Original Article

Effect of clear aligner therapy on the buccolingual inclination of mandibular canines and the intercanine distance

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ABSTRACT
Objective: To compare the changes in buccolinugal inclination of mandibular canines and intercanine distance in patients treated with clear aligners to those treated with preadjusted edgewise appliances.
Materials and Methods: The buccolingual inclination of mandibular canines and the intercanine distance were measured on pre- and posttreatment cone-beam computed tomograms of 30 patients who had been treated with clear aligners and 30 patients who had been treated with fixed preadjusted edgewise appliances. Differences between the aligner and fixed appliance groups and between pre- and posttreatment measurements were tested for statistical significance.
Results: In both groups, most of the mandibular canines had positive buccolingual inclinations (ie, their crowns were positioned lateral to their roots) both before and after treatment. While there was no difference between the groups pretreatment, the posttreatment buccolingual inclination was significantly greater in the aligner group. In the fixed appliance group, the canines became more upright with treatment, while the buccolingual inclination did not change significantly in the clear aligner group. The intercanine distance did not differ between the groups either before or after treatment. However, it increased significantly over the course of treatment in the aligner group, whereas it did not change significantly in the fixed appliance group.
Conclusions: Orthodontic treatment with clear aligners tends to increase the mandibular intercanine distance with little change in inclination in contrast to treatment with fixed appliances, which leaves the intercanine distance unchanged but leads to more upright mandibular canines. (*Angle Orthod.* 2016;86:10–16.)

KEY WORDS: Aligner; Buccolingual inclination; Cone-beam computed tomography; Intercanine distance; Mandibular canine

INTRODUCTION

Among the various clear aligner treatment modalities available to orthodontists today, Invisalign® is one of the most widely recognized. Developed by Align Technology Inc in the late 1990s, Invisalign uses three-dimensional (3-D) technology to create a series of aligners to move teeth.[1] Advantages of aligner therapy have been suggested to include improved oral hygiene and periodontal health, superior esthetics, high patient acceptance, and flexibility in terms of their ability to be used in combination with other orthodontic treatment modalities.[1,2] Disadvantages of aligner therapy have been reported to include limited control of root movement and intermaxillary correction, inability to alter course of treatment once aligners are fabricated, limited treatment success with more complex cases, and reliance on patient compliance for treatment success.[1–3] While the efficacy of aligner therapy is well documented,[4–6] objective evidence of its treatment effects is limited. In an effort to gain more knowledge about the clinical effects of aligner therapy, the present study measured its effects on the buccolingual inclination and intercanine distance of mandibular

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Table 1. Descriptive Summary of Patient Age, Pretreatment Crowding, and Treatment Time[a]

Group	Age, y		Crowding, mm		Treatment Time, mo	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Clear aligner (n = 30)	25.0 ± 11.8	13.8–64.0	1.5 ± 1.9	−4.5 to 4.5	13.4 ± 6.8*	6.0–35.0
Fixed appliance (n = 30)	26.3 ± 13.5	12.7–56.5	1.3 ± 2.7	−7.0 to 5.5	20.2 ± 5.3*	13.0–31.0

[a] SD indicates standard deviation.
* Statistically significant differences between groups (unpaired *t*-test, $P < .05$).

canines compared to those of preadjusted edgewise appliances.

The buccolingual inclination of teeth influences factors such as anterior and canine guidance, adequate intercuspation, and the absence of occlusal interferences.[7] Moreover, buccolingual tooth inclinations are related to dental and periodontal features such as wear patterns and gingival recession, respectively.[8] Therefore, the ability to obtain standardized measurements of the buccolingual inclinations of teeth together with the quantification of changes in these inclinations resulting from orthodontic treatment is of significant interest. With their single, long roots, mandibular canines are relatively easy to measure and, more importantly, are of special interest as a result of their location, their role in resolving incisor crowding, and their importance in achieving canine guidance.

Influenced by buccolingual inclination, the mandibular intercanine distance has been shown to be of critical importance for the long-term stability of mandibular anterior alignment.[9] Although changes in the mandibular intercanine distance with age, during orthodontic treatment, and following retention are well described,[9–11] most studies have used dental models to assess these changes. Combining intercanine distance data with information on the buccolingual inclination of mandibular canines would provide better insight into the 3-D positional changes of these teeth during orthodontic treatment.

Although attempts have been made to assess the buccolingual inclination of some teeth on 2-D views, such as panoramic radiographs, these views are of limited clinical usefulness for the assessment of tooth orientation.[12] In fact, panoramic radiographs have been shown to be of questionable reliability even when measuring mesiodistal root angulations.[13] Recently, 3-D imaging using cone-beam computed tomography (CBCT) has given orthodontists the ability to reliably assess individual tooth positions in any given plane with good accuracy,[14] specifically the buccolingual inclination.[15] For this reason, the present study used CBCT to assess the effects of orthodontic treatment with clear aligners, as compared to that with preadjusted edgewise appliances, on the buccolingual inclination and intercanine distance of mandibular canines.

MATERIALS AND METHODS

The research protocol, including the use of existing CBCT scans, was approved by the Institutional Review Board of the University of Minnesota. A total of 60 patients, 30 consecutively treated with aligners and 30 treated with fixed appliances, were selected for this retrospective cohort study based the following inclusion criteria: (1) Fully erupted permanent dentition including incisors, canines, premolars, and first molars; (2) Angle Class I malocclusion with normal interarch molar relation; (3) No periodontal attachment loss; (4) Orthodontic treatment completed without extraction of permanent teeth; (5) Pre- and posttreatment full–field of view (17 × 23 cm) CBCT scans obtained with an i-CAT Next Generation (Imaging Sciences International, Hatfield, Pa) at a voxel size of 0.3 mm^3, scan time of 8.9 seconds, tube voltage of 120 kV, and tube current of 18.54 mAs as part of the diagnostic records for comprehensive orthodontic treatment; and (6) Both mandibular canines clearly visible in the CBCT scans. The patients in the fixed appliance group were matched to those in the aligner group for age and gender; for this reason, the groups each consisted of eight male and 22 female patients with similar average ages (Table 1). All patients had completed treatment under the supervision of experienced orthodontic specialists who were thoroughly trained in the use of aligners, practiced similar mechanotherapy, and pursued identical treatment goals (eg, correct crown angulation and inclination, no rotations, tight interproximal contacts, level Curve of Spee). Patients were not included if they had facial malformation or cleft lip and/or palate or if their treatment involved the use of extraoral traction, functional appliances, intraoral auxiliaries such as transpalatal or lingual arches, or maxillary expansion.

The patients in the aligner group had treatment completed exclusively with clear aligners (Invisalign®, Align Technology, San Jose, Calif) with 0.38 ± 0.48 mm of interproximal enamel reduction (IPR) in the lower anterior segment as part of their treatment plans. The patients in the fixed appliance group had

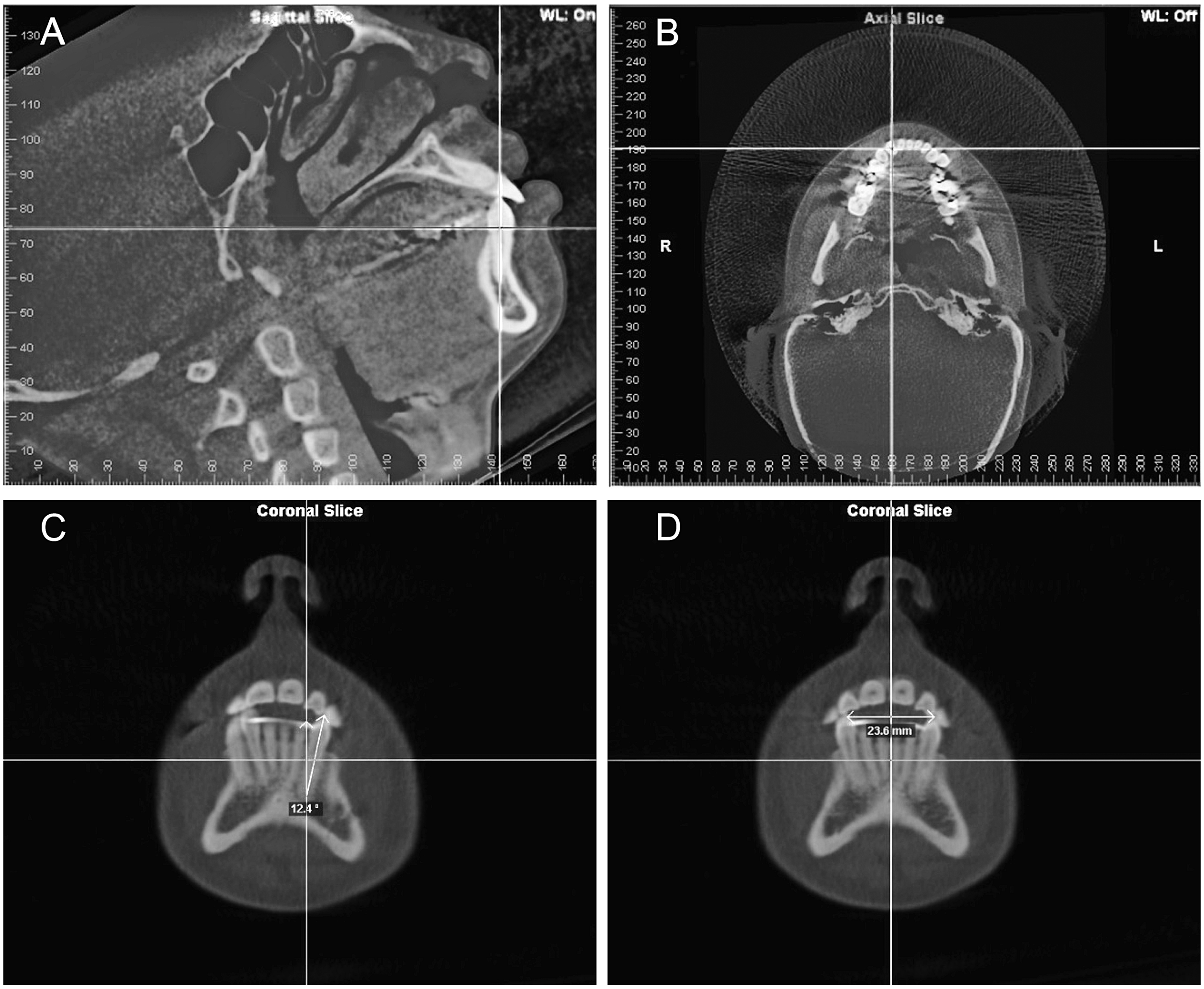

Figure 1. Measuring the buccolingual inclination of mandibular canines and the intercanine distance. (A) The sagittal slice is rotated until the coronal (vertical) line is superimposed on the long axis of the canine. (B) In the axial slice, the sagittal (vertical) and coronal (horizontal) lines are set to intersect in the center of the canine. (C) In the coronal slice, the cusp tip and the apex are connected to form a line that reflects the long axis of the canine. The sagittal (vertical) line is moved until it intersects at the center of the apex. The angular measurement between the lines is positive if the canine is tipped buccally and negative if it is tipped lingually. (D) The intercanine distance is measured in the coronal slice as the linear distance between the canine cusp tips.

treatment completed with preadjusted edgewise appliances using metal twin brackets with built-in angulation of 3° and torque of 0° on the mandibular canines and 0.016 × 0.022-inch or 0.019 × 0.025-inch stainless-steel archwires in 0.018-inch or 0.022-inch slot brackets, respectively, allowing a calculated torque "slop" of 9°. The treatment of the patients in the fixed appliance group included 0.14 ± 0.40 mm of IPR in the lower anterior segment.

All measurements were performed on deidentified CBCT scans using Dolphin Imaging 11.5 (Dolphin Imaging, Chatsworth, Calif) viewed on a 19-inch computer monitor with landscape orientation at a resolution of 1280 × 1024 pixels (1908FPC, Dell, Round Rock, Tex). For each patient, the buccolingual inclinations of mandibular canines and the intercanine distance were measured in pre- and posttreatment CBCT scans, as follows. The midsagittal plane (MSP) was identified as the plane that includes the superior tip of the odontoid process of the axis (Dent), the tip of the anterior nasal spine (ANS), and nasion (N). Each CBCT scan was oriented so that this MSP coincided with the sagittal plane designated by the imaging software. In the coronal view, the skull orientation was tilted anteriorly or posteriorly so that the mandibular canines came into full view. The buccolingual inclination of mandibular canines was then measured to the nearest 0.1° as the angle between the tooth's long axis and the MSP. Positive values were given to canines with the crown positioned lateral to the root, whereas negative values were given to canines with the crown positioned medial to the root (Figure 1). The

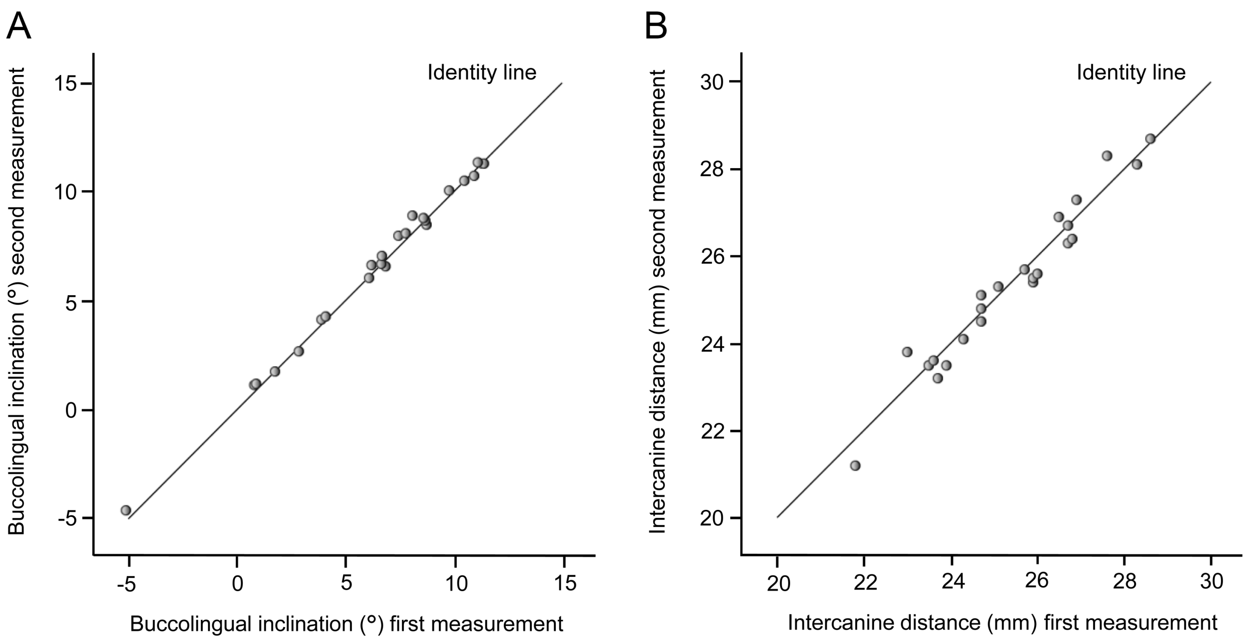

Figure 2. Identity plots generated as parts of the Bland-Altman analyses for repeatability of measurements at two different time points. (A) Buccolingual inclination; (B) Intercanine distance.

intercanine distance was measured to the nearest 0.1 mm as the linear distance between the right and left mandibular canine cusp tips. If a cusp tip was worn flat, the intercanine distance was measured from the midpoint of the flattened cusp tip. A single operator performed all measurements in a randomized order, blinded to treatment group. Twelve of the 60 patients—six per group—were randomly chosen and the measurements were repeated after a 3-week washout period to assess repeatability.

Statistical Analysis

Bland-Altman analyses were performed, separately for buccolingual inclination of canines and intercanine distance, to assess repeatability of the measurements. Mean values, standard deviations, and coefficients of variation (COVs) were calculated, separately for each group, for the buccolingual inclination and intercanine distance before (T1) and after (T2) treatment. Differences between the groups and differences between T1 and T2 were tested for statistical significance using unpaired and paired *t*-tests, respectively, after the data had been tested for normality (Kolmogorov-Smirnov test) and equality of variances (Levene's test). In order to quantify the relationship between the change (T2-T1) in buccolingual inclination and the change (T2-T1) in intercanine distance, Pearson's correlation coefficients were calculated, separately for each group, after the right and left angular measurements of each patient had been averaged. Statistical analyses were performed using SigmaStat 3.5 (Systat Software, Point Richmond, Calif) and SAS 9.4 (SAS Institute Inc, Cary, NC). For all tests, $P < .05$ was considered statistically significant.

RESULTS

Bland-Altman analyses of the buccolingual inclination of mandibular canines and the intercanine distance measured at two time points yielded a mean difference of 0.158°, with limits of agreement (LoA) of −0.373 to 0.689°, for the buccolingual inclination and a mean difference of −0.046 mm, with LoA of −0.799 to 0.708 mm, for the intercanine distance. The proximity of the data points to the identity line

Table 2. Buccolingual Inclination of Mandibular Canines Before and After Orthodontic Treatment[a]

	Before Treatment (T1)		After Treatment (T2)	
Group	Inclination, °	COV, %	Inclination, °	COV, %
Clear aligner (n = 30)	6.6 ± 3.2	48.8	7.3 ± 2.8*	37.6
Fixed appliance (n = 30)	6.6 ± 3.4†	52.2	4.7 ± 4.8*†	101.6

[a] COV indicates coefficient of variation. Results are mean values ± standard deviation.
* Statistically significant differences between groups (unpaired *t*-test, $P < .05$)
† Statistically significant differences between T1 and T2 (paired *t*-test, $P < .05$).

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Table 3. Mandibular Intercanine Distance Before and After Orthodontic Treatment[a]

Group	Before Treatment (T1)		After Treatment (T2)	
	Distance, mm	COV, %	Distance, mm	COV, %
Clear aligner (n = 30)	24.8 ± 1.9†	7.7	25.4 ± 1.3†	5.2
Fixed appliance (n = 30)	25.3 ± 2.3	9.2	25.2 ± 1.5	6.0

[a] COV indicates coefficient of variation. Results are mean values ± standard deviation. No statistically significant differences between groups (unpaired *t*-test, $P > .05$).

† Statistically significant differences between T1 and T2 (paired *t*-test, $P < .05$).

in the identity plots (Figure 2) indicates excellent repeatability.

Mean values, standard deviations, and COVs of the buccolingual inclination are shown in Table 2. Most of the mandibular canines had positive buccolingual inclinations (ie, their crowns were positioned lateral to their roots both before [all 60 in the aligner group; 57 in the fixed appliance group] and after treatment [all 60 in the aligner group; 49 in the fixed appliance group]). Differences between the groups were statistically significant as follows: The buccolingual inclination was greater in the aligner group than in the fixed appliance group at T2 ($P = .011$). In the fixed appliance group, the buccolingual inclination decreased over the course of the treatment, leaving the teeth more upright at T2 ($P = .046$). In contrast, the buccolingual inclination tended to increase with treatment in the aligner group; however, this change was not statistically significant ($P = .132$).

Mean values, standard deviations, and COVs of the mandibular intercanine distance are shown in Table 3. There were no statistically significant differences in intercanine distance between the groups at T1 ($P = .336$) or at T2 ($P = .546$). In the aligner group, the intercanine distance increased significantly over the course of treatment ($P = .021$), whereas it did not change significantly in the fixed appliance group ($P = .869$).

The changes (T2-T1) in buccolingual inclination of mandibular canines and intercanine distance are displayed in Table 4. Pearson's correlation coefficients calculated for the changes in these variables were 0.665 ($P < .001$) in the aligner group and 0.812 ($P < .001$) in the fixed appliance group, indicating statistically significant positive correlations between buccolingual inclination and intercanine distance in both groups.

Table 4. Changes (Difference T2-T1) in Buccolingual Inclination of Mandibular Canines and Intercanine Distance Over the Course of Treatment[a]

Group	Inclination, °	Distance, mm	Pearson's *r*
Clear aligner (n = 30)	0.7 ± 2.5	0.7 ± 1.5	0.665*
Fixed appliance (n = 30)	−1.9 ± 5.1	−0.1 ± 2.4	0.812*

[a] Results are mean values ± standard deviation.

* Statistically significant positive correlation ($P < .001$).

DISCUSSION

This study explored the effects of orthodontic treatment with clear aligners on the buccolingual inclination and linear distance of mandibular canines. Using existing CBCT scans of patients who had undergone treatment with either clear aligners or preadjusted edgewise appliances, our principal finding was that clear aligner therapy generally led to an increased mandibular intercanine distance, with relatively unchanged buccolingual inclination, in contrast to fixed appliance therapy, which led to more upright mandibular canines, with unchanged intercanine distance.

The statistically insignificant change in buccolingual inclination of mandibular canines with aligners is an unexpected finding in that many studies[1,2,5,6] report limitations of aligner therapy, especially with respect to translational tooth movement and torque control. Some authors[16] even doubt whether bodily movements or torque can be accomplished at all by aligners and therefore recommend using aligners only in cases in which tipping movements are needed. Moreover, the posttreatment buccolingual canine inclination in the aligner group was less variable than in the fixed appliance group. This finding may be attributed to a variety of reasons. For example, despite being treated by different clinicians, all aligner cases were completed using the same treatment simulation software and CAD/CAM process to fabricate the aligner series. Furthermore, the ideal canine position was determined prior to starting treatment, and canine movement was restricted by full coronal coverage of the aligner to allow for movement into the predetermined position. It is clear that the movement of the coronal portion of the tooth is well defined, and one may think that root movement is too. However, this is not necessarily the case. According to Ali and Miethke,[2] "all teeth receive a rudimentary root" when the dentition is scanned into the Invisalign software, suggesting that root position is not an important factor when simulating treatment. However, rather than assuming that the final root position is incidental, it can be surmised that the software has sufficient accuracy in placing the "rudimentary roots" onto the teeth.

In contrast to the aligner group, the fixed appliance group showed a significant change in mandibular canine buccolingual inclination over the course of treatment and a more variable final inclination. There are a number of possible explanations for these findings. First, the change in inclination can be attributed to buccal root movement, which resulted mainly from the expression of the torque built into the preprogrammed brackets. Comparison of pre- and posttreatment CBCT scans indicated that the canine roots in the fixed appliance group were also tipped distally and therewith moved into a wider part of the arch. This change in angulation, which made the teeth appear more lingually inclined in the frontal plane, was not as noticeable in the aligner group. Secondly, the bracket placement undoubtedly varied among the different clinicians and the different patients. One study[17] reports the greatest angular variation in bracket placement to be on the canines. Additionally, anatomical variations of teeth, specifically the convexity of the buccal surfaces, have a notable effect on the amount of torque that actually occurs.[18] Moreover, interbracket distance and mode of ligation influence the torque movement with fixed appliances.[19] Lastly, with fixed appliance treatment, the final canine position is typically not predetermined, as in clear aligner therapy, but may be adjusted by the clinician throughout treatment.

The mandibular intercanine distances determined in our study are in accordance with average mandibular intercanine distances of 24–26 mm reported by others.[20,21] Whereas there was no change in the intercanine distance over the course of treatment in the fixed appliance group, the intercanine distance increased slightly in the aligner group. This is noteworthy, as it has been suggested that increased intercanine distance may lead to decreased buccal bone thickness in some cases, thereby predisposing mandibular canines to gingival recession and bony defects.[22] Moreover, the intercanine distance became less variable with treatment in both groups. It is known that mandibular incisor widths tend to fall within a narrow range of variation in the general population;[23] therefore, it is comprehensible that the intercanine distance became more uniform as irregularities in the lower anterior segment were corrected.

It is clear that the initial space situation can influence the treatment outcome. Since there were no significant differences in the amounts of pretreatment crowding or IPR performed between the groups, the change in intercanine distance must be attributed to the different tooth movements in the two groups. Combining the information on buccolingual canine inclination and linear distance of their cusp tips, it becomes clear that these teeth were more upright in the fixed appliance group, whereas they were, albeit statistically insignificantly, tipped buccally in the aligner group, which increased the intercanine distance. These differences in tooth movement most likely result from the different abilities of the orthodontic appliances to control root movement. It has been suggested that one of the most difficult problems to address with aligners is control of root movement, especially the buccolingual inclination.[24] The force couple generated by an aligner torquing a tooth consists of a tipping force near the gingival margin and a resulting force produced by movement of the tooth against the opposite inner surface of the appliance, near the incisal edge. Since the gingival margin of the aligner is elastic, it is difficult to control the forces applied in this region.[16] Because of these biomechanical limitations, fixed appliance therapy has been suggested to be superior at correcting buccolingual inclination.[4] The present findings corroborate these suggestions for mandibular canines, as they indicate relatively poorer control of root position with aligners.

CONCLUSION

- Orthodontic treatment with clear aligners tends to increase the mandibular intercanine distance, with little change in inclination, in contrast to treatment with fixed appliances, which leaves the intercanine distance unchanged but leads to more upright mandibular canines.

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