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Finite Element Analysis Of Stress Distribution To Adjacent Structures During Traction Of Palatally Impacted Canine Using Temporary Anchorage Device Vs Ballista Spring - Invitro Study

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Abstract

Introduction

Successful treatment of Palatally Impacted Canine depends on many factors and most important being aligning the canine with minimal damage to adjacent roots. This study aims to compare and evaluate the stress distribution to adjacent structures during traction of favourable Palatally impacted canine of classification (Sector3) using Temporary Anchorage Devices Vs Ballista spring .

Materials & Methods:

Two FEA models were obtained from a CBCT scan of palatally impacted canine of 15 year old female patient to simulate traction of impacted canine with Model1 using Mini-screw (1.5X8mm) and elastic power chain passing over the wire (0.019X0.025SS wire) and Model2 using Ballista spring (0.018SS wire). Both models are simulated under equal force of 100grams which is in upward and buccal direction and are tested for stress distribution in lateral incisors and first premolars and results are recorded.

Results:

In this study, there were more stress reported at coronal third of root of lateral incisor in Model1 that is 10% more in model and at molar and premolar area in model2 which was 4% higher than model. Hence, the obtained values are minimal to conclude for root resorption

Conclusion:

There is no difference between stress distribution to adjacent structures during traction of Palatally impacted canine using Mini-screws and Ballista spring. Though the obtained values showed minimal difference, comparing both the models ballista spring is better in control of force distribution than TAD supported orthodontic traction by same force and its direction of impacted canine.

Keywords: FEM model, Mini-screw, Ballista spring, Von Misses Stress

Introduction

Maxillary canine impaction (1-3%) are frequently impacted palatally and more common after 3rd molars [1,2]. Treatment included surgical removal, orthodontic traction, or surgical removal and reimplantation [3,4,5]. Orthodontic management of this Palatally Impacted Canine may result in various complications such as gingival recession labially or palatally, root resorption and longer orthodontic treatment period time [6,7,8,9,10].

Successful treatment of Palatally Impacted Canine depends on many factors and most important being aligning the canine with minimal damage to adjacent roots and direction of traction should be determined based on the pathway which causes minimal damage [11,12,13]. Direction of traction pathway for Palatally Impacted Canine can be determined accurately with CBCT [14]. Various mechanics are available to bring the Palatally impacted canine into occlusion which includes Ballista spring and TAD'S [15].

Ballista spring exerts a vertical force and retracts the tooth by a continuous force which is accumulated by twisting the spring on its long axis and prevents the impacted tooth from compressing adjacent roots and with this spring, controlled force can be given and is less traumatic [16,17,18]. With TAD's, unwanted movement which was seen with conventional treatment on adjacent tooth can be prevented which in turn increases treatment effectiveness [19,20].

The Finite Element Modelling analyses the biomechanical effects of different modalities of orthodontic treatment and calculates the deformation and the stress distribution in the bodies exposed to the external forces[21,22]. Quantification of these active forces can be done with FEM analysis which is a non-invasive process and FEM allows the assessment of distribution of stress in different loading conditions and in displacement of Palatally Impacted Canine and its adjacent tooth [23,24].

While there were few previous studies reported on FE analysis of traction of palatally impacted canine, only stress distribution on canine PDL and maxillary dentition was reported, none of the studies compared the stress distribution to adjacent structures during traction of Palatally Impacted Canine using temporary anchorage device VS ballista spring [25]. The hypothesis tested in this study is that there is difference between the stress distribution to the adjacent structures during traction of Palatally impacted canine using Mini-screws and Ballista spring

The aim of the study is to compare and evaluate the stress distribution to the adjacent structures during traction of the favourable Palatally impacted canine of sector classification 3 (sector 3) using Temporary Anchorage Devices Vs Ballista spring.

Materials & Methods:

Study Design:

Invitro experimental study to compare the areas of stress in the adjacent structures using Temporary anchorage devices and Ballista spring

Study Center:

The study was performed in the Department of Orthodontics and Dentofacial Orthopeadics in Tamilnadu Government Dental College and Hospital, Chennai – 03.

Study Duration:

The study duration was 6 months

Ethical Clearence:

Ethical approval was given by Tamilnadu Government Dental College and Hospital, Chennai – IRB Reference No: 4/IERB/2021

Study Sample:

Two FEA models were obtained from a CBCT scan of palatally impacted canine of 15 year old female patient to simulate the traction of the impacted canine with Model 1 using Mini-screw (1.5 X 8 mm) and elastic power chain passing over the wire (0.019 X 0.025 SS wire) and Model 2 using Ballista spring (0.018 SS wire) for traction

Inclusion Criteria:

1. CBCT of patient with favourable Palatally impacted canine of sector 3 (Ericson and Kurol – 1987)
2. 29
3. Age – >13 years
4. Normal bone architecture
5. No Previous history of Orthodontic treatment
6. Patients without syndromes
7. Patients without any pathologic conditions

Methodology:

CBCT scan was obtained from a 15 years old female patient who had maxillary palatal canine impaction

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before the start of the treatment for the localization of impacted canine

The scan consisted of 333 transverse sections with a 0.200- mm voxel resolution of the following dimensions: 400 X 400 X 333.

The scanned images were saved in the DICOM format and uploaded in 3D images processing software scan IP 7.0 for conversion to STL file (Standard Tessellation Language) which is compatible for Meshing

All the structures in the sample is separated and distinguished.

Figure 1: 3D CBCT model of the Patient showing Canine impaction

The greyscale intensity was used to differentiate maxillary teeth, alveolar bone, and Periodontal ligament. PDL space was created by duplication and expansion of the roots of all teeth by 0.3mm

Figure 2: Tooth, Alveolar bone separated and distinguished 3D model constructed from CBCT A. Frontal aspect and B. Palatal aspect

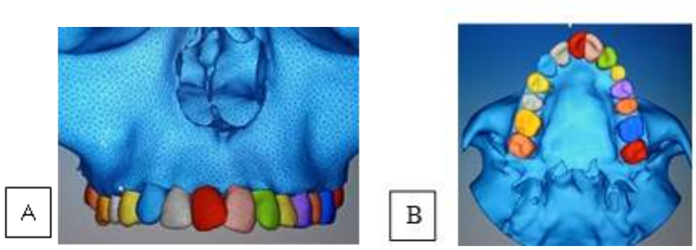


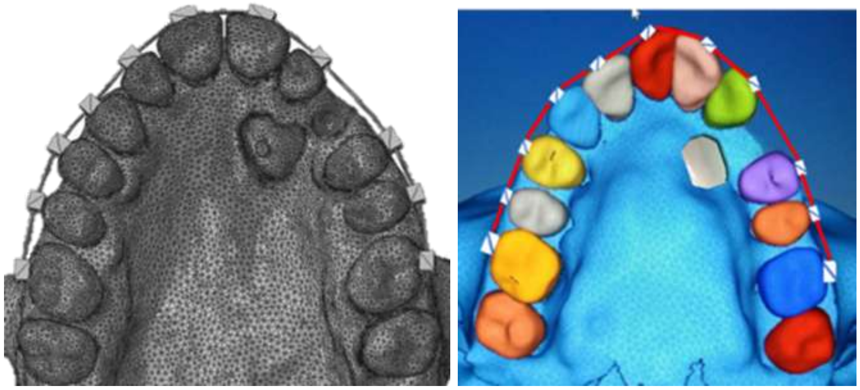
Figure 3 : Meshed FEM Model and separated teeth

Appliance Modeling :

A Nonmeshed model was imported to 3D modelling software to duplicate the following appliance patterns:

1. MBT Brackets for testing in the model. Brackets was placed on the teeth and the brackets will be connected through arch wires(0.0019 X 0.0025). All these were stimulated in FEM Model.

Figure 4 : Meshed FEM model of maxilla with brackets and arch wire along with exposed impacted teeth

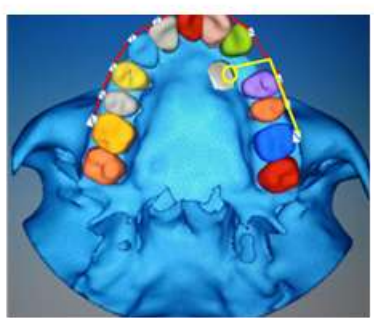


2. Mini-implant (1.5 X 8 mm) and Ballista spring (0.018" SS) were placed in consecutive analysis to the fixed appliance, forces were applied and assessed for the stress distribution to adjacent structures

Figure 5: Model 1 simulated with TADS and Mini screw

Figure 6: Model 2 simulated with Ballista spring

Figure 5: Model 1 simulated with TADS and Mini screw



3. All the meshed model and the elements were assembled

The final model consisted of 629,435 tetrahedral elements and 176,876 nodes. The Material properties were obtained for teeth, alveolar bone, and PDL, which were assumed to be isotropic and homogeneous materials. The reaction stress on the teeth were analysed under static loading with no active movements of sliding of teeth by brackets and wire. Constraints was established for brackets and wire. And full constraints was est 31 for maxilla to simulate the surrounding bone associated to it which prevents motion

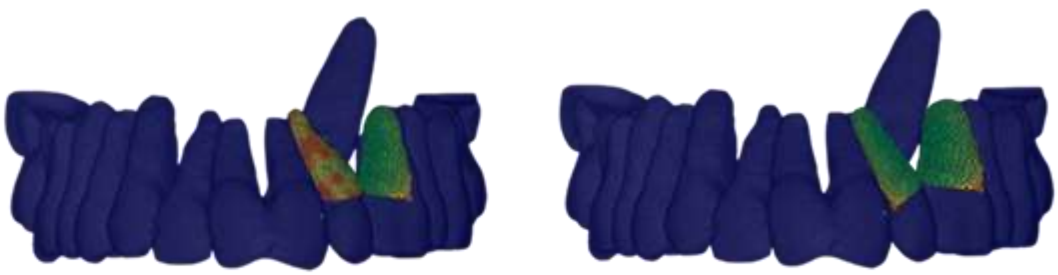
Forces Apllied

As Ballista spring exerts upward and lateral force (buccal force), the same has to be simulated in the other model and same force to be used for its comparison to be reliable. Ballista spring in a 0.018 SS wire exerts 120 – 150 grams of force as mentioned by Jacoby. Therefore, we used 120 grams of force in both models (Models 1 & 2).

Von Mises Stresses

Von Mises stresses was recorded at the apical, middle, and cervical thirds of the PIC root, and for the adjacent teeth roots with each of the forces and the effects of both the model appliances are tested.

Figure 7: Von Mises stresses (kPa) that is seen in the lateral incisor and first premolar – Model 1



Result:

In this study the value of stresses of PDL of each tooth are determined in kPa and its corresponding percentages are evaluated. The stress values are compared to the original maximum stress value obtained by the mechanical properties of the periodontal ligament. The mechanical properties of PDL, bone, teeth, and stainless steel are predetermined (Table 1). They are determined by the Youngs modules of the material. These values are the maximum values of the material that can hold tension without permanent deformation, above which there may be permanent deformation. Here, the value of PDL is taken for comparison of this study and the predetermined value is takes as 100% in kPa and the obtained values are converted to percentage corresponding to it and compared.

Table 1: Material Properties used in Finite Element model

Material	Youngs modulus	Poisson's ratio
Teeth	20,000 MPa	0.2
Bone	15,750 MPa	0.33
PDL	0.13 MPa	0.45
Stainless steel	1,80,000 MPa	0.3

Table 2: Von Mises stresses (kPa) and corresponding percentages of PDL in right side teeth of Model 1

S.NO	TOOTH	STRESS VALUES (kPa)	PERCENTAGE (%)
1.	Central Incisor	0.32	4.704%

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2.	Lateral Incisor	0.15	2.205%
3	First Premolar	0.12	1.764%
4.	Second Premolar	0.16	2.352%
5.	First Molar	0.14	2.058%
6.	Second molar	0.11	1.617%

It is observed that the stress values were very less in the contralateral side and the corresponding percentage were not more than 5%. This shows that there were hardly any stress in that region.

Table 3: Von Mises stresses (kPa) and corresponding percentages of PDL in left side teeth of Model 1

S.NO	TOOTH	STRESS VALUES (kPa)	PERCENTAGE (%)
1.	Central Incisor	0.55	8.085%
2.	Lateral Incisor	**1.93**	**28.371%**
3	First Premolar	**1.31**	**19.275%**
4.	Second Premolar	0.42	6.1798%
5.	First Molar	0.45	6.615%
6.	Second molar	0.17	2.434%

This table shows that lateral incisor and First premolar has more stresses encountered than other teeth as the teeth. Lateral incisor received 10% more stress than first premolar. There may be a chance of resorption in this region. So, force has to be carefully applied and should be maintained away from the adjacent teeth to minimize its effect.

Table 4: Von Mises stresses (kPa) and corresponding percentages of PDL in right side teeth of Model 2

S.NO	TOOTH	STRESS VALUES (kPa)	PERCENTAGE (%)
1.	Central Incisor	0.12	1.764%
2.	Lateral Incisor	0.09	1.911%
3	First Premolar	0.13	1.764%
4.	Second Premolar	0.17	2.352%
5.	First Molar	0.19	2.793%
6.	Second molar	0.09	1.911%

This table makes clear that the percentage values even less than that of model 1 in contralateral side of ballista spring. The stress values were not more than 0.2 kPa which is most favourable.

Table 5: Von Mises stresses (kPa) and corresponding percentages of PDL in Left side teeth of Model 2

S.NO	TOOTH	STRESS VALUES (kPa)	PERCENTAGE (%)
1.	Central Incisor	0.48	7.056%
2.	Lateral Incisor	**1.28**	**18.819%**
3	First Premolar	**1.72**	**23.814%**
4.	Second Premolar	0.51	7.497%
5.	First Molar	0.65	9.555%
6.	Second molar	0.09	1.911%

This table shows that lateral incisor and First premolar encountered more stress than any other in the ipsilateral side of ballista spring. But, less than the values of the model 1 in lateral incisor and first premolar. Lateral incisor received less stress than first premolar. Even first molar received stress more because ballista spring being inserted in the molar tube. There is increase in the stress values in the areas of Ballista spring in the bracket.

Discussion:

Maxillary Canines are play a significant role in smile aesthetics and referred as a cornerstone of dental arch. The common problem orthodontist encounter with canine is ectopic canine eruption or impacted canine. The incidence of canine to be impacted is 1-3% [1,2]. There are various treatment modalities available for such problems involving canine which includes surgical removal, orthodontic traction or surgical removal and reimplantation in deciduous teeth extracted site. The help in maintaining Functional occlusion. Hence, extractions of impacted canines should be avoided. Impacted canines if left untreated they may undergo cystic change, may cause adjacent tooth resorption, occlusal imbalance, and aesthetic limitation [10,12]. Therefore, treatment has to be considered.

Orthodontic traction of impaction also has complication as a consequence of disimpaction, which includes too much tension on the adjacent teeth causing root resorption, bone loss, gingival recession in the disimpacted canine. Numerous techniques are available for bringing impacted or ectopically erupting canine to occlusion. Of which ballista spring introduced by Jacoby gained more attention and works efficiently without causing damage to adjacent structures [18]. Mini implants also has its advantages in orthodontics and also in disimpaction of canine.

Finite Element Analysis is the method of solving differential equation in a mathematically generated model. It is a computerised method for predicting how a system reacts to the forces, heat, fluid dynamics, and other physical effects. When a 3D object is scanned and fed into the computer it will create a mesh in small triangles each of which will have its own algebraic equation based on density or intensity or any way based on the 3D object scanned [23]. There are many studies in orthodontics done in Finite Element Analysis to determine the centre of resistance of required area of interest, torque control during retraction of incisors, stress distribution during different orthodontic treatments and so on [24].

In this study, traction of Palatally impacted canine was done using Ballista spring and Mini-screws in a Finite element model. There are various studies that are conducted in relation to finite element analysis and canine impaction. And there are studies conducted to find out the most efficient methods and appliances that is favourable for disimpaction of palatal canines through many surgical and orthodontic techniques. The most common consequence most orthodontist encounter during disimpaction of impacted canine is root resorption of adjacent tooth. Root resorption of the adjacent tooth is because of the tractional forces applied during disimpaction which distributes stress to the adjacent

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bone, PDL and ultimately to the roots of the teeth which is already erupted in the arch. Hence, the force distribution to the adjacent structures are to be studied. There are few studies investigated the stress distribution to the adjacent structures using Finite element modelling [25].

Ballista spring is advantageous in exerting vertical force that does not interfere in the roots of the adjacent teeth. Also they exert continuous force when twisted along its long axis. They have modifications to control the directions eruption. Many concluded that ballista spring causes less tissue damage to the tissue around the impacted teeth [18]. The anchorage system used for ballista spring disimpaction system consists of transpalatal bar connecting molars on both sides since the spring may cause moments in the molars. In addition, ballista spring can be used in the levelling and aligning stage or even before. Considering these advantages Ballista spring is used in the study.

Temporary anchorage device and canine impaction are quite favourable because of absolute anchorage system helps in better control of force applied to the tooth impacted. Site of implant placement is crucial for the treatment. Here in this study implant is placed buccally 8 mm away from the marginal gingiva. This site was selected because as Ballista spring was the appliance to be used for the comparison. As Ballista spring creates vertical and lateral force, the same force has to simulated for comparison hence the site was chosen. The other problem that can be expected is the length of the screw that is inserted may interfere in bringing the canine to its anatomic site, as mini implant is lying 8mm above the gingival margin. This can be conquered by removing TAD as soon as the crown of canine is visible clinically and some other techniques can be used to bringing it to occlusion.

The results of this study is favourable for ballista spring because they had stress values less than model 1. The region of stress in the ballista spring model is the area where the spring is attached in the bracket. They exerted less stress on lateral incisor as they are directed vertical and laterally. This spring can be manipulated in the direction away from the tooth also to have better control of adjacent teeth damage. The stress values in the Ballista spring model is high in the area distal to the impacted site. This is because the ballista spring attached which is facing vertically will be twisted towards the tooth and given force. This twist in wire is the reason for the stress in premolar region and in molar region. Also the spring is attached to the buccal tube of the molar that exhibit some force in molar region. These increase in stress values are not much higher to cause resorption and not too high compared to the premolar and molar regions of model 1. The difference in percentage of molar and premolar region in not more than 5% in comparison of both the models. The model 1 has higher percentage of stress in Lateral incisors which are more susceptible to root resorption. In Ballista spring model the stress on Lateral incisor is less than model 1 which is favourable. In first premolar area, there is 4% percentage higher force in model 2. The stress that is mostly seen is at the coronal one third of the root of lateral incisor and first premolar. Apical third of the root has less force received than the coronal third of the root. This is because the level of crown that is impacted is at the coronal third of the root.

The young modulus of elasticity is the material property that is used in the finite element study whose value of PDL is 0.68 MPa. The values obtained are in kPa. Hence, the conversion values will tend to give even less percentage that is obtained in the study. The percentage conversion done in this study is for kPa. This makes clear the obtained percentage values are very less to match the modulus of elasticity of PDL to disturb the stability. The value of stress obtained is not sufficient to cause root resorption.

Conclusion:

There is no difference between the stress distribution to the adjacent structures during traction of Palatally impacted canine using Mini-screws and Ballista spring. The null hypothesis is accepted. Though the values are minimal, comparing both the models ballista spring is better in control of force distribution than TAD supported orthodontic traction by same force and its direction of impacted canine. Ballista spring has many advantages in controlling direction by bending the wire in the required direction and force by using the wire of different dimension (0.014’,0.016’,0.018’ SS). TADs can be used for canine impaction but the site of placement and direction of force should be evaluated properly.

REFERENCES:

1. Grover PS, Lorton L. The incidence of unerupted permanent teeth and related clinical cases. Oral Surg Oral Med Oral Pathol. 1985 Apr;59(4):420-5.
2. Cooke J, Wang HL. Canine impactions: incidence and management. Int J Periodontics Restorative Dent. 2006 Oct;26(5):483-91.
3. Bishara SE. Clinical management of impacted maxillary canines. SeminOrthod. 1998 Jun;4(2):87-98.
4. Izadikhah I, Cao D, Zhao Z, Yan B. Different management approaches in impacted maxillary canines: an overview on current trends and literature. J Contemp Dent Pract. 2020 Jul 23;21(3):326-36.
5. Bedoya MM, Park JH. A review of the diagnosis and management of impacted maxillary canines. The Journal of the American Dental Association. 2009 Dec 1;140(12):1485-93.
6. Chaushu S, Abramovitz I, Becker A. [Failure in the orthodontic treatment of impacted maxillary canines]. RefuatHapehVehashinayim (1993). 2013 Apr;30(2):45-52, 81.
7. Szarmach IJ, Szarmach J, Waszkiel D, Paniczko A. Assessment of periodontal status following the alignment of impacted permanent maxillary canine teeth. Adv Med Sci. 2006;51 Suppl 1:204-9.
8. Alqahtani H. Management of maxillary impacted canines: A prospective study of orthodontists' preferences. Saudi Pharmaceutical Journal. 2021 May 1;29(5):384-90.
9. Brusveen EM, Brudvik P, Bøe OE, Mavragani M. Apical root resorption of incisors
1. after orthodontic treatment of impacted maxillary canines: a radiographic stu 56
2. Orthod Dentofacial Orthop. 2012 Apr;141(4):427-35.
10. Oz AZ, Ciger S. Health of periodontal tissues and resorption status after orthodontic treatment of impacted maxillary canines. Niger J ClinPract. 2018 Mar;21(3):301-305
11. Stewart JA, Heo G, Glover KE, Williamson PC, Lam EW, Major PW. Factors that relate to treatment duration for patients with palatally impacted maxillary canines. Am J Orthod Dentofacial Orthop. 2001 Mar;119(3):216-25.
12. 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 Jan- Feb;25(1):75-81.
13. Ucar FI, Celebi AA, Tan E, Topcuoğlu T, Sekerci AE. Effects of impacted maxillary canines on root resorption of lateral incisors : A cone beam computed tomography study. J OrofacOrthop. 2017 May;78(3):233-240.
14. Walker L, Enciso R, Mah J. Three-dimensional localization of maxillary canines with cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2005 Oct;128(4):418-23.
15. Becker A, Zilberman Y. The palatally impacted canine: a new approach to treatment. Am J Orthod. 1978 Oct;74(4):422-9.
16. Kornhauser S, Abed Y, Harari D, Becker A. The resolution of palatally impacted canines using palatal-occlusal force from a buccal auxiliary. Am J Orthod Dentofacial Orthop. 1996 Nov;110(5):528-34.
17. Caprioglio A, Siani L, Caprioglio C. Guided eruption of palatally impacted canines through combined use of 3-dimensional computerized tomography scans and the easy cuspid device. World J Orthod. 2007 Summer;8(2):109-21.
18. Jacoby H. The 'ballista spring" system for impacted teeth. Am J Orthod. 1979 Feb;75(2):143-51. Nienkemper M, Wilmes B, Lübberink G, Ludwig B, Drescher D. Extrusion of impacted teeth using mini-implant mechanics. J ClinOrthod. 2012 Mar;4 57
19. 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 Mar-Apr;21(2):65-72.
20. Knop L, Gandini LG Jr, Shintcovsk RL, Gandini MR. Scientific use of the finite element method in Orthodontics. Dental Press J Orthod. 2015 Mar-Apr;20(2):119-25.
21. Al-Khatib AR., Hasan LA., Al-Hafidh NN. An Overview on the Applications of Finite

Element Analysis in Orthodontic. AL–Rafidain Dent J. 2021; 21(2):185-192

22. Geramy A. Stresses around a miniscrew. 3-D analysis with the finite element method (FEM). AustOrthod J. 2009 Nov;25(2):104-9.
23. Jing Y, Han X, Cheng B, Bai D. Three-dimensional FEM analysis of stress distribution in dynamic maxillary canine movement. Chinese science bulletin. 2013 Jul;58(20):2454-9.
24. 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 May;89(3):418-425.