Initial changes of centres of rotation of the anterior segment in response to horizontal forces

Kwangchul Choy*, Kyung-Ho Kim* and Charles J. Burstone**

Department of Orthodontics *Yongdong Severance Dental Hospital, Yonsei University, Korea and **School of Dental Medicine, University of Connecticut, USA

SUMMARY This study investigated the changes in the initial centres of rotation (Crot) of the upper six anterior teeth in response to a horizontal load. Six upper anterior teeth were extracted, splinted as a unit, and embedded in dental stone after the roots were uniformly coated with silicone. An aluminium fixture was bonded to the anterior segment and three linear variable differential transformers (LVDTs) were attached to measure the microdisplacement of the segment. A pulley and dead weight assembly were used to apply a 200 g occluso-gingivally varying horizontal force to the segment. The changes in the Crot for the anterior segment to the horizontal load were recorded.

The results showed that the centre of resistance (Cres) of the upper anterior segment was located 14.5 mm apical and 9.5 mm distal from the incisal edge of the central incisors. A linear *functional axis* (a trace of the measured Crot) was recorded. The *functional axis* maintained an angle of 14.5 degrees to the vertical axis of the anterior segment passing through the Cres of the segment. The Crot constant, which determines the tipping sensitivity of the segment, was 23 mm^2. The results demonstrate that the upper anterior segment may be slightly intruded when a horizontal force is applied and is less prone to tipping than a single tooth.

Introduction

The vertical position of a force applied to a single rooted tooth of a parabolic shape and its relationship to the type of tooth movement has been extensively explored. Forces at the level of the bracket produce tipping and forces applied further apically result in controlled tipping and possible translation. Much of orthodontic treatment involves more than single tooth movement. Groups of teeth require movement as a unit or a block. Clinically, it is very important to determine the vertical position of a force to produce different and required centres of rotation (Crot) for multiteeth units. For example, *en masse* retraction of an entire six teeth anterior segment can be carried out in many techniques using loop, springs, and cantilevers. Where should the vertical position of the force be placed? This determines the equivalent force and torque need at the bracket.

The biomechanical response of a tooth or a group of teeth to an orthodontic force is determined by the relationship between the location of the force and the centre of resistance (Cres). The tooth translates when a force is applied through the Cres and a tooth rotates around the Cres when a couple is applied. Therefore, the Crot of a tooth approaches the Cres as the location of the force moves away from the Cres.

Many models and methods have been developed to study the relationship between the location of force, the Cres, and the Crot. Mathematical models (Haack, 1972; Nikolai, 1974) have been developed and have provided some insight into the displacement characteristics of the dentition from the applied forces. However, they have not been proven experimentally.

A clinical *in vivo* experiment (Christiansen and Burstone, 1969) has been performed in human subjects to locate the Cres for a single tooth. Difficulties in measuring the microdisplacement using gauges or the complexity of the holographic technique have limited these studies. Nägerl *et al.* (1991) developed a basic theoretical background of the relationship between location of force and the Crot and proved the theory using *in vitro* experiments on a single tooth. Many studies (Van Den Bulcke *et al.*, 1986, 1987; Pedersen *et al.*, 1991; Yoshida *et al.*, 2001) aimed at locating the Cres on a group of teeth have been performed. However, the relationship between the location of the force and the Crot during 'group' movement has not been clearly demonstrated. The purpose of this study was to determine the initial Crot for the six maxillary anterior teeth in response to a constant horizontal force applied at different occluso-gingival levels.

Materials and methods

The upper anterior segment consisted of six anterior teeth comprising incisors and canines which were obtained from several subjects and stored in saline. The root surfaces were uniformly coated with silicone (polyvinylsiloxane type 3, Kerr, Romulus, Michigan, USA) to simulate the periodontal ligament (PDL). The roots of the segment were embedded and secured in dental stone using cyanoacrylate. An impression of the crowns was taken and a metal splint covering the crowns was cast using a chrome cobalt non-precious metal alloy and cemented to the crowns (Figure 1A, B).

To calculate the uniplanar Crot, an aluminium rectangular fixture was bonded above the metal splint and three linear variable differential transformers (LVDTs; 0351-0006, TransTek, Ellington, Connecticut, USA) were attached to the fixture. Two LVDTs measured the horizontal displacements and one the vertical displacement (Pedersen *et al.*, 1991). Signals from the LVDTs of a microdisplacement of the segment were fed into a microcomputer via an analogue–digital converter and calibrated into actual distance. The resolution of the LVDTs was 0.0001 mm. A custom-made computer program was coded to calculate the locations of the Crot from the measured three microdisplacements in accordance with the method reported by Nägerl *et al.* (1991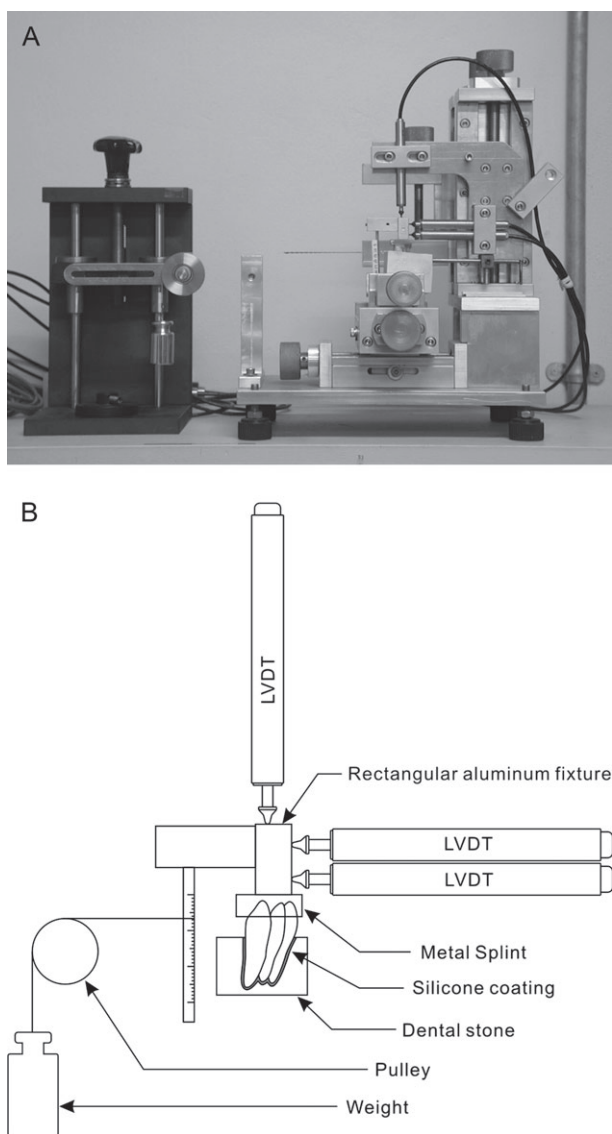). The incisal tip of central incisor was set to 0, 0 of the *x-y* co-ordinates. The sign conventions for the co-ordinates and rotation angles are shown in Figure 2.

When stability of the specimen was tested using an applied horizontal force to the dental stone, no displacement was detected up to 300 g. A horizontal force of 200 g was applied to the vertical extension of the splint in the midsagittal plane of the anterior segment using a pulley and dead weight (see Figure 1). A horizontal force was applied from the 0.0 mm position (level of incisal tip of the central incisor) to the −28.0 mm position with an interval of 1 mm. The Crot and angle of rotation were calculated for each application of the horizontal force. Five recordings of the anterior segment displacement at each level were obtained, averaged, and analysed.

Results

Location of the Cres

Figure 3 shows the segment rotating counterclockwise (+) from 0 to −14.0 mm and clockwise (−) below −15.0 mm. No rotation of the anterior segment occurred at the point of intersection of the curve and the *y*-axis but a pure translation was observed. This intersection was equivalent to 4.5 mm below the alveolar crest or 14.5 mm below the incisal edge.

Locations of Crot

The locations of Crot on the *x-y* plane in accordance with the varying application locations of the horizontal force are shown in Figure 4. The trace of the Crots was linear with a correlation coefficient of $r^2 = 0.989$. The linearized trace of the Crot appeared to be inclined 14.5 degrees to the *Y*-axis. The rotation was in a positive direction below the Crot and negative above the Cres. The rotation direction changed at (−9.5, −14.5).

The relationship between the location of force and Crot

Horizontal loading to the anterior segment showed a relationship of $a \times b = s^2$ (Figure 5A), where *a* is the distance

Figure 1 (A) Overall set-up of the apparatus. A pulley was used to apply a horizontal force while three linear variable differential transformers (LVDTs) were used to detect the displacement of the anterior segment. (B) Schematic drawing of the anterior segment, horizontal force, and LVDTs.
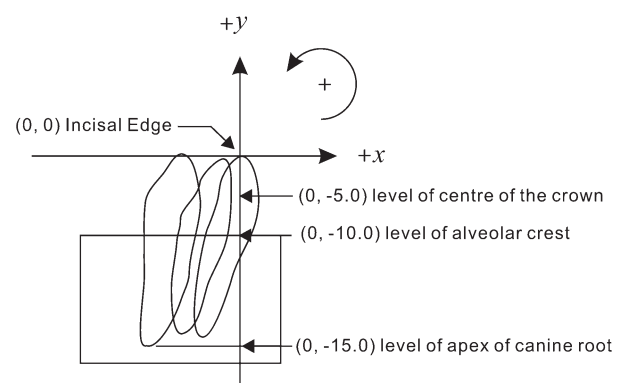
Figure 2 Geometric information of the anterior segment. The incisal tip of the central incisor was set to (0, 0) and a counterclockwise rotation of the segment corresponds to a positive value.

between the applied force and the Cres, and *b* the distance between the Cres and the Crot (Nägerl *et al.*, 1991; Choy *et al.*, 2000). Figure 5B shows a linear relationship between *b* and $1/a$ which means that $a \times b$ can be presented as a 'centre of rotation constant' (s^2), which is in fact the slope of the curve (23 mm²).

Discussion

The vertical position of the Cres for the anterior segment was 4.5 mm below the alveolar crest, which is 30 per cent of the length of the longest root (canine) measured from the alveolar crest. Burstone and Pryputniewicz (1980) and Nägerl *et al.* (1991) have shown, with single rooted teeth, that the Cres is located at a distance of 33 per cent from the alveolar crest. Since incisor roots are shorter than canines, it appears the Cres in this model is intermediate in position between the canine and the incisors. Clinically, the location of the Cres of the anterior segment based on this single tooth model can be 9.5 mm apical to the centre of a typical canine crown where a bracket might be typically placed (Figure 2).

The most interesting finding was the trace of the Crot in relation to the horizontal forces applied to the various locations. It shows a linear line with a 14.5 degree angle to the *y*-axis. Because this axis was calculated from the behaviour of the anterior segment under horizontal loading, this was defined as the '*functional axis*' of the anterior segment to the horizontal forces. As the horizontal force is moved from the crown towards the Cres, the location of the Crot moves apically from the Cres. In addition, the Crot also moves labially since the *functional axis* is angled at 14.5 degrees. Under this horizontal loading, the Cres of the anterior segment moves perpendicular to this *functional axis*. This suggests that a small intrusive component is observed during lingual loading to the anterior segment with a horizontal force.

There may be many factors affecting the angle of the *functional axis*, including an inclination of the roots and the anisotropic physical properties of the PDL. When the
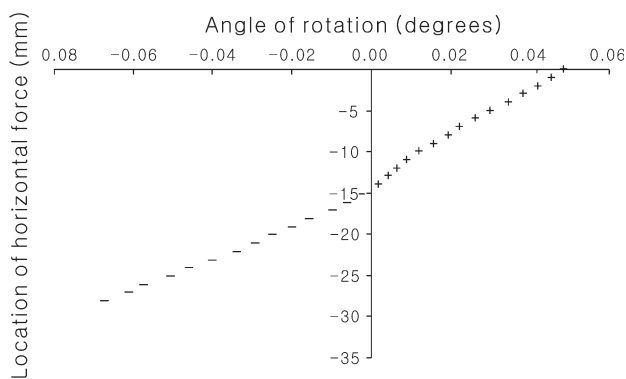
functional axis is not perpendicular to the force, shear occurs in the PDL. Because silicone cannot precisely simulate the behaviour of the PDL during shearing, the *in vivo* angle of the *functional axis* for the anterior segment will differ from the current *in vitro* model.

The value of the Crot constant (s^2) was 23 mm², which was larger than the reported value of a two-dimensional single tooth model (17.5 mm²; Choy *et al.*, 2000) but lower than that of a three-dimensional model of a single tooth (90 mm²). A larger Crot constant means that the segment of the tooth is more resistant to tipping movement (Nägerl *et al.*, 1991; Choy *et al.*, 2000). The length, shape, width, and angulation of the root also affect the s^2 value. The model in this study also assumed a uniform alveolar crest.
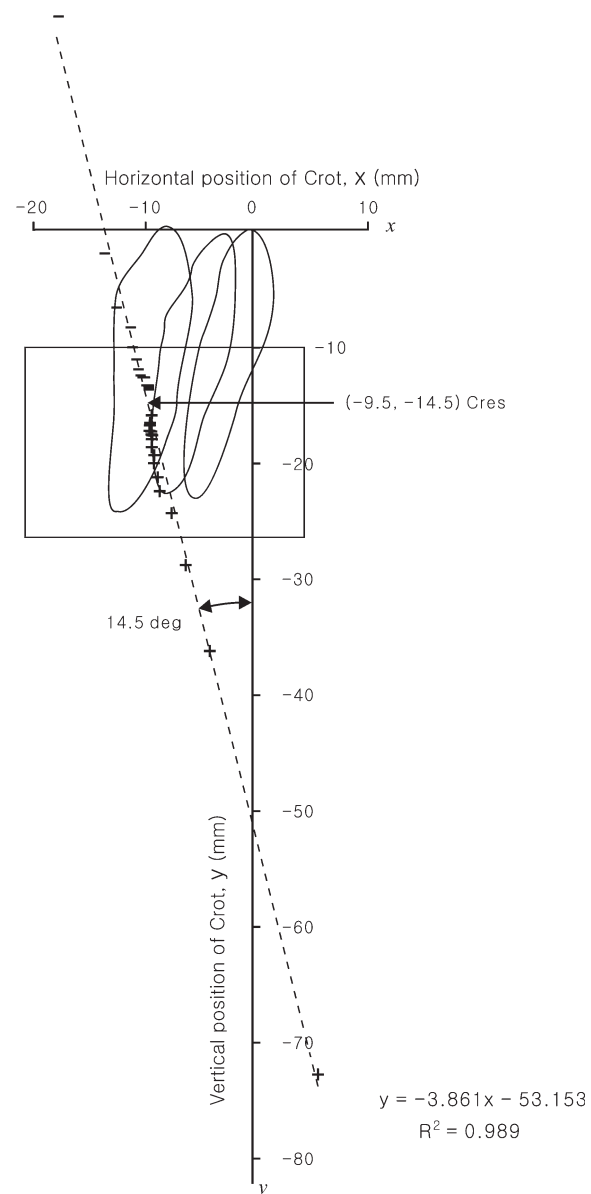
Figure 3 The angle of rotation of the segment at the level of the horizontal forces. The intersection of the curve at the *y*-axis is the centre of resistance. +: counterclockwise rotation, −: clockwise rotation.

Figure 4 Locations of the centre of rotations in the *x-y* plane. +: counterclockwise rotation, −: clockwise rotation.
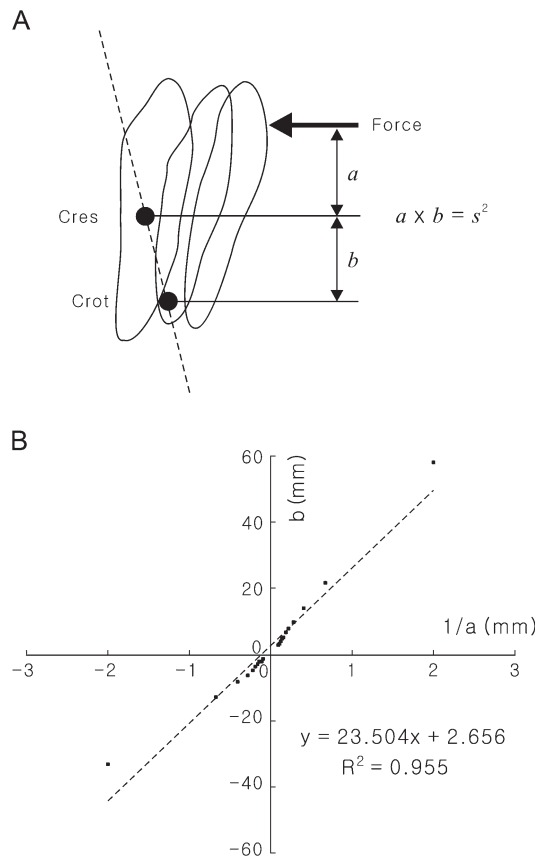
A

B

Figure 5 (A) *a* is the distance between the applied force and the centre of resistance (Cres), *b* is the distance between the Cres and the centres of rotation (Crot). (B) The relationship between the location of the force and the Crot. The curve was linear and the slope represents s^2.

This model was designed to predict tooth displacement of the anterior group of teeth involving stresses and strains in the PDL. Of less interest, therefore, are any displacements that occur *in vivo* of the alveolar or basal bones of the jaws. Silicone was selected to keep the model simple. The living PDL may be linear under initial loading but exhibits visco-elastic non-linear properties as the load is increased. PDLs are thicker at the alveolar crest and apex. Most likely, this effect might average out and not alter the results of the study. The weight of the apparatus adds a vertical force during loading and its significance to the results is not obvious. This weight was constant for all the loading levels used and therefore, may have no significant effect on the data.

Further experimental studies are expected to reveal the exact relationship between the length, shape, and angulation of the root in three dimensions and to consider in more detail morphological variation.

Conclusions

The changes of the initial Crot of the anterior segment under horizontal loading were investigated and the following findings were observed.

1. The location of the Cres of the upper six teeth anterior segment was 14.5 mm apical and 9.5 mm distal from the incisal edge of the upper central incisors.
2. The location of the Crot (*functional axis*) was linear with an angle of 14.5 degrees to the vertical axis when a horizontal force was applied. This finding indicates that a lingual horizontal force may have a vertical effect on the crowns of the anterior segment.
3. The relationship between the locations of the horizontal force and Crot was established using the Crot constant (s^2).

Address for correspondence

Kwangchul Choy
Department of Orthodontics
Yongdong Severance Dental Hospital
Yonsei University
146-92 Dogokdong
Seoul 135-270
Korea
E-mail: kchoy@yumc.yonsei.ac.kr

References

Burstone C J, Pryputniewicz R J 1980 Holographic determination of center of rotation produced by orthodontic forces. American Journal of Orthodontics 77: 396–409

Choy K, Pae E, Kim K, Park Y, Burstone C J 2000 The effect of tooth and bone morphology in stress distribution in the periodontal ligament. American Journal of Orthodontics and Dentofacial Orthopedics 117: 98–105

Christiansen R L, Burstone C J 1969 Centers of rotation within the periodontal space. American Journal of Orthodontics 55: 353–369

Haack C D 1972 An analysis of stress in a model of the periodontal ligament. International Journal of Engineering Science 10: 1093–1106

Nägerl H, Burstone C J, Becher B, Messenburg D K 1991 Center of rotation with transverse forces: an experimental study. American Journal of Orthodontics and Dentofacial Orthopedics 99: 337–345

Nikolai R J 1974 Periodontal ligament reaction and displacements of a maxillary central incisor subjected to transverse crown loading. Journal of Biomechanics 7: 93–99

Pedersen E, Isidor F, Gjessing P, Andersen K 1991 Location of centres of resistance for maxillary anterior teeth measured on human autopsy material. European Journal of Orthodontics 13: 452–458

Van Den Bulcke M M, Dermaut L R, Sachdeva R C, Burstone C J 1986 The center of resistance of anterior teeth during intrusion using laser reflection technique and holographic interferometry. American Journal of Orthodontics and Dentofacial Orthopedics 90: 211–219

Van Den Bulcke M M, Burstone C J, Sachdeva R C L, Dermaut L R 1987 Location of the center of resistance for anterior teeth during retraction using laser reflection technique. American Journal of Orthodontics and Dentofacial Orthopedics 91: 375–384

Yoshida N, Koga Y, Mimaki N, Kobayashi K 2001 *In vivo* determination of the centers of resistance of maxillary anterior teeth subjected to retraction forces. European Journal of Orthodontics 23: 529–534