TURKISH JOURNAL of ORTHODONTICS

DOI: 10.4274/TurkJOrthod.2022.2022.10

Original Article

Effects of Ballista and Kilroy Springs on Palatally Impacted Canines: A Finite Element Model Analysis

Ecem Nagihan Başer[1], Nevin Kaptan Akar[2], Gülşilay Sayar[3]

[1]Department of Orthodontics, Faculty of Dentistry İstanbul Medipol University, İstanbul, Turkey
[2]Department of Orthodontics, Faculty of Dentistry Kocaeli University, Kocaeli, Turkey
[3]Department of Orthodontics, School of Dental Medicine Bahçeşehir University, İstanbul, Turkey

Cite this article as: Başer EN, Kaptan Akar N, Sayar G. Effects of Ballista and Kilroy Springs on Palatally Impacted Canines: A Finite Element Model Analysis. *Turk J Orthod.* 2023; 36(1): 30-38

Main Points

- The von Mises stress values of impacted canines were greater in the Kilroy model.
- The distribution of von Mises stress values of the first premolar tooth was similar in both models.
- Different stress values occurred in the different spring designs.

ABSTRACT

Objective: This study evaluated the stress distribution and displacement on impacted maxillary canines and their adjacent teeth of orthodontic forced eruption using Ballista and Kilroy springs by finite element model (FEM) analysis.

Methods: Two different FEMs applying the same force level on an impacted canine tooth (Model 1: Ballista spring, Model 2: Kilroy spring) were conducted using FEM analysis and the principal stresses, von Mises stresses, and displacements were evaluated.

Results: Von Mises values at the cusp tip of impacted canines were measured as 0.009896 N/mm^2 in the Ballista model and 0.015334 N/mm^2 in the Kilroy model. The highest value was measured in the buccal apex of the first premolar in both spring designs. The extrusion was observed in Ballista, and intrusion was observed in the Kilroy model at the apex of the first premolar. The Ballista model showed the highest value (0.003642 N/mm^2) at the buccal tip of the first premolar, while in the Kilroy model, the highest measurement (0.002989 N/mm^2) was shown at the incisal edge of the lateral tooth.

Conclusion: Von Mises stress values were higher in the Kilroy model at the cusp tip and apical part of the impacted tooth than that in the Ballista model. The highest von Mises stress values were concentrated on the buccal root apex of the first premolar in both models. Although the amount of force applied by the springs was the same, the stress values were different depending on the spring design.

Keywords: Canine impaction, finite element analysis, force, Ballista, Kilroy, impacted teeth

INTRODUCTION

The condition that a tooth can not erupt due to malposition or lack of space is called impaction.[1] Among the impacted teeth, maxillary canines are the second most frequently impacted lesions following the third molar,[2] and the incidence of impacted maxillary canine teeth was reported as 0.92%-2.2% in the literature.[3-5] Approximately two-thirds of the reported impacted teeth were in the palatal position, while one-third of them were in the labial alveolar region.[6,7]

An examination of the literature revealed that lasso wire, threaded pins, gold chains, bands-brackets, eyelets, or attachments have been used in various orthodontic treatment approaches for orthodontic eruption of impacted teeth.[8] Ballista and Kilroy springs are also used for the traction of the impacted canines.[9,10]

Corresponding author: Gülşilay Sayar, e-mail: silaysayar@yahoo.com

Received: April 14, 2022
Accepted: July 6, 2022
Epub: March 09, 2023
Publication Date: March 21, 2023

Applied orthodontic forces during the forced eruption of impacted canines create stress areas in supporting tissues and may cause varying degrees of damage to periodontal tissues. Therefore, it is extremely important to maintain the applied forces within physiological limits to avoid side effects on the impacted teeth, surrounding periodontal tissues, and adjacent teeth.[11,12] Temporary anchorage devices can be used to manage the successful orthodontic traction of impacted canines with minimal side effects.[13]

The Ballista spring was introduced by Jacoby[9] in 1979, and the Kilroy spring was invented by Bowman and Carano[10] in 2003. Ballista and Kilroy springs were reported that they deliver light and continuous force on impacted canines due to being twisted on their long axes. Both of these springs were introduced to have no harm on adjacent teeth while the canine was in orthodontic traction,[9,10] therefore it was aimed to compare these two springs in this study.

The finite element model (FEM) can be used to simulate force-dependent stress distributions in different orthodontic treatment approaches as an effective and non-invasive method.[14] Since this analysis is conducted in a virtual environment, it can be reproduced as many times as desired under identical conditions. The standardization of fixed variables provides reliability and makes the analysis valuable.[15]

In this study it was aimed to perform a three-dimensional (3D) simulation, which could not be conducted in clinical studies or animal experiments, and to elucidate the stress distribution of eruption of palatally impacted teeth. The null hypothesis of the study was that there was no significant difference in the force distribution between the Ballista and Kilroy springs.

METHODS

This study was approved by the Istanbul Medipol University Clinical Research Ethics Committee with the decision number 10840098-604.01.01-E.8437. Ballista spring can be made from 0.014, 0.016, or 0.018 inch round stainless steel (SS) wire. It is twisted on its long axis and this bending accumulates its energy. The anchorage part of the wire enters the first or second molar tube and is tied to prevent rotation. Its horizontal part enters the slot of the premolar bracket and can rotate so that the hinge axis is formed. The last part of the spring facing the canine tooth is bent vertically down, when the wire is attached to the tooth with a ligature or elastomeric thread, it transmits the energy, that is received from the horizontal part, to the canine and acts like a Ballista.[9]

The Kilroy Spring slides on a rectangular archwire over the region of the impacted canine and gives a constant force. Bending of the spring can be performed using 0.014 inch or 0.016 inch SS arch wires. The configuration looks like "Kilroy Was Here" graffiti. The vertical loop of Kilroy Spring is perpendicular to occlusal plane when the spring is passive. The spring is activated when a SS ligature is passed through the helix at the end of the vertical loop of the spring and attached to the button on the impacted tooth. The spring gets the support from the archwire and contacts the adjacent teeth with the lateral extensions of the spring.[10]

Two different FEM models were prepared with Kilroy and Ballista springs to apply 60 g of force to a unilateral palatally impacted maxillary canine tooth. The stress distribution was evaluated by finite element analysis.

The models were defined as follows; first model: a Ballista spring (0.016 inch SS) model was formed by applying 60-g force, the second model: a Kilroy spring (0.016 inch SS) model was formed applying 60-g force. A preliminary archive study was previously conducted (Istanbul Medipol University, Ethic Committee number 10840098-604.01.01-E.3649) to determine a realistic localization of the impacted canines. The archive of Istanbul Medipol University Faculty of Dentistry was searched, and 67 cone-beam computed tomography (CBCT) images of impacted maxillary canine cases were examined. In this study, the impacted maxillary canines (N=50) were evaluated by the method of Dağsuyu et al.[16] and root resorption of adjacent teeth was not examined based on the study of Silva et al.[17] 1- In sagittal plane: Impacted canine angulation to the occlusal plane, canine cusp tip and apex distances to the occlusal plane, 2-Coronal plane: Maxillary impacted canine angulation to the midline and lateral incisor; 3-Axial plane: Maxillary impacted canine cusp tip and apex distances to the midline were measured.[16] Subsequently, an average position was determined. Because of the measurements, the left maxillary canine (no 2.3) was accepted to be used in the FEM analysis as the impacted tooth.

To create the geometric model of the upper jaw, tomography image of a fully edentulous adult patient was used. The image was scanned in CBCT (ILUMA, Orthocad, CBCT, 3M Imtec, Oklahoma, USA). Then the volumetric data were reconstructed with a section thickness of 0.2 mm. The sections obtained because of the reconstruction were exported in DICOM 3.0 format. Exported sections were imported into 3D-Doctor (Able Software Corp., MA, USA) software. U-shaped, medium-width, and medium-length alveolar arch shape was chosen for use in this study. During modeling, the width of the alveolar crest was taken as 6 mm and the height as 25 mm based on a previous study.[18] After the decomposition process, a 3D model was obtained with the "3d Complex Render" method and the bone tissue was modeled in this way. Through these software programs, the cortical bone, spongy bone, teeth, and periodontal ligament (PDL) were reflected in the model to show their true morphology. The thickness of the PDL was modeled as 0.25 mm homogenously. After the models were created geometrically with VRMesh software, they were transferred to Algor Fempro (Algor Inc., USA) software in Standart Tessellation Format (STL) for analysis, and thus maxilla and dental building materials were introduced to the software. Material values (modulus of elasticity and Poissson's ratio) describing their physical properties were given to each structure that make up the models. In this study, the moduli of elasticity and Poisson ratios were similar to those in the previous literature.[19,20] The teeth scanned in the x, y, and z axes were combined in Rhinoceros software (Rhinoceros 4.0, 3670 Woodland Park Ave N, Seattle, WA, USA). After merging, the morphology of the teeth was arranged according to the Wheeler atlas. PDL and Lamina Dura tissues were modeled in the parts of the teeth that remained in the bone. The position of the impacted canine (2.3) was modeled according to the position that determined in a preliminary study. Models were made in Rhinoceros software, were placed in the correct coordinates in 3D space and the modeling process was completed. Kilroy and Ballista springs, on the other hand, were manually modeled in 3D software for appropriate sizes.

In the rigid body properties are assumed to be linear, elastic, homogeneous and isotropic in the program. For Algor software, models were filled with mesh. In the meshing process, the models were formed from elements with 8 nodes (brick type). In the FEM analysis, the smallest unit was divided into shapes called "elements", which are expressed as simple geometric models and serve to maintain a constant distance between the nodes to which they are connected.[21] By dividing the models, a finite number of elements are connected to one another at certain points, and these points are called nodes. In the models, displacements are associated with displacements in each element.[22] The final model contained 169283 nodes and 714629 elements for Kilroy spring, 168705 nodes and 713286 elements for Ballista spring. In the modeling phase, the maxillary arch block was formed with 0.016 x 0.022 inch SS archwire in a 0.018 slot Roth bracket system, and the arch wire and bracket system was combined with a 1.0-inch SS trans palatal arch (TPA) that was used as an anchorage unit. After the introduction of the material properties to the system, force was applied and analysis was performed. The force vectors were applied on the button of the impacted canine in two dimensions due to the properties of the Ballista and Kilroy springs. The canine tooth was modeled based on a preliminary study and the mucosa was not present in the model. The exposed surface of the canine was disto-palatal portion of the canine crown and the button was placed in the middle of this surface. The force was applied from the bottom up toward the tip of the spring that terminates toward the impacted tooth.

Principal stresses, von Mises stresses, and displacements in three directions of space were determined by FEM analysis. Principal stresses were used for fragile materials (bone, teeth, etc.), and von Mises values were used for retractable materials (screws, restorations, etc.). In this study, von Mises stress values were formed at the reference point cusp tips, incisal edges and apices of all teeth, including the impacted tooth, and the condensation regions were examined in Ballista and Kilroy models (Figures 1a, b). Total displacement and displacement values in the X, Y, and Z directions were determined in the measurements of the Ballista and Kilroy spring models (Figures 2, 3). X direction displacement: the plus value indicates the buccal displacement for posterior teeth, and the distal displacement for anterior teeth. Y direction displacement: the plus value indicates the distal displacement for posterior teeth, and palatal displacement for anterior teeth. Z direction displacement: the plus value indicates the intrusion, and the minus value indicates the extrusion movement.

The values that obtained in the FEM analysis were the result of mathematical calculations without variance; therefore, statistical analyses could not be performed due to the nature of the study.

RESULTS

When the displacement of adjacent teeth was evaluated, in the Ballista model, the maximum total displacement was 0.001228 mm in the palatal cusp tip of the first premolar tooth, while in the Kilroy model, it was 0.001247 mm in the incisal edge of the lateral tooth.

In the Ballista model, the first premolar buccal cusp tip moved most buccally, while in the Kilroy model, the most buccal movement was in the lateral tooth. In all the cusp tips of first premolars moved palatally in Kilroy model whereas in Ballista model the cusp tips of the first premolars moved buccally (Figures 2, 3).

In the Ballista model, the palatal cusp tip of the first premolar was the most mesially displaced. In the Kilroy model, the incisal edge of the lateral tooth was mesially displaced. In the Ballista model, the lateral tooth was more distally displaced (0.000614 mm) than that in the Kilroy model. The lateral tooth in the Kilroy model was mesially displaced by 0.000441 mm (Figures 2b, 3b).

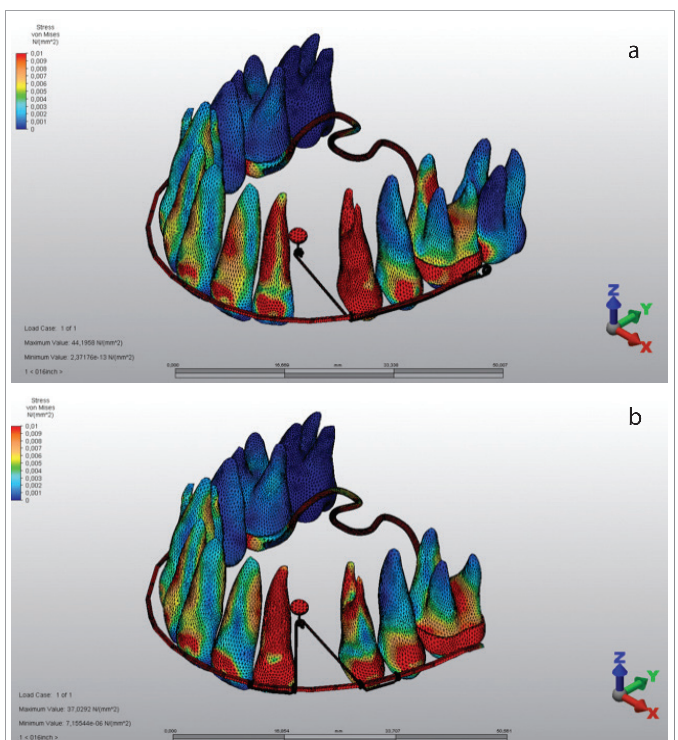

Figure 1. a) Von Mises Stress Values of Ballista Model, **b)** von Mises Stress Values of Kilroy Model

In the Kilroy model, the lateral tooth was intruded (0.000037 mm), while it was extruded in the Ballista model (0.00002 mm). The extrusion was observed at the palatal tip of the first premolar tooth in Kilroy. An intrusion was observed at the first premolar tooth. In both models, the extrusion of the central tooth and intrusion at the buccal tip of the premolar tooth were observed (Table 1), (Figures 2c and 3c).

Apical displacement of adjacent teeth to the impacted canine showed that the greatest total displacement for Ballista was at the palatal tip of the first premolar, whereas for Kilroy, it was at the lateral tooth. While the lateral tooth was displaced 0.000409 mm in Kilroy, the palatal root apex of the first premolar tooth was displaced 0.000495 mm in Ballista.

In the Kilroy model, the apex of the lateral tooth was distally displaced (-0.000351 mm), while in the Ballista model, the palatal apex of the first premolar tooth buccal displaced (-0.000319 mm). The apex of the central and lateral teeth moved buccally in both models except for the lateral tooth in the Ballista model. while the apex of the first premolar tooth in the Ballista model showed buccal displacement, the apex of the first premolar tooth in the Kilroy model showed palatal displacement (Figures 2a and 3a).

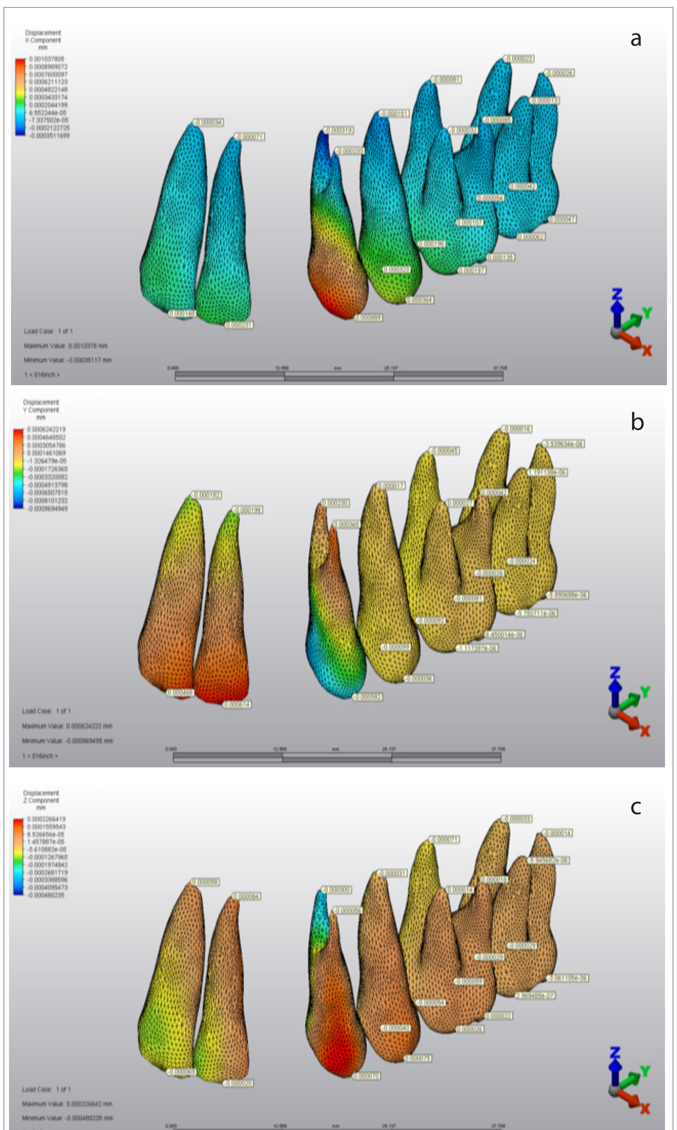

Figure 2. a) Displacement of X-Direction Values of Ballista Model, **b)** Displacement of Y-Direction Values of Ballista Model, **c)** Displacement of Z-Direction Values of Ballista Model

In both models, the greatest displacement was observed at the buccal apex of the first premolar tooth, the value was 0.000365 mm distally in the Ballista model and 0.000125 mm distally in the Kilroy model. In the Ballista model, the lateral tooth apex moved 0.000198 mm mesially, while in the Kilroy model, the apex of the lateral tooth moved 0.000065 mm palatally (Figures 2b and 3b).

In the Ballista model, the maximum extrusion was 0.0003 mm in the first premolar palatal apex, whereas in the Kilroy model, the maximum extrusion was 0.0002 mm in the lateral tooth apex. An apical intrusion of the central tooth was observed in both models. The intrusion was observed in the lateral tooth apex in the Ballista model, and extrusion was observed in the lateral tooth apex in the Kilroy model (Figures 2c and 3c). Extrusion was observed in the apex of the first premolar in the Ballista model, and an intrusion was observed in the apex of the first premolar in the Kilroy model (Table 1).

When the von Mises stress values on the incisal and cusp tips were compared, the von Mises values were found to be highest in different teeth of the two models (Figures 1a, b) In Ballista model, the highest value was measured at 0.003642 N/mm^2 at the buccal cusp tip of the first premolar tooth, while in the Kilroy model, the highest value was measured at the lateral tooth incisal edge of 0.002989 N/mm^2 (Table 2).

Considering the findings of the impacted canine teeth (Figures 4a, b), the von Mises values were measured as 0.009896 N/mm^2 at the cusp tip and 0.000164 N/mm^2 at the apex in the Ballista model (Table 3). These values were 0.015334 N/mm^2 at the cusp tip and 0.000205 N/mm^2 at the apex in the Kilroy model (Table 3).

Considering von Mises values at the apical, the highest value was measured in the same tooth in both spring designs with the value of 0.023371 N/mm^2 at the buccal apex of the first premolar in Ballista and 0.009941 N/mm^2 at the Kilroy model.

DISCUSSION

Techniques for orthodontic eruption of impacted canines remain a controversial issue.[1] During the orthodontic eruption of the impacted tooth, various force changes occur in both the impacted tooth and the adjacent teeth or their periodontal structures.[23-25]

Although there were some FEM studies related to the eruption of the impacted canine in the literature, no studies examined the stress and displacement values caused by Ballista and Kilroy springs in adjacent teeth and surrounding tissues.[26] Han et al.[27] stated that 0.3-0.4 Newton amount of orthodontic force was needed for extrusion. Bishara[2] stated that this force should be a maximum of 60 g. Nagendraprasad et al.[28] reported that the pressure values that affected the tooth and surrounding tissues showed minimal differences depending on the angle of the impacted tooth in the maxilla when 50 g, 70 g, and 100 g of force were applied, however, the spring design was not mentioned in their study.

Although there was an increase in movement of the impacted teeth when the amount of force increased, a certain value of increase might cause an opposite effect by increasing the tensile pressure in the surrounding tissues. Some studies have reported that pressures higher than 16 kPa (0.016 mPa), which is equal to human systolic pressure, might cause soft tissue necrosis and hyalinization in periodontal ligaments.[29-31] Thus, this study was designed with a sustaining force of 60 g in accordance with the previous literature.[2,26,27]

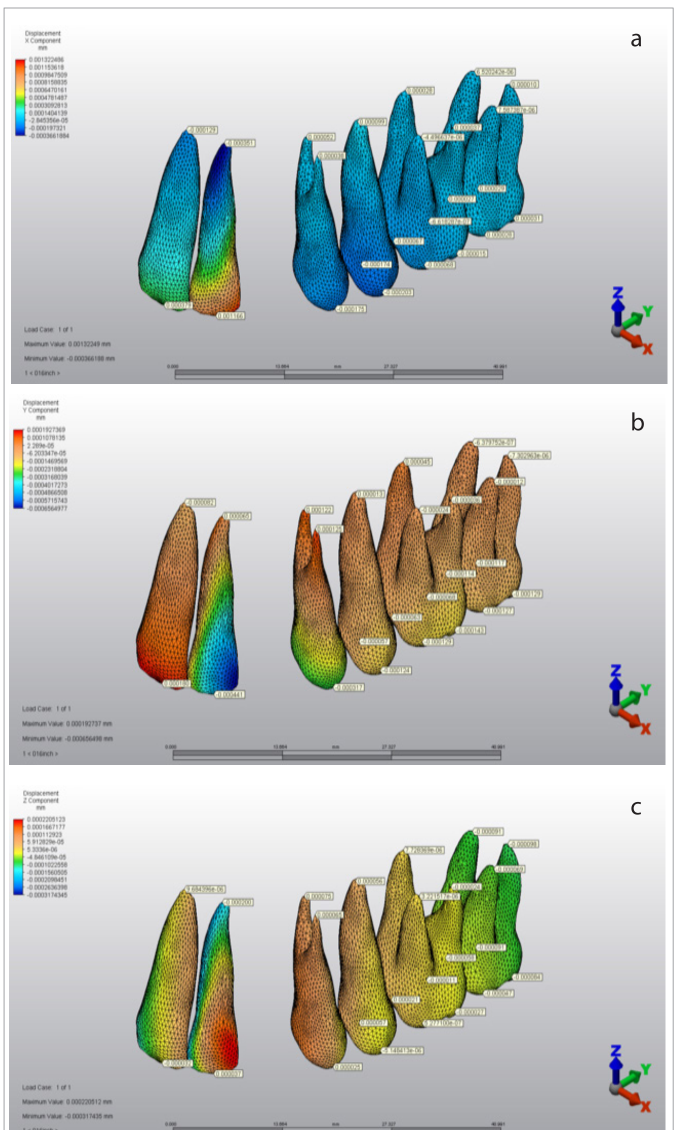

Figure 3. a) Displacement of X-Direction Values of Kilroy Model, **b)** Displacement of Y-Direction Values of Kilroy Model, **c)** Displacement of Z-Direction Values of Kilroy Model

Table 1. Total and X-, Y-, and Z-direction displacement values of the incisal edges, cusp tips, and apices of the adjacent teeth (mm)

	Tooth	Total		X-direction		Y-direction		Z-direction	
		Model 1 Ballista	Model 2 Kilroy	Model 1 Ballista	Model 2 Kilroy	Model 1 Ballista	Model 2 Kilroy	Model 1 Ballista	Model 2 Kilroy
Displacement values of the incisal edges and cusp tips (mm)	Central	0.000494	0.000421	0.000148	0.000379	0.000466	0.00018	-0.000069	-0.000032
	Lateral	0.000656	0.001247	0.000231	0.001166	0.000614	-0.000441	-0.00002	0.000037
	1. Premolar Buccal	0.001065	0.000363	0.000889	-0.00017	-0.00058	-0.000317	0.00007	0.000025
	1. Premolar Palatal	0.001228	0.000392	0.000709	-0.00017	-0.00095	-0.000347	-0.000314	0.000064
Displacement values of the apices (mm)	Central	0.000195	0.000153	-0.000034	-0.000129	-0.000182	-0.000082	0.000058	0.00000968
	Lateral	0.000226	0.000409	-0.000071	-0.000351	-0.000198	0.000065	0.000084	-0.0002
	1. Premolar Buccal	0.000437	0.000146	-0.000233	0.000038	0.000365	0.000125	-0.000056	0.000065
	1. Premolar Palatal	0.000495	0.000152	-0.000319	0.000052	0.00023	0.000122	-0.0003	0.000075

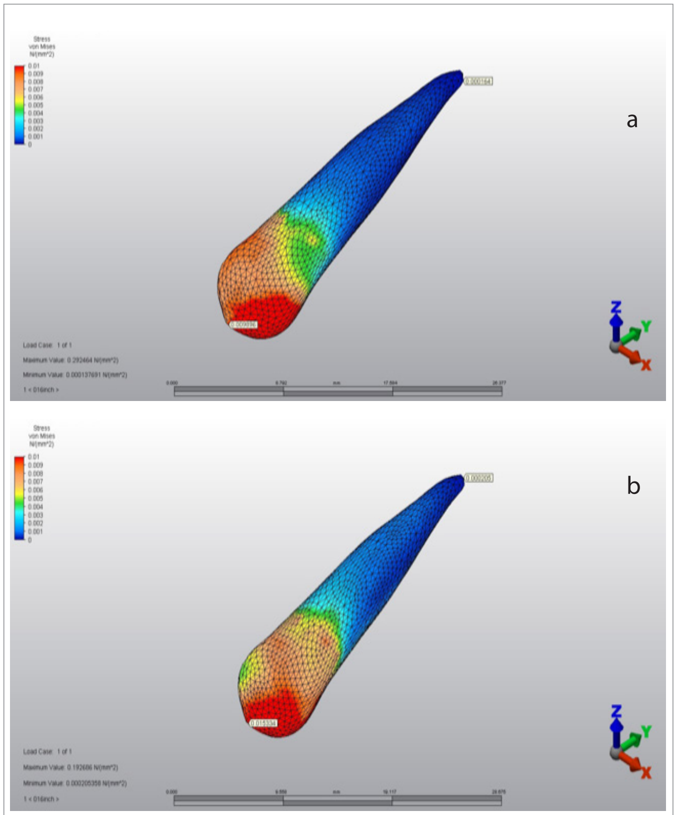

Figure 4. a) von Mises Stress Values at the Impacted Canine of Ballista Model, **b)** von Mises Stress Values at the Impacted Canine of Kilroy Model

In orthodontic forced eruption, to apply a continuous, light and controlled force on palatally impacted canines results in effective tooth movement and may prevent side effects on both the impacted tooth and adjacent teeth. Despite the presence of the same force loading, use of different mechanics creates biomechanical differences. Yadav et al.[23] found that the Kilroy spring showed the most consistent force than that of elastic chain and steel ligature, therefore in this study it was aimed to compare two different kinds of springs.

FEM analysis is often preferred to investigate the force and stress distribution during the eruption of impacted canines because of its advantages, such as simplicity of application, high speed, and repeatability.[26,28,31-33]

The properties of the materials and textures were the most important factors that affected the stress distribution in FEM studies, and the modulus of elasticity of the springs, bone and Poisson ratio was critical distinguishing features.[34] The evaluated structures were assumed to be homogeneous, isotropic, and linearly elastic, and models were made based on this concept. In practical use, it is not possible for any 3D structure or material to be completely homogeneous and isotropic,[34] unlike clinical conditions, which must be treated with caution. The outcomes in clinical conditions may differ depending on the age, bone thickness, quality and complexity of the malocclusion of the patient.[35]

Table 2. Von Mises stress of the incisal edges and cusp tips, and the apices of the adjacent teeth (N/mm^2)

		Model 1 Ballista	Model 2 Kilroy
Von Mises stress of the incisal edges and cusp tips (N/mm^2)	Central	0.000731	0.000591
	Lateral	0.000665	0.002989
	1. Premolar Buccal	0.003642	0.002563
	1. Premolar Palatal	0.002411	0.000670
Von Mises stress of the apices (N/mm^2)	Central	0.004382	0.004652
	Lateral	0.00441	0.008243
	1. Premolar Buccal	0.023371	0.009941
	1. Premolar Palatal	0.017724	0.005327

Table 3. Ballista and Kilroy models total displacement and von Mises stress at the impacted canine

		Cusp Tips	Apex
Ballista Model	Total displacement (mm)	0.000015	0.00000939
	X-direction displacement (mm)	0.0000071	-0.00000345
	Y-direction displacement (mm)	-0.0000013	-0.00000178
	Z-direction displacement (mm)	-0.000013	-0.00000855
	von Mises (N/mm^2)	0.009896	0.000164
Kilroy Model	Total displacement (mm)	0.000017	0.000014
	X-direction displacement (mm)	0.00000647	-0.000003
	Y-direction displacement (mm)	-0.000015	-0.00000664
	Z-direction displacement (mm)	-0.00000497	-0.000012
	von Mises (N/mm^2)	0.015334	0.000205

In this study, 2 simulated models were formed, and the amount of movement of the maxillary teeth in three directions of space and von Mises stress values at adjacent teeth (tooth numbers 21, 22 and 24) and those of the impacted canine were measured. The measured values were similar to the tooth displacement amounts and forces that were reported in previous studies.[26,28,30]

Although the applied forces in the literature were 0.5-2.5 N, Zeno et al.[26] also applied 1 N (100 g) forces in their study, and the lowest stresses were observed under vertical forces. They also found that the average stress value in the impacted canine tooth was 6.41 kPa buccal, 5.97 kPa vertical, and 6.64 kPa distal.[25] In this study, the values at impacted canines were measured as 15.334 kPa in the Kilroy model and 9.89 kPa in the Ballista model, which were higher than those in Zeno et al.[26] and the authors of this study thought that spring designs of Kilroy and Ballista models might be the cause of this difference. Zeno et al.[26] applied 100 g/F in their study, and although the force was 60 g in this study, the higher von Mises values at the tip of the impacted canine tooth cusp were higher. This can be attributed to the technical sensitivity in the model design and spring design, therefore controlled studies are needed in this regard. Also, the resultant stresses in the study were an average of a sample of impacted canines of varying severity, which could explain the difference compared to the current study as the impacted canine model used was possibly of higher severity and therefore resulted in higher stress.

In this study, 0.0002 mm extrusion was observed in the apex of the lateral tooth in the Kilroy model and 0.000084 mm intrusion in the lateral tooth in the Ballista model. Sezici et al.[31] measured more extrusion (0.0885 mm) in the lateral tooth in the Kilroy spring model. The lower displacement of the apex of the lateral tooth in the palatal direction in the Kilroy group showed that the final torque requirement of the impacted tooth was clinically less important when a Kilroy spring was used.

Apical extrusion at the incisal edge of the lateral tooth in the Kilroy model was measured as 0.001247 in this study, whereas Sezici et al.[31] measured the total value as 0.19324 mm. This difference can be attributed to the model design and the difference in the FEM method. Sezici et al.[31] reported that the Kilroy spring design caused a more mesial displacement in the lateral teeth than the Niti coil spring design. The authors also reported buccal movement in the lateral and premolar teeth.[31] When the X-direction displacement was examined, the mesial movement was the largest in the lateral tooth in Kilroy.

In this study, the von Mises stress value of the incisal edge of the lateral tooth was 0.002989 MPa, while the total value for the lateral tooth was 0.00529 MPa in a similar study.[31] The value for the premolar tooth in this study (0.002563 MPa) was lower than that in the previous report (0.00641 MPa).[31]

In this study, the two spring designs showed higher von Mises values in different teeth. In the Ballista model, the highest value was measured at the buccal tip of the first premolar tooth, while in the Kilroy model, the highest value was measured at the incisal edge of the lateral tooth and the values were compatible with the literature.[31]

The displacement value of the tip of the impacted canine was close to the reported value of Nagendraprasad et al.[28] in this study the highest stress value was recorded around the impacted canine in Kilroy model like a previous report,[31] in which the same kind of spring was used.

When the position of the impacted tooth changed in three directions of space, the movement patterns occurring in the mesial, buccal, and occlusal plane directions, were compatible with the literature.[28] In this study, the most displacement was detected at the incisal edge of tooth number 2.2 in the Kilroy model and at the palatal cusp tip of tooth number 2.4 in the Ballista model.

Shastri et al.[36] used a model of erupting impacted canine teeth with a modified K-9 spring to eliminate side effects in adjacent teeth. For this purpose, the authors applied a buccal crown torque to the posterior teeth and stated that they also protected periodontal health by reducing the tipping of the teeth.[35] In this study the greater buccal movement was seen in tooth 2.2 in Kilroy model, theoretically it can be thought that a need for palatal crown torque may arise when Kilroy springs are used.

In this study, the von Mises stress value measured in the impacted canine of the Ballista model was also compatible with the literature.[26,30] Comparing the Kilroy model and the Niti coil, Sezici et al.[31] reported that the von Mises stress values in the impacted canine tooth in the Kilroy models (60 g) were very similar to the results observed in this study.

The differences in the number of nodes, model designs, and forces used in FEM studies can explain the differences between the previous reports in the literature.[26,29,31]

When evaluating the possible shortcomings of this study, the limitations of the FEM compared with clinical methods should be discussed first. Meanwhile, performing such mechanical studies under clinical conditions also poses serious difficulties due to patient-related variables.

Another possible limitation of this study was that the canine teeth were analyzed assuming that they were in a fixed position in all 3 planes and all models. When the position of the impacted canine becomes horizontal, the required force changes, and accordingly, the location and degree of stress on the tooth and surrounding tissues can vary, therefore more studies are required on this issue.

CONCLUSION

The null hypothesis was rejected. The von Mises stress values were higher in the Kilroy model at the cusp tip and the apical part of the impacted tooth than in the Ballista model. The von Mises values of lateral tooth measured in the Kilroy spring model were higher than those of the Ballista model. The highest von Mises stress values were concentrated in the buccal root apex of the first premolar tooth in both models, and the Ballista model had higher stress values than that of the Kilroy model.

Acknowledgements

The authors would like to thank Ay Tasarım for their effort in performing the FEM analysis of the study.

Ethics

Ethics Committee Approval: This study was approved by the Istanbul Medipol University Clinical Research Ethics Committee (Approval number: 10840098-604.01.01-E.8437).

Informed Consent: Written informed consent was obtained from all participants who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - N.K.A.; Design - N.K.A.; Supervision - G.S., N.K.A.; Materials - E.N.B., N.K.A.; Analysis and/or Interpretation - G.S., E.N.B., N.K.A.; Literature Review - E.N.B., N.K.A.; Writing - G.S., E.N.B, N.K.A.; Critical Review: G.S., N.K.A.

Declaration of Interests: The authors have no conflicts of interest to declare.

Funding: This research was funded by TÜBİTAK - Turkish Scientific and Technological Research Council.

REFERENCES

1. Counihan K, Al-Awadhi EA, Butler J. Guidelines for the assesment of the impacted maxillary canine. *Dental Update.* 2013;40(9):770-772. [CrossRef]
2. Bishara SE. Impacted maxillary canines: a review. *Am J Orthod Dentofacial Orthop.* 1992;101(2):159-171. [CrossRef]
3. Ericson S, Kurol J. Radiographic assessment of maxillary canine eruption in children with clinical signs of eruption disturbance. *Eur J Orthod.* 1986;8(3):133-140. [CrossRef]
4. Dachi SF, Howell FV. A survey of 3, 874 routine full-month radiographs. II. A study of impacted teeth. *Oral Surg Oral Med Oral Pathol.* 1961;14:1165-1169. [CrossRef]
5. Thilander B, Myrberg N. The prevalence of malocclusion in Swedish schoolchildren. *Scand J Dent Res.* 1973;81(1):12-21. [CrossRef]
6. Johnston WD. Treatment of palatally impacted canine teeth. *Am J Orthod.* 1969;56(6):589-596. [CrossRef]
7. Ericson S, Kurol J. Early treatment of palatally erupting maxillary canines by extraction of the primary canines. *Eur J Orthod.* 1988;10(1):283-295. [CrossRef]
8. Faber J, Berto PM, Quaresma M. Rapid prototyping as a tool for diagnosis and treatment planning for maxillary canine impaction. *Am J Orthod Dentofacial Orthop.* 2006;129(4):583-589. [CrossRef]
9. Jacoby H. The "ballista spring" system for impacted teeth. *Am J Orthod.* 1979;75(2):143-151. [CrossRef]
10. Bowman SJ, Carano A. The Kilroy Spring for impacted teeth. *J Clin Orthod.* 2003;37(12):683-688. [CrossRef]
11. Boyd RL. Clinical assessment of injuries in orthodontic movement of impacted teeth. II. Surgical recommendations. *Am J Orthod.* 1984;86(5):407-418. [CrossRef]
12. Wisth PJ, Norderval K, Boe OE. Periodontal status of orthodontically treated impacted maxillary canines. *Angle Orthod.* 1976;46(1):69-76. [CrossRef]
13. Heravi F, Shafaee H, Forouzanfar A, Zarch SH, Merati M. The effect of canine disimpaction performed with temporary anchorage devices (TADs) before comprehensive orthodontic treatment to avoid root resorption of adjacent teeth. *Dental Press J Orthod*. 2016;21(2):65-72. [CrossRef]
14. Akış H, Doruk C. Dentofacial Effects of Fixed Functional Appliances with or without Mini Screw Anchorage in the Treatment of Class II Division I Malocclusion: A Finite Element Analysis. *Turk J Orthod.* 2018;31(1):7-12. [CrossRef]
15. Ramoğlu S, Ozan O. Finite element methods in dentistry. *J Dent Fac Atatürk Uni*. 2014;(Suppl 9):175-180. [CrossRef]
16. Dağsuyu İM, Kahraman F, Okşayan R. Three-dimensional evaluation of angular, linear, and resorption features of maxillary impacted canines on cone-beam computed tomography. *Oral Radiol.* 2017;34(1):66-72. [CrossRef]
17. Silva AC, Capistrano A, Almeida-Pedrin RR, Cardoso MA, Conti AC, Capelozza L Filho. Root length and alveolar bone level of impacted canines and adjacent teeth after orthodontic traction: a long-term evaluation. *J Appl Oral Sci.* 2017;25(1):75-81. [CrossRef]
18. Bilgin T. Tam protezlerde kullanılan hazır ölçü kaşıkları için ülkemize uygun standartların araştırılması. Doktora Tezi, İstanbul Üniversitesi; 1989. [CrossRef]
19. Liang W, Rong Q, Lin J, Xu B. Torque control of the maxillary incisors in lingual and labial orthodontics: a 3-dimensional finite element analysis. *Am J Orthod Dentofacial Orthop.* 2009;135(3):316-322. [CrossRef]
20. Boyer R, Welsch G, Collings EW. Materials properties handbook: titanium alloys. *ASM International*; 1993. [CrossRef]
21. Moaveni S. Finite element analysis: theory and application with ANSYS,3/e. *Pearson Education India*; 2011. [CrossRef]
22. Geng JP, Tan KB, Liu GR. Application of finite element analysis in implant dentistry: a review of the literature. *J Prosthet Dent.* 2001;85(6):585-598. [CrossRef]
23. Yadav S, Chen J, Upadhyay M, Jiang F, Roberts WE. Comparison of the force systems of 3appliances on palatally impacted canines. *Am J Orthod Dentofacial Orthop.* 2011;139(2):206-213. [CrossRef]
24. Datana S, Londhe SM, Kumar P, Mathur V. Orthodontic guidance of an impacted maxillary canine: a review. *J Oral Health Community Dent.* 2014;8(2):101-103. [CrossRef]
25. Kocsis A, Seres L. Orthodontic screws to extrude impacted maxillary canines. *J Orofac Orthop.* 2012;73(1):19-27. [CrossRef]
26. 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. *Am J Orthod Dentofacial Orthop.* 2020;157(3):377-384. [CrossRef]
27. Han G, Huang S, Von den Hoff JW, Zeng X, Kuijpers-Jagtman AM. Root resorption after orthodontic intrusion and extrusion: an intraindividual study. *Angle Orthod.* 2005;75(6):912-918. [CrossRef]
28. Nagendraprasad K, Mathew S, Shivamurthy P, Sabrish S. Displacement and periodontal stress analysis on palatally impacted canine - a finite element analysis. *Indian J Dent Res.* 2019;30(5):788-793. [CrossRef]
29. Choy K, Pae EK, Park Y, Kim KH, Burstone CJ. Effect of root and bone morphology on the stress distribution in the periodontal ligament. *Am J Orthod Dentofacial Orthop.* 2000;117(1):98-105. [CrossRef]
30. Rygh P. Ultrastructural changes in pressure zones of human periodontium incident to orthodontic tooth movement. *Acta Odontol Scand.* 1973;31(2):109-122. [CrossRef]

31. Sezici YL, Gediz M, Akış AA, Sarı G, Duran GS, Dindaroğlu F. Displacement and stress distribution of Kilroy spring and nickel-titanium closed-coil spring during traction of palatally impacted canine: a 3-dimensional finite element analysis. *Orthod Craniofac Res.* 2020;23(4):471-478. [CrossRef]

32. Zeno KG, Ghafari JG. Palatally impacted canines: a new 3-dimensional assessment of severity based on treatment objective. *Am J Orthod Dentofacial Orthop.* 2018;153(3):387-395. [CrossRef]

33. Zeno KG, El-Mohtar SJ, Mustapha S, Ghafari JG. Finite element analysis of stresses on adjacent teeth during the traction of palatally impacted canines. *Angle Orthod.* 2019;89(3):418-425. [CrossRef]

34. Bişirici G. Evaluation of en masse retraction of anterior teeth by finite element method. Dissertation. Selçuk University; 2008. [CrossRef]

35. Uysal C, Baloş Tuncer B, Tuncer C. Maxillary posterior intrusion with corticotomy-assisted approaches with zygomatic anchorage-a finite element stress analysis. *Prog Orthod.* 2019;20(1):8. [CrossRef]

36. Shastri D, Nagar A, Tandon P. Alignment of palatally impacted canine with open window technique and modified K-9 spring. *Contemp Clin Dent.* 2014;5(2):272-274. [CrossRef]