Three-Dimensional Finite Element Analysis of Maxillary Molar Distalization Using Different Attachments with Clear Aligners

Jingwen Chi[1], Yicong Liu[1], Lixia Yang[1], Shengteng Sun[1], Wen LIU[*1,2]

[1] School of Stomatology of Qingdao University, Qingdao, Shandong, China

[2] Department of Stomatology, Qingdao Municipal Hospital Affiliated to Medical College of Qingdao University, Qingdao, Shandong, China

*Corresponding author

E-mail: Anadhdqhs@163.com

*Corresponding Author

Keywords: Attachment, Finite element, Clear aligner, Molar distalization

Abstract: Objectives: To compare biomechanical characteristics of maxillary tooth in molar distalization against different orthodontic attachment. Materials and Methods: Three-dimensional finite models of maxilla molar distalization with clear aligner containing the different components(teeth,periodontal ligament,maxillary bone,clear aligner,attachment)was generated from a computed tomographic scan. According to the shapes of different attachment, four models were set up: non-attachment (model A), horizontal rectangular attachment (model B), vertical rectangular attachment (model C) and combine attachment (model D). Next, a finite element analysis was used to simulate the modalities of molar distalization. Results: The displacement rotation center of second molar of model A and B were located at the root furcation. In model C, the displacement rotation center of the buccal sides was located at the middle third of the mesiobuccal root, and the palate side was located at the coronal third of the palate root. In model D, the displacement rotation center of the buccal and palate side were located at the middle thirds of root. All the displacements of the anchorage tooth in the four groups tended were found mesial tipping movement. Conclusions: Applying attachments was more efficient for tooth displacement patterns. The second molars of the four groups all showed a clockwise tendencies of distal crown tipping and mesial root tipping. The model with a combined attachment of tooth movement was the most efficient, followed by traditional attachment models. When applying the molar distraction technique in clinical practice, care should be taken to strengthen the support to avoid unnecessary labial tipping of the anterior teeth.

1. Introduction

Despite the fact that clear aligner therapy (CAT) has been widely used in clinical practice for its advantages of aesthetics, comfort, easy cleaning and removability[1], it is still controversial due to its effects in controlling tooth movements in orthodontic. This continued debate could stem from the fact that it is difficult to solve complex force systems(eg, bodily tooth movement, torque control).

Compared with the fixed orthodontic appliance, which makes use of the interactions between wire and brackets to implement the displacement of tooth structures, CAT came into effect through the predetermined mismatch between tooth and aligner. It employs a sustainable and gradual tooth reposition by wearing sequential aligners to reach the final dental position.

To control tooth movement in three -dimensions, different attachments were designed in the CAT as an auxiliary device, such as rectangular attachments, elliptical attachments and composite attachments[2, 4, 5]. Scholars Ravera[3] indicated that applying attachments would enhance control over tooth movement. The different shapes of the attachments and the force and moments generated by the aligner would be

different, which would lead to difference in tooth movements. However, how teeth were moved by aligners and how attachments effected tooth movement were not clear. The most accurate movement during CAT is molar distalization. The efficient control of tooth movement in orthodontic could have something to do with the fact that pushing is the easiest method to apply force in PDT. Therefore, observing different attachments in molar distalization could avoid unfavorable factors in this study.

According to some authors, the finite element method (FEM) is a non-invasive and accurate method, which can provide quantitative and detailed data on physiological responses of tissues such as periodontal membrane and alveolar bone. FEM is a kind of engineering technology used to calculate stress and deformation, which is widely used for medical purposes, developed on the geometric entities under external force.

2. Materials and Methods

One healthy adult (female, 22 years old, East Asian, individual normal occlusion) was selected and scanned by CBCT (Philips Company, Netherlands) for the study. The CBCT image was stored in the standard digital imaging and communications in medicine (DICOM) format and then imported and segmented in Mimics17.0 (Materialize Software Company, Belgium) and Geomagic Studio (3D System Company, USA) to obtain the complete 3D geometric surface model of the maxilla and maxillary dentition. PDLs were fabricated as a linear elastic film with an average thickness of 0.25mm around the roots of all teeth . The maxillary second molar was distally shifted by 0.25 mm in Geomagic and then a 0.75 mm shell extraction was performed on the crown to construct a clean aligner model. Attachments were drawn by Solidworks (Dassault Systems Company, USA), including a horizontal rectangular attachment (3 mm width, 2 mm height, and 1 mm thickness), a vertical rectangular attachment (3 mm height, 2 mm width, and 1 mm thickness), and a combine attachment with two semi-elliptical convex structures (2 mm diameter, and 0.8 mm thickness). After four models were designed, all of the components were imported into the finite element software Ansys Workbench 19.0 (Swanson Analysis Company, USA) as Figure 1.
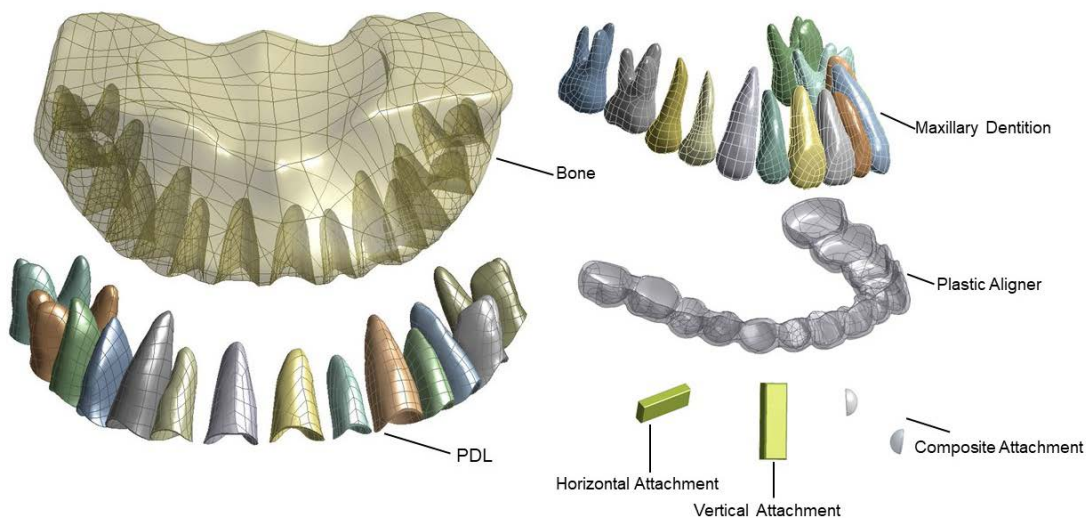

Fig.1 Fe Model.

Teeth, attachments, clean aligners, PDL and maxilla were considered as homogeneous and isotropic materials. The Young's Modulus and Poisson's ratios of all components are in Table 1. The mesh sizes were set at 0.35mm for bone, 0.25 mm for teeth and attachments, 0.10mm for PDL, and 0.30mm for clear aligner (Table 2).

Table 1 Elasticity Modulus And Poisson's Ratios of Different Materials

Grouping	No. of Elements	No. of Nodes
Model A	2847436	4053641
Model B	2847420	4053680
Model C	2847543	4056774
Model D	2847767	4055840

Table 2 Numbers of Nodes and Elements of the Four Groups of Fe Models

Material	Elasticity modulus(MPa)	Poisson ratio
Bone	1.37×10^3	0.3
Tooth	1.96×10^4	0.3
periodontal ligament	6.67×10^{-2}	0.45
Clear aligner	528	0.36
Attachment	12.5×10^3	0.36

Bonded contact conditions were established at the interface between the teeth and PDL, teeth and bone, PDL and bone, and teeth and attachment, while frictionless contact conditions were established at the interface between teeth and clear aligners. To simulate the influence of alveolar bone on teeth, fixed boundary conditions were applied to the posterior and upper regions of the maxilla.

Four experimental models were developed, including different attachment shapes:

Model A: No attachment

Model B: Horizontal rectangular attachment on the buccal crown surface of second molar.

Model C: Vertical rectangular attachment on the buccal crown surface of the second molar.

Model D: Composite attachment on the buccal crown surface of the second molar.
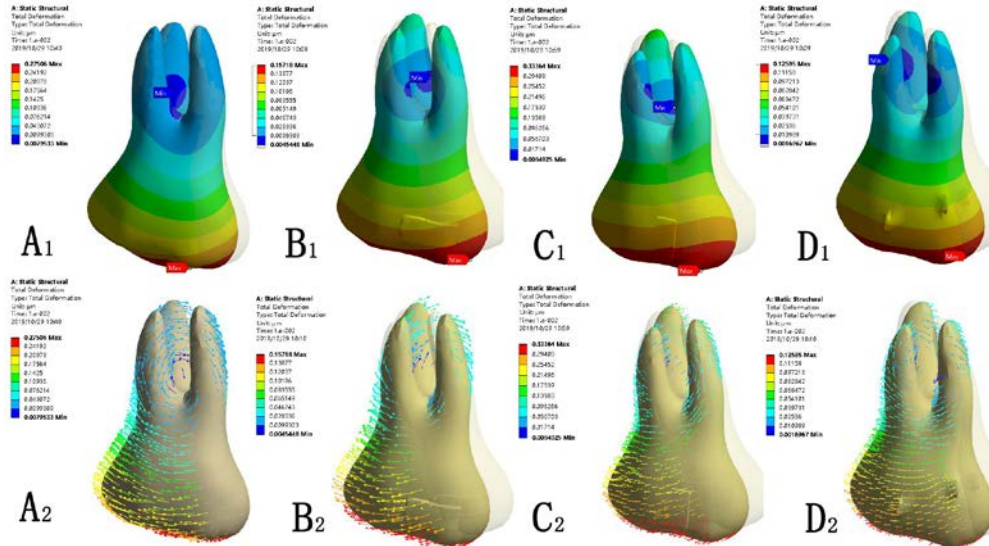
3. Rusults

Fig.2 Displacement Pattern of the Second Molar. a: Displacement Trend of Model a, B: Displacement Trend of Model B, C: Displacement Trend of Model C, d: Displacement Trend of Model d.

In model A (no attachment), the second molar showed tendencies of distal crown tipping and mesial root tipping, and the initial displacements of the buccal and palatal sides were not significantly different. At this point, the minimum displacement(center of rotation) was located at the root furcation (Fig. 2).

In model B (horizontal rectangular attachment), as in model A, the second molar showed tendencies of distal crown tipping and mesial root tipping,; however, the value of displacement was higher than in model A, and the minimum displacement was closer to the root tip (Fig 2).

In model C, the second molar showed a tendency that the distal buccal movement of the crown was significantly higher than the distal palatal movement of the crown. The minimum displacement was located at the middle third of the palate root (Fig 2).

In model D, the displacement pattern was similar to model A, but the minimum displacement was located at 1/3 of root tip, and the initial displacement was the smallest of all the models (Fig. 2).

Displacement trend of anchorage teeth in four models were showed a mesial crown tipping in the four models. Compared with the other models, model C had the highest initial displacement value, while model A had the lowest displacement value (Tab 3).

Table 3 Displacement Values Of Markers of Each Tooth(Mm)

	11		12		13		14		15		16		17	
	Crown	Root	Crown	Root	Crown	Root	Crown	Root	Crown	Root	Crown	Root	Crown	Root
Group A	+1.04	-0.27	+1.67	-0.33	+1.93	-0.54	+2.31	-0.68	+2.56	-0.82	+4.59	-1.90	-26.7	+10.2
Group B	+1.47	-0.67	+1.76	-0.95	+2.47	-1.23	+2.71	-1.36	+3.15	-1.64	+5.19	-2.14	-28.4	+13.7
Group C	+1.96	-1.44	+2.14	-1.41	+3.61	-2.49	+3.97	-2.63	+4.13	-2.81	+6.31	-3.75	-33.3	+17.1
Group D	+1.25	-0.71	+1.72	-0.43	+2.11	-0.69	+2.38	-0.81	+2.85	-1.34	+4.76	-2.01	-24.6	+6.20

4. Discussion

An aligner is formed by introducing a geometric mismatch relative to the actual tooth position to induce a loading system that moves the target tooth to a preadjusted position[16,17]. Given the special touching mode between the aligner and the teeth, it is difficult for the aligner to "grasp" the teeth during tooth movement. Accordingly, the orthodontic force cannot be completely applied to the tooth. The attachment, like the "brackets" in traditional fixed orthodontics technology, is used to increase retention of the aligner and to assist in tooth movement. However, different attachments affect tooth movement differently. In this study, four The combined attachment helped generate a force system that approximated root movement of the second molar. The distal semi-elliptical attachment of the power attachment will move 0.25mm to the distal direction during the matching process of the model assembly.

A vertical rectangular attachment displayed an obvious tendency of palate torsion during molar distalization. This was probably because the stress surface of the vertical attachment was more than that of other attachments, and it received more lateral force. In addition, with this great stress surface, the vertical attachment had the greatest efficiency of molar distalization. Thus, a vertical attachment could be considered in some cases of molar buccal torsion with mesio-inclination. The second molar in the horizontal rectangular attachment and nonattachment groups showed a tendency toward uncontrolled tipping movement, but the molar movement efficiency of horizontal attachment was higher than that of nonattachment. Therefore, a horizontal attachment could be applied to Class II cases caused by the inclination of molars to rapidly achieve an upright orientation and gap formation.

During molar distalization, mesial anchorage teeth can move in the opposite direction due to the interaction of forces, which often negatively affects the orthodontic effect. According to the results, the anchorage teeth in the four models were all inclined to move towards mesial direction. In the

application of clear aligner, especially in cases designed for molar distalization, implant anchorage or intermaxillary anchorage could be used to reinforce the anchorage in the anterior teeth, to avoid the loss of anchorage and to achieve better clinical results.

5. Conclusion

This study showed that the different attachment forms have different influence on the movement of the teeth. If molar distalization is planned prior to treatment, the appropriate application of attachments can help us to achieve more ideal tooth movements.

References

[1] Boyd RL. "Esthetic orthodontic treatment using the invisalign appliance for moderate to complex malocclusions". Journal of Dental Education, Vol.8, No.72, pp. 948, 2008.

[2] 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". American Journal of Orthodontics & Dentofacial Orthopedics, Vol.3, No.135, pp.316-322, 2009.

[3] Ravera S, Castroflorio T, Garino F, Daher S, Cugliari G, et al. "Maxillary molar distalization with aligners in adult patients: a multicenter retrospective study". Progress in Orthodontics, No.17, pp .12, 2016.

[4] Duong T, Kuo E. "Finishing with invisalign". Prog Orthod, Voi.1, No,7, pp.44-55, 2006.

[5] Simon M, Keilig L, Schwarze J, Jung BA, Bourauel C. "Treatment outcome and efficacy of an aligner technique – regarding incisor torque, premolar derotation and molar distalization". BMC Oral Health, Vol.1, No.14, pp.68, 2014.