

Locating the center of resistance of maxillary anterior teeth retracted by Double J Retractor with palatal miniscrews

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ABSTRACT

Objective: To locate the center of resistance of six maxillary anterior teeth retracted by the Double J Retractor (DJR) and to find the optimal position of palatal miniscrews.

Materials and Methods: The three-dimensional (3D) finite element model included 12 teeth with two first premolars extracted. The DJR was modeled as a 3D beam element. The miniscrew was sagittally placed between the second premolar and the first molar, and the vertical position of the miniscrew was established at five conditions: 6, 7, 8, 9, and 10 mm apically from the cervical line of the first molar. The length of the retraction lever arm was determined according to the position of the miniscrew, for the direction of retraction force to be parallel to the maxillary occlusal plane. The 3D finite element method was used to determine the location of the center of resistance of the maxillary anterior teeth by visualizing the tooth displacement and stress distribution.

Results: As the miniscrew was located apically, the stress spread out to the root apex and the adjacent alveolar bone. At the 8-mm level of miniscrews, a bodily-like parallel retraction could be obtained with DJR.

Conclusion: In this study, the center of resistance of the six maxillary anterior teeth retracted by DJR with palatal miniscrews was estimated to be 12.2 mm apically from the incisal edge of the central incisor. (*Angle Orthod.* 2010;80:1023–1028.)

KEY WORDS: 3D finite element analysis; Center of resistance; Lingual retractor; Six maxillary anterior teeth; Temporary anchorage device

INTRODUCTION

When the six maxillary anterior teeth are retracted in premolar extraction cases, the control of force vectors and moments is important to achieve the desired tooth movement. The applied moment-to-force ratio on the six anterior teeth determines the type of tooth

movement, such as uncontrolled tipping, controlled tipping, bodily movement, or root thrusting. In addition, the direction and the application point of retraction force in relation to the location of the center of resistance (C_{res}) are critical factors in predicting and planning the esthetic tooth movement of anterior teeth.¹ The direction of force application has been controlled mainly by changing the vertical vector of the force, influenced by the length and the sagittal position of retraction hooks on working wire. However, anatomic limitations and individual patient variations have made this control difficult.

The development of the temporary anchorage device (TAD) has contributed to various applications of retraction force on anterior teeth as well as to the establishment of absolute anchorage. Chung et al.^{2,3} successfully retracted the anterior teeth using a palatal plate and lingual retractor. De Clerck et al.⁴ used zygomatic anchorage during retraction of maxillary anterior teeth. Hong et al.⁵ reported en masse retraction using a palatal mini-implant and lingual appliance after estimating an appropriate mini-implant position and the hook length on the cephalogram. Park

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Figure 1. Clinical application of the Double J Retractor.

and Kwon⁶ reported the efficacy of sliding mechanics with microcrew implant anchorage on the treatment of skeletal Class II malocclusion.

Among various retraction methods, the lingual approach is preferred to the labial appliance in cases demanding not only esthetic braces but also critical torque control of anterior teeth. From a biomechanical viewpoint, TAD on the palatal area has a greater advantage in applying force toward the wanted direction rather than on the buccal area. Longer retraction hooks beyond the level of C_{res} are possible when the TAD is placed on the palatal area. The key is to find a proper combination of retraction device design and the position of TAD for each treatment plan. A lingual retractor in combination with palatal skeletal anchorage has been used.^{2,3} Although the lingual retractor has long lever arms, it still shows problems, such as anterior torque loss and vertical bowing of the occlusal plane. It is not possible to determine the optimum length of lever arms and the fittest vertical position of TAD in relation to the location of the C_{res} in each individual.

To overcome this clinical limitation, a modified type of lingual retractor, Double J Retractor (DJR), was introduced. The DJR has additional torquing springs with helixes on the conventional lingual retractor (Figure 1). The torquing springs are designed to slide along the palatal miniscrew, providing reinforced vertical support, especially on the canine area, while en masse retraction proceeds. It is presumed clinically that the torquing springs play a role in counterbalancing the torque loss of anterior teeth and intrusion with distal tipping of canine teeth during retraction. Moreover, the combination of DJR with the proper position of miniscrew is expected to allow bodily-like parallel retraction of anterior teeth.

The purpose of this study was to locate C_{res} of six maxillary anterior teeth retracted by DJR and to find

Table 1. Mechanical Properties of Tooth, Periodontal Ligament, Compact Bone, Cancellous Bone, Lingual Mesh, and Wire

Material	Young's Modulus, kg/mm ²	Poisson's Ratio
Tooth	2.0×10^3	0.300
Periodontal ligament	0.0007×10^3	0.490
Compact bone	1.2×10^3	0.330
Cancellous bone	0.018×10^3	0.450
Lingual mesh	21.4×10^3	0.300
Wire	21.4×10^3	0.300

the optimal position of palatal miniscrew enabling parallel retraction of anterior teeth.

MATERIALS AND METHODS

Finite Element Method Model

The standard dentiform representing adult normal occlusion (Model i21D-400G, Nissin Dental Product, Kyoto, Japan) was scanned using a 3D laser scanner (Orapix KCI, Seoul, Korea) to prepare the 3D finite element model. The 3D finite element model included 12 teeth, with 2 first premolars extracted. The size and the dimension of the teeth were defined as in the study by Wheeler,⁷ and the periodontal ligament was modeled to have a uniform thickness of 0.25 mm, in accordance with Coolidge.⁸ The compact bone was modeled to have a thickness of 2 mm. The socket of the first premolar tooth was constructed with only cancellous bone. All materials for the teeth, periodontal ligament, compact and cancellous bone, wire, and so forth were isotropic, homogeneous, and linear elastic. Any interface between different materials was assumed to be perfectly bonded. Young's modulus and Poisson's ratio were given as the material properties (Table 1) based on the studies by Tanne et al.⁹ and McGuinness et al.¹⁰ A total of 69,093 elements and 209,258 nodes were created for the model. ALGOR[®] (ALGOR Inc, Pittsburgh, PA), as the finite element analysis software, was used to analyze the data.

Dental Arch, Periodontal Ligament, and Alveolar Bone

The 3D coordinate system was defined. The origin was at the midpoint on the line between the incisal points of both central incisors (Figure 2B): transverse x-axis (+: left, -: right); anteroposterior y-axis (+: anterior, -: posterior); vertical z-axis (+: up, -: down). The x-axis and the y-axis were set on the plane formed by the incisal edge and mesiobuccal cusp of both maxillary first molars, and this was established as the occlusal plane in this study.

The dental arch was modeled using Roth's Tru-arch form. The angulation and the inclination of teeth were

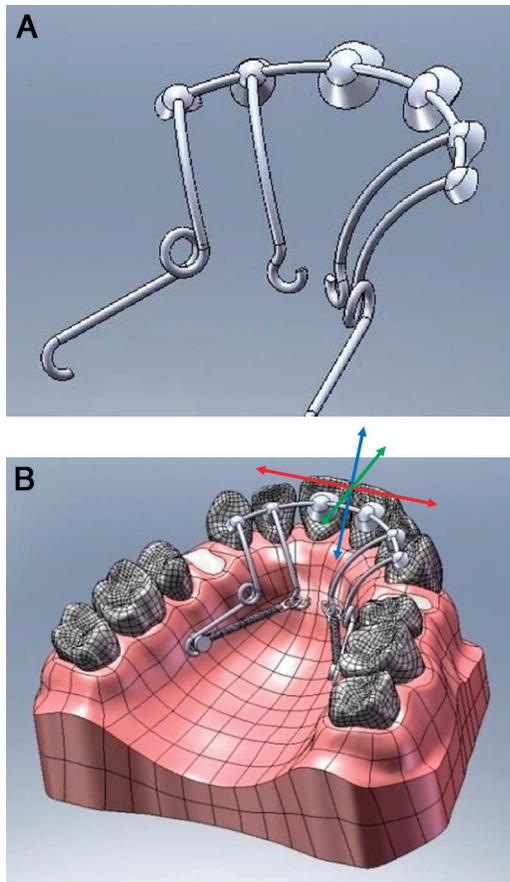


Figure 2. Schematic diagram of the three-dimensional finite element model. (A) Double J Retractor. (B) The coordinate system of maxillary teeth. X-axis (red), y-axis (green), z-axis (blue).

established according to Arnett et al.,¹¹ Andrews,¹² and Germane et al.¹³ The periodontal ligament and alveolar bone were designed to be deformed by the retraction force on the anterior teeth. Because six anterior teeth were retracted in this study, the top end of the least affected palatal bone was constrained to remain fixed. The reaction to the retraction force was neglected.

Appliances and Miniscrews

A modified lingual retractor, DJR, was modeled as a 3D beam element with a 0.8 mm diameter, with the lingual meshes of lingual button (Tomy Inc, Fukushima, Japan) attached on the lingual surfaces of the teeth. The retraction lever arms were soldered on the lateral incisors, and the torquing springs were soldered on the lingual surfaces of canines. NiTi closed-coil spring (Jeil Medical Corp, Seoul, Korea) and miniscrew (Jeil Medical Corp) were modeled with the 3D beam element (Figure 2A,B). The retractor force was 200 g per side, with reference to the studies by Vanden Bulcke et al.^{14,15}

The miniscrew was sagittally placed between the second premolar and the first molar, and its vertical

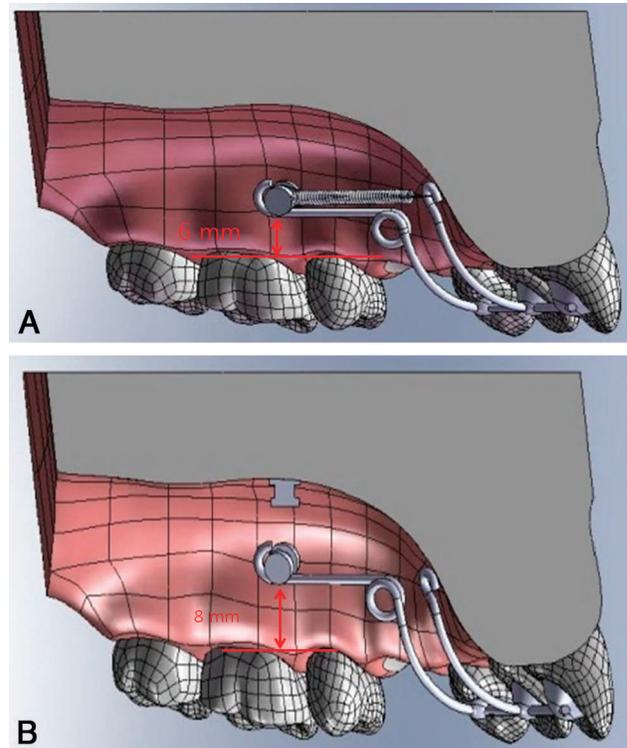


Figure 3. Location of miniscrew. (A) Vertical height of miniscrew (d) = 6 mm. (B) d = 8 mm.

position was changed on the XZ plane. To determine the stress distribution and teeth displacement depending on the vertical position of the miniscrew, the location of the miniscrew was established at five conditions: 6, 7, 8, 9, and 10 mm apically from the cervical line of the first molar (Figure 3). The length of the retraction lever arm was determined according to the position of miniscrew in order for the direction of the retraction force to be parallel to the maxillary occlusal plane.

Analysis Condition

The 3D finite element method was used to determine the location of the C_{res} of six maxillary anterior teeth by visualizing the teeth displacement and stress distribution. Since the direction of retraction force was confined to be parallel to the XY plane in this study, the C_{res} could be defined by verifying the vertical location of miniscrew where the parallel displacement of anterior teeth was observed.

Tooth displacement was identified based on the coordinate system. The midpoint of the incisal edge of the incisal teeth and the cusp point of the canine tooth was named A, and the root apex was named B, respectively. A' and B' denoted the new positions of A and B displaced by the retraction. The type of tooth movement was assessed by a displacement ratio. The

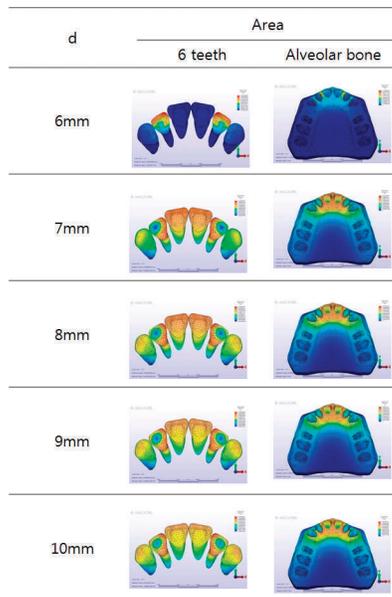


Figure 4. Von Mises stress distribution of teeth and alveolar bone. “d” represents the vertical height of the miniscrew.

tooth movement was regarded as parallel movement when the displacement ratio was near 1.

RESULTS

Stress Distribution

Figure 4 shows the stress distribution of six anterior teeth and alveolar bone when the retraction force was applied. In all experimental conditions, the maximum stress was seen at the middle portion of the lingual surface of the lateral incisors, where the retraction lever arm was attached. As the miniscrew was located apically, the stress spread out to the root apex and the adjacent alveolar bone. The amount or type of tooth movement could not be explained exactly by the Von Mises stress distribution. Rather, the increased moment of lingual root thrusting can be explained indirectly by the increased stress distribution on the lingual root surface and the alveolar bone area associated with the apically positioned miniscrew (8, 9, and 10 mm).

Tooth Displacement

Tooth displacement was estimated by the displacement ratio (A-A' to B-B') in the coordinate system. The displacement of each tooth was represented depending on the placement of the miniscrew in Figure 5. A controlled tipping movement having a center of rotation on the root apex area was observed when the vertical position of the miniscrew was 6 mm from the cervical line of the first molar (Figure 5A). At the 7 mm vertical

position, the displacement of root apices was in the opposite direction to that of incisal edges, resulting in an uncontrolled tipping movement (Figure 5B). At the 8 mm vertical position, the amount and direction of distal displacement of the incisal edges and root apices were the same, meaning bodily movement (Figure 5C). At the 9 and 10 mm vertical position, root-thrusting movement, with more displacement of root apices than that of incisal edges, was observed (Figure 5D,E).

Center of Resistance

Bodily displacement of the anterior teeth was achieved when the miniscrew was placed at the 8 mm vertical position. The vertical location of the C_{res} of six maxillary anterior teeth retracted by DJR was estimated to exist at the 12.2 mm level from the incisal edge of the central incisor in the XY plane, corresponding to the level of miniscrew at 8 mm from the cervical line of the first molar. The level of C_{res} divided the length of the central incisor into 1.8:1 from the incisal edge toward the apex. The converted result of this study was 55.56% apical to the incisal edge.

DISCUSSION

The center of resistance of six maxillary anterior teeth retracted by the DJR with palatal miniscrews was estimated to be 12.2 mm apically from the incisal edge of the central incisor in this study. This estimation was possible due to our experimental condition in which the line of retraction force was parallel to the maxillary occlusal plane regardless of the position of the miniscrew.

As far as the vertical location of the C_{res} of the six maxillary anterior teeth during retraction is concerned, it was reported to be 7.0 mm apical to the interproximal bone level between the central incisors in a dry skull,¹⁵ 6.5 mm apical to the bracket of the central incisors in human autopsy material,¹⁶ 14.5 mm apical to the incisal edge of the central incisors in a stone model made of extracted anterior teeth,¹⁷ and 13.5 mm apical to the incisal edge of the central incisors in 3D finite element analysis.¹⁸ In terms of lingual approach, Lee and Chung¹⁹ suggested that the C_{res} of the anterior teeth retracted by a conventional lingual retractor was located 6.76 mm, 44.32%, apical to the cemento-enamel junction in a finite element model. Sia et al.²⁰ had determined the C_{res} of the anterior teeth during anterior retraction stage in vivo by using a labial appliance. The C_{res} of the maxillary central incisor was approximately 0.77 of the root length from the apex.

This study found the C_{res} of the anterior segment retracted by DJR in a more occlusal position than that found in other studies, taking different measuring

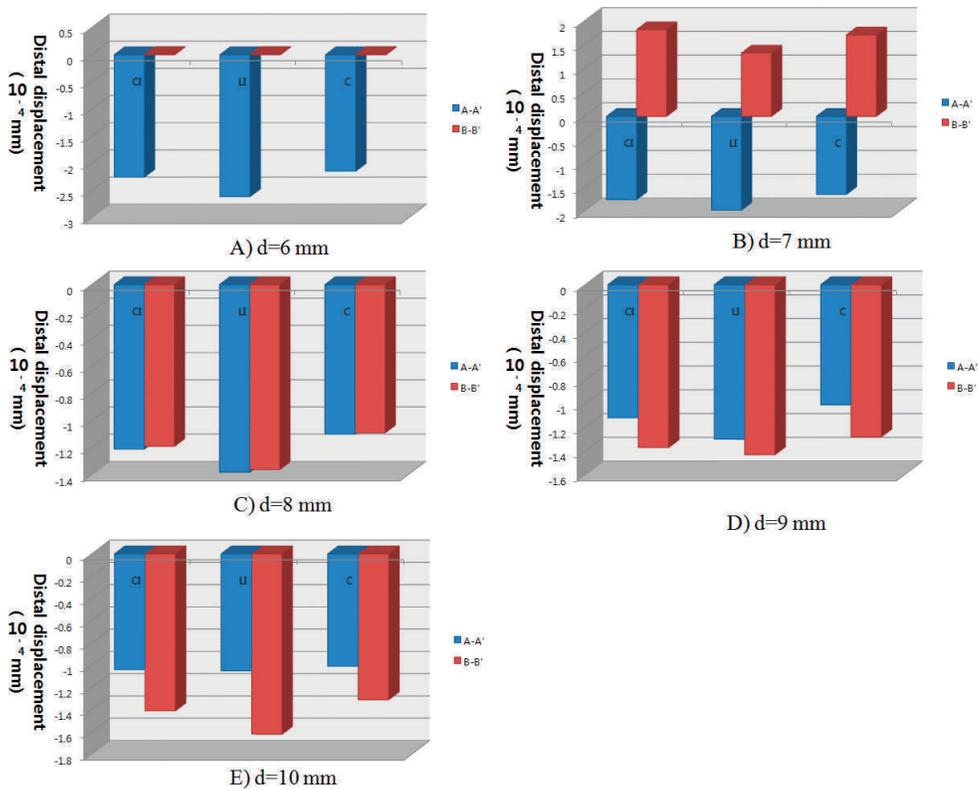


Figure 5. Distal displacement of anterior teeth. “d” represents the vertical height of the miniscrew.

references into consideration. However, it should be noticed that diverse modeling conditions, including the inclination and angulation of anterior teeth, the inclination of the occlusal plane, the size of each tooth, the shape of the alveolar bone and teeth, and the physical property of the synthetic periodontal ligament, produce different outcomes among studies. The important thing is that each condition leading to each consequence should be grasped and put into practice by clinicians. The present study has value on information about the length of lever arms and the position of miniscrew in consideration of the C_{res} of anterior teeth when applying DJR to each patient.

The 3D finite element analysis is only theoretical and has limitations for considering periodontal ligament and alveolar bone as isotropic, homogeneous, and linear elastic materials. In addition to the various modeling conditions, the different physiologic responses in each patient may make this analysis impractical. Even with the model designed by average measurements for every property, the result of finite element analysis will be constricted to the initial short-term response just at the time of force application, ignoring biological events of tissue remodeling. Nevertheless, the finite element method study surely provides the orthodontists with biomechanical guidelines for planning the orthodontic force system in each case.

Teeth displacement when retracted by DJR was proven to be affected primarily by the vertical position of palatal miniscrews associated with lever arm length, rather than the existence of torquing springs.

At the 6- or 7-mm level of palatal miniscrews, crown tipping movement with incisor extrusion was observed even with DJR due to the line of force passing below the C_{res} of six anterior teeth associated with shorter lever arms. Noticeable root movement is shown when the position of miniscrew moved from 6 mm to 7 mm. This seems to be caused by the vertical displacement of the tooth. When the miniscrew position changed from 6 mm to 7 mm, the root labial movement occurred instead of the extrusion movement, which occurred at 6 mm. In contrast, at the 9- or 10-mm level, root lingual displacement was larger than crown lingual displacement in relation to longer lever arms. This root-thrusting movement can be explained by the line of force passing above the C_{res} of six anterior teeth. At the 8 mm level of miniscrews, bodily-like parallel retraction could be obtained with DJR (Figure 5C). Although the pure function of torquing springs on torque control could not be elucidated in this study, their action was supposed to be insufficient to overcome the torque loss tendency when retracted by short lever arms. Further study for investigating the effect of the torquing spring itself of DJR is needed to

elucidate the usefulness of this modified design of lingual retractor.

The direction of the retraction force that correlated with the points of force application is another critical factor affecting the type of tooth movement in relation to the location of the C_{res} . Whether the force direction is upward, downward, or parallel is determined according to the length of the lever arms and the vertical position of anchorage, affecting the degree of torque loss. The present study adjusted the lever arm length depending on the five locations of the miniscrews to confine the force direction to be just parallel to the maxillary occlusal plane. Additional study regarding the effects of force direction (upward or downward direction to the occlusal plane) on the teeth displacement retracted by a lingual retractor and miniscrew will suggest practical guidelines for their clinical application, especially when torque control is critical in the anatomically compromised patient.

CONCLUSION

- The C_{res} of six maxillary anterior teeth was located vertically 12.2 mm (55.56%) apical to the incisal edges of central incisors, in accordance with the 8-mm level of miniscrews from the cervical line of the first molar.

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