Finite Element Analysis of Torque Changes During en Masse Retraction of Maxillary Anterior Teeth in Completely and Incompletely Leveled Arches

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Abstract

Objective: This study is aimed to evaluate the changes in torque during en masse retraction of maxillary anterior teeth segment in, completely leveled and incompletely leveled arches. A maxillary arch form and continuous tooth movement was stimulated by finite element analysis. **Materials and Methods:** It is an *in vitro* observational study. Three 3D finite element method models were constructed with different tip values in posterior segment. (1) 2nd Premolar tip 0° and 1st and 2nd Molar tip 5° (completely leveled arch), (2) 2nd PM tip 2° and 1st and 2nd M tip 7°, and (3) 2nd PM tip 4° and 1st and 2nd M tip 9° (2 and 3 were incompletely leveled arches). Extraction of first premolar was hypothesized. Torque change was calculated by measuring the displacement of the anterior teeth during en masse retraction at crown tip and root apex in two different planes, that is, sagittal and vertical using Y and Z axis, respectively, in all three models. **Results:** When the extraction space of first premolar was closed, the anterior teeth were extruded and bite deepened. Torque loss was evident in all the three models. Least torque loss was noted in model 1 and most in model 3. **Conclusion:** After analyzing the three models of different tip values, anterior segment torque change in en masse retraction with the extraction of first premolar can be predicted. Torque change of anterior segment is of functional and esthetic importance in achieving optimal orthodontic treatment results.

Keywords: Continuous teeth movement, En masse retraction, Finite element method, Incompletely leveled arches, Leveled arch, Torque changes, Variable tip values.

Introduction

In clinical orthodontic practice, maxillary protrusion is a common malocclusion, primarily seen in patients with Angle's class I bimaxillary protrusion and Angle's class II division 1 malocclusion. To reduce proclination and enhance facial esthetics, first premolar extractions followed by en masse retraction of anterior teeth is a routine orthodontic treatment modality. Achieving proper alignment and leveling of dental arches is mandatory before the space closure can be initiated to minimize friction and avoid undesirable side effects.[1,2] Torque in orthodontics is represented by crown inclination or the third order relationship and tip is represented by crown angulation or the second order relationship of wire and bracket. The recommended ideal tip and torque in the bracket gets expressed through sequential individualized arch wire changes moving from a more flexible undersized round nickel titanium (Niti) wire to a more rigid rectangular stainless steel (SS) wire to completely align and level the arches. Improper bracket positioning or frequent wire changes may result in incompletely aligned and leveled arch. During orthodontic therapy, maintaining ideal incisor torque, optimal overbite, and overjet during space closure with en masse retraction is essential along with anchorage management. The orthodontic treatment should ensure proper control over both the root angulation and inclination during space closure to obtain optimal functional and esthetic results.[3] Orthodontic research has undergone several changes in the past two decades. To find out the mechanical changes taking place within a biological system numerous studies such as photoelastic strain gauge,[4]

Access this article online

Website:
www.jrad.co.in

DOI:
https://doi.org/10.53064/jrad.2022.15.4.508

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Received: May. 04, 2024; **Accepted:** May. 11, 2024; **Published:** May, 13. 2024

How to cite this article: Gupta S, Kallury A, Jayade C, Balani RK, Upadhyay S, Pawar P. Finite Element Analysis of Torque Changes During en Masse Retraction of Maxillary Anterior Teeth in Completely and Incompletely Leveled Arches. J Res Adv Dent 2024;15(4):1-5.

laser holographic interference techniques[5] and finite element methods (FEM)[6] have been attempted. The FEM makes it possible to apply various force systems analytically at any point or in any direction. It also quantitatively assesses the distribution of such forces through the wire and related structures. Finite element models can be used to analyze tooth movement in a non-invasive manner.

The aim of this study is to compare the torque changes in maxillary anterior teeth during en masse retraction in completely and incompletely aligned and leveled arches during space closure through finite element analysis (FEA).

Materials and Methods

Finite element modeling

The following procedures were involved when constructing the finite element model: Constructing the geometric model, transforming it into a finite element model, representing material property data, defining the boundary condition, configuring the loading, and interpreting the von Mises stress. For the finite element tooth model, a cone-beam computed tomography (CBCT) (Carestream CS 9600) of maxillary arch with extracted 1st premolar and ready for space closure is taken. The arch form was modeled based on the Broad Arch form of Ormco (Ormco, USA). The size of the bracket was modeled based on the (American Orthodontics Mini Master Series, Wisconsin, USA) SS bracket.[7] Brackets were positioned at the facial axis point of each crown.[8-10] With the CBCT scan, a geometric model of maxillary teeth was created. After processing, the CBCT was exported in the stereolithography format and the surface data were generated. ANSYS (version 19.2, ANSYS Inc, Southpointe, Pittsburgh, USA) software was used to create the geometric models of the maxillary central incisor, lateral incisor, canine, second premolar, first molar, and second molar, as well as the alveolar bone, cancellous bone, and periodontal ligament (Figure 1). Each tooth was independent, having a contact point with adjacent teeth on the mesial/distal side.[11] The curve of Spee and the curve of Wilson were not considered.

Model design

Three geometric models were constructed for simulation of this study. The first model depicted retraction with completely leveled arch having 2nd premolar tip 0° and 1st and 2nd molar tip 5° (Figure 2). The second and third models depicted retraction with incompletely leveled arch having 2nd premolar tip 2° and 1st and 2nd molar tip 7° (Figure 3) and 2nd premolar tip 4° and 1st and 2nd molar tip 9° (Figure 4), respectively (Table 1). All the three models had brackets with 0.022 × 0.028 slot dimension and 0.019 × 0.025 SS wire within the bracket slot. A 5 mm length 0.9 mm diameter, SS retraction hook mesial to the canine with a power chain extending from the second molar hook to retraction hook was modeled. 150 g/1.5 N of retraction force was produced through power chain. The thickness of the periodontal ligament was modeled as 0.2 mm based on the study by Coolidge and Kronfeld.[12,13] Periodontal ligaments (PDLs) were assumed to be isotropic, homogenous, and elastomer. The alveolar bone was modeled so that the level was located 1 mm apical from the cement-enamel junction.[14] Young's modulus and Poisson's ratio were based on the previous studies[15-18] (Table 2). For the ease of calculations, unilateral modeling and simulations were done.

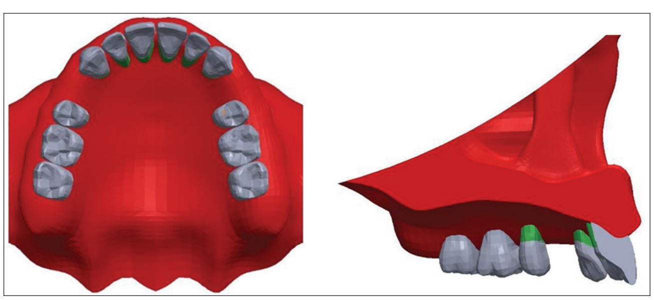


Figure 1: Geometric model of maxillary arch

Interpretation method

When orthodontic forces are applied to teeth in clinical practice, tooth movement occurs. In this process, the PDLs are affected creating compression and elongation areas. If the orthodontic force continued, remodeling of the alveolar bone takes place and tooth assumes a new position.[19] The original position and the changed position of the tooth can be expressed by three, that is, X, Y, and Z-axis displacement and rotation about each axis. The brackets are tied to the arch wire and can be seen as a point representing each tooth. All teeth were placed

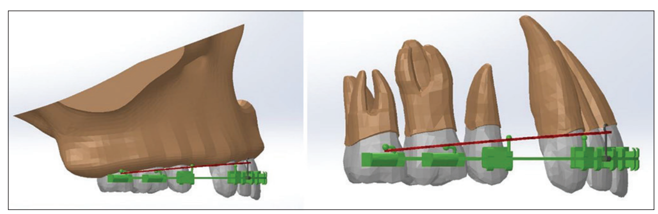


Figure 2: Model 1 (premolar tip 0° and molars tip 5°)

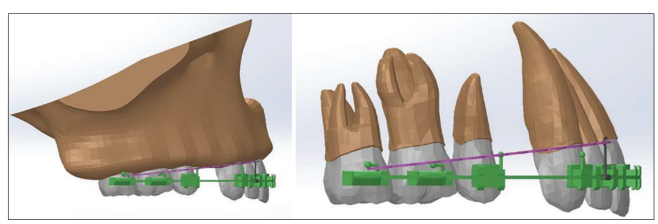


Figure 3: Model 2 (premolar tip 2° and molars tip 7°)

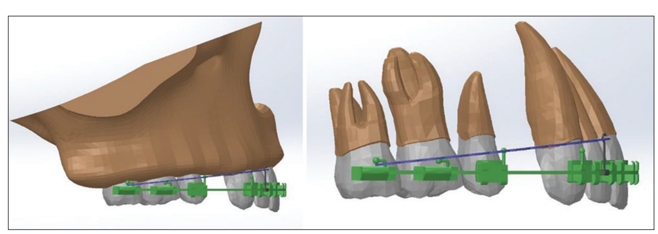


Figure 4: Model 3 (premolar tip 4° and molars tip 9°)

in contact with each other through a contact point. Conditions were given to prevent interference with each other. The arch wire was mathematically combined with the bracket while maintaining the stiffness. Therefore, it was possible to push and pull the bracket when the arch wire was moved by force. The bracket integrated with the teeth was free to rotate under the influence of the arch wire. As a result, when force was applied to the teeth, angulation and inclination were applied similarly to those in the clinical process. Variable tip in the posterior segment led to an increase in the frictional forces between bracket and wire interface due to which the torque of the anterior segment got affected. The displacement of the teeth at the crown tip and root apex in two distinct planes – the sagittal and vertical – using the Y and Z axis, respectively, were used to determine torque variations.

Results

The occlusal surface showed no significant difference, before and after tooth movement in all the three models (Figure 5). From the buccal side, it could be seen that the magnitude of extrusion and torque changes of the maxillary incisors increased from model 1 to model 3 after space closure was completed (Figure 6). Bite deepening is observed in all cases.

Table 1: Model configuration

Component	2nd premolar tip		1st and 2nd molar tip
Completely leveled arch	Model 1	0°	5°
Incompletely leveled arch	Model 2	2°	7°
	Model 3	4°	9°

Table 2: Common material properties

Material	Young's modulus (MPa)	Poisson's ratio
Teeth	2.0×10^4	0.30
PDL	6.8×10^{-2}	0.49
Stainless steel bracket	21.4×10^3	0.30
Alveolar bone	1.4×10^3	0.30
Arch wire/hook	21.4×10^3	0.30

PDL: Periodontal ligaments

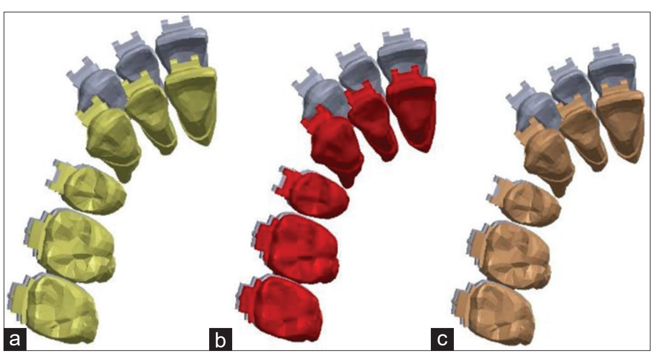


Figure 5: Occlusal view (a) model 1 (yellow) after space closure; (b) model 2 (red) after space closure; and (c) model 3 (brown) after space closure

Changes in maxillary central incisors

The long axis of maxillary central incisors showed a tendency to be lingually tipped in all three cases increasing from model 1 to model 3. The change in coordinates of the root apex and incisal edge gives change in long axis of the tooth.

Changes in maxillary lateral incisor

The long axis of maxillary lateral incisors showed a tendency to be lingually tipped in all three cases increasing from model 1 to model 3. The change in coordinates of the root apex and incisal edge gives change in long axis of the tooth.

Changes in maxillary canine

The long axis of maxillary canine showed a tendency to be lingually tipped in all three cases increasing from model 1 to model 3. The change in coordinates of the root apex and incisal edge gives change in long axis of the tooth.

Since all the teeth are connected via rigid SS wire and experience similar degree of freedom at the bracket, the change in coordinates for the three anteriors (central incisor, lateral incisor, and canine) is similar before and after the space closure for their respective model. The values of coordinate changes are shown in Table 3 for all three models.

Graph 1 shows the change in position of long axis of central incisor before and after the space closure (Yellow- Model 1, Red- Model 2, and Green – Model 3). The graph is plotted using the coordinate values of root apex and incisal edge before and after space closure in all three models. It was noted that the incisal edge in all three cases has extruded and tipped lingually and the degree of extrusion and tipping has increased from model 1 to model 3.

The lateral incisor and canine also showed similar coordinate change as that of central incisor, a similar graph can be used to depict the change in long axis of the respective teeth in all three models.

Discussion

One of the major challenges faced by the orthodontists is to understand and predict the complexities involved in the response of teeth to the forces and the moments. Many finite element studies have looked at changes in the teeth based on their initial responses when an orthodontic force is applied.[20-22] In the present study, the space closure in the maxillary first premolar extraction model was simulated through continuous FEA.[22,23]

In the present study, three FEM models were constructed with different tip values in posterior segment (premolar and molars) representing complete and incomplete aligning and leveling and were simulated for space closure. The force applied was 150 g/1.5 N[24-26] provided by a power chain, extending from second molar to a hook placed mesial to canine. The results showed that as the tip value of the posterior segment increased, torque loss, and bite deepening increased in the anteriors, thereby establishing the importance of aligning and leveling before space closure.

Table 3: Coordinate changes of incisal edge and root apex change in maxillary central incisor, lateral incisor, and canine in all three cases after space closure

Component	Model 1		Model 2		Model 3	
	ΔZ (mm)	ΔY (mm)	ΔZ (mm)	ΔY (mm)	ΔZ (mm)	ΔY (mm)
Incisal Edge	−8.16	−2.23	−8.86	−2.96	−9.12	−3.25
Root apex	3.29	2.96	3.82	2.66	4.08	2.05

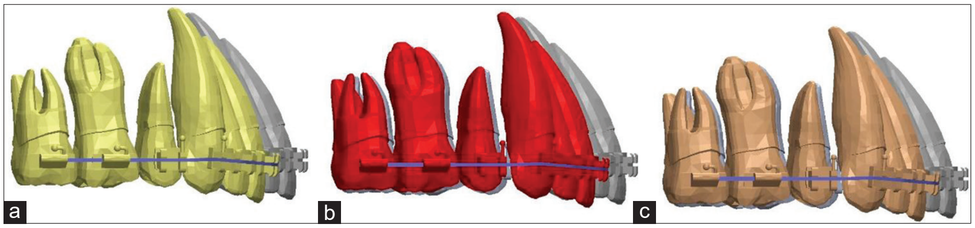


Figure 6: Overlap of lateral view (a) model 1 (yellow) after space closure; (b) model 2 (red) after space closure; (c) model 3 (brown) after space closure. Grey colored teeth-teeth before movement

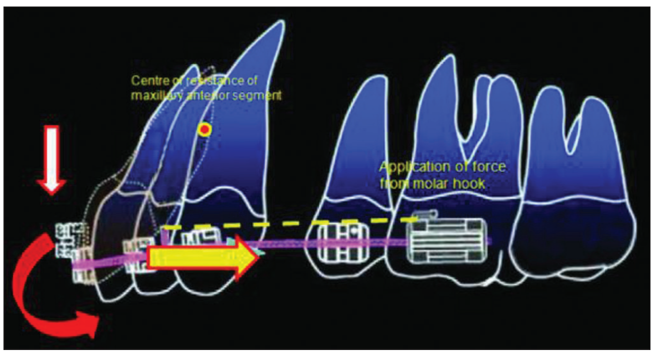
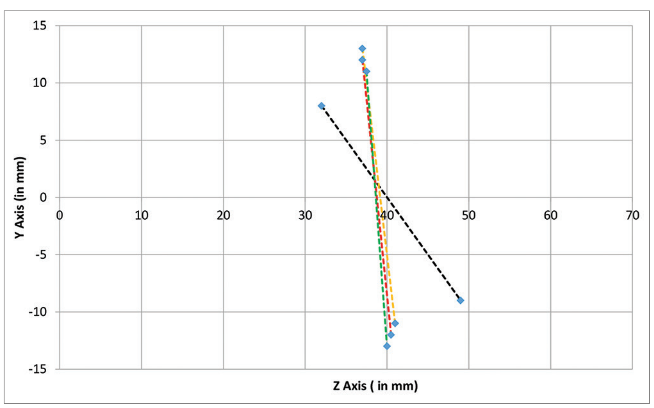


Figure 7: Biomechanics of tooth movement



Graph 1: Change in long axis of teeth before (black) and after space closure (yellow - model 1, red - model 2, and green - model 3)

According to Melsen *et al*.[27] the center of resistance (CR) was located 13.5 mm posteriorly and 9 mm superiorly from the center of the archwire. If the force passes through the CR, bodily movement is observed whereas if it passes below the CR, uncontrolled tipping is observed. This could be confirmed in present study as force application was below CR and lingual tipping of anteriors was observed in sagittal plane (Z axis) (Figure 7). Further, torque loss was calculated by measuring the difference between the displacement of crown tip and root apex. Torque maintenance is essential in first premolar extraction case as it is of functional and esthetic concern. Torque loss results in bite deepening and loss of anterior guidance. Clinically, tipping can be prevented by applying lingual root torque to the rigid 019x025 SS archwire and applying light forces for retraction.[28] In vertical plane (Y axis) since the point of force application was occlusal to the center of resistance, extrusion of teeth was noted.

The results of the present study are similar to the results of the study by Parashar *et al*.[29] that when power chain runs from molar hook to retraction hook while space closure, the anteriors showed torque loss.

The results of the present study also agree with the results of the study by Chetan *et al*.[30] that anterior teeth showed torque loss and extrusion when the force was applied between molar hook and retraction hook.

The only factors clinicians should keep in mind are the direction of the force and the response of the teeth to the force.[31] The limitations of this study were: Although the FEM is a wonderful tool, it cannot represent the human skull perfectly and the result of this study is only valid with patients exhibiting similar bone density, root lengths, root angulations, crown sizes, etc.

Conclusion

In our continuous FEA study attempting space closure through en masse retraction in first premolar extraction case, it was confirmed that movement patterns of dentition were different depending on the tip values of posteriors.

1. All three models showed significant extrusion of incisal edges of maxillary anterior teeth increasing from model 1 to model 3
2. All three models showed lingual tipping/uprighting of maxillary anterior teeth increasing from model 1 to model 3, indicating increasing torque loss.

Hence, it is advisable to achieve complete aligning and leveling before space closure is attempted on 019 × 025 SS wire.

Funding

No funding or grant support.

Organization Support

We would like to acknowledge the assistance of Engineering DNA, Mumbai for all FEA Analysis carried out.

Institutional Review Board Statement

This study is approved under Review Board sequenced - RAC/2023/006/06 and IEC/2023/600/06

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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