Original Article

Effect of Corticotomy Patterns on the Center of Resistance Location of the Upper Six Anterior Teeth During En Masse Retraction: Finite Element Analysis

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Abstract

To determine the center of resistance location of six maxillary anterior teeth during en masse retraction after combination with different corticotomy patterns. Five finite element models were constructed from CBCT. Standard brackets were passively positioned on maxillary anterior teeth at the center in mesiodistal dimension and 3 mm vertically from the cusp tip. The power arm was set mesial to the canine bracket and the mini-implant was placed between the upper second premolar and the first molar. Five decorticated bone patterns were created, the patterns started at 1 mm above the crest of the alveolar bone of the upper first premolar to central incisor areas. The upper anterior teeth were retracted from the power arm to the mini-implant. The center of the resistance location was determined by varying the force locations parallel to the occlusal plane until bodily movement of the upper anterior teeth was obtained. The center of resistance in all models was located at the same 10.8 mm distance apically from the middle of the bracket slot in the mesiodistal dimension or 13.8 mm apically from the incisal edge. Different corticotomy patterns did not change the center of resistance location of the upper anterior teeth in en masse retraction.

Keywords: Center of resistance, Corticotomy pattern, En masse retraction, Finite element analysis

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Introduction

Speedy orthodontic treatment aids in the preservation of periodontal tissue. To increase the rate of tooth movement, various methods[1] have been developed. Mechanical, chemical, and surgical methods are usually considered to achieve those goals.

Corticotomy with orthodontic movement can accelerate tooth movement by delineated bone block, reduced resistance of the cortical bone and increased bone turnover from surgical trauma can change the bone properties which results in a localized decrease in the bone density. Consequently, the rate of orthodontic tooth movement can increase.[2,3] The patterns for alveolar decortication varies, such as vertical cuts or dot-shaped decortication or a combination of vertical cuts and dot-shaped decortication.[4] The upper incisal movement patterns in patients with corticotomy and without corticotomy are similar but the upper incisal inclinations after retraction were different.[5]

En masse retraction is the retraction of all six anterior teeth which is usually used in orthodontic treatment because en masse retraction does not create unaesthetic spaces at the front of canine during retraction. A retraction force that passes through the center of resistance that causes pure translation of the anterior teeth would be a benefit in reducing the treatment time in the finishing phase.[6]

In order to specify the position and direction of the force exerted, the most significant factor is to locate the position of the center of resistance. This position depends upon various analytical techniques, for instance, laser reflection, human autopsy, photoelastic, and finite element analysis.[7-10]

Finite element analysis is a mathematical method that can be used to analyze structural stress and strain and to solve biomechanical problems. This technique has proved to be a powerful tool to study orthodontic tooth treatment.[11] Finite element analysis is used to specify the location of the center of resistance of teeth by analyzing teeth displacement.

Furthermore, the location of the center of resistance relates to periodontal support.[12] Corticotomy affects the change in bone properties such as bone density[13] that may alter the position of the center of resistance. However, the effect of corticotomy patterns on the location of the center of resistance of the upper anterior teeth is still unknown. The aim of this study was to determine the position of the center of resistance of six upper anterior teeth combined with different corticotomy patterns.

Material and Methods

Five finite element models were constructed from a data set of maxillary full arch via cone-beam computed tomography (CBCT) scan (3D Accuitomo, J. Morita MFG. Corp., Kyoto, Japan). The 3D data set had a voxel dimension of FOV 170x120. The CBCT data provided average tooth and root length[14] and normal surrounding alveolar bone. These data can be used to generalise the subjects.

The finite element model was developed using ITK-Snap software[15] by using data from the CBCT scan (this study was approved by the ethics committee of Faculty of Dentistry, University). The thickness of the periodontal ligament was constructed to be uniform over all of the roots at 0.25 mm.[16] The maxilla and teeth were constructed from the CBCT scan file with an average cortical bone thickness of 0.5 mm.[17] Standard brackets with a 0.022x0.028-inch slot were placed passively in all the anterior teeth and set at the center of the buccal surface in mesiodistal dimension. The vertical distance from the cusp tip to the bracket slot was 3 mm. A stainless steel segmented archwire, which was the same size as the bracket slot, was inserted in the upper anterior teeth.

The mini-implant was set at 1 mm apical from the alveolar crest between the second premolars and the first molars. The power arm was bonded to the archwire at mesial of the canine brackets and the height of the power arm varied from 8 to 14 mm at 0.2 mm intervals. The level of the mini-implant at 1 mm from the alveolar crest is equal to 8 mm of the power arm length. The power arm length and position of the mini-implant were changed together to keep the force parallel to the occlusal plane with a 0.2 mm interval beginning at 1 mm from the alveolar crest level of the upper second premolar and upper first molar to apical root position. The coefficient of friction between the bracket slots and archwire was set to be 0.2.[18]

Only half of the model was fabricated based on the assumption that the opposite sides were exactly the same and the prescription of symmetry boundary conditions was made at the nodes on the symmetry plane.[18-20]

The material properties of the model were assumed to be homogeneous, isotropic, linear elastic and obtained from previous studies (Table 1).[17,21-25]

Table 1 Properties of materials

Material	Young's modulus (MPa)	Poisson's ratio
Cortical bone	13,800	0.26
Cancellous bone	345	0.31
Tooth	20,000	0.30
PDL	1	0.45
Stainless steel wire	200,000	0.30

In the finite element analysis, the upper first premolar was removed from the model. Decorticated bone was performed from the upper right premolar tooth to the central incisor area. The patterns of decorticated bone were classified into five categories (Fig. 1).[4]

1. Dot decortication size 1 mm diameter depth 0.5 mm every 1 mm (decorticated only cortical bone layer) was performed from a point at 1 mm above the crest of the alveolar bone (Model 1; Fig. 1A).

2. Dot decortication size 1 mm diameter depth 0.5 mm every 2 mm was performed from a point 1 mm above the crest of the alveolar bone (Model 2; Fig. 1B).

3. Dot decortication size 1 mm diameter depth 0.5 mm every 3 mm was performed from a point 1 mm above the crest of the alveolar bone (Model 3; Fig. 1C).

4. Inter-radicular cut with horizontal cut decortication was performed from a point 1 mm above the crest of the alveolar bone (Model 4; Fig. 1D).

5. Combination of inter-radicular cuts with horizontal cuts and dots decortication every 1 mm was performed from a point 1 mm above the crest of the alveolar bone (Model 5; Fig. 1E).

The calculation of finite element models was performed using Marc/Mentat® 2010 (MSC Software Corp., Santa Ana, California, USA). The model was meshed with tetrahedral elements and constructed with elements varying from 113,341 to 118,728 and nodes ranging from 27,500 to 28,330 (Fig. 3).

To simulate tooth movement, 150 g retraction force was applied in the direction from the power arm to the mini-implant. The location of force on the power arm was varied to represent the change of the power arm length and position of the mini-implant simultaneously (Fig. 2). The center of resistance was determined by observing the type of tooth movement.

Data records and data analysis

Orthodontic movement was analyzed from the initial movement due to the applied force. The center of resistance of the upper anterior teeth was evaluated before and after decortication.

The location of the center of resistance of the upper anterior teeth following en masse retraction was determined from the movement of the midpoints of the apex and incisal edge of the upper anterior teeth and analyzed on 3 planes (transverse, vertical and anteroposterior plane) from both the initial and final positions (Fig. 4) by varying the location of force on the power arm until there was only translation. The movement of nodes at the apical and incisal points were determined from their initial and final positions. The least difference between the movement of the incisal edge and apex indicated that there was only translation. This condition implied the location of the center of resistance.

Results

The displacement of the upper anterior teeth to each force direction was used to evaluate the location of the center of resistance by measuring the differential changes of the incisal edge and apex from the initial and displaced position.

When the force level was applied at 10.8 mm from the bracket slot level, the smallest difference between the incisal edge and apex movements were obtained as shown at the lowest point in Figure 5. The center of resistance of the upper anterior teeth was located at 10.8 mm from the middle of the bracket slot level or 13.8 mm from the incisal edge of the central incisor.

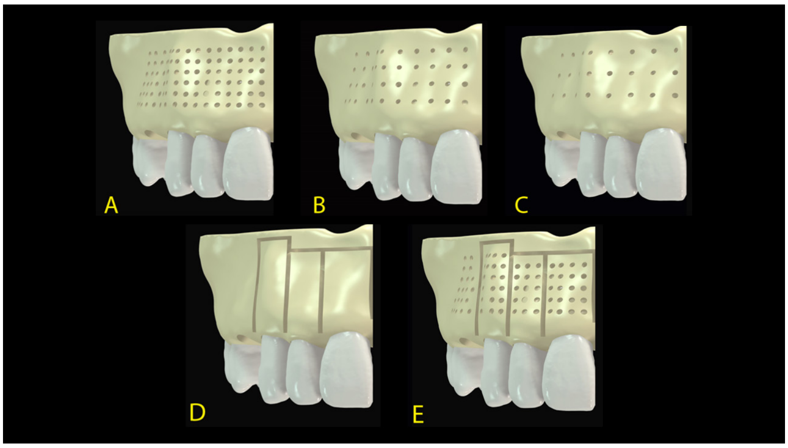

Figure 1 *Geometric models: (A) Dot-shaped decortication every 1 mm; (B) Dot-shaped decortication every 2 mm; (C) Dot-shaped decortication every 3 mm; (D) Inter-radicular cuts with horizontal cuts; (E) Combination.*

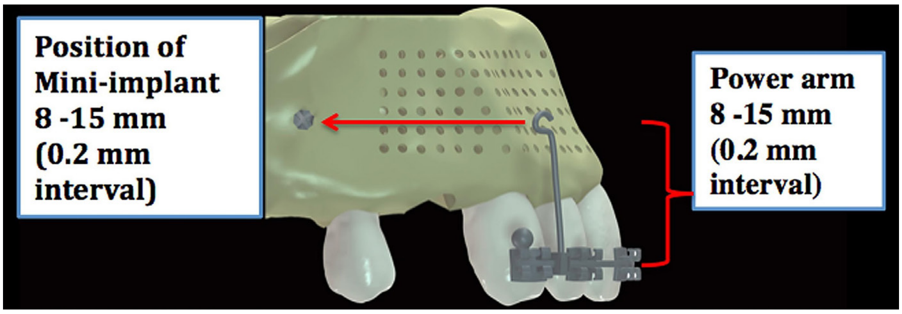

Figure 2 *Schematic illustration of the anterior teeth retraction with various lengths of power arm and mini-implant.*

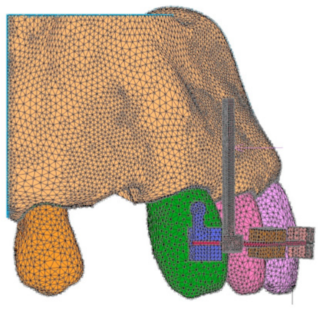

Figure 3 *Finite element model.*

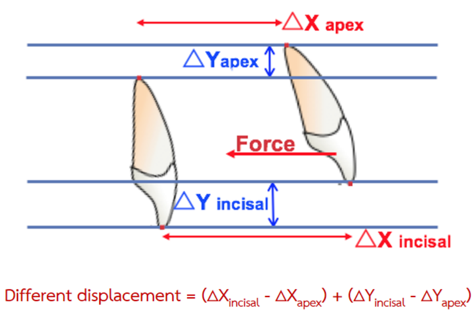

Figure 4 *Schematic illustration of the differential changes of the incisal edge and apex.*

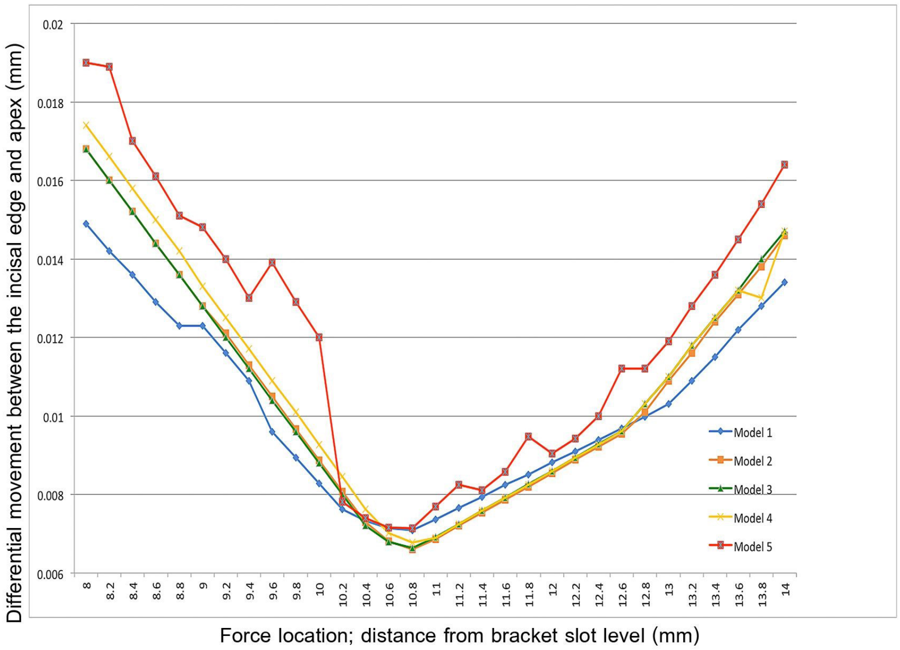

Figure 5 Differential movement between the incisal edge and apex versus the force location.

After differential corticotomy approaches, the center of resistance was in the same position obtained from the lowest point from Figure 5. Although multiple corticotomy patterns were used, the center of resistance of all the models was at 10.8 mm since the smallest difference between the incisal edge and apex movements was observed.

This study found no alteration in the location of the center of resistance among the models with different corticotomy patterns.

Discussion

The present finite element study was undertaken to investigate the influence of corticotomy patterns on the location of the center of resistance of the upper anterior teeth. The present findings showed that the location of the center of resistance of the upper anterior teeth was the same in all the models with various corticotomy patterns.

The greatest differential movement of apical and incisal of the upper anterior teeth was seen in the vertical cut and combination cut models (Models 5 & 6). However, in all the models, no obvious difference in the upper anterior teeth movement was observed.

This study found that the type of tooth movement corresponded with the position of the retraction force of the power arm and the position of the mini-implant. In all five finite element models, the retraction force at 13.8 mm above the incisal edge seemed to produce the least difference between the incisal edge and apex movements which should be ideal pure translation.

When the distance between the force and the incisal edge was less than 13.8 mm, lingual crown tipping movement occurred because the line of force passed below the center of resistance of the upper six anterior teeth. On the other hand, lingual root torque was displayed when the force distance was greater than 13.8 mm from the incisal edge because the line of force passed above the center of resistance of the upper six anterior teeth.

This indicated that corticotomy performed only in the cortical bone layer with preservation of the alveolar height did not affect the location of the center of resistance. In the initial period, the bone properties, such as bone density, did not change; therefore, the location of the center of resistance was not different in any of the models. According to the model without any decortication, the location of the centre of resistance of the upper anterior teeth remained in the same position of 13.8 mm from the incised edge [26] Similar results were obtained by Jeong *et al*[27] who reported that the center of resistance of the upper anterior teeth was 13.5 mm apical to the incisal edge of the upper central incisor in finite element analysis. From an *in vivo* study by Yoshida *et al*[28] the center of resistance of the upper anterior teeth was 13.7 mm apical to the incisal edge. However, these findings contradict the *in vivo* study by Tamer Turk *et al*[29] who reported that the center of resistance of the upper anterior teeth was situated 9 mm apical to the lateral incisor bracket. Moreover, Pedersen *et al*[30] reported that the center of resistance of the upper anterior teeth was 6.5 mm apical to the central incisor bracket slot from the human autopsy technique. However, the various technical and measurement methods in order to specify the location of the center of resistance of all previous studies were undertaken without a surgical technique.

This study investigated the center of resistance of the upper anterior teeth after corticotomy by the finite element method. The center of resistance varies among patients, depending on root length,[31] number of teeth,[28] surrounding bone, and the properties of the bone.[32] There are other factors that could alter the biomechanical properties affecting the movement of teeth which were not included in this study; for example, sizes of wire and bracket slot, play in the wire-bracket slot, type of archwire, and the variable anatomical parameters. Referring to a clinical situation, different patients have different root lengths and bone properties which could be more or less than this study's standard value. These could be the limitations in this study.

Also, an interpretation should be made carefully because the non-linear and viscoelastic material of the periodontal ligament was set to be linear and isotropic. Furthermore, time also affected these movements. The results are appropriate for the initial movement.

The information obtained from this study can be useful in determining the center of resistance location for effective upper anterior teeth movement by applying orthodontic force with different corticotomy patterns.

Conclusion

In this study, the effects of the different corticotomy patterns on the location of the center of resistance of upper anterior teeth were investigated by finite element analysis. The results indicated that corticotomy patterns have no influence on the location of the center of resistance of the upper anterior teeth.

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