Content available at: https://www.ipinnovative.com/open-access-journals

Journal of Contemporary Orthodontics

Journal homepage: https://www.jco-ios.org/

Original Research Article

Finite element analysis of displacement and stress pattern on maxillary impacted canine placed at different heights and inclinations

Mahapara Jabeen Qari[1], Akshay Sharma[1], Anil Singla[1], Harupinder Singh Jaj[1]*, Vivek Mahajan[1], Indu Dhiman[1], Shikha Thakur[1]

[1]Dept. of Orthodontics, Himachal Dental College, Sundar Nagar, Himachal Pradesh, India.

Abstract

Introduction: The failed eruption of tooth to its normal occlusion is termed as impacted. After third molar permanent maxillary canines are most commonly impacted. Maxillary canine plays an important role in creating good facial and smile esthetics. Finite element analysis is used as a solution for understanding biomechanical response

Aims and Objectives: To evaluate the stress magnitude and displacement of maxillary impacted canines placed at different heights and inclinations using FEM.

Materials and Methods: FEM models comprising of palatally impacted canine housed in alveolar bone at different heights and inclinations were constructed using ANSYS software. Displacement of impacted canine, lateral incisor and first premolar was measured and stress distribution of impacted canine, Lateral incisor and first premolar at different height and inclinations with force of varying magnitude measured.

Results: The stress distribution in the PDL was found to be highest in first premolar, lateral incisor followed by least in the palatally impacted maxillary canine and the rate of displacement was highest in first premolar followed by impacted canine and least in the lateral incisor.

Conclusion: The stress generated in the PDL increases as the inclination of the impacted canine to the midline increases and the rate of tooth displacement decreases with the increase in inclination of palatally impacted canine.

Keywords: Stress distribution, Displacement, Impacted canine, Finite element method.

Received: 13-03-2024; **Accepted:** 06-06-2024; **Available Online**: 27-05-2025

1. Introduction

Interruption in the eruption of teeth due to malposition or lack of space is called impaction. Among the impacted teeth, maxillary canines are second most frequently impacted following the third molar. Approximately two-third of reported impacted teeth were in palatal region while one-third in labial region.[1]

A wide variety of conditions can give rise to impaction of maxillary canines. Due to its tortuous course and because of its late eruption in the oral cavity it gets frequently impacted. Local hard tissue obstruction, local pathology, disturbances in the eruption of incisors and heredity are some of other predisposing factors which can give rise to impactions.[2]

Maxillary canine plays an important role in creating good facial and smile esthetics since they are positioned at the corner of dental arch and hence disturbance in the eruption of permanent maxillary canines can cause problems in the dental arch.[3] Diagnosis and localization of impacted canines can be done during a routine clinical and radiographic examinations which provides accurate location of impacted canines and their relationship to adjacent anatomical structures. Position and angulation of the impacted canines affect treatment modality and prolongs orthodontic treatment and this complexity also effects the response of surrounding supporting structures during orthodontic treatment.[4]

Clinically, it is not possible to study the relationship between the stress generated by the orthodontic forces with

*Corresponding author: Harupinder Singh Jaj
Email: qarimahparah@gmail.com

https://doi.org/10.18231/j.jco.2025.027

the severity of impaction, so finite element method provides the necessary information about the stress generated by the traction of impacted canine under various mechanical setups. Finite element method (FEM) is a computer simulation technique which uses the mathematical matrix analysis of structures to predict the biomechanical performance of biological tissues, can quantify stresses and displacement in a three dimensional configuration.[5] Hence the aims and objectives of the present study were to evaluate the displacement and stress pattern of maxillary impacted canine placed at different heights and inclinations using FEM.

2. Materials and Methods

The designing of 72 FEM models were done in SolidWorks software and simulation in Ansys Software version 14 to evaluate the stress distribution in maxillary impacted canine placed at different heights and inclinations. Finite element model of all maxillary teeth including the palatally impacted canine, periodontal ligament, alveolar bone, buccal tubes, brackets, and arch wires were constructed using mechanical elastic properties of the materials such as Young's Modulus of elasticity and Poisson's ratio as shown Table I. All the materials were homogenous, isotropic, and linearly elastic.

To determine the stress magnitude, a 3-dimensional model of maxillary palatally impacted canine was constructed along with periodontal ligament and alveolar bone and the interface between the alveolar bone socket and root surface was 0.2 mm as the width of periodontal ligament (PDL) is 0.25 to 0.35 mm. The final meshwork consisted of 165378 nodes and 1045917 tetrahedral elements. Standard edgewise prescriptions with no torque and no angulation brackets were used for all models based on computer-aided design with slot dimension of 0.022×0.028inch slot and a rectangular cross section wire of (0.019 x 0.025 inch) which was passively inserted and ligated with ligature wire. The brackets were placed at the centre of the labial surface of maxillary teeth crown with composite resin adhesive layer which had mean thickness of 0.2mm.

FEM model were constructed with the long axis of palatally impacted canine was inclined at 10◦,20˚,30˚ to the midsagittal plane which is perpendicular to the occlusal plane as shown in Color Plate Ia, Ib, Ic, IIa IIb, and IIc**.** Thenthebone covering the palatal surface of impacted canine was removed in the finite element model, exposing it to the palatal vault such that the virtual attachment was placed for the application of traction force of 50 gms and 100 gms magnitude in the buccal direction. The force was directed from the main archwire at a point from the centre of the wire between mesial surface of first premolar bracket to the distal surface of lateral incisor bracket to the eyelet attachment on the palatal surface of the impacted canine crown, simulating the clinical situation.

Based on height and inclination and force of magnitude 50 gms and 100 gms FEM models were divided into two groups:

1. **Group I:** The FEM models of maxillary dental arch in which the vertical position of the cusp tip of impacted canine was at the coronal half of the lateral incisor root depicted as 'A'
2. **Group II:** FEM models of maxillary dental arch, in which the vertical position of the cusp tip of impacted canine was at the middle half of the lateral incisor root depicted as 'B'

After simulation of all the FEM models, Von Mises Stresses was recorded at apical, middle and cervical thirds of impacted canine. Displacement of impacted canine, lateral incisor and first premolar was measured and stress distribution of impacted canine, Lateral incisor and first premolar at different height and inclinations with force of varying magnitude were measured and tabulated using ANSYS software version 19.2.

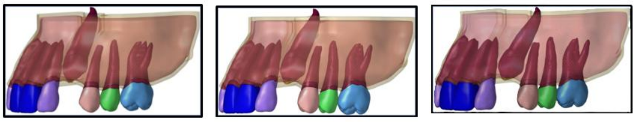

Figure 1: Color plate I: Three-dimensional finite element model of palatally impacted canine, placed at the coronal half of lateral incisor root depicted as 'a' at inclination of 10,20,30 degrees

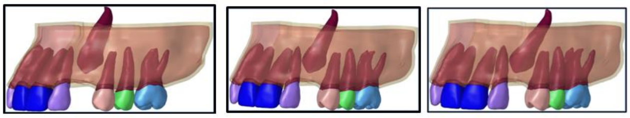

Figure 2: Colour Plate II: Three-dimensional finite element model of palatally impacted canine, placed at the middle half of lateral incisor root depicted as 'b' at inclination of 10, 20, 30 degrees

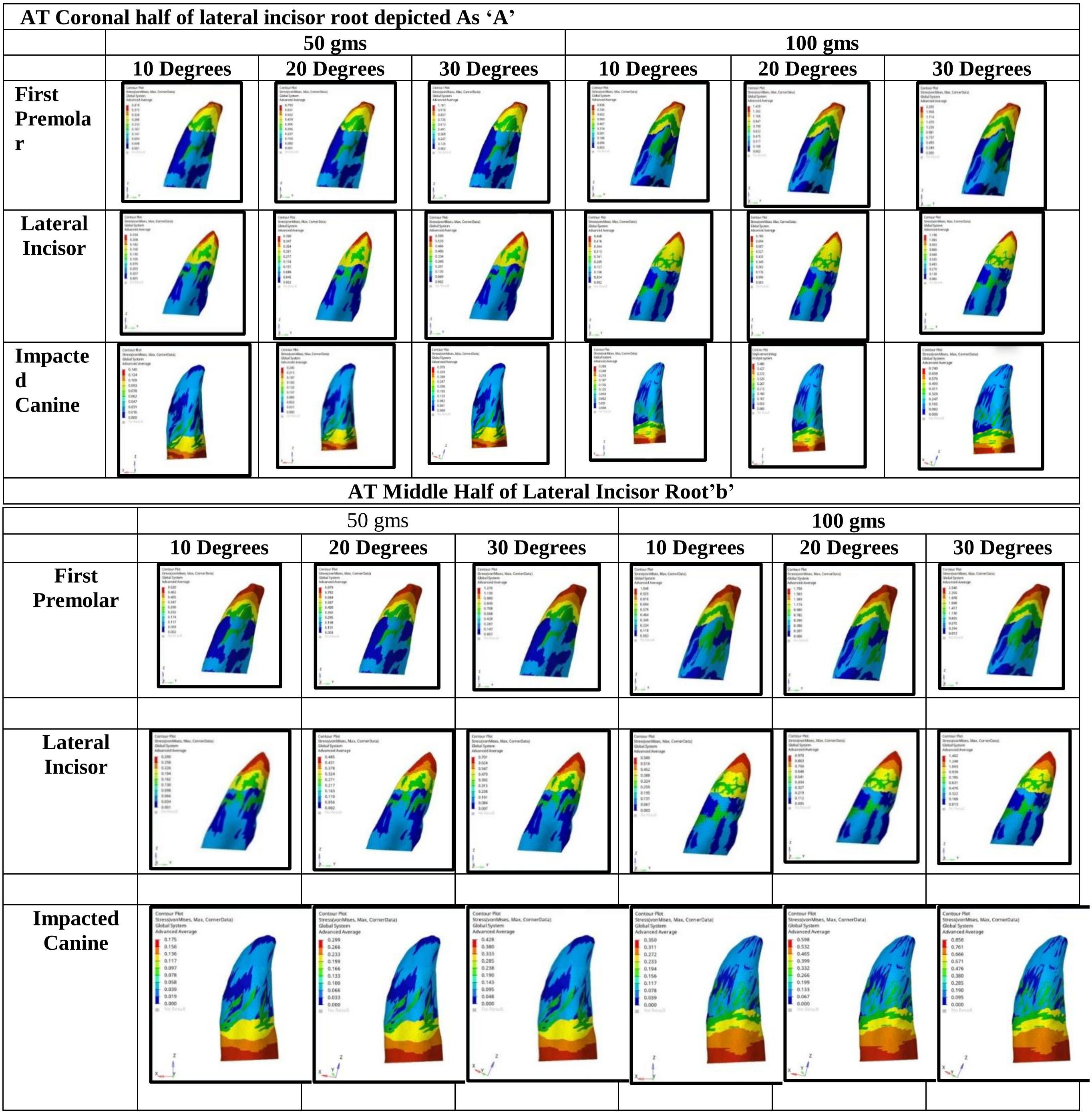

Figure 3: Color Plate: **-** Stress distribution of various fem models of first premolar, lateral incisor & canine during traction of impacted canine with a force of 50 and 100 gms placed

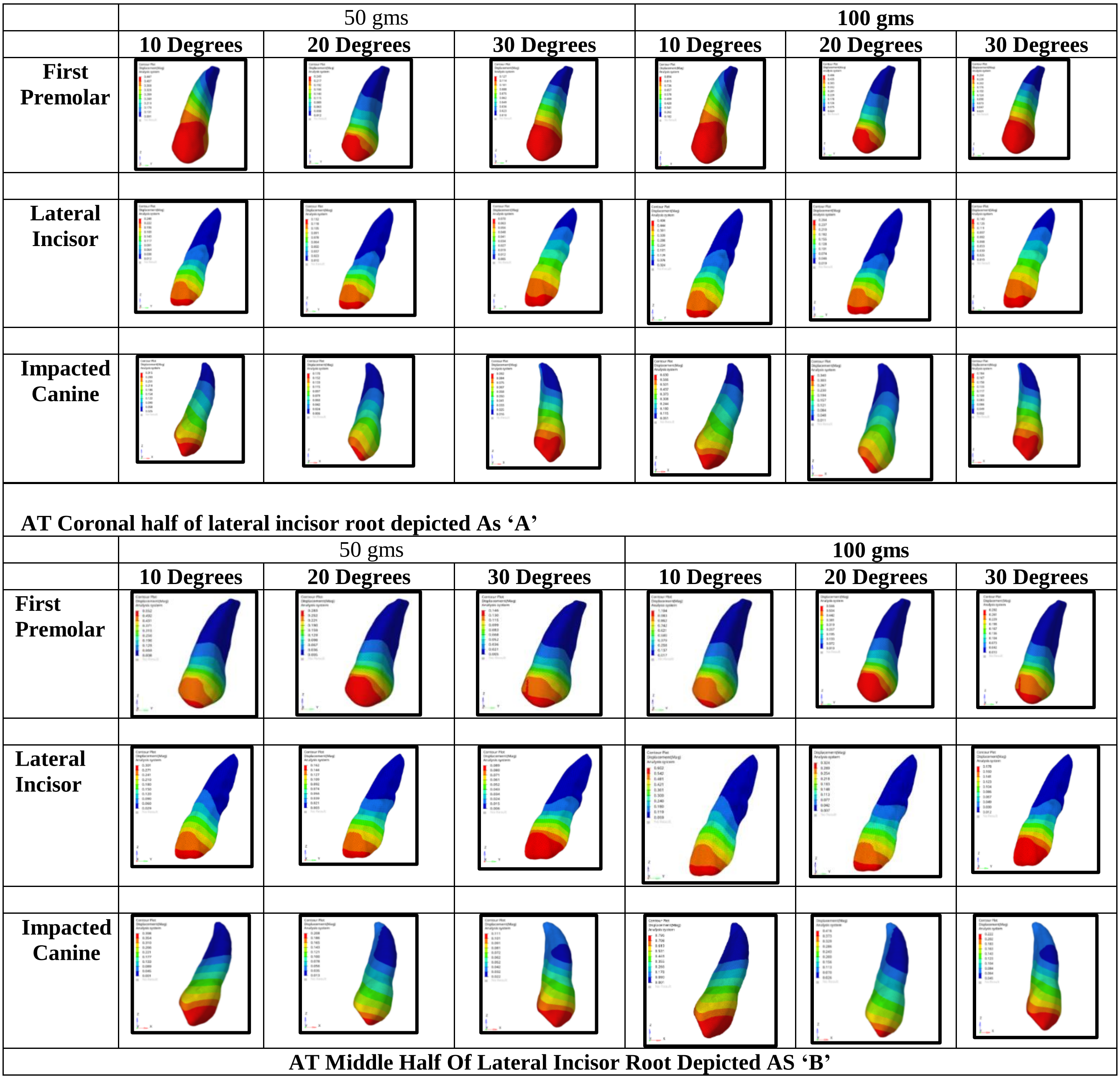

Figure 4: Color plate IV:- Displacement of various fem models of first premolar, lateral incisor & canine during traction of impacted canine with a force of 50 gms and 100 gms placed.

Table 1: Mechanical properties of the material used in the study

Materials	Young’s modulus (mpa)	Poisson’s ratio
Teeth	18,600	0.30
PDL	0.69	0.45
Bone	13,700	0.26
Cortical/ hard bone	13,700	0.30
Trabecular/soft bone	1370	0.30
Stainless steel wire	2,00,000	0.30
Bracket- stainless steel	2,00,000	0.30
Adhesive-composite	16,600	0.24
Ligature-stainless steel	2,00,000	0.30
Eyelet attachment	2,00,000	0.30

Table 2: Numerical values of stress distribution in various fem models used in the study as derived from finite element software

Stress Distribution At 'A' Coronal Half Of Root Of Lateral Incisor (Mpa)					
		Force			
Models	Inclination Of Canine	50gms		100gms	
		Tooth	Von Mises Stress	Models	Von Mises Stress
FEM 1 A	10°	First Premolar	0.419	FEM 10 A	0.838
FEM 2 A		Lateral Incisor	0.234	FEM 11 A	0.468
FEM 3 A		Palatally Impacted Canine	0.140	FEM 12 A	0.280
FEM 4 A	20°	First Premolar	0.710	FEM 13 A	1.420
FEM 5 A		Lateral Incisor	0.390	FEM 14 A	0.780
FEM 6 A		Palatally Impacted Canine	0.240	FEM 15 A	0.480
FEM 7 A	30°	First Premolar	1.101	FEM 16 A	2.202
FEM 8 A		Lateral Incisor	0.599	FEM 17 A	1.198
FEM 9 A		Palatally Impacted Canine	0.370	FEM 18 A	0.740
Stress Distribution At 'B' Middle Half of Root of Lateral Incisor (Mpa)					
Models	Inclination Of Canine	Force			
		50 gms		100 gms	
	10°	Tooth	Von Mises Stress	Models	Von Mises Stress
FEM 19 B		First Premolar	0.520	FEM 28 B	1.040
FEM 20 B		Lateral Incisor	0.290	FEM 29B	0.580
FEM 21 B	20°	Palatally Impacted Canine	0.175	FEM 30 B	0.350
FEM 22 B		First Premolar	0.879	FEM 31 B	1.758
FEM 23 B		Lateral Incisor	0.485	FEM 32 B	0.970
FEM 24 B	30°	Palatally Impacted Canine	0.299	FEM 33 B	0.598
FEM 25 B		First Premolar	1.270	FEM 34 B	2.540
FEM 26 B		Lateral Incisor	0.701	FEM 35 B	1.402
FEM 27 B		Palatally Impacted Canine	0.428	FEM 36 B	0.856

Table 3: Numerical values of the displacement at 'a' of various fem models used in the study as derived from finite element software

Displacement At Coronal Half of Lateral Incisor Root (A) (mm)					
Models	Inclination of Canine	Force = 50 gms		Force =100gms	
		Tooth	Displacement (mm)	Models	Displacement (mm)
FEM 37 A	10°	First Premolar	0.552	FEM 46 A	1.104
FEM 38 A		Lateral Incisor	0.301	FEM 47 A	0.602
FEM 39 A		Palatally Impacted Canine	0.398	FEM 48 A	0.796
FEM 40 A	20°	First Premolar	0.283	FEM 49 A	0.566
FEM 41 A		Lateral Incisor	0.162	FEM 50 A	0.324
FEM 42 A		Palatally Impacted Canine	0.208	FEM 51 A	0.416
FEM 43 A	30°	First Premolar	0.146	FEM 52 A	0.292
FEM 44 A		Lateral Incisor	0.089	FEM 53 A	0.178
FEM 45 A		Palatally Impacted Canine	0.111	FEM 54 A	0.222
Displacement At Middle Half Of Lateral Incisor Root(B) (mm)					
Models	Inclination Of Canine	Force = 50 gms		Force =100gms	
		Tooth	Displacement (mm)	Models	Displacement (mm)
FEM 55 B	10°	First Premolar	0.447	FEM 64 B	0.894
FEM 56 B		Lateral Incisor	0.248	FEM 65 B	0.496
FEM 57 B		Palatally Impacted Canine	0.315	FEM 66 B	0.630
FEM 58 B	20°	First Premolar	0.243	FEM 67 B	0.486

FEM 59 B		Lateral Incisor	0.132	FEM 68 B	0.264
FEM 60 B		Palatally Impacted Canine	0.170	FEM 69 B	0.340
FEM 61 B	30°	First Premolar	0.127	FEM 70 B	0.254
FEM 62 B		Lateral Incisor	0.070	FEM 71 B	0.140
FEM 63 B		Palatally Impacted Canine	0.092	FEM 72 B	0.184

3. Results

The von Mises stress on the PDL and the displacement of lateral incisor, palatally impacted canine, and first premolar on the impacted side of maxilla were evaluated when force of increasing magnitude (50gm and100gm) was applied. The stress distribution in the periodontal ligament was found to be highest in first premolar, lateral incisor followed by least in the palatally impacted maxillary canine as shown in **Table 2** and Color plate III, and the rate of displacement was highest in first premolar followed by impacted canine and least in the lateral incisor as shown in **Table 2** and **Table 3** Color Plate IV.

4. Discussion

On evaluation of the stress distribution in all the teeth at 50 gm and 100 gm of traction force the stress in the periodontal ligament was found to be more on the first premolar, lateral incisor followed by least in the palatally impacted maxillary canine as shown in **Table 2**, and Color plate III. This could be explained on the basis that the lateral incisor and first premolar are acting as the anchor unit to bring the palatally impacted canine to the occlusal level through orthodontic extrusive force. Furthermore, the palatally impacted canine have least stress because more distal the position of impacted canine in relation to the root of lateral incisor, lesser is the stress on the PDL of the impacted canine when an extrusive force is applied which was in accordance to the study done by Prasad N et al (2017).**Error! Reference source not found.** Furthermore, on evaluation of stress distribution was found to be increased at an inclination of 30 degrees followed by 20 degrees and 10 degrees as shown in **Table 2** and Color Plate III. This is because when the direction of force is in line with the long axis of the impacted tooth maximum stress is smaller and evenly distributed and when the direction of the force was placed at an increased angle to the long axis of the impacted tooth higher stresses are generated as reported by Zang et al (2008).**Error! Reference source not found.**

The results showed that the stress distribution on the PDL has been increased with the increase in the magnitude of force from 50gms to 100 gms on the palatally impacted canine as shown in **Table 2** and Color Plate III. This indicates that when forces to extrude the impacted canine increases there is increase in the stress on the pdl of all the teeth which was supported by Prasad N et al (2017)**Error! Reference source not found.**

Moreover, the rate of displacement was found to be highest in first premolar followed by impacted canine and least in the lateral incisor as shown in

Table 3 and Colour Plate IV. This difference in the rate of the displacement might be because of the variations in the tooth size, morphology, alveolar bone height or the tooth inclinations, and as the roots of first premolar are placed almost at 90 degrees to occlusal plane thereby having least resistance to displacement while lateral incisor are placed at an inclination to occlusal plane so that the surface area of contact between the root and alveolar bone increased, thus influencing it to have least rate of displacement. This was in accordance to the studies done by the Nagendraprasad et al (2019)**Error! Reference source not found.** and Tanne et al (1991)**Error! Reference source not found.** who reported similar results.

Furthermore, the rate of displacement is more at 10 degrees inclination followed by 20 degrees and 30 degrees as shown in

Table 3 and Color Plate IV. This might be because more highly the canine is inclined, more is the stress generated resulting in more resistance to the tooth movement and less inclined canine would have least resistance to movement therefore greater displacement of the tooth which was reported by Zeno et al (2020)**Error! Reference source not found.** and Gerami et al (2016).**Error! Reference source not found.**

On further evaluation the rate of displacement with 100 gms of traction force was more as compared to 50 gms shown in

Table 3 and Color Plate IV. This might be due to the difference in the magnitude of force applied on the FEM model which leads to increase in the rate of displacement which was in accordance to the studies done by Hixon et al (1970)**Error! Reference source not found.** and Prasad et al (2017).**Error! Reference source not found.**

Furthermore, the stress was higher when the canine was inclined at 30 degrees followed by 20 and 10 degrees as shown in Table II and Color plate III. The reason behind this could be attributed to the increased inclination of the canine results in more resistance to the orthodontic traction leading to more concentration of stress. This was in accordance to Jacoby (1979).**Error! Reference source not found.** Kanjanaouthai A et al (2012)**Error! Reference source not found.** and Kornhauser et al (1996).**Error! Reference source not found.**

Further, the results showed that the stress distribution was different when the palatally impacted canine placed at different vertical heights were compared, the stress distribution was more in palatally impacted canine placed at

'B' than 'A' as shown in **Table 2** and Color Plate III. This could be explained on the basis that more the canine is positioned vertically higher more will be the applied orthodontic traction force so more will be the stress generated which was in accordance to Zeno et al (2020)**Error! Reference source not found.** and Kornhauser et al (1996).**Error! Reference source not found.**

Moreover, the rate of displacement was found more in palatally impacted canine placed at 'A' as compared to FEM models positioned at 'B' as shown in

Table 3 and Color Plate IV. This could be explained on the basis of stress distribution in FEM models used in the study. As the FEM models of impacted canine placed at 'A' showed less stress hence the rate of displacement would be more and impacted canine placed at 'B' showed more stress and hence the rate of displacement would be less. This was in accordance to the study done by Gerami et al (2016).**Error! Reference source not found.**

This study provides valuable insights into how the periodontal ligament (PDL) and teeth respond during orthodontic disimpaction. Further Finite Element Analysis (FEA) studies can explore various clinical scenarios, enabling orthodontists to adjust their treatment mechanics for the benefit of the patient. This method can serve as a diagnostic tool to plan appropriate treatment strategies for specific cases.

5. Conclusion

1. The stress distribution pattern varied with inclination of the impacted canine. As the inclination of the impacted canine to the midline increases, the stress generated in the PDL increases.
2. The rate of tooth displacement decreases with the increase in inclination of palatally impacted canine.
3. Stress distribution was higher when the impacted canine was placed at the middle half of the lateral incisor root than at the coronal half. The displacement was higher when the canine was placed at the coronal half of lateral incisor root than at the middle half.

6. Source of Funding

None.

7. Conflict of Internets

None

References

1. Baser EN, Akar NK, Sayar G. Effects of ballista and Kilroy springs on palatally impacted canines: A Finite Element Model analysis. *Turk J Orthod* 2022.2022.10
2. McSherry PF. The ectopic maxillary canine: A review. *Brit J Orthod.* 1998;25:209-16.
3. Aslan BI, Üçüncü N. Clinical consideration and management of impacted maxillary canine teeth. *Emer Trends Oral Health Sci Dent. Intech*; 2015; Ch-21, 465-500.
4. Zasciurinskiene E, Bjerklin K, Smailiene D, Sidlauskas A, Puisys A. Initial vertical and horizontal position of palatally impacted maxillary canine and effect on periodontal status following surgical-orthodontic treatment. *Angle Orthod* 2008,78(2);275-80.
5. Marya A, David G, Eugenio MA. Finite element analysis and its role in orthodontics. *Dent Oral Health.* 2016;2(2):5-6
6. Prasad KN, Mathew S, Shivamurthy P, Sabrish S, Sagarkar R. Orthodontic Displacement and Stress Assessment: A Finite Element Analysis. *World J Dent.* 2017;8(5):407-12.
7. 7. Zhang J, Wang XX, Ma SL, Ru J, Ren XS. 3-dimensional finite element analysis of periodontal stress distribution when impacted teeth are tracted. Hua Xi Kou Qiang Yi Xue Za Zhi. 2008;26(1):19-22.
8. Nagendraprasad K, Mathew S, Shivamurthy P, Sabrish S. Displacement and periodontal stress analysis on palatally impacted canine. *Indian J Dent Res*. 2019;30(5):788-93.
9. Tanne K, Nahataki T, Inoue Y, Sakuda M, Burstone CJ. Patterns of initial tooth displacements associated with various root lengths and alveolar bone heights. *American Journal of Orthodontics and Dentofacial Orthopedics 1991;100(1):66-71.*
10. Zeno KG, Mustapha S, Ayoub G, Ghafari JG. Effect of force direction and tooth angulation during traction of palatally impacted canines: A finite element analysis. *American Journal of Orthodontics and Dentofacial Orthopedics 2020;157(3):377–84*.
11. Gerami A, Dadgar S, Rakhshan V, Jannati P, Sobouti F. Displacement and force distribution of splinted and tilted mandibular anterior teeth under occlusal loads: an in silico 3D finite element analysis. *Progr Orthod*. 2016;17(1):1-10.
12. Hixon L H, Aaoen T O, Arango J, Clark R A, Klosterman R, Miller S S, Odom W M. Force and tooth movement. *Amer. J. Orthodont.1970.*
13. Jacoby H. The "ballista spring" system for impacted teeth. *American journal of Orthodontics 1979;75(2):143-51.*
14. Kanjanaouthaia A, Mahatumaratb K, Techalertpaisarnc P, Versluis A. Effect of the inclination of a maxillary central incisor on periodontal stress Finite element analysis. *Angle Orthodontist 2012;*82(5):812-9.
15. Kornhauser S, Abed Y, Harari D, Becker A. The resolution of palatally impacted canines using palatal occlusion force from a buckle auxiliary. *Am J Orthod Dent Fac Orthop*. 1996;110(5):528-34.

Cite this article: Qari MJ, SharmaA, Singla A, JaJ HR, Mahajan V, Dhiman I, Thakur S. Finite element analysis of displacement and stress pattern on maxillary impacted canine placed at different heights and inclinations. *J Contemp Orthod* 2025;9(2):201-207.