Comparison of movement rate with different initial moment-to-force ratios

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Introduction: The objective of this clinical prospective study was to evaluate the effect of the 2 treatment strategies, translation or controlled tipping, followed by root correction on canine retraction efficiency, specifically canine movement rate. **Methods:** Twenty-one patients who needed bilateral maxillary canine retraction to close extraction space as part of their treatment plan were selected for this study. Segmental T-loops designed for controlled tipping or for translation were applied randomly to each side. Two digital maxillary dental casts (taken before and after treatment) were used to measure the tooth displacements of each patient. The coordinate system located at the center of canine crown on the pretreatment model with the 3 axes defined in the mesial-distal (M-D), buccal-lingual, and occlusal-gingival directions was used to express the 6 tooth displacement components. The movement rates on the occlusal plane and in the M-D direction were computed. Movement rates were calculated by dividing the M-D displacements or the resultant displacement on the occlusal plane with the corresponding treatment time. **Results:** T-Loops for controlled tipping moved canines faster (33.3% on occlusal plane and 38.5% in the M-D direction) than T-loops for translation. The differences were statistically significant ($P = 0.041$ on the occlusal plane and 0.020 in the M-D direction). **Conclusions:** Moment-to-force ratio (M/F) affects the canine movement rate in a maxillary canine retraction treatment with the use of a segmented T-loop mechanism. Within the neighborhood of the ratio for translation, lower M/F moves the canine faster than higher M/F both on the occlusal plane and in the M-D direction. (Am J Orthod Dentofacial Orthop 2019;156:203-9)

Tooth movement rate is one of the most important orthodontic treatment outcomes. It has been commonly used to evaluate effectiveness of treatment strategies and orthodontic appliances. Accurate quantification of the movement rates is critical for the evaluation.

Tooth movement rate has been estimated in previous studies. The relationship between the magnitude of the orthodontic force and tooth movement rate was investigated in animal studies.[1-4] A mathematic model to describe the relationship was also developed based on the experimental studies in beagle dogs.[5] In human studies, movement rates were used to compare the effects of force magnitudes,[6-8] treatment efficiency among different appliances,[9-11] and different types of anchorage.[12] In those studies, tooth movement rate was quantified with the use of either digital caliper[13-16] or 2-dimensional (2D) cephalometric analysis.[17,18] These methods could provide only linear or 2D measurements between landmarks. The point-to-point measurement did not provide information on tooth movement type, translation, and rotation. The off-plane movement and rotations were not assessed. These components are equally important because they characterize the side-effects. Therefore, 3-dimensional (3D) tooth movement needs to be quantified.

With the development of 3D imaging and modeling techniques, digital alternatives are available to calculate the 3D tooth movements. The clinical 3D displacements can be calculated with the use of cone-beam computed tomographic (CBCT) images.[16] Digital dental casts also can be used to quantify the 3D tooth displacements.[19-23]

Canine retraction after first premolar extraction is a treatment stage of space closure. Two treatment strategies, translation or controlled tipping, followed by root correction, are commonly used. Different canine movement patterns (ie, translation [TR] and controlled tipping [CT]) were achieved by implementing different treatment strategies characterized by corresponding

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moment-to-force ratios (M/F).[24] Three-dimensional clinical evaluation has not been reported on the effect of M/F on canine retraction efficiency, specifically canine movement rate, which is the objective of this study.

MATERIAL AND METHODS

Twenty-one patients (9 male and 12 female) participated in this split-mouth prospective trial study. The study was approved by the Indiana University Institutional Review Board and a signed consent form was documented for each patient. The average age of the patients was 21 ± 8.8 years. These patients were planned for bilateral maxillary canine retractions (symmetric pattern) after the maxillary dental arch was bracketed, leveled, and aligned with sequential archwires to close first premolar extraction spaces. Canine roots were radiographically evaluated by the clinician for typical dental anatomy (average root sizes, support, and shape). No palatal expansion was performed during the treatment, and no metal or ceramic restorations were on the teeth of interest or their adjacent teeth. Patients were allocated into 2 groups by means of the fixed allocation randomization method. Therefore, equal numbers of canines were treated with CT and TR strategies. The CT and TR strategies were accomplished by using specifically designed segmental T-loops, which could provide a distal retraction force of 124 cN along the maxillary arch[25] and an antitipping and an antirotation moment along with minimized force and moment components in other directions.[24] The average desired M/F for the 21 patients was 10.69 for TR and 8.06 for CT. The details of the wire design and orthodontic force verification were reported previously.[24] Patients were scheduled with regular appointments every 5-6 weeks and normally underwent multiple treatment intervals (TIs). A TI was defined as a time interval when the interbracket distance between the canine and the second premolar on one side decreased >1 mm. When a TI ended, a pair of new T-loops was redesigned, fabricated, and reactivated consistently with the designated treatment strategies. The study was completed when either the CT or the TR side finished the canine retraction with the canine in the upright position as judged by the clinicians by means of visual evaluation. Patients' posttreatment CBCT images were used to validate the final positions of the CT-side canines.

Two dental casts were used for each patient in this study. The first cast was taken before starting the canine retraction, which was called the pretreatment cast; and the second one was taken before the last TI started, which was considered to be the posttreatment cast. The movements from the last TI were not included, because tooth movements might stop at some time within the period, which was not recorded. The 2 casts were scanned and digitized with the use of an Optix 400S 3D laser scanner (3D Digital Corp, Sandy Hook, Conn). The resolution of the scanner was 60 μm. The corresponding 3D digital models were reconstructed with the use of RapidForm (INUS Technology, Seoul, South Korea). The digital models were used to calculate the overall canine displacement in treatment.

For each canine, the origin of the coordinate system was set at the crown center on the pretreatment model. The positive x-axis was directed buccally, y-axis distally, and z-axis apically for the left side canine; and the positive y-axis was directed mesially for the right side.[26] To be consistent, the displacement components on the right side were converted to be expressed on the left side. The x and y axes formed a plane that was parallel to the posterior occlusal plane.[26]

The two digital models were superimposed by overlapping the 3D palatal (rugae) area. After the superimposition, the posttreatment model was in a position comparable with the pretreatment model. Next, the crowns of the canine in the two locations were aligned according to the entire crown surface points. Then the canine movement's 6 components in terms of translation along and rotation about the 3 coordinate axes were computed from the entries of the transformation matrix between the 2 crowns. The details of the superimposition and calculation methods were reported in a previous publication.[26]

Two of the displacements were used to calculate the movement rate, the resultant displacement, and the displacement in the distal direction, y. The resultant displacements represent the total movement rate on the occlusal plane (XY plane); and the mesial-distal (M-D) direction data were used to show the movement rate of the desired major movement in a space closure case. The rate of tooth movement considered in this study was determined by dividing total actual canine movement except the movement in the last TI by the treatment time in days (also excluding the days of the last TI). The resultant movement rate on occlusal plane, RG, is defined in Eq 1, where x and y are the 2 translation components and T is the treatment time. The corresponding movement direction, θ, is defined in Eq 2. It is the angle between the resultant movement direction on the occlusal plane and the distal direction (Fig 1).

$$RG = \frac{\sqrt{x^2+y^2}}{T} \qquad \text{(Eq 1)}$$

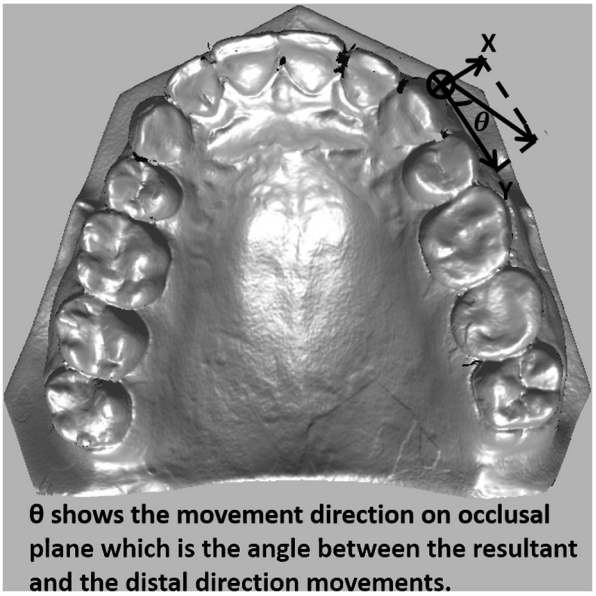

Fig 1. Movement directions on occlusal plane (XY plane).

$$\theta = \tan^{-1}\left(\frac{x}{|y|}\right) \quad \text{(Eq 2)}$$

To find the movement rate in the desired distal direction, the y component was used. The movement rate, RC, is defined in Eq 3, which was directed distally.

$$RC = \frac{|y|}{T} \quad \text{(Eq 3)}$$

The intrusion (+) and extrusion (−) were represented by the z components in the coordinate system.

The means and standard deviations of the resultant movement rates, the movement direction angle, and movement rates in the distal direction were calculated. Differences in canine movement rates between CT and TR sides were compared with the use of paired *t* tests, because there was only 1 observation on each side for each subject. The equal variance and normality assumptions were checked by means of normal probability plots. Differences were considered to be significant at $P < 0.05$.

The angle between the crown vestibular long axis of the CT-side canine and the occlusal plane (Fig 2) was measured with the use of each patient's posttreatment CBCT image to ensure that the CT-side canine was in its upright position when the treatment stopped.

RESULTS

The resultant movement rates are shown in Figure 3. The rate for the CT-side canine ranged from 0.000 to 0.041 mm/day and for the TR side from 0.001 to 0.042 mm/day. The movement rate difference varied among patients (from 0.000 to 0.029 mm/day).

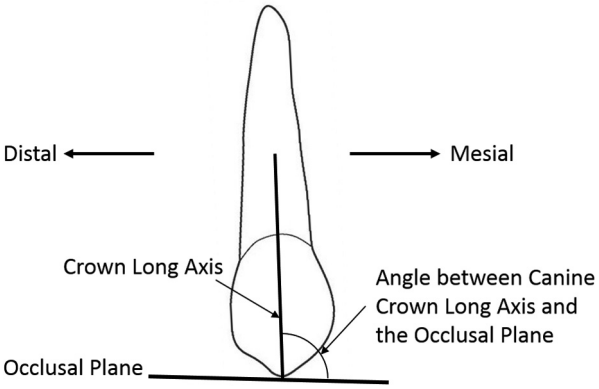

Fig 2. Angle between canine long axis and the occlusal plane.

Distal movement rates are shown in Figure 4. The rate for CT ranged from 0.000 to 0.040 mm/day and for TR from 0.000 to 0.035 mm/day. The movement rate difference varied among patients (from 0.000 to 0.026 mm/day).

The means and standard deviations of movement rates are presented in Table I. Both on the occlusal plane and in the M-D direction, CT T-loops moved canines 33.3% (0.005/0.015) and 38.5% (0.005/0.013) faster than translation T-loops, respectively. In general, differences were statistically significant.

In both the occlusal plane data and the M-D direction data, most patients had a larger movement rate on the CT side than on the TR side. The differences were calculated with the use of Eq 4:

$$\begin{aligned} Difference &= tipping\ side\ rate \\ &\quad - translation\ side\ rate \end{aligned} \quad \text{(Eq 4)}$$

Six patients—2, 3, 4, 7, 16, and 17—had larger TR movement rate on the occlusal plane and also in the distal direction (Figs 5 and 6). One patient, 19, had the same CT and TR movement rate on the occlusal plane (Fig 5); and 1 patient, 9, had the same CT and TR movement rate in the M-D direction (Fig 6). The average difference was 0.005 mm/day on the occlusal plane as well as in the M-D direction.

The resultant movement directions on the occlusal plane varied from −60.3° to +58.7° with an average being +16.64° ± 26.583°. Positive moving direction angle implied that the tooth moved in the buccal and distal direction, whereas negative angle implied that the tooth moved in the lingual and distal direction.

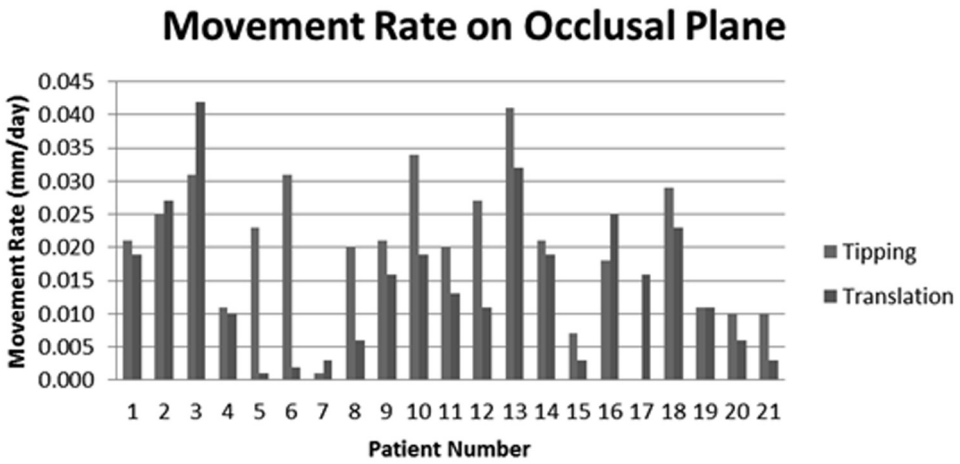

Fig 3. Canine movement rate results on occlusal plane.

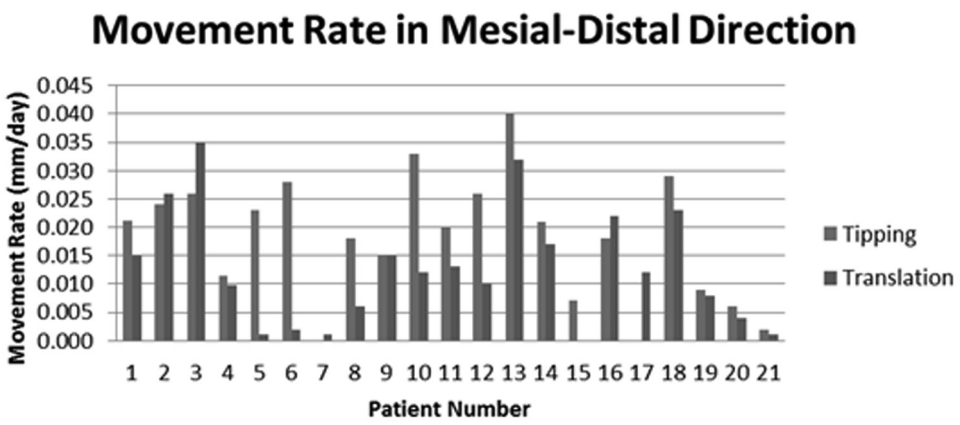

Fig 4. Canine movement rate results in mesial-distal direction.

Table I. Statistical analysis results of movement rates (mm/day, mean ± SD)

Context	*Tipping*	*Translation*	*Difference*	P *value*
Occlusal plane	0.020 ± 0.011	0.015 ± 0.011	0.005 ± 0.010	0.041
Mesial-distal direction	0.018 ± 0.011	0.013 ± 0.010	0.005 ± 0.010	0.020

Four CT-side and 5 TR-side canines had the magnitude of the angles >45°.

The means and standard deviations of intrusion and extrusion movement (*z*-axis) rates are presented in Table II. Intrusions are positive and extrusions negative.

The average angle between the CT-side canine's crown long axis and the occlusal plane was 93.611° ± 1.158° among all 21 patients, which indicated that the CT-side canines returned to their upright positions when the treatments were completed.

DISCUSSION

The CT and TR here represented treatment intentions, which were implemented with the use of different M/F: higher M/F for TR and lower M/F for CT. They did not represent clinical displacement patterns owing to the fact that the T-loop's M/F is very sensitive to the interbracket distance change due to tooth movement so that it changes as the tooth moves.[24]

This study measured the absolute displacement relative to the established coordinate systems. Absolute displacement provides a more accurate description of the tooth movement in response to an orthodontic force than relative displacement. Previous studies quantified relative displacement between 2 landmarks on the moving and anchorage teeth, respectively. Anchorage loss

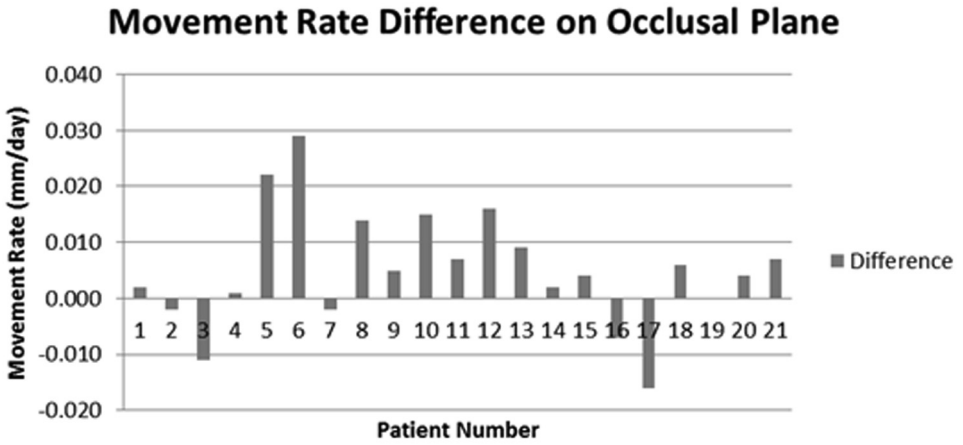

Fig 5. Movement rate difference (tipping side rate − translation side rate) on occlusal plane.

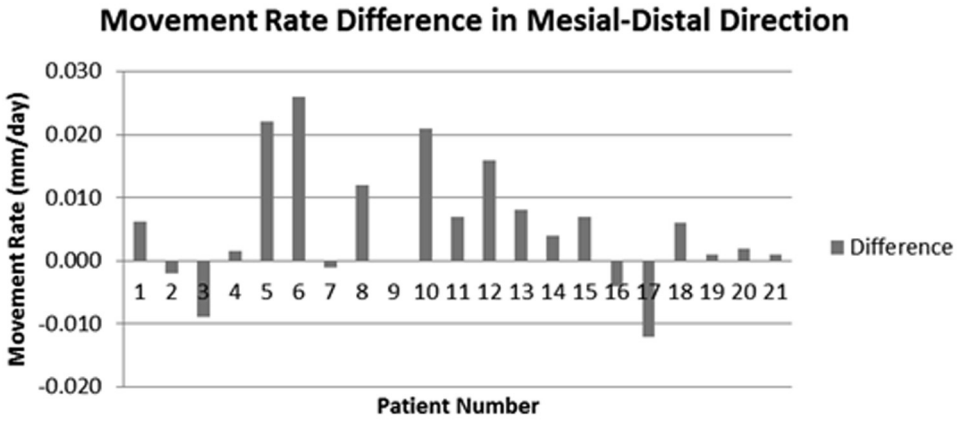

Fig 6. Movement rate difference (tipping side rate − translation side rate) in mesial-distal direction.

Table II. Movement rate of intrusion or extrusion (mm, mean ± SD)

Tipping	*Translation*	*Overall*
−0.002 ± 0.013	−0.006 ± 0.016	−0.004 ± 0.014

occurred clinically, which affected the measurement accuracy. Furthermore, the displacement was commonly described on a point. Choosing different points resulted in different displacement, especially when a large tipping was involved. These factors would affect accuracy and make comparisons unreliable.

Reported maxillary canine retraction rates varied greatly. For the frictionless mechanics, the largest value reported was >2.5 mm/month among 10 patients using a calibrated sectional archwire,[27] and the smallest one was ~0.6 mm/month measured from 6 patients using a vertical loop, which would cause the force to rapidly decline.[28] The average value was ~1.6 mm/month.[18,22,29-31] In the present study, the average movement rate on the occlusal plane was calculated as 0.56 mm/month for the CT side and 0.42 mm/month for the TR side (28 days per month). The values were relatively smaller compared with previous studies, likely because of different displacement quantification methods. The absolute 3D displacement of the crown center was calculated, and only the movements in the occlusal plane were used (Eqs 1 and 3) in this study, whereas others did point-to-point measurements, which might not be in the occlusal plane or in the directions clearly defined in this study, and might have used relative displacement.

Intuitively, the same orthodontic load system would produce consistent clinical tooth movement rate. That was not observed in this study, meaning that load system is not the only dominant factor controlling the tooth movement rate. The movement rate varied significantly

among patients, which might be caused by multiple factors, such as bone quality, functional habit, and genotype.

Description of tooth movement with respect to a static reference helps the clinician to quantify real tooth displacement and effects of various treatment strategies. Many previous studies reported tooth movement relative to an anchorage tooth, which might move during the treatment. Thus, the absolute movement was not obtained. In this study, movements of the moving and anchorage teeth were described relative to the rugae area. They were decoupled so that they could be analyzed separately. Thus, the reported movement would be the true response to the applied orthodontic load for a specified tooth. Furthermore, the intrusion/extrusion was reliably quantified, which was not possible from the relative displacement. On the other hand, clinicians could still use distal displacement to evaluate clinical outcomes in the space closure case. For this reason, the distal displacement, y, was used to calculate the closing movement rate.

Our previous study showed that M/F could not uniquely determine the pattern of clinical tooth movement when a segmental T-loop was used.[26] As the canine moves during treatment, M/F changes which causes the change of the canine movement pattern. However, the results in this study showed that initial M/F still had important impact on the efficiency of tooth movement in terms of movement rate. Based on the segmental T-loop design for each patient, the initial M/F for the controlled tipping side was lower than the initial M/F for the translation side.[24] The results of this study showed that the canine with lower initial M/F moved statistically faster on the occlusal plane and in the M-D direction for 71.4% patients (Figs 4 and 5; Table I).

There were discrepancies between movement rates in the M-D direction and on the occlusal plane. The difference was due to the coupled movement in either lingual or buccal direction. In this canine retraction treatment, with a well controlled orthodontic load system, ideally canines should move in the M-D direction to close the space, thus both movement rates should be close. In reality, teeth had significant movements along other directions, ie, buccal-lingual or occlusal-gingival. The variation of the movement directions was large, indicating that the well controlled orthodontic load was not the only dominant factor controlling the tooth movement direction. The large variation in angle indicated large interpatient variation in the movement direction. There were also coupled movements in the occlusal-gingival direction. The average movement rate was 0.004 mm/day, which was very slow compared with the movement rate on the occlusal plane (20%) or in the M-D direction. This observation showed that no trend on intrusion or extrusion could be found.

CONCLUSIONS

1. M/F affects the canine movement rate in a maxillary canine retraction treatment with the use of a segmented T-loop mechanism.
2. Within the neighborhood of the ratio for translation, lower M/F moves the canine faster than higher M/F both on the occlusal plane and in the M-D direction.

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