Original Article

Determining the Center of Resistance of Maxillary Anterior Teeth Subjected to Retraction Forces in Sliding Mechanics

An In Vivo Study

SheauSoon Sia[a]; Yoshiyuki Koga[b]; Noriaki Yoshida[c]

ABSTRACT

Objective: To determine the location of center of resistance and the relationship between height of retraction force on power arm (power-arm length) and movement of anterior teeth (degree of rotation) during sliding mechanics retraction.

Materials and Methods: Three human subjects with maxillary protrusion were selected for this study. Initial tooth displacements of maxillary right central incisor under sliding mechanics with various heights of retraction forces were measured in vivo using a two-point three-dimensional displacement magnetic sensor device. By calculating the angle of rotation from the displacements measured, the location of the center of resistance was determined.

Results: The results suggested that different heights of retraction forces could affect the direction of anterior tooth movement. The higher the retraction force was applied, the lower the degree of rotation (crown-lingual tipping) would be. The tooth rotation was in the opposite direction (from crown-lingual to crown-labial) if the height of the force was raised above the level of the center of resistance.

Conclusion: The location of the center of resistance of the maxillary central incisor was approximately 0.77 of the root length from the apex. During anterior tooth retraction with sliding mechanics, controlled crown-lingual tipping, bodily translation movement, and controlled crown-labial movement could be achieved by attaching a power-arm length that was lower, equivalent, or higher than the level of the center of resistance, respectively. The power-arm length could be the most easily modifiable clinical factor in determining the direction of anterior tooth movement during retraction with sliding mechanics.

KEY WORDS: Center of resistance; Sliding mechanics; Magnetic sensor; Anterior teeth retraction/space closure; Power arm/sliding hook; Implant

INTRODUCTION

Ever since the Andrews[1] straight wire appliance was introduced commercially, many new bracket prescriptions and techniques have been developed and modified as treatment mechanics progress. These developments all move toward one ultimate goal: to create a force system that can work efficiently and shorten the orthodontic treatment period.[2,3] At the same time, treatment mechanics for space closure have mostly changed from closing loop mechanics to sliding mechanics, which contributes to reducing chair time for orthodontists, improving patient comfort, and preventing excessive force application.

With the closing loop mechanics, activated loop forces would only work at the bracket level, whereas in sliding mechanics, retraction forces can be transferred to any height level on a power arm to move the tooth in a preprogrammed direction (eg, controlled crown-lingual tipping, bodily translation movement, and controlled crown-labial movement). Hence, sliding mechanics have the potential to simplify the force system for tooth movement because the horizontal level

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of retraction force can be freely adjusted by soldering various lengths of power arms to an archwire.[4–10]

However, the biomechanical conditions for achieving accurate control of anterior teeth during space closure in sliding mechanics are still unknown. Guidelines on force system, force magnitude, and force vectors to be used in sliding mechanics are not yet established. For example, the optimum length of a power arm (sliding hook) to be applied in relation to the height of retraction-force level remains unclear, and clinicians hesitate or overlook this important step during sliding mechanics retraction.

For the past three decades, many analytic and experimental studies have been carried out to determine the center of resistance and center of rotation of teeth.[11–18] Still, the results obtained from these analyses were very subjective and inconsistent. This was mainly because most studies could not approximate the actual intraoral and anatomic conditions. Moreover, to our knowledge, no previous study has been performed to measure the initial displacements of anterior teeth during space closure in sliding mechanics in vivo. A new system, a two-point three-dimensional displacement magnetic sensor device, which was developed by Yoshida and his research team[19–21] at Nagasaki University in Japan, was used to overcome these disadvantages and to measure tooth movement in vivo in five degrees of freedom.

The purpose of this study was to determine the location of the center of resistance of the maxillary central incisor subjected to multiheight levels of retraction forces in human subjects, to determine the relationship between height of the retraction force on the power arm (power-arm length) and anterior tooth movement (degree of rotation) during retraction with sliding mechanics, and to discuss its clinical application toward efficient anterior tooth retraction with a sliding mechanics force system.

MATERIALS AND METHODS

Subjects were one male and two female adult patients who were randomly chosen and diagnosed with maxillary protrusion. Subjects were given informed consent forms, and the research protocol was examined and approved by the related authorities. The selection criteria for those patients were as follows:

- Diagnosed as Angle Class II division 1 malocclusion;
- Availability of good and normal periodontal condition;
- Underwent orthodontic treatments with maxillary first premolars extractions and anterior crowding relieved (if any); and
- The target tooth was set to be the maxillary right central incisor, with absence of root resorption (determined by periapical radiographs).

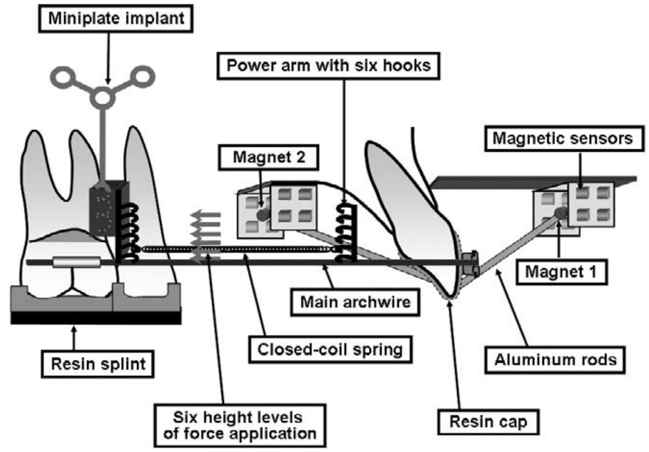

Figure 1. Schematic diagram of the two-point, three-dimensional magnetic sensor device system for measuring initial tooth displacement in vivo.

A magnetic sensor device used here was described previously,[20] and therefore will be only summarized in this paper. The main part of the system was composed of two magnets and 16 magnetic sensors for measuring motion in five degrees of freedom. A schematic diagram of the system is shown in Figure 1.

Hall elements (HW-302B, Asahi Kasei Electronics Co, Tokyo, Japan) were used as magnetic sensors because they are small enough to be placed in the oral cavity and sensitive enough to detect a small displacement. Dimensions of the sensor were 2.7 mm × 2.35 mm × 0.95 mm. Neodymium magnets (NE412, IBS Magnet Ing, Berlin, Germany) were used for target points as they are small and powerful. The magnet was cylindrical and 4.0 mm in diameter and 1.2 mm in length. Eight sensors were arranged in a cubic array around a magnet to measure three-dimensional displacement. Two sensor units were placed labially and palatally to the maxillary central incisor and rigidly fixed to the posterior teeth by a splint. Two magnets were placed in the center of each sensor unit and attached to the maxillary central incisor by aluminum rods.

An appliance with 0.018-in slot brackets with 0.016 × 0.022-in Elgiloy archwire was used. Two titanium miniplate implants (Orthoanchor SMAP system, Dentsply-Sankin, Tokyo, Japan) were inserted at both sides of the buccal region of the maxillary first molars as a source of anchorage for retracting the anterior teeth. Two power arms were soldered at both sides of the mesial canine region of the archwire to simulate en-masse retraction of anterior teeth in the clinical situation. The power arms were perpendicular and apical to the occlusal plane. Each power arm contained six small hooks with 2 mm distance per hook. Hence, the first hook in each power arm was set to be level 1 at 0 mm (corresponding to the bracket position, or 4.5

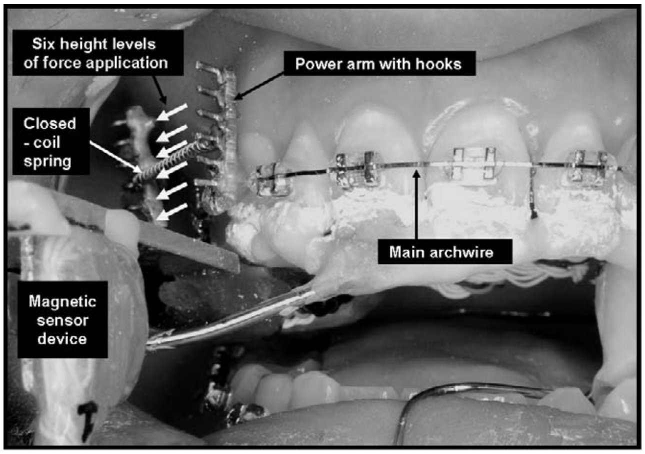

Figure 2. Initial tooth displacements under sliding mechanics with various heights of retraction forces were measured by magnetic sensor device.

mm apical to the incisal edge), followed by second hook at level 2 (2 mm from bracket position) until the sixth hook at level 6 (10 mm from the bracket position).

A horizontal retraction force of 150 g was applied bilaterally parallel to the archwire. Precalibrated closed-coil springs were hooked between the posterior attachments with six hooks (capped onto titanium miniplate implants) and the anterior power arms bilaterally at the same height of the hook level and parallel to the archwire (Figure 2). The vertical heights of the hooks on the posterior attachments were similar to the vertical heights of the hooks on the anterior power arms. Height of the posterior attachments was changed in tandem with the height of the anterior power arms. Vertical distances from the closed-coil spring to the archwire were measured at a few reference points throughout the experiment to keep the force vector parallel to the archwire for every height level of force application.

Three measurements were performed for each of the three subjects and averaged. Tooth movements projected on the midsagittal plane were analyzed from the displacements of the two magnets, as these movements are clinically important when anterior teeth are retracted. By calculating the angle of rotation from the displacements measured, the location of the center of resistance was determined. The process of calculations is detailed in a previous study.[20]

RESULTS

The relationship between the degree of rotation ($\theta°$) of the target tooth, against the height of force application on the power arm (or length of power arm), is shown in Figure 3 (subjects A, B, and C). Positive signs of the degree of rotation ($\theta°$) indicate lingual crown tipping, whereas negative signs ($-\theta°$) indicate labial crown movement. Figure 3 shows the degree of rotation ($\theta°$) decreased in accordance with the increased heights of retraction force applied. In other words, the direction of tooth rotation changed from lingual crown tipping to labial crown tipping as the height of retraction force on power arm was raised toward the apex. The height level where no rotation occurred was considered to be the level where the center of resistance is located.

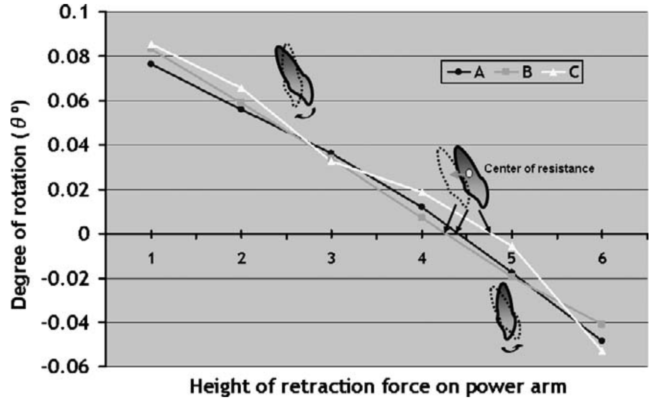

Figure 3. Degree of rotation ($\theta°$) against the height of retraction force on power arm for subjects A, B, and C.

From graphs, the center of resistance for all three subjects could be determined at the point where the graph lines crossed the X axis (when $\theta° = 0°$) between hook 4 and 5, which were 6.8 mm, 6.5 mm, and 7.5 mm for subjects A, B, and C, respectively. Also, Figure 3 shows that three subjects produced almost the same graphic pattern.

Table 1 represents the length of the target tooth, root length, length of power arm when $\theta° = 0°$, center of resistance from apex, and center of resistance/root length for the three subjects.

DISCUSSION

Although only three subjects were investigated because of difficulties in experiment set-up and lengthy experiments, the results were consistent among all three subjects. Coefficients of variation of the values for nine measurements were less than 4.7 percent.

Table 1. Anatomic Parameters in Relation to Center of Resistance for Subjects A, B, and C[a]

	Millimeter (mm)				
Subject	U 1 TL	U 1 RL	Power arm length when $\theta° = 0°$	CRe from apex	CRe from apex/RL
A	26.0	17.1	6.8	13.33	0.7794
B	27.2	18.1	6.5	14.02	0.7747
C	27.1	17.6	7.5	13.66	0.7762

[a] U 1 indicates maxillary central incisor; TL, tooth length; RL, root length; and CRe, center of resistance.

Therefore, the reproducibility of the measurements of tooth movement was considered to be acceptable and reliable.

From the results described, three findings of clinical significance may be derived. The first relates to determining the location of the center of resistance on a three-dimensional in vivo model, using a magnetic sensor device, which takes into consideration the actual anatomic parameters involved per individual.

Figure 3 shows that on applying a force on hook 5, the degree of rotation ($\theta°$) was noticed to move toward the negative $\theta°$ portion, where the crown rotated in a reverse direction (from lingual crown tipping to labial crown movement). This scenario was in relatively good agreement with results obtained from theoretical analyses by Burstone[6] and Burstone and Pryputniewicz.[14] They showed that the center of rotation moved apically from the center of the root as the height of force application was raised toward the apex. When the height of the force application rose above the level of the center of resistance, the center of rotation was coronal to the crown of the tooth; hence, the direction of tooth movement was changed from lingual crown tipping to labial crown tipping at this level. Burstone and Pryputniewicz[14] reported that the center of resistance was located at 0.67 of the root length from the apex on a three-dimensional model, with parabolic root geometry. By using two-dimensional model theoretic analysis, Nikolai[13] showed that the location of the center of resistance was at 0.45 of the root length from the apex. Meanwhile, by using finite element models, Tanne et al[15] determined that the location of the center of resistance for the maxillary central incisor was at 0.76 of the root length from the apex.

Table 1 shows the location of the center of resistance for all subjects. The ratios of the location of the center of resistance from the apex/root length of three subjects were distributed within a very limited range, which was around 0.77. This finding is similar to the result obtained from Tanne et al[15] but differed greatly from the results obtained by Burstone and Pryputniewicz[14] and Nikolai[13] as their models were based on in vitro measurement and could not approximate the actual intraoral anatomic conditions as mentioned previously. Therefore, this finding is of clinical significance: the location of the center of resistance could be determined more precisely than in previous studies by taking into consideration all of the actual individual anatomic parameters involved.

The second finding relates to how different heights of retraction force on the power arm (lengths of power arm) could affect the degree and course of anterior tooth movement during retraction with sliding mechanics. Generally, as shown in Figure 3, the degree of rotation ($\theta°$) of the target tooth varied according to the different heights of retraction force on the power arm. In other words, the $\theta°$ could be modified, yet it was sensitive toward slight changes of the length of the power arm itself. This also clarified that by only blindly "guessing" the length of the power arm during sliding mechanics retraction, sometimes the degree and course of movement of the anterior teeth may be opposite from what is expected. As a result, clinicians will need to spend more time correcting unwanted tooth movement, which will prolong the treatment period.

The third finding is that the height of the retraction force on the power ram (length of power arm) is the main yet the easiest modifiable factor, and it can influence the degree and course of movement of anterior teeth during sliding mechanics retraction.

Anatomic parameters such as the length and shape of the root, width of the periodontal ligament, palatal alveolar bone height,[21] angle of crown inclination, and physical properties of periodontal tissue are among the factors that may influence the degree and course of movement of anterior teeth during sliding mechanics retraction.

Nonetheless, if the graphs are analyzed from subject to subject (eg, subject A in Figure 3), it is clear that under the same loading and anatomic conditions, the degree of rotation ($\theta°$) is very much influenced by the length of power arm itself. The higher the retraction force level was applied, the lower the degree of rotation ($\theta°$) would be. Hence, the length of power arm could be considered the main influencing factor in determining the degree and course of movement of anterior teeth during sliding mechanics retraction. Besides, the length of the power arm is the easiest modifiable factor among factors mentioned. Clinically, this leads to a very important clue: a clinician could easily modify the power-arm length to achieve a preprogrammed tooth movement rather than focusing on other unchangeable yet complicated factors (eg, alveolar bone height and periodontal ligaments properties). This would not only simplify the anterior retraction process but would also shorten the treatment period.

The clinical application of these findings relates to the chair-side simple estimation of the location of the center of resistance and height of retraction force on power arm in relation to preprogrammed tooth movement. The results show that the key to applying the correct height of a retraction force on the power arm is very much dependent on the location of the center of resistance of the maxillary central incisor. Retraction force levels below and above the center of resistance will produce controlled crown-lingual tipping movement and controlled crown-labial movement, respectively. Meanwhile, bodily translation movement (lingual movement) will occur when the retraction force level is at the same level as the center of resistance. Thus,

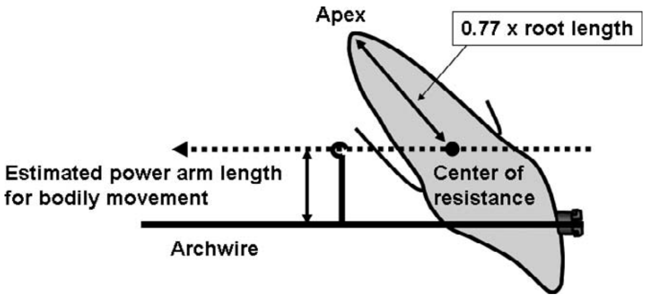

Figure 4. Chair-side simple estimation of location of center of resistance of maxillary central incisor (by lateral cephalogram tracing) and the required height of retraction force on power arm in order to produce preprogrammed tooth movement during anterior retraction with sliding mechanics.

it is important for clinicians to estimate the location of the center of resistance correctly in order to apply the power-arm lengths accordingly and to produce preprogrammed tooth movement during retraction with sliding mechanics.

Clinically, a clinician may roughly estimate (chair-side) the location of the center of resistance of the maxillary central incisor by measuring the root length from the lateral cephalogram tracing (along its tooth axis) and multiplying the value by 0.77 to approximate the location of the center of resistance from the apex. Then an imaginary line could be drawn passing through the center of resistance and parallel to the archwire. The perpendicular distance between the imaginary line and the archwire is the estimated power-arm length, which should result in bodily tooth movement during retraction with sliding mechanics (Figure 4). Likewise, a power-arm length below and above the center of resistance will produce controlled crown-lingual tipping and controlled crown-labial movement, respectively.

CONCLUSIONS

- The location of the center of resistance of the maxillary central incisor was shown to be approximately 0.77 of the root length from the apex
- During anterior tooth retraction with sliding mechanics, controlled crown-lingual tipping and controlled crown-labial movement can be achieved by attaching a power-arm length that is lower or higher than the level of center of resistance, respectively. Bodily translation movement (lingual movement) can be achieved by attaching a power-arm length that lies on the same level of the center of resistance.

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