Original article

Effect of power arm on anterior tooth movement in sliding mechanics analyzed using a three-dimensional digital model

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ABSTRACT

Purpose: The present study tested the hypothesis that the type of anterior tooth movement is correlated with the height level of the power arm with respect to the center of resistance (CRe) of a tooth, but not with the power arm length itself in sliding mechanics using three-dimensional (3D) model analysis.

Materials and methods: Anterior teeth were retracted with sliding mechanics using power arms of different lengths in five subjects with maxillary protrusion. Anterior tooth movements during three months' retraction were assessed by means of 3D model analysis, and the relationship between the power arm length and the distance from the center of rotation (CRo) to CRe, and the relationship between the distance from the level of the power arm hook to CRe and the CRo-CRe distance were evaluated.

Results: The height level of the power arm relative to CRe was significantly correlated with the CRo-CRe distance, but there was no significant correlation between the power arm length and the CRo-CRe distance.

Conclusion: Anterior tooth movement during retraction varied with the anatomical parameters of individual patients, even if the same power arm length was employed. The present findings suggest that the height level of the power arm relative to CRe is the most influential factor determining the tooth movement, while the power arm length itself has less impact on subsequent tooth movement. Therefore, it is recommended that an optimal power arm length be calculated back from the location of CRe at the beginning of treatment and treatment progress be monitored using 3D model analysis.

1. Introduction

Premolar extraction is frequently indicated in the treatment of Class II Division 1 malocclusion with increased over-jet caused by proclined maxillary incisors. To improve facial esthetics and obtain the desired closed spaces within the arch, it is essential to maintain control of the movement of the anterior teeth. Two types of mechanics have been employed for space closure; however, sliding mechanics has replaced loop mechanics due

to its simplicity, reduced chair time and improved patient comfort [1].

The utilization of sliding mechanics has become increasingly widespread in recent years because it is more applicable for temporary anchorage devices (TADs) than loop mechanics [2–8]. The advantage of sliding mechanics is that the force system involving the direction and the height level of retraction force can be freely adjusted by attaching various lengths of power arms onto the archwire. It is therefore believed that the use of power arms allows clinicians to perform effective torque control of the anterior teeth in sliding mechanics. However, the mechanical conditions for achieving the desired type of anterior tooth movement are still unknown. To date, no guidelines on biomechanical parameters, such as power arm length or its relative height to the center of resistance (CRe) of the anterior tooth in sliding mechanics have been established.

In previous studies, the movement patterns of the anterior teeth before and after space closure in sliding mechanics with the combined use of TAD have been evaluated, mostly using cephalometric analyses [3–8], which could impose additional radiation risks on patients. Some studies have investigated the effect of power arm length on anterior tooth movement based on *in vivo* measurements or the numerical analysis of initial tooth displacement by means of a magnetic sensing device [9,10] or finite element method (FEM) [11–14]. However, the initial tooth displacement obtained in these studies only reflected the physical distortion of the periodontal ligament, thereby only momentary displacement was observed. Consequently, there is a need for an alternative method for precise cephalometric analysis of long-term orthodontic tooth movement. Such a method would also prevent unnecessary radiation exposure to the patient. Superimposition of digital images of serial dental casts using a three-dimensional (3D) surface scanning system [15–17] may be a suitable method for assessing orthodontic tooth movement following bone remodeling. To our knowledge, no previous study has investigated the effect of power arms in sliding mechanics using 3D model analysis.

The aims of the present study were as follows: (1) to assess the movement pattern of the anterior teeth when the length of power arms varied depending on individual patients in sliding mechanics with the combined use of TADs by means of 3D model analysis; and (2) to test the hypothesis that the type of anterior tooth movement correlates with the height level of power arm with respect to CRe of a tooth, but not with the power arm length itself.

2. Materials and methods

2.1. Sample

The sample consisted of dental casts obtained from 5 patients (2 males, 3 females; mean age, 18 years 7 months; age range, 18 years 6 months to 19 years 8 months) who were undergoing orthodontic treatment after a diagnosis of maxillary protrusion at the Department of Orthodontics, Nagasaki University Hospital.

2.2. En masse retraction with sliding mechanics

As part of orthodontic treatment, the bilateral maxillary first premolars were extracted, and two titanium screws (1.6 mm in diameter, 8 mm in length, Dual-Top, Jeil Medical Corp., Seoul, South Korea) or plates (SMAP system, Dentsply-Sankin, Tokyo, Japan) were inserted in the buccal region between the second premolars and first molars or between the first and second molars on both sides. Preadjusted 0.018 in. × 0.025 in. slot edgewise appliances with Roth prescription (Sincere Brace, Rocky Mountain Morita Corp., Tokyo, Japan) were bonded in all patients. A 0.017 in. × 0.022 in. stainless steel archwire was used as a working archwire. Power arms were attached to the archwire between lateral incisors and canines. To perform en-masse retraction with sliding mechanics, a force of 250 g parallel to the occlusal plane was applied to the power arm hooks with elastic chains (Super Chain, Tomy International Inc., Tokyo, Japan).

2.3. 3D model analysis

Impressions for maxillary dental casts were taken twice just after the completion of the leveling phase and three months after the initiation of the retraction phase using alginate impression material (Aroma Fine Plus, GC Corp., Tokyo, Japan). Dental casts were made with extra hard dental die stone (New Fujirock, GC Corp., Tokyo, Japan) and then scanned by a laser surface scanning system (VMD-25, UNISN, Osaka, Japan). Based on scanned data, reconstruction and analysis of 3D images were performed using commercial software (Imageware 9, UGS PLM Solutions, Plano, TX, USA). 3D images of dental casts before and after three months of retraction were superimposed and then anterior tooth movements were evaluated according to the method described in a previous study [18]. The location of the center of rotation (CRo) of the left maxillary central incisor, which represents the pattern of tooth movement during retraction, was determined according to the above-mentioned procedure. Although there are several definitions of CRo, the present study used the definition of Christiansen and Burstone [19], wherein CRo is the intersection of two lines coincident with the extensions of the tooth axis before and after displacement (Fig. 1). The location of CRe was measured from the cephalogram according to the finite element study [20] that determined its location for a single-root tooth at two-fifths of the root length from the alveolar crest.

2.4. Mechanical, biomechanical and anatomical parameters

A geometric representation of the mechanical, biomechanical and anatomical parameters of sliding mechanics with the combined use of power arms and TADs is shown in Fig. 2. An intraoral view of the treatment mechanics employed in this study is shown in Fig. 2. Both power arm length (PAL) and the perpendicular distance from the level of the power arm hook to CRe (PAH-CRe) are initial loading conditions. If stated in detail, PAL indicates the height of retraction force, and PAH-CRe represents the height of retraction force relative to the level of CRe. Therefore, they are considered to be mechanical
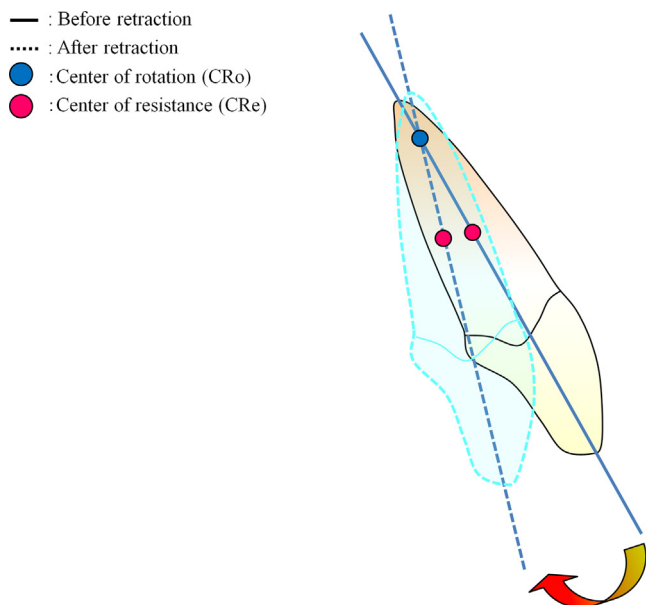
Fig. 1 – Definition of the location of the CRo of the central incisor during retraction.

and biomechanical parameters, respectively, that initiate orthodontic tooth movement.

The distance from CRo to CRe (CRo-CRe) indicates the movement pattern of subsequent tooth movement. In case CRo-CRe is shorter than RA-CRe, the center of rotation is located inside of the root, which causes uncontrolled tipping wherein the root apex moves in the labial direction, namely, in the reverse direction of retraction force as shown in Fig. 3(A). When CRo-CRe is closely equal to RA-CRe, namely, the center of rotation is located approximately at the root apex, the incisor tips nearly around the root apex as shown in Fig. 3(B). If CRo-CRe is longer than RA-CRe, the center of rotation is
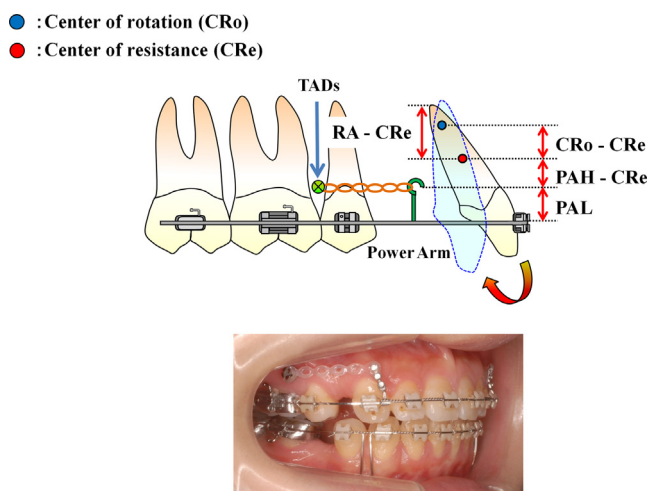

Fig. 2 – Sliding mechanics with combined use of power arms and TADs. Geometric representation of mechanical, biomechanical and anatomical parameters.

located apically to the root apex, which causes controlled tipping wherein the root apex moves in the palatal direction as shown in Fig. 3(C). RA-CRe indicates the perpendicular distance from the root apex to CRe.

2.5. Statistical analysis

The relationship between PAL and CRo-CRe, and the relationship between PAH-CRe and CRo-CRe were evaluated using Pearson's correlation analysis.

All statistical analyses were performed using SPSS software (Version 16.0, IBM SPSS, Armonk, NY, USA). The level of statistical significance was set at $P < 0.05$.

3. Results

Mechanical and biomechanical parameters and the locations of CRo and RA (root apex) relative to CRe for each case are shown in Table 1. In all patients, the maxillary central incisors showed lingual crown tipping. For cases 1 to 3, CRo-CRe was larger than RA-CRe. In other words, each CRo of the incisor was located at a position apical to the root apex, indicating that controlled tipping of the incisor occurred. On the other hand, for case 4, CRo was located at a position coronal to the root apex, since CRo-CRe was smaller than RA-CRe. This indicates uncontrolled tipping, in which the incisal edge was retracted posteriorly, while the root apex moved to the opposite direction, was produced. For case 5, CRo was located approximately at the root apex, and consequently, the incisor tipped nearly around the root apex as the rotation axis.

The correlation coefficients between PAL and CRo-CRe and that between PAH-CRe and CRo-CRe are shown in Table 2. The Pearson's correlation coefficient between PAL and CRo-CRe

Table 1 – Mechanical and biomechanical parameters, and locations of CRo and RA relative to CRe.

Case no.	PAL (mm)	Distance from PAH-CRe (mm)	Distance from CRo-CRe (mm)	RA-CRe (mm)
1	8	−0.01	16.10	5.30
2	4	2.68	10.11	4.94
3	6	2.82	8.19	5.87
4	6	4.15	3.86	7.34
5	4	6.32	5.44	6.17

PAL, power arm length; PAH, power arm hook; CRe, center of resistance; CRo, center of rotation; RA, root apex.

Table 2 – Pearson's correlation coefficients between power arm length (PAL) or the distance from power arm hook (PAH) to CRe and distance from CRo to CRe.

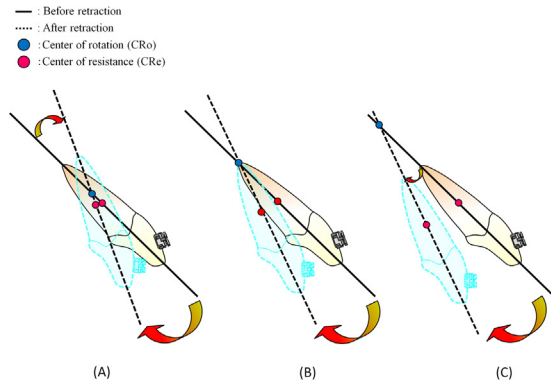|	Correlation coefficient	P value
PAL vs. CRo-CRe	0.444	0.454
PAH-CRe vs. CRo-CRe	−0.886	0.046[*]

[*] $P < 0.05$.

Fig. 3 – Movement pattern of anterior tooth in association with CRe-CRo. (A) Uncontrolled tipping. (B) Tipping around root apex. (C) Controlled tipping.

was 0.444. This indicates that there was no significant correlation between power arm length and the location of CRo with respect to CRe.

On the other hand, the correlation coefficient between PAH-CRe and CRo-CRe was −0.886. This indicates that the height of the retraction force relative to the level of CRe was significantly correlated with the location of CRo relative to CRe.

The scattergrams presented in Fig. 3 show the association between PAL and CRo-CRe, and that between PAH-CRe and CRo-CRe, and regression lines. These data also show the strong correlation between PAH-CRe and CRo-CRe (Fig. 4).

4.   Discussion

The present results demonstrate that PAH-CRe was highly correlated with CRo-CRe, which indicates the type of subsequent incisor movement (Table 2). Although the sample size in this study was small, the correlation coefficient between these variables was −0.886 and was considered to be significantly

high based on a previously published study [21] and literature [22] that reported that there is a statistically significant correlation when the absolute value of the correlation coefficient is larger than 0.878 with a sample size of five. On the other hand, power arm length itself was not significantly correlated with the resultant tooth movement pattern.

Comparisons of cases 2 and 5 and cases 3 and 4 revealed that even when the retraction force was applied at the same height level on the power arm, there were discrepancies in CRo-CRe, which indicated how the incisor moved during retraction, (Table 1). These observations suggest that anatomical parameters, such as the position of CRe or the condition of the adjacent alveolar bone, vary among individuals and may affect tooth movement. To date, it has been considered that a close relationship exists between power arm length and the type of anterior tooth movement in sliding mechanics [9–11]. However, the results of the present study suggest that the height of the power arm hook relative to the level of the CRe has a greater impact on anterior tooth movement than power arm length alone.

Consequently, an appropriate method for estimating the location of the CRe would be clinically important for determining the optimal loading conditions in order to achieve the desired type of tooth movement. In a previous finite element study, the location of the CRe for a single-root tooth was determined at two-fifths of the root length from the alveolar crest [17]. The approximate location of the CRe could be estimated from the cephalogram, and then required length of the power arm can be prescribed depending on the incisor inclination at the initial stage. It has been suggested by Tominaga et al. [14] that it is essential to give full consideration to anatomic parameters that vary among individuals in order to determine an optimal power arm length for the controlled movement of the anterior teeth in sliding mechanics.

In the present study, the power arm length for each patient was selected according to the criteria described in a previous study that was performed based on *in vivo* measurements of initial tooth displacement [10]. Four-mm power arms were prescribed for cases 2 and 5, since these patients were diagnosed as Class II Division 1 malocclusion with proclined
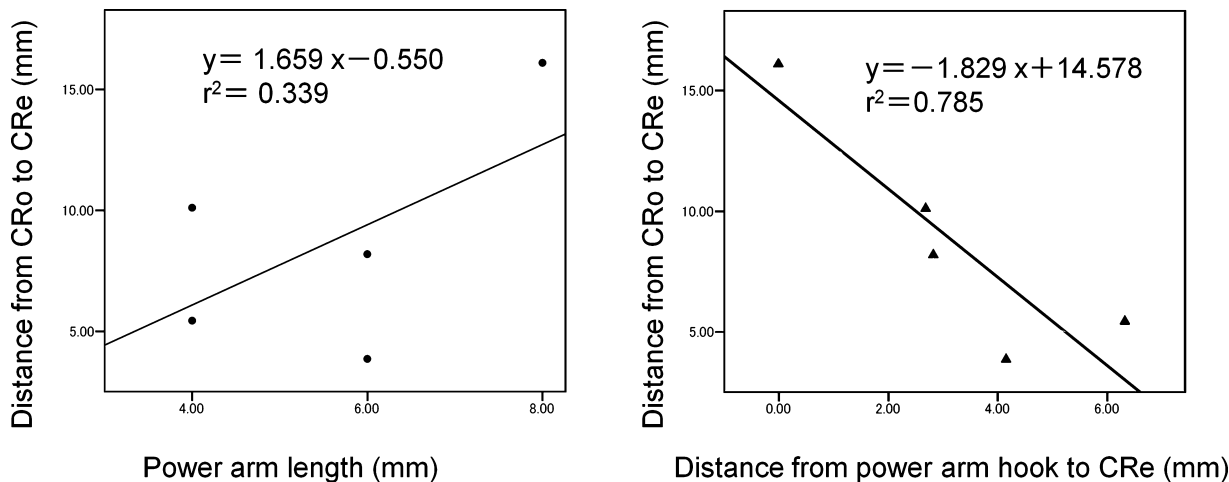

Fig. 4 – Scattergrams of PAL *versus* CRo-CRe and PAH-CRe *versus* CRo-CRe. Regression lines were drawn and equations with coefficients of determination (r^2) were calculated.

incisors; therefore, controlled tipping was indicated. Six-mm power arms were employed to obtain bodily movement for cases 3 and 4 with normal inclination. For case 1, a height of 8 mm was selected to achieve lingual root tipping for the correction of Class II Division 2 malocclusion.

Contrary to expectations, lingual crown tipping of the incisor was observed in all cases. Substantial discrepancies were observed between the present results and those from previously published *in vivo* measurements. This may be due to the fact that initial tooth displacement in previous studies had mostly reflected physical distortion of the periodontal ligament, thereby the displacement was momentary and reversible. On the other hand, the results obtained in this study, which reflected long-term orthodontic tooth movement, were observed as a result of histological changes of periodontal tissues adjacent to the teeth. Therefore, it is necessary to distinguish between initial tooth displacement and long-term tooth movement following bone remodeling. In this study, it was considered that much longer power arm than the clinical criteria advocated in a previous article [10] is required to achieve controlled movement of the anterior teeth.

From the perspective of biomechanics, bodily movement was expected to be produced in case 1, since the retraction force almost passed the level of CRe. Nevertheless, lingual crown tipping occurred. This may be attributed to the existence of a play between bracket slots and the archwire. Finite element studies [13,14] showed that the dimension of the play between the bracket slot and the archwire has a significant impact on anterior tooth movement, and the greater the play exists, less torquing force is transmitted to the incisor; therefore longer power arms (9.1 mm in length, 1.9 mm apical to the CRe) than the perpendicular distance from the bracket level to the CRe are required to attain bodily movement with a 0.017 in. × 0.022in. archwire in a 0.018 in. slot. The present results obtained from clinical cases were in agreement with the results analyzed by means of FEM.

Various treatment techniques have been developed in recent years in order to obtain better treatment results and shorten the treatment period. It is expected that therapeutic efficiency would be greatly improved if a monitoring method of tooth movement in the course of treatment is established. In the present study, the movement pattern of the incisor during retraction was successfully evaluated by means of 3D model analysis. Using this method, the treatment progress could be monitored at frequent intervals by taking impressions for dental casts, which do not require radiation exposure to the patient. Since it remains difficult to predict tooth movement prior to orthodontic treatment, the initial loading condition prescribed at the time of diagnosis would not necessarily lead to the treatment goal. Therefore, it is considered to be essential to regularly monitor the treatment progress using 3D model analysis and redirect the anterior tooth movement to its final destination by adjusting the power arm length if unexpected movements are produced during treatment.

We conclude that the height level of the power arm relative to the level of the CRe may be the most influential factor affecting tooth movement, while power arm length alone has less impact on the subsequent tooth movement. Therefore, it is necessary to calculate an optimal power arm length back from the location of the CRe. Further studies are needed to establish clinical criteria or guidelines for sliding mechanics with combined use of power arms in studies with larger sample sizes.

Ethical approval

Subjects signed informed consent forms prior to the start of the study, and the research protocol was examined and approved by the Ethics Committee of Nagasaki University Graduate School of Biomedical Sciences (no. 1182).

Conflicts of interest

None of the authors have a conflict of interest to declare.

Acknowledgement

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