

Types of tooth movement, bodily or tipping, do not affect the displacement of the tooth's center of resistance but do affect the alveolar bone resorption

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ABSTRACT

Objective: To investigate how types of tooth movement, bodily or tipping, influence the displacement of the center of resistance in teeth and alveolar bone resorption.

Materials and Methods: Ten-week-old female Wistar rats were divided into eight groups of different factors, as follows: type of movement (bodily and tipping) and force magnitude (10, 25, 50, and 100 cN). The maxillary left first molars were moved mesially with nickel-titanium coil springs for 28 days. Micro-computed tomography (micro-CT) images were taken before and after tooth movement. The position of the center of resistance was determined by using finite element models constructed from the micro-CT image. The displacement of the center of resistance and the volume of alveolar bone resorption were measured.

Results: The displacement of the center of resistance showed no significant difference between the bodily and tipping groups. The displacements of the center of resistance were increased with force magnitude at 10 and 25 cN, whereas they were not further increased at 50 and 100 cN. On the other hand, cervical alveolar bone resorption was significantly greater in the tipping group than in the bodily group.

Conclusions: Displacement of the center of resistance was not influenced by the types of tooth movement. However, volume of cervical alveolar bone resorption was greater in the tipping movement group than in the bodily movement group. (*Angle Orthod.* 2017;87:563–569)

KEY WORDS: Type of tooth movement; Center of resistance; Alveolar bone resorption

INTRODUCTION

Orthodontic tooth movement occurs as a result of a biological reaction of periodontal tissues caused by an external force, and ideal orthodontic treatment achieves maximum tooth movement without damaging periodontal tissues. Until now, tooth movement has been widely studied under various contexts, such as force magnitude, force interval, and appliance design.

To date, most previous studies^{1–6} have analyzed tipping tooth movement to measure the amount of tooth movement. However, few studies^{7,8} have experimentally performed bodily tooth movement because of its difficulty. In addition, many studies have reported on the relationship between the magnitude of orthodontic force and the amount of tooth movement. Some clinical studies^{1–5} reported that the amount of tooth movement increased with force magnitude. On the other hand, some animal studies^{6,7} reported that the amount of tooth movement decreased with force magnitude. In other animal studies,^{8–10} no relationship was reported between the force magnitude and the amount of tooth

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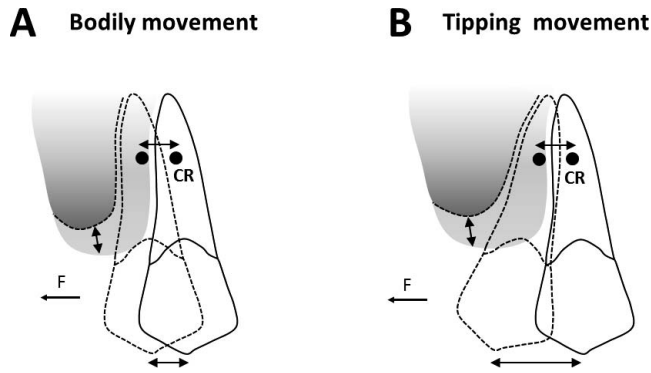


Figure 1. Purpose of this study: To study the difference between bodily (A) and tipping (B) tooth movement in the displacement of tooth crown, center of resistance (CR), and the alveolar bone resorption. The dotted line represents the tooth after movement. F indicates orthodontic force.

movement. Therefore, no consensus has hitherto been reached concerning how to move teeth most efficiently.

To clarify these issues, animal experiments have been frequently performed in which the amount of tooth movement has been measured using a caliper, a stereomicroscope, or radiographic images. These methods have generally used the tooth crown as the reference point. However, the movement of the center of resistance (CR) should be used to more realistically represent the tooth movement.

CR is defined as the point crossed by a force vector at which bodily tooth movement is achieved.^{11,12} CR is considered to be located at approximately one-third of the tooth root in height, and, therefore, applying orthodontic force to a crown generally causes a tipping tooth movement.^{11,12} If the position of CR is clearly determined during orthodontic treatment, tooth movement will be accurately predicted without difficulty. In addition, it was reported that the CR is advocated to be most suitable as a reference point for measuring tooth movement.^{11,12} However, there have been no reports analyzing tooth movement using CR as the reference point in animal experiments.

In this study, we applied various levels of orthodontic force to bodily and tipping movement models and aimed to investigate the effect of these factors on displacement of the crown and CR. Furthermore, we identified the difference in alveolar bone resorption between bodily and tipping tooth movements (Figure 1).

MATERIALS AND METHODS

This study was conducted with the approval of the Animal Welfare Committee of Nagasaki University (No. 0603170498). Ten-week-old female Wistar rats (SLC, Shizuoka, Japan; weight: 170–180 g) were used as experimental animals. The rats were kept in plastic

Table 1. Number of Experimental Animals

| Force, cN | Movement Type | |
|-----------|---------------|---------|
| | Bodily | Tipping |
| 10 | 5 | 5 |
| 25 | 5 | 5 |
| 50 | 6 | 6 |
| 100 | 5 | 5 |

cages in a mass animal room and allowed to eat normal, solid food and to drink water freely.

Forty-two rats were randomly divided into two groups: the bodily group and the tipping group. Each group was further divided into four groups based on the different orthodontic force magnitudes (Table 1). After rats were administered general anesthesia with an intramuscular injection of ketamin hydrochloride at a dose of 87 mg/kg (Ketalar 50; Sankyo, Tokyo, Japan) combined with xylazine hydrochloride at a dose of 13 mg/kg (Celactal 2%; Bayer-Japan, Tokyo, Japan), orthodontic appliances were placed and micro-computed tomography (micro-CT) images were acquired.

The orthodontic appliances used in this study were designed as described previously.¹³ Orthodontic anchor miniscrews of 1.4 mm in diameter and 6 mm in length (Dual-top, Anchor Screw; Jeil Medical, Seoul, Republic of Korea) were placed into the anterior palatal bone with a hand screwdriver. Then, a 0.016-inch-diameter, round, cobalt-chromium wire (Elgiloy; Rocky Mountain Morita, Tokyo, Japan) was fixed over the occlusal surfaces of the left second and third molars, all right molars, and the orthodontic anchor screws with a self-curing resin (Super-Bond; Sun Medical, Shiga, Japan). For bodily tooth movement, we placed a 2-mm-long resin sliding tube through the wire and fixed it to the occlusal surface of the maxillary left first molar. Then, a nickel-titanium closed coil-spring (Sentalloy; Tomy, Fukushima, Japan) was set between the maxillary left first molar and the anchor screws to move the first molar mesially (Figure 2A). The first molar was moved mesially without the sliding tube in the tipping group (Figure 2B). In order to eliminate the occlusal force to the left first molar, resin was built up to the occlusal surface of the teeth, except for the left first molar. We acquired radiographic in vivo micro-CT (RmCT; Rigaku, Tokyo, Japan) images on days 0 and 28. The micro-CT conditions were set as follows: X-ray source voltage, 90 kV; current, 100 mA; scanning time, 2 minutes; and resolution, 20 $\mu\text{m}/\text{pixel}$.

To determine the positions of CR, we created a three-dimensional (3D) finite element method (FEM) model of the maxillary left first molar of the rats (number of nodal points: 78,695, element count: 386,075). The model was created from the micro-CT images of the rat using Mimics 11.11 (Materialise

Appliance design

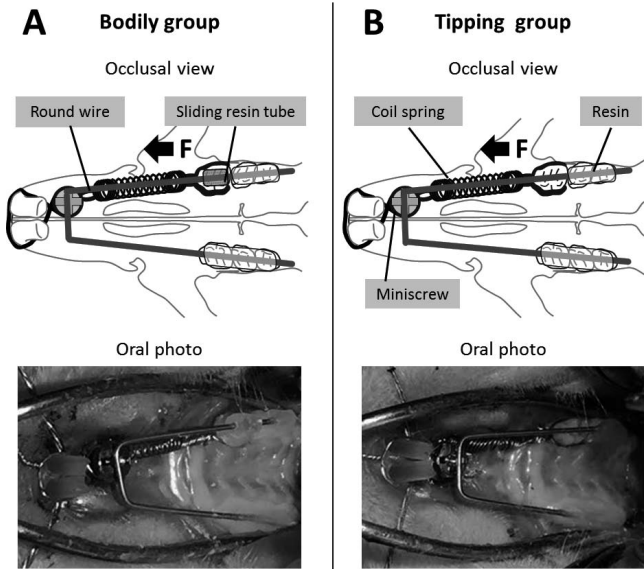


Figure 2. Appliance design. Arrows indicate the direction of the applied orthodontic force (F). (A) Bodily movement group; a sliding resin tube was fixed over the occlusal surface of the maxillary left first molar. (B) Tipping movement group.

Software, Leuven, Belgium) and Patran 2008 r1 (MSC Software Corp, Los Angeles, Calif). The Young's moduli for the tooth and the alveolar bone were set to 20,000 MPa and 2000 MPa, respectively.¹⁴⁻¹⁶ The periodontal ligament was set to be nonlinear elastic, and its width was set to be 0.2 mm.^{17,18} All Poisson ratios were set to be 0.3.¹⁴⁻¹⁶ The position of CR was determined following the method reported previously.¹⁹ In short, we applied the 0.05-Nmm torque to the FEM model, and the CR was located at the point that was closest to the arbitrary three axes of rotation in the directions of the sagittal, coronal, and transversal (Figure 3A). With the procedure, the CR was finally found to be located on the plane parallel to the occlusal plane that passed through two points on the axes of roots: point A, 50.7% in length of the disto-palatal root from the root apex, and point B, the center of the mesial root. Furthermore, the CR was located 57.3% in length from point A to point B (Figure 3B).

Tooth movement was measured from the micro-CT images using 3D image software (TRI-BONE; Ratoc System Engineering, Tokyo, Japan). The micro-CT images on days 0 and 28 were superimposed using the maxillary left second molar, the third molar, and the surrounding alveolar bone as reference structures. The following three parameters were defined to measure tooth movement: (1) the displacement of contact points, which is the distance between contact points of the maxillary left first molar and the second molar in the direction of the orthodontic force (Figure 4A); (2)

A Calculation method of the CR position

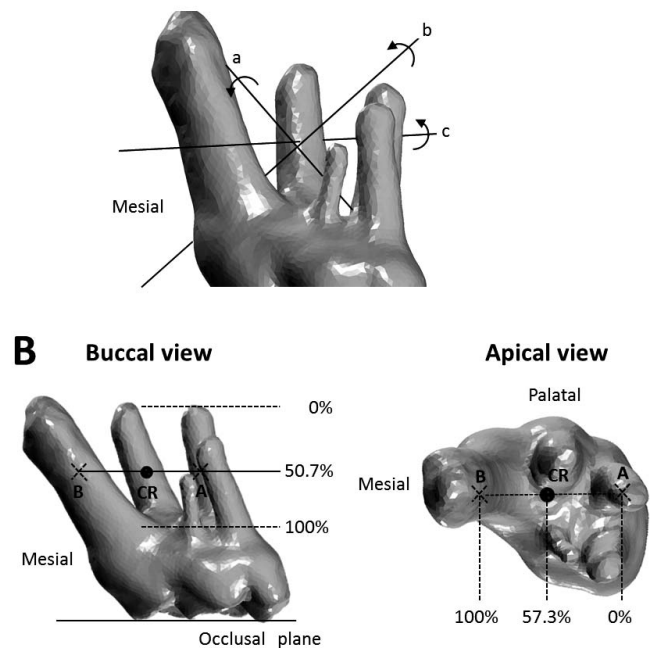


Figure 3. (A) a, b, and c indicate the arbitrary three axes of rotation in the directions of the sagittal, coronal, and transversal, respectively. (B) The position of CR in the image of FE model.

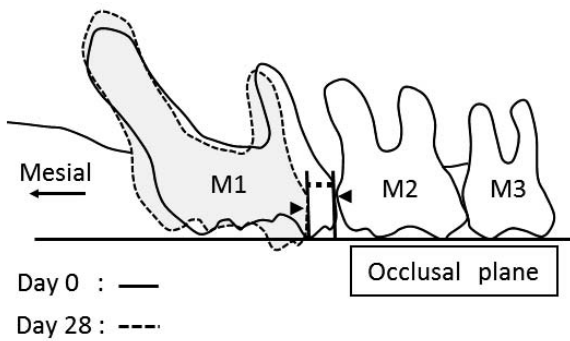
the change in tooth inclination, which is the angle of tooth inclination of the maxillary left first molar (Figure 4B); and (3) the displacement of CR, which is the distance between positions of the CR measured at days 0 and 28. Following the superimposition of CR-plotted micro-CT images, the displacement of respective CR was measured in the 3D space.

In the present study, the volume of alveolar bone resorption was measured using 3D image software, as described previously.²⁰ In short, micro-CT images from days 0 and 28 were superimposed using the second and third molars as reference structures (Figure 5A). The volume of alveolar bone resorption was measured around the mesial root (Figure 5B), and the volume of cervical alveolar bone resorption was measured using the mesiocervical regions (Figure 5C) of the maxillary left first molar. The same investigator performed all measurements, which were repeated three times each. The mean value of measurements was used as the final measurement.

Statistical Analysis

All statistical analyses were performed with EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan). The data presented a normal distribution (Shapiro-Wilk test, $P > .05$ for all of the data) and homoscedasticity (F -test and Bartlett test, $P > .05$ for all of the data). Two-way analysis of variance

A Displacement of contact points



B Change in tooth inclination

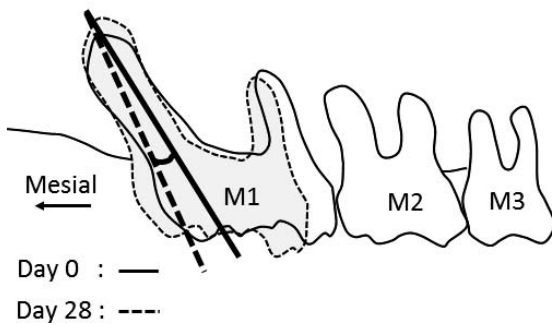


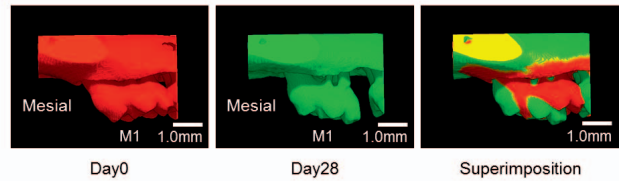
Figure 4. Measurement of tooth movement. (A) Displacement of contact points. A movement of the contact points before and after tooth movement (arrowheads) of the first and second molars was measured parallel to the occlusal plane. (B) Change in tooth inclination. The angle of the mesial root axis of the first molar before and after tooth movement was measured in a sagittal section. M1, M2, and M3 indicate the first, second, and third molar, respectively. The dotted line represents the tooth after movement.

was used for the comparison of the tooth movement parameters and the volume of alveolar bone resorption. Furthermore, a *t*-test was used to compare between the bodily and tipping groups, and a Tukey test was used to compare each force magnitude for multiple comparisons. The correlation between the tooth movement and the alveolar bone resorption was assessed with the Pearson's product-moment correlation coefficient. The significance level was set at $P < .05$.

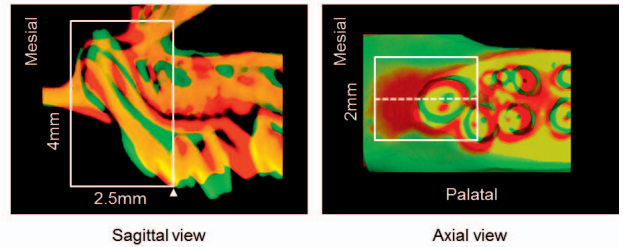
RESULTS

The displacement of contact points was greater in the tipping group than in the bodily group at all force magnitudes. Between types of tooth movement, the average displacement of the contact point was significantly greater ($P < .05$) in the tipping group than in the bodily group (Figure 6A).

A Image of micro-CT superimposition



B Measuring range of alveolar bone resorption



C Measuring range of cervical alveolar bone resorption

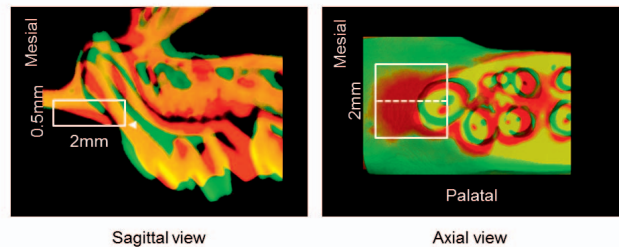


Figure 5. (A) Image of micro-CT superimposition. Images on day 0 and day 28 and the superimposition are shown in red, green, and yellow, respectively. (B) Measuring range of alveolar bone resorption. White boxes indicate the measurement range (sagittal view: 2.5 mm mesially and 4 mm apically from the mesial cusp [arrowhead] before tooth movement; axial view: extended 2 mm in a bucco-lingual direction from the center of the mesial root [dotted line] before tooth movement). (C) Measuring range of the cervical alveolar bone resorption. White boxes indicate the measurement range (sagittal view: 2 mm anterior from the center of the mesial root and 0.5 mm inferior from the alveolar crest [arrowhead]; axial view: 2 mm in a bucco-lingual direction from the center of the mesial root [dotted line] before tooth movement).

The displacement of CR was significantly greater ($P < .05$) in the 50-cN and 100-cN groups compared to that in the 10-cN group. Although small differences were observed between the measurements of CR in bodily and tipping movements at each force magnitude, they were not statistically significant (Figure 6B).

The change in tooth inclination was greater in the tipping group compared to the bodily group at all force magnitudes, and it was significantly different ($P < .05$) between the averages of the bodily and tipping groups (Figure 6C).

The volumes of alveolar bone resorption were similar between the bodily and tipping groups at all force magnitudes. There was no significant difference ($P = .57$) among the different force magnitudes for each group (Figure 7A).

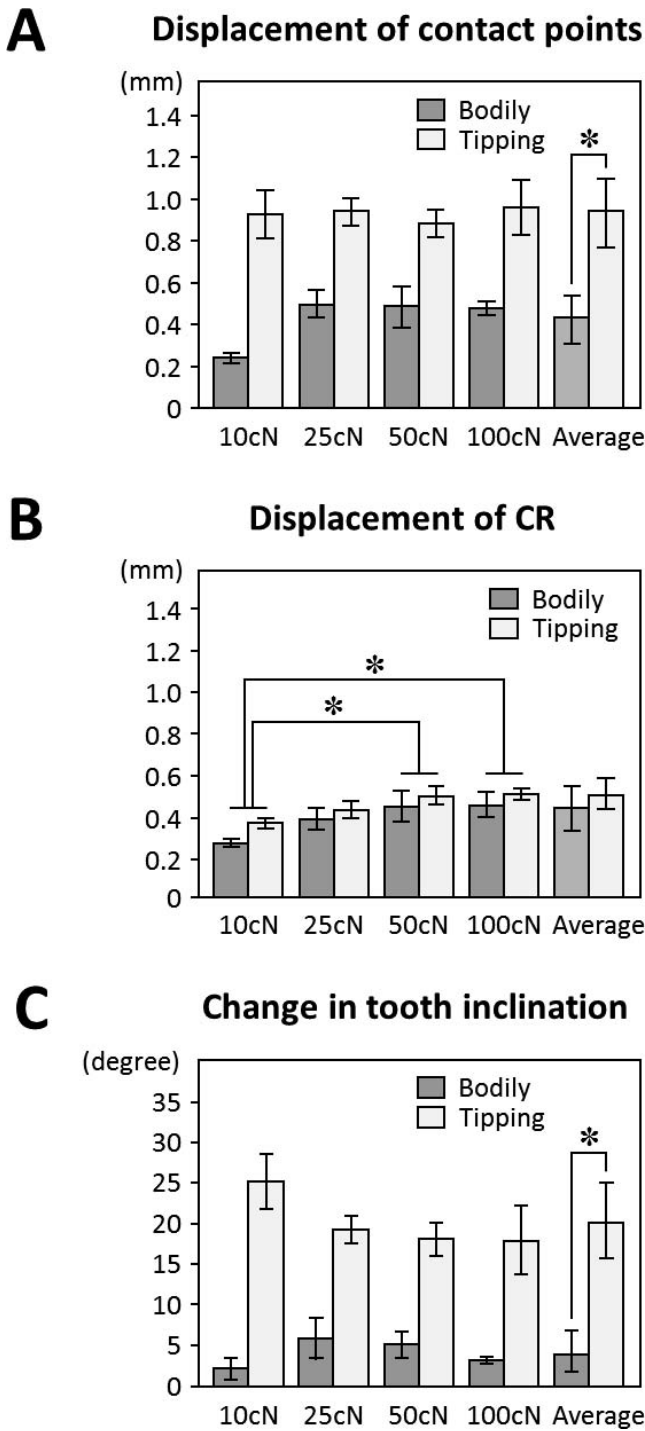


Figure 6. Tooth movement. (A) Displacement of contact points. (B) Displacement of center of resistance (CR). (C) Change in tooth inclination. The average indicates the average of all force magnitudes in bodily or tipping group. All results are expressed as the mean and the standard deviation. * $P < .05$; Two-way analysis of variance test, *t*-test, Tukey test.

The volume of cervical bone resorption tended to be greater in the tipping group than in the bodily group. The average of the total volume of cervical bone resorption was significantly greater ($P < .05$) in the

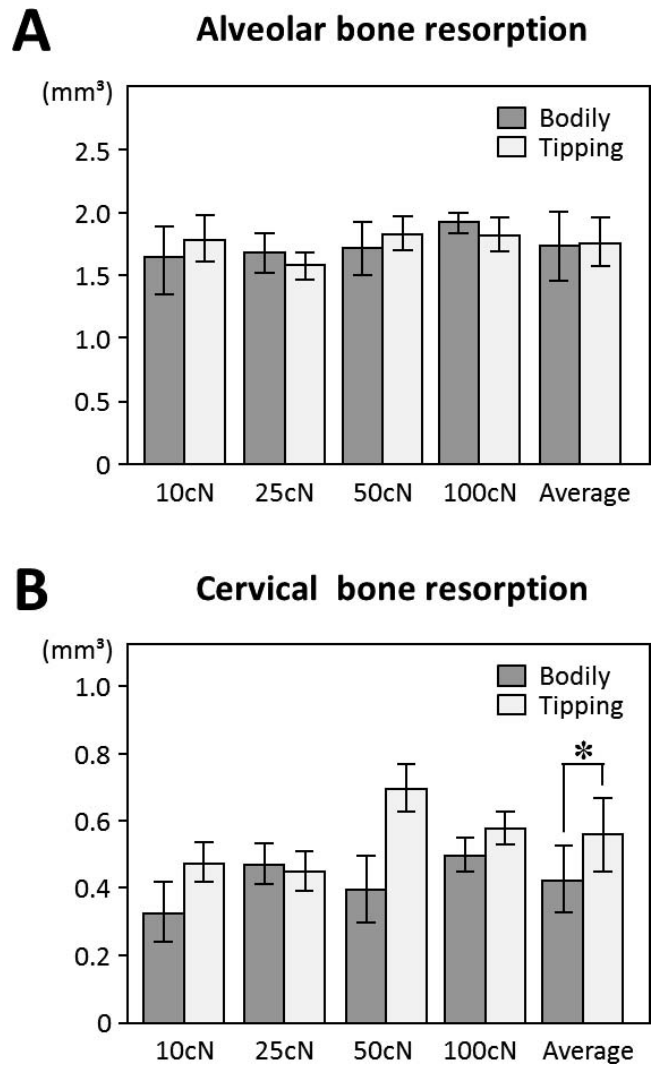


Figure 7. Bone resorption. (A) Volume of alveolar bone resorption. (B) Volume of cervical bone resorption. The averages of all force magnitudes in the bodily or tipping groups are presented. All results are expressed as the mean and the standard deviation. * $P < .05$; Two-way analysis of variance test, *t*-test, Tukey test.

tipping group than in the bodily group. The greatest cervical bone resorption was 0.69 mm³ in the tipping group at 50 cN (Figure 7B).

In the bodily group, the displacement of CR and contact point revealed a statistically significant, positive correlation, whereas the displacement of CR had no correlation with the change in tooth inclination. Conversely, the displacement of CR correlated with neither the displacement of contact points nor the change in tooth inclination in the tipping group (Table 2).

There was no correlation between the volume of alveolar bone resorption and the change in tooth inclination, whereas there was a statistically significant, positive correlation between the volume of cervical

Table 2. Pearson's Correlation of Displacement of CR and Tooth Movement Parameters^a

| | Bodily Group | | Tipping Group | |
|-------------------------|----------------|-------------------|----------------|-------------------|
| | Contact Points | Tooth Inclination | Contact Points | Tooth Inclination |
| Correlation coefficient | 0.84 | 0.10 | 0.32 | -0.02 |
| P-value | <.001*** | .67 | .14 | .91 |

^a CR, center of resistance; Contact points, the distance between contact points; Tooth inclination, the angle of tooth inclination.

*** $P < .001$.

bone resorption and the change in tooth inclination (Table 3).

DISCUSSION

To date, no study has analyzed the displacement of CR in vivo. In this study, we analyzed the displacement of contact points and CR in bodily and tipping movement groups. Interestingly, in this study the displacement of CR was similar between the bodily and tipping groups, despite the fact that the average displacement of the contact point in the bodily group was significantly smaller than that in the tipping group. This result suggested that the displacement of CR may not be influenced by the types of tooth movement. In clinical treatments, an uncontrolled tipping tooth movement often requires the correction to be moved to an upright position, and this additional treatment procedure may prolong the duration required to bring a tooth to its spatial destination. Therefore, when the displacement of CR is similar between the bodily and tipping movements, the treatment period may become longer with tipping movement than with bodily movement. Furthermore, a statistically significant, positive correlation was observed between the cervical alveolar bone resorption and the change in tooth inclination. This indicates that the factor of tooth inclination may increase the risk of losing alveolar bone level.

Although there was no significant difference between the bodily and tipping groups with regard to the volume of alveolar bone resorption around the mesial root, the bone resorption of the cervical area of the tooth was greater in the tipping group than in the bodily group. Compared to bodily tooth movement, tipping tooth movement may destructively influence the periodontal tissue of the cervical area, and therefore bodily tooth

movement may be more advantageous in terms of maintaining the height of the alveolar bone.

In this study, the displacement of CR was significantly greater in 50- and 100-cN groups than in the 10-cN group, but there was no significant difference individually between the 50- and the 100-cN groups. These results indicate that the optimal orthodontic force in the rats may be less than 50 cN, which is in accordance with the findings of a previous study.¹³

There appear to be a lot of advantages to evaluating and controlling CR in orthodontic treatment. However, some clinical studies²¹ reported that the location of CR during treatment will change depending on the change in periodontal morphology, including that of the tooth and the alveolar bone. In order to analyze tooth movement more accurately, we need to identify the changes in the location of CR over time. Novel real-time methods that analyze the periodontal tissue, including the moving tooth, and simultaneously reconstruct the FE model will resolve this issue.

CONCLUSIONS

- The displacement of CR is not influenced by tooth movement type, although displacement of contact points is greater in tipping tooth movement than in bodily tooth movement.
- The volume of cervical bone resorption is greater in tipping movement than in bodily movement.

ACKNOWLEDGMENT

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Table 3. Pearson's Correlation of Tooth Inclination and Bone Resorption Parameters^a

| | Alveolar Bone Resorption | Cervical Resorption |
|-------------------------|--------------------------|---------------------|
| Correlation coefficient | 0.05 | 0.51 |
| P-value | .75 | <.001*** |

^a Tooth inclination, the angle of tooth inclination; Alveolar bone resorption, the volume of alveolar bone resorption; Cervical resorption, the volume of cervical resorption.

*** $P < .001$.

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