371	0.284	0.27
4	14	19010	5462	0.287	0.26
5	15	18605	5395	0.289	0.22

GRAPH 11: *CENTRE OF RESISTANCE: 1ST MOLAR*



GRAPH 12: *CENTRE OF ROTATION: 1ST MOLAR*

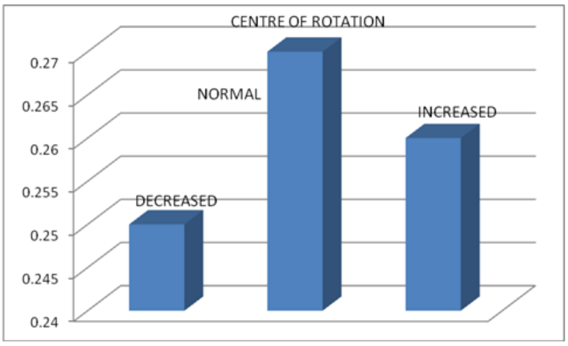
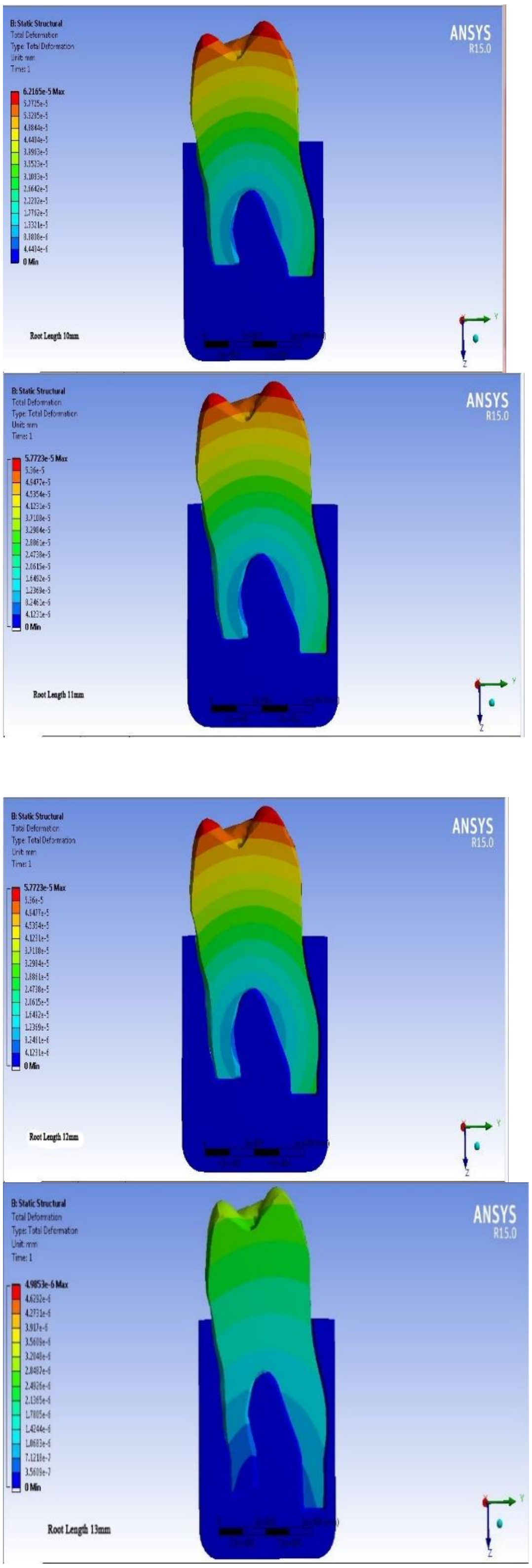
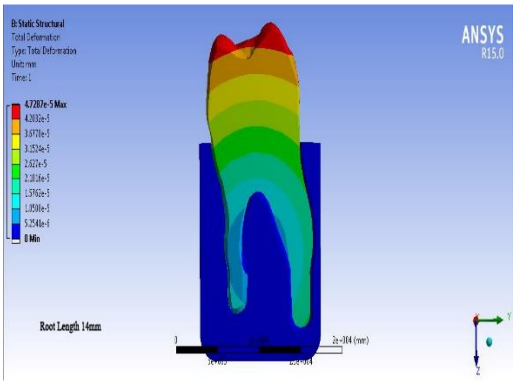


FIGURE 6: *1ST MOLAR*





RESULTS

CENTRE OF RESISTANCE WITH INCREASED ROOT LENGTH

The centre of resistance was 5.2mm and 6.8mm from apex for increased root length of 14mm, 15mm respectively for central incisor. Asthe root length increased, the Centre of Resistance shifted more cervically.(Table 2, Figure 1,2)The centre of resistance was 9.2mm and 9.8mm from the apex for increased root length of 14mm, 15mm respectively for lateral incisor. Asthe root length increased, the Centre of Resistance shifted more cervically.(Table 3, Figure 3,4)The centre of resistance was 0.298mm and 0.299mm from the apex for increased root length of 18mm and 19mm respectively for canine. Asthe root length increased, the Centre of Resistance shifted more cervically.(Table 4, Figure 5,6)The centre of resistance was 0.286mm and 0.283mm from the apex for increased root length of 15mm and 16mm respectively for 1st pre molar. Asthe root length increased, the Centre of Resistance shifted more apically.(Table 5, Figure 7,8)The centre of resistance was 0.274mm and 0.279mm from the apex for increased root length of 15mm and 16mm respectively for 2nd pre molar. Asthe root length increased, the Centre of Resistance shifted more cervically.(Table 6, Figure 9,10)The centre of resistance was 0.287mm and 0.289mm from the apex for increased root length of 14mm and 15mm respectively for 1st molar. Asthe root length increased, the Centre of Resistance shifted more cervically.(Table 7, Figure 11,12)

CENTRE OF RESISTANCE WITH DECREASED ROOT LENGTH

The centre of resistance was 2.8mm and 2.73mm from apex for decreased root length of 12mm, and 11mm respectively for central incisor. As the root length decreased the centre of resistance shifted more apically(Table 2).The centre of resistance was 7.0mm and 6.8mm from the apex for decreased root length of 12mm and 11mm respectively for lateral incisor. As the root length decreased the centre of resistance shifted more apically(Table 3).The centre of resistance was 0.269mm and 0.268mm from the apex for decreased root length of 16mm and 15mm respectively for canine. As the root length decreased the centre of resistance shifted more apically(Table 4).The centre of resistance was 0.282mm and 0.281mm from the apex for decreased root length of 12mm and 11mm respectively for 1st pre molar. Asthe root length increased, the Centre of Resistance shifted more apically(Table 5).The centre of resistance was 0.277mm and 0.278mm for decreased root length of 13mm and 12mm respectively for 2nd pre molar. Asthe root length increased, the Centre of Resistance shifted more cervically(Table 6).The centre of resistance was 0.284mm and 0.285mm for decreased root length of 12mm and 11mm respectively for 1st molar. Asthe root length increased, the Centre of Resistance shifted more cervically(Table 7).

CENTRE OF ROTATION WITH INCREASED ROOT LENGTH

The centre of rotation was 4.2mm and 4.6mm for increased root length of 14mm and 15mm respectively for central incisor. As the root length increased the centre of rotation shifted more cervically(Table 2, Figure 2).The centre of rotation was 6.5mm and 6.6mm for increased root length of 14mm and 15mm respectively for lateral incisor. As the root length increased the centre of rotation shifted more cervically(Table 3, Figure 4).The centre of rotation was 0.26mm and 0.24mm for increased root length of 18mm and 19mm respectively for canine. As the root length increased the centre of rotation shifted more apically(Table 4, Figure 6).The centre of rotation was 0.27mm and 0.23mm for increased root length of 15mm and 16mm respectively for 1st pre molar. As the root length increased the centre of rotation shifted more apically(Table 5, Figure 8). The centre of rotation was 0.26mm and 0.23mm for increased root length of 15mm and 16mm respectively for 2nd pre molar. As the root length increased the centre of rotation shifted more apically(Table 6, Figure 10).The centre of rotation was 0.26mm and 0.22mm for increased root length of 14mm and 15mm respectively for 1st molar. As the root length increased the centre of rotation shifted more apically(Table 7, Figure 12).

CENTRE OF ROTATION WITH DECREASED ROOT LENGTH

The centre of rotation was 2.8mm and 2.5mm for decreased root length of 12mm and 11mm respectively for central incisor. As the root length decreased the centre of rotation shifted more apically(Table 2).The centre of rotation was 5.8mm and 5.9mm for decreased root length of 12mm and 11mm respectively for lateral incisor. As the root length decreased the centre of rotation shifted more apically(Table 3).The centre of rotation was 0.23mm and 0.24mm for decreased root length of 16mm and 15mm respectively for canine. As the root length decreased the centre of rotation shifted more apically(Table 4). The centre of rotation was 0.25mm and 0.26mm for decreased root length of 13mm and 12mm respectively for 1st pre molar. As the root length decreased the centre of rotation shifted more apically(Table 5).The centre of rotation was 0.24mm and 0.25mm for decreased root length of 13mm and 12mm respectively for2nd pre molar. As the root length decreased the centre of rotation shifted more apically(Table 6).The centre of rotation was 0.25mm and 0.26mm for decreased root length of 12mm and 11mm respectively for1st molar. As the root length decreased the centre of rotation shifted more apically (Table 7).

DISSCUSION

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 studies8. 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 behaviour 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 method (FEM) is a highly precise technique used to analyze structural stress. Used in engineering for years, FEM is a powerful computational tool for solving stress-strain problems; 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 analyzing systematically and quantitatively the biomechanical tissue response.

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

- It is a non-invasive technique.
- The periodontal ligament can also be generated.
- 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.
- The actual stress experienced at any given point can be measured.
- The actual displacement of the tooth can be visualized.
- Reproducibility does not affect the physical properties of the involved material and the study can be repeated as many times as desired.

A finite element model of upper central incisor and lateral incisor with its supporting structure was created using ANSYS software on intel icore3(Figure 13- 42).

Since pattern of initial displacement of a tooth may be influenced by anatomic variables as dimension of the tooth, Alveolar bone and PDL space. Variation in root length can modify the Bio-mechanical behaviour of a tooth when subjected to orthodontic forces. Present study showed that there was greater displacement of the apex which can probably lead to root resorption and excessive injury to the periodontal ligament which can lead to tooth mobility. It was seen that as the root length increased the Centre of Resistance shifted more cervically for central incisor, lateral incisor, canine, 1st pre molar and 1st molar, whereas the root length increased the Centre of Resistance shifted more apically for 2nd pre molar.

The location of the Centre of Resistance is important because, when there is 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 with fixed orthodontic appliances. This results in an increased crown-to-root ratio9.

The present study showed as the root length increased the centre of rotation also shifted cervically for maxillary central incisor, lateral incisor. and as the root length decreased the centre of rotation shifted apically for canine, 1st premolar, 2nd premolar and 1st molar. Study by Smith and Burrstone proves that, for a pure translator displacement the centre of rotation, is considered to be at infinity10. For the controlled tipping, the centre of rotation is located at root apex. A pure rotation movement occurs around the centre of resistance. For uncontrolled tipping of a tooth, the centre of rotation is located between centre of resistance and the root apex. For controlled root movement, the centre of rotation is at incisor edge. Present study showed that the centre of rotation is apically to centre of resistance in case of increased root length. So for a desired tooth movement it is important to predict the location of centre of rotation and centre of resistance so that undesirable tooth movements can be controlled. The present study also demonstrated that the displacement of the tooth increased with shorter root length.

The limitations of our model include approximation in the material behaviour and shapes of the tissues. Similar to previous studies,11,12,13,14,15, the PDL was modeled as a layer of uniform thickness(0.2mm) and was treated as linear-elastic and isotropic, even though the PDL exhibits anisotropy and nonlinear viscoelastic behaviour because of tissue fluid16. There are no reliable and adequate data that pertain to anisotropic and nonlinear properties of the PDL. The effect 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 remodelling 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.

CONCLUSION

The centre of resistance and rotation isn't a fixed point for increased and decreased root length, for varied root length depending upon the morphology of the tooth, the centre of rotation and resistance changes when compared to control model. Clinical significance of study is for translatory and controlled tipping, the centre of resistance and rotation need to be known for desired orthodontic tooth movement.

A finite element model of upper central incisor and lateral incisor with its supporting structure was subjected to simple tipping of the tooth with point of application of the force of 100gms was applied 5.5mm apical to incisor edge and was centredmesiodistally. The root length of the model was changed in increments of 1mm. As the root length increased centre of resistance shifted more cervically for central incisor, lateral incisor, canine, 1st pre molar and 1st molar. and as the root length increased the centre of resistance shifted more apically for 2nd pre molar,. As the root length increased the centre of rotation shifted more cervically for central incisor, lateral incisor, and as the root length increased the centre of rotation shifted more apically for canine, 2nd pre molar and 1st molar. The displacement of the tooth was also noticed. Displacement of tooth increased with short root length for maxillary central incisor, lateral incisor, canine, and 1st molar. Whereas displacement of tooth did not increase with shorter root length for 1st pre molar and 2nd pre molar.

As the root length increased the Centre of Resistance is shifted more cervically for maxillary central incisor, lateral incisor, canine and 1st Premolar, and Molar whereas it shifted apically in 2nd Premolar.As the root length increased the position of Centre of Rotation also shifted cervically for maxillary central incisor, lateral incisor, whereas it shifted apically for canine, 1st premolar, 2nd premolar and 1st molar.The displacement of the tooth increased with shorter root length formaxillary central incisor, lateral incisor, canine, and 1st molar. Whereas displacement of tooth did not increase with shorter root length for 1st pre molar and 2nd pre molar.The future scope of studies could be focused on increasing the magnitude of the force,applying force on lingual aspect and including intrusive forces.

Reference

[1] Adrain N. Wilson et al.(1991) A finite element study of canine retraction with a palatal spring. British Journal of Orthodontics.18: 211 – 218.

[2] KazuoTanne et al.(1991) Patterns of initial tooth displacements associated with various root lengths and alveolar bone heights. American Journal of orthodontics.100: 66-71

[3] OsamuMiyakawa et al.(1985) A new method for finite element simulation of orthodontic appliance – teeth - periodontium alveolus system: Journal of Biomechanics. 18(4): 277 – 284.

[4] Ioannis S. Papageorgiou.(2005) The centre of resistance of teeth in orthodontics. Hell Orthod review. 8: 41-55.

[5] RohanMascarenhas.(2014) Effect of intrusive and retraction forces in labial and lingual Orthodontics: A Finite Element study. APOS trends in Orthodontics. 4(2).

[6] Niall Mc Guinness et al. (1992)Stresses induced by edgewise appliances in the periodontal ligament a finite element study: Angle orthodontist. 62(1): 15- 22.

[7] Kim L. Andersen et al.(1991) Material parameters and stress profiles within the periodontal ligament: American Journal of Orthodontics.99(5): 427 – 440.

[8] Juan Cobo et al.(1996)Dentoalveolar stress from bodily tooth movement at different levels of bone loss: American Journal of Orthodontics.110(3): 256 – 262.

[9] Boyd R.L. et al.(1989) Periodontal implications of orthodontic treatment in adults with reduced or normal periodontal tissues versus those of adolescents: American Journal of Orthodontics. 96(3): 191-9.

[10] Smith RJ, Burstone CJ. (1984)Mechanics of tooth movement. Am J Orthod.85(4):294-307.

[11] Peter D. Jeon et al.(2001) Three – Dimensional finite element analysis of stress in the periodontal ligament of the maxillary first molar with simulated bone loss. American Journal of Orthodontics.119(5): 498 – 504.

[12] Niall Mc Guinness et al.(1992) Stresses induced by edgewise appliances in the periodontal ligament a finite element study: Angle orthodontist. 62(1): 15- 22.

[13] D. Vollmer et al. (1999)Determination of the centre of resistance in an upper human canine and idealized tooth model: European Journal of Orthodontics.21: 633 – 648.

[14] Juan Cobo et al. (1993)Initial stress induced in periodontal tissue with diverse degrees of bone loss by an orthodontic force: three-dimensional analysis by means of the finite element method: American Journal of Orthodontics.104(5): 448 – 454.

[15] JuanCobo et al. (1996)Dentoalveolar stress from bodily tooth movement at different levels of bone loss: American Journal of Orthodontics.110(3): 256 – 262.

[16] Jost Brinkman P.G. et al. (1993)A FEM study for the biomechanical comparison of labial and palatal force application on the upper incisors. Finite element method. FortschrKieferorthop. 54(2): 76 – 82.

[17] Aru, Suraj, et al. "Design and Analysis of Centrally Suspended Cage-Less Differential." International Journal of Mechanical and Production Engineering Research and Development 4.4 (2014): 49-60.

[18] SINHA, DEBASHISH, and M. RAMACHANDRAN. "AN INVESTIGATION OF STRESS AND STRAIN DISTRIBUTION OF PLANETARY GEAR SYSTEM USING NUMERICAL ANALYSIS." International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) Special Issue, Dec 2018, 167 172.

[19] Arora, Rahul, and S. S. Dhami. "Finite Element Analysis and Multibody Dynamics of 6-DOF Industrial Robot." International Journal of Mechanical and Mechatronics Engineering 4 (2017): 1-12.

[20] Suresh, N., B. Srinivasa Reddy, and M. Ravindra Gandhi. "Manufacturing and analysis of four-way hacksaw machine by pedaling." International Journal of Industrial Engineering & Technology (IJIET) 8.2 (2018): 13-20.

[21] Devi, SUNKARA KAVITHA, and YV HANUMANTHU RAO. "The optimization of layer densities for multilayered insulation systems by using ansys." International Journal of Mechanical and Production Engineering Research and Development 8.4 (2018): 1087-1098.
[22] Mahroogi, Faisal O., and S. Narayan. "Design and analysis of Double Wishbone suspension systems for automotive applications." International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) 9 (2019): 1433-1442.