

Comparison of Stress Distribution Induced by Kilroy Spring during the Alignment of Palatally Impacted Canine with Increase in Angulation of Impaction: A Finite Element Analysis

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Abstract

Introduction: Canines are the second most commonly impacted teeth. Treatment of an impacted canine is associated with demanding anchorage control, increased treatment duration, and undesirable side effects. Accurate localization of the impacted canine and force application impact the success of the treatment. The aim of the study was to determine the stresses on the palatally impacted canine (PIC) and on the adjacent teeth by Kilroy spring with an increase in degree of angulation ($<30^\circ$, $30^\circ - 45^\circ$, $>45^\circ$) using Finite element method. **Materials and Methods:** PICs with increase in horizontal impaction angulation with respect to the midlines underwent finite element modeling. A prototype 3D models were reconstructed and segmented into its anatomic components. Each PIC was precisely positioned according to impaction position. Von Mises stresses in response to 60 g of force were evaluated on the canine as well as on the adjacent teeth. **Results:** In all the three models, the highest stress was observed on the impacted canine with 60° angulation (0.62731 MPa). Canine showed the maximum von Mises stresses followed by lateral incisor and first premolar, respectively, in all the three models (M1, M2, and M3). **Conclusion:** The PIC with 60° angulation yielded higher stresses than the 30° and 15° angulated canines, respectively.

Keywords: Finite element method, Kilroy spring, Palatally impacted canine, von Mises stress.

INTRODUCTION

Impacted canines are the second most common impacted teeth after the third molars. According to Ericson and Kurol, the incidence of impacted canine is 1.7%, with a female prevalence of 1.17% when compared to males (0.51%). Among the patients with maxillary impacted canine, it is estimated that 8% have bilateral impactions. Incidence of mandibular canines is 0.35%, the prevalence of impacted maxillary canine ranges from 0.92% to 4.3%.^[1] Becker *et al.* reported an increase in the incidence of palatally impacted canines (PIC) by 2.4 times in cases with missing lateral incisors when compared with general population.^[2] The etiology of canine impaction can be explained on the basis of two main theories: Guidance theory^[3-5] and genetic theory.^[6,7]

Canines are seemed more prone to impaction if, during the clinical examination, they are not palpable in the vestibule, leading to the need for additional radiographic confirmation, and if they have not erupted in the oral cavity by the age of 13 years.^[8]

Application of proper orthodontic force is necessary to avoid unwanted side effects, such as prolonged duration of treatment^[9-11] and resorption of adjacent root especially of

lateral incisor.^[12] Various treatment modalities have been used for the traction of impacted canines, from direct pull into the arch to the use of various auxiliary springs such as Ballista spring Kilroy spring.^[12,13-17] Although various methods for traction have been widely used, studies of relation between the angulation of canine impaction and the stresses generated by Kilroy spring are not possible clinically. For this reason, finite element analysis (FEA) an engineering method provides the capability of stimulating the effect of Kilroy spring on palatally impacted and helps in knowing the amount of stress that is being produced and its relation to the degree of angulation of canine. FEA has become a common research tool in orthodontics, yet scarce in the investigation of PIC traction.^[18,19]

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The aims of this study were to determine stress levels on the impacted canine and adjacent teeth with various difficulty levels (different angulations with respect to midline) when subjected to force using Kilroy Spring.

MATERIALS AND METHODS

This study was approved by the Institutional Ethical Committee at the People's Dental Academy. The material consisted of cone-beam computed tomography (CBCT) scan of a patient who had PICs and came to our department for orthodontic treatment. The CBCT scans of the patients were prescribed for the accurate localization of the impacted canines after clinical examinations and radiographic investigations (orthopantomography, Lateral Cephalogram). 3D Modeling was carried out using Solidworks 2023 Software. FEA was done with the help of Ansys Workbench 19.2 Software. Followed by importing the 3D geometrical models into the Ansys Workbench 19.2 and meshing was carried out. Finally, boundary conditions were assigned and the stimulation was carried out to know the von Mises stress.

Inclusion criteria

The following criteria were included in the study:

- Patient with permanent dentition
- Presence of maxillary PIC
- No history of previous orthodontic treatment.

Exclusion criteria

The following criteria were excluded from the study:

- Patient with other anomalies (fused teeth, dilaceration, and fractured teeth)
- Patient having prosthesis
- Patient with compromised periodontal health
- Patient with missing teeth except for the 3rd molars.

FEA

Virtual placement of materials and assignment of material properties

Material properties were assigned and the virtual 3D models were prepared (Table 1).

Finite element model consisted of three models (M1, M2, and M3) of PIC with an angulation to midline of 15°, 30°, and 60°, respectively (Figures 2-4).

Table 1: Material properties used in the stimulations

S. no.	Component	Density (kg/m ³)	Youngs modulus (MPa)	Poissons ratio
1	Tooth	1960	20000	0.3
2	Cortical bone	1300	13700	0.3
3	Cancellous bone	1300	1370	0.33
4	Periodontal ligament	1100	68.9	0.45
5	Stainless steel	8000	200000	0.3
6	Beta titanium	4430	115000	0.34

Definition of boundary condition and contact analysis

The boundary condition imposed constraints on all degrees of freedom at the bottom and outer edge of the bone model to prevent any sliding movements. The traction force of 60 g was exerted using Kilroy spring. It was ensured that all contacts were treated as fully bonded, indicating a solid model with no gaps between structures.

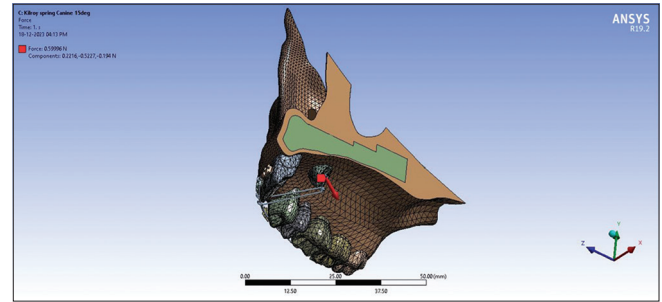


Figure 1: Palatally impacted canine with all the attachments and spring attached

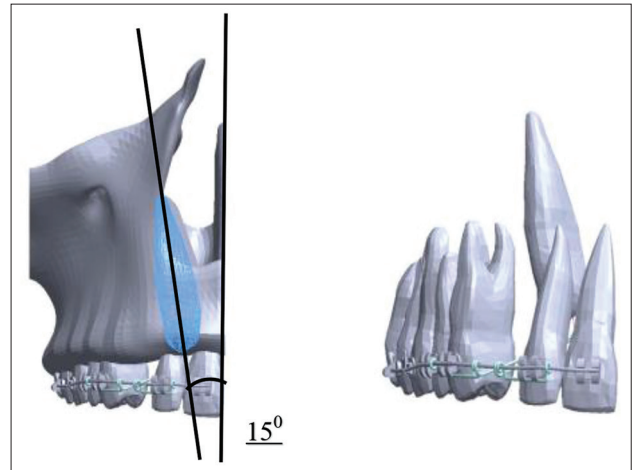


Figure 2: Model 1 - palatally impacted canine with 15° angulation to the midline

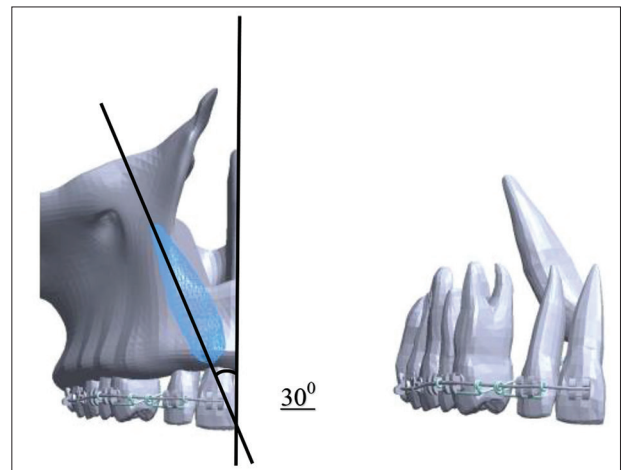


Figure 3: Model 2 - palatally impacted canine with 30° angulation to the midline

Definition of loading conditions

An attachment was bonded to the crown of the PIC which was connected to Kilroy Spring (Figure 1). FEM was employed to assess the stress distribution in the adjacent bone, on the canine and the adjacent teeth.

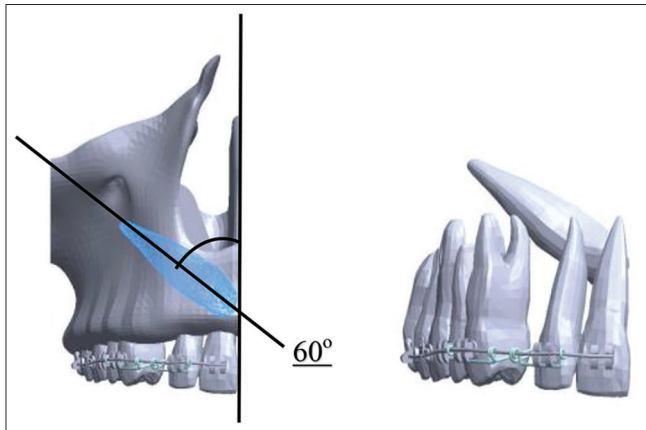


Figure 4: Model 3 - Palatally impacted canine with 60° angulation to the midline

The von Mises stresses levels on the canine as well as on the adjacent teeth were noted. The stresses in all the three models a Constant force of 60 g was applied, and Kilroy Spring was modeled with the dimension of 0.016" Stainless Steel.

RESULTS

- The stresses on the canine were directly proportional to the canine angulation, that is, the stresses increased with increase in angulation of the canine (Table 2).
- Maximum stresses were seen with model 3 (60°), followed by model 2 (30°) and model 1 (15°), respectively. (Figures 5-7)
- The order of stresses on the teeth in descending order was as follows: Canine > lateral incisor > first premolar > second premolar > central incisor > first molar > second molar (Figures 8-11).

DISCUSSION

Pitt *et al.*, in their study for determining the treatment difficulty index for unerupted maxillary canines, concluded that horizontal

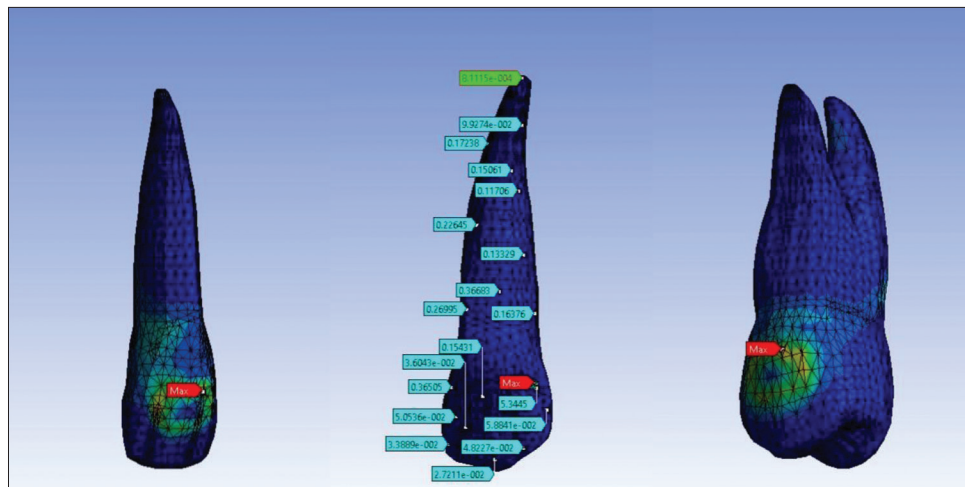


Figure 5: Von Mises stresses on lateral incisor, canine and 1st premolar in model 1

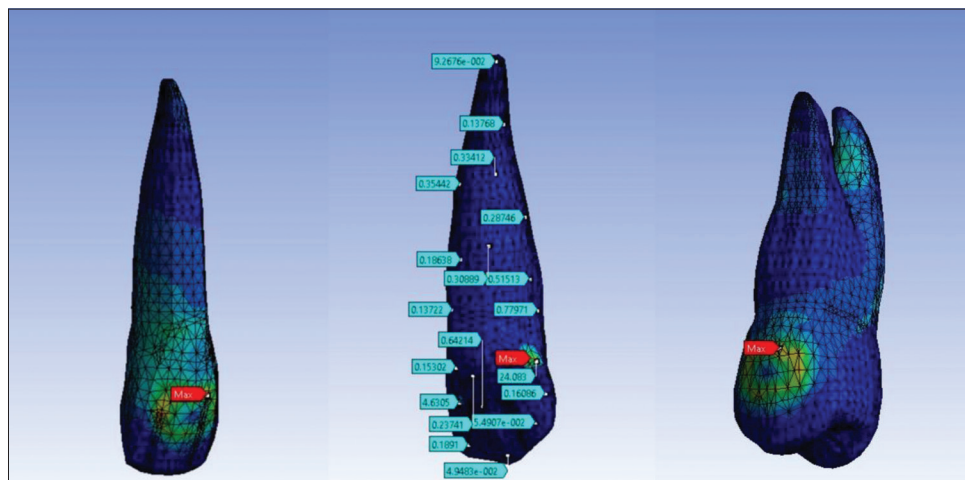


Figure 6: Von Mises stresses on lateral incisor, canine and 1st premolar in model 2

Figure 7: Von Mises stresses on lateral incisor, canine and 1st premolar in model 3

Figure 8: Von Mises stresses on all the teeth in model 1

Figure 9: Von Mises stresses on all the teeth in model 2

Figure 10: Von Mises stresses on all the teeth in model 3

position, age of patient, vertical height, and buccopalatal position, in descending order of importance, are the factors which determine the difficulty of canine alignment.^[20] Canines

Table 2: Average von Mises stresses in all the three models

S. no	Entity	Average von Mises stresses (Mpa)		
		15°	30°	60°
1.	Central incisor	0.017721	0.025291	0.029707
2.	Lateral incisor	0.049682	0.053639	0.061842
3.	Canine	0.21065	0.34791	0.62731
4.	First premolar	0.027263	0.033554	0.061471
5.	Second premolar	0.021071	0.02777	0.044886
6.	First molar	0.0067304	0.014446	0.02348
7.	Second molar	0.00287	0.0073725	0.013771

angulated toward the horizontal are difficult to manage and have a poorer alignment prognosis.^[21] According to Stivaros and Mandall as angulation of impacted canine to the midline increases the likelihood of extraction increases rather than attempt for orthodontic alignment.^[22] As the angulation of horizontal impaction was a key factor in determining the difficulty of canine alignment, this study determines the effect of canine angulation on the stresses on the canine as well as on the adjacent teeth. Kilroy spring is one of the most commonly used method for traction of a PIC as it is easy to fabricate and its modification has a upper hand when compared to the other methods used for canine traction. The recommended force levels for moving impacted teeth are generally low, no more than 2 ounces (approximately 60 g) of force.^[23] The use of light forces, to move impacted teeth is a common practice in orthodontics. In the case of impacted teeth, orthodontic forces can be utilized to gradually coax the tooth into its proper alignment. However, it is crucial to apply these forces cautiously and precisely to avoid damaging surrounding tissues and structures. To ensure safe and effective treatment, orthodontists carefully calculate the magnitude and direction of the forces applied to the impacted tooth. The amount of force exerted is closely monitored throughout the treatment process. This level of force is considered gentle and minimizes the risk of adverse effects such as root resorption or damage to the surrounding periodontal tissues.

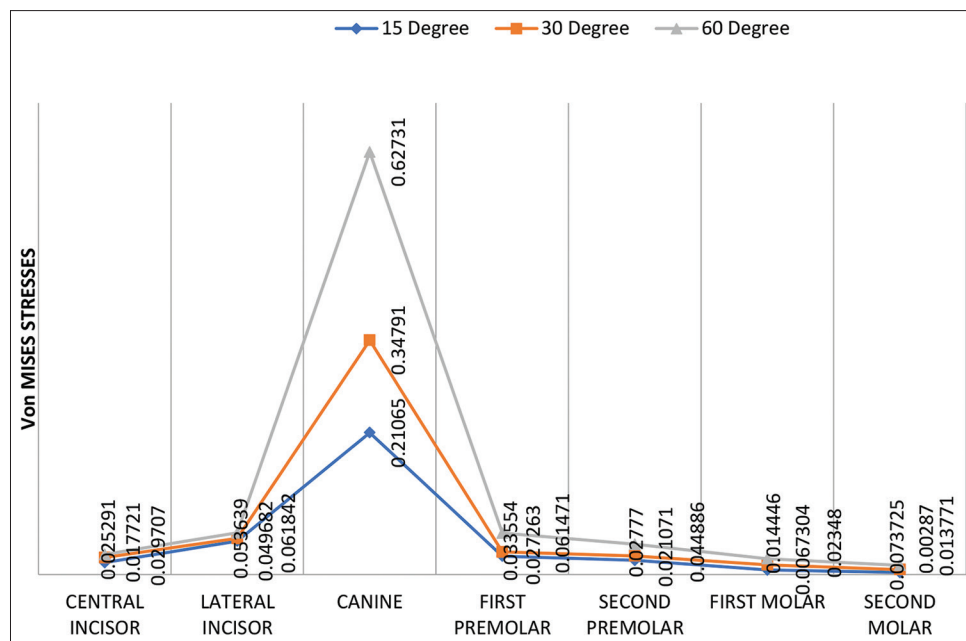


Figure 11: Graphical representation of differential stresses on the teeth in all the three models

CONCLUSION

1. The von Mises stresses on the canine increased with increase in horizontal angulation of the palatally impacted maxillary canine
2. The maximum von Mises stresses were generated on canine followed by lateral incisor and 1st premolar, respectively.

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INSTITUTIONAL REVIEW BOARD STATEMENT

This study is approved under Review Board sequenced - RAC/2023/007/07 and IEC/2023/600/07

CONFLICTS OF INTEREST

The authors reported no competing financial interests or personal relationships that could appear to influence the work reported in this paper.

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