Orthodontics & Craniofacial Research

ORIGINAL ARTICLE

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Effect of orthodontic treatment with preadjusted edgewise appliances on the buccolingual inclination of mandibular canines: a CBCT study

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Date:
Accepted 3 March 2015

DOI: 10.1111/ocr.12092

Hamdan H. A., Grünheid T., Larson B. E. Effect of orthodontic treatment with preadjusted edgewise appliances on the buccolingual inclination of mandibular canines: a CBCT study
Orthod Craniofac Res 2015; **18**: 156–164. © 2015 John Wiley & Sons A/S. Published by John Wiley & Sons Ltd

Structured Abstract

Objectives – To assess the effects of treatment with preadjusted edgewise appliances on the buccolingual inclination of mandibular canines and the intercanine distance.

Setting and Sample Population – The Division of Orthodontics at the University of Minnesota. Thirty patients whose treatment included extraction of mandibular first premolars and 30 patients whose treatment did not include extractions.

Material and Methods – The buccolingual inclination of mandibular canines and their linear distance were measured on cone beam computed tomograms before and after treatment in both patient groups. Differences between extraction and non-extraction groups and between pre- and post-treatment measurements were tested for statistical significance, and the correlation between the buccolingual inclination and the intercanine distance was computed.

Results – Post-treatment, the buccolingual inclination of mandibular canines was significantly greater in the non-extraction group than in the extraction group. In both groups, the canines became more lingually inclined with treatment (non-extraction group: −2.1°; extraction group: −4.1°). The intercanine distance increased significantly in the extraction group (+1.2 mm) but not in the non-extraction group (−0.5 mm). While there was a significant positive correlation between the buccolingual inclination and the mandibular intercanine distance in both groups before treatment, after treatment this correlation was significant only in the non-extraction group.

Conclusion – Orthodontic treatment with preadjusted edgewise appliances results in more lingually inclined mandibular canines together with an increased intercanine distance, especially in patients whose treatment involves the extraction of mandibular first premolars.

Key words: buccolingual inclination; cone beam computed tomography; intercanine distance; mandibular canine

Introduction

The buccolingual inclination of teeth is an integral part of orthodontic diagnosis, treatment, and assessment of treatment results (1, 2). Anterior and canine guidance, adequate intercuspation, and the absence of occlusal interferences, for example, are reliant to a degree on appropriate buccolingual tooth inclination. Moreover, buccolingual tooth inclinations are related to dental and periodontal features such as wear patterns and gingival recession, respectively (3). For these reasons, 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 and has the potential of adding a new parameter for orthodontic treatment success. This study explored the buccolingual inclination of mandibular canines. With their single, long roots, these teeth are relatively easy to measure and, more importantly, are of special interest due to their location, their role in resolving incisor crowding, and their importance in achieving canine guidance.

Although attempts have been made to assess the buccolingual inclination of some teeth on two-dimensional (2D) views, such as panoramic radiographs, these views are of limited clinical usefulness for the assessment of tooth orientation (4). In fact, panoramic radiographs have been shown to be of questionable reliability even when measuring mesiodistal root angulations (5, 6). Recently, 3D imaging using cone beam computed tomography (CBCT) has given orthodontists the ability to reliably assess the positions of individual teeth in any given plane (7, 8), view their long axes, and measure their inclination against any line or plane with good accuracy (9).

The buccolingual inclination influences the mandibular intercanine distance, which has been shown to be of critical importance for the long-term stability of mandibular anterior alignment (10, 11). Although changes in the mandibular intercanine distance with age, during orthodontic treatment, and following retention are well described (12–15), most studies have used dental models to analyze these changes. Combining intercanine distance data with information on the buccolingual inclination of mandibular canines would provide better insight into the 3D positional changes of these teeth during orthodontic treatment. Therefore, the aim of this study was to assess the buccolingual inclination of mandibular canines before and after orthodontic treatment using CBCT scans and to explore a possible correlation between the buccolingual inclination of mandibular canines and their linear distance.

Materials and methods

A total of 60 patients were selected for this retrospective cohort study using the following inclusion criteria: 1) fully erupted permanent dentition including incisors, canines, premolars, and first molars; 2) Angle Class I malocclusion with a normal interarch molar relation; 3) completed orthodontic treatment with preadjusted edgewise appliances using metal twin brackets with built-in angulation of 3° and torque of 0° on mandibular canines (3M Unitek, Monrovia, CA, USA); 4) treatment finished with 0.016 × 0.022″ or 0.019 × 0.025″ stainless steel arch wires in 0.018″ or 0.022″ slot brackets, respectively, allowing a calculated torque slop of 9°; 5) pre- and post-treatment full field of view (17 × 23 cm) CBCT scans obtained with an i-CAT Next Generation (Imaging Sciences International, Hatfield, PA, USA) at a voxel size of 0.3 mm^3, scan time of 8.9 s, tube voltage of 120 kV, and tube current of 18.54 mAs as part of the diagnostic records for comprehensive orthodontic treatment as per the protocol used at the Division of Orthodontics at the University of Minnesota; and 6) both mandibular canines clearly visible in the CBCT scans. All patients had completed comprehensive orthodontic treatment under the supervision of experienced orthodontic specialists. Patients were excluded if they had syndromes exhibiting facial malformation or cleft lip and/or palate, if their orthodontic treatment had been performed using removable appliances, such as clear aligners or functional appliances, or if their treatment involved maxillary expansion.

The patients were selected in pairs matched for age and gender, each pair consisting of one patient whose treatment involved bilateral extractions of mandibular first premolars and another whose treatment did not involve such extractions, to form a non-extraction and an extraction group. Consequently, the non-extraction and extraction groups each consisted of 15 male and 15 female patients with similar average ages. A descriptive summary of patient age and treatment time is shown in Table 1. The reasons for extraction of premolars included alleviation of moderate to severe crowding (range 4.29–9.03 mm) and/or correction of incisor proclination, but not orthodontic camouflage of an underlying skeletal discrepancy. This is important as it determines relative anchorage demands in the mandible and the amount of lower canine distalization in extraction cases.

All measurements were performed on de-identified CBCT scans using Dolphin Imaging Software (v. 11.5; Dolphin Imaging and Management Solutions, Chatsworth, CA, USA) using a 19-inch computer monitor with landscape screen orientation at a resolution of 1280 × 1024 pixels (1908FPC; Dell, Round Rock, TX, USA). The research protocol including the use of existing CBCT scans had been approved by the Institutional Review Board at the University of Minnesota.

The midsagittal plane (MSP) was defined 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 the nasion (N). Each CBCT scan was oriented so that the MSP coincided with the sagittal plane designated by the imaging software (Fig. 1). In the coronal view, skull orientation was tilted anteriorly or posteriorly so that the mandibular canines came into full view. The buccolingual inclination was defined as the angle between a tooth's long axis and the MSP and measured to the nearest 0.1°. Positive values were given to canines whose crowns were lateral to their roots, whereas negative values were given to canines whose crowns were medial to their roots (Fig. 2). The intercanine distance was defined as the linear distance between the cusp tips of mandibular canines and measured to the nearest 0.1 mm. If a cusp tip was worn flat, the intercanine distance was measured from the midpoint of the flattened cusp tip.

For each patient, the buccolingual inclinations of right and left mandibular canines as well as the intercanine distance were measured in pre- and post-treatment CBCT scans. All measurements were performed in duplicate, in a randomized order, by a single operator with a washout period of three weeks between measurements to assess repeatability.

Statistical analysis

Intraclass correlation coefficients were calculated and Bland-Altman analyses were performed, separately for buccolingual inclination of canines and intercanine distance, to assess repeatability of measurements. Mean values, standard deviations, and coefficients of variation (COVs) were calculated, separately for each group, for the buccolingual inclination and linear distance of mandibular canines before (T1) and after (T2) orthodontic treatment. Differences between the groups and differences between T1

Table 1. **Descriptive summary of patient age and treatment time**

	Age (years)		Treatment time (months)	
Group	Mean (SD)	Range	Mean (SD)	Range
Non-extraction (n = 30)	26.2 (11.4)	16.8–58.2	21.2 (5.1)	14.2–32.4
Extraction (n = 30)	26.9 (12.0)	16.5–57.5	26.1 (5.9)	15.2–38.0

SD, standard deviation.

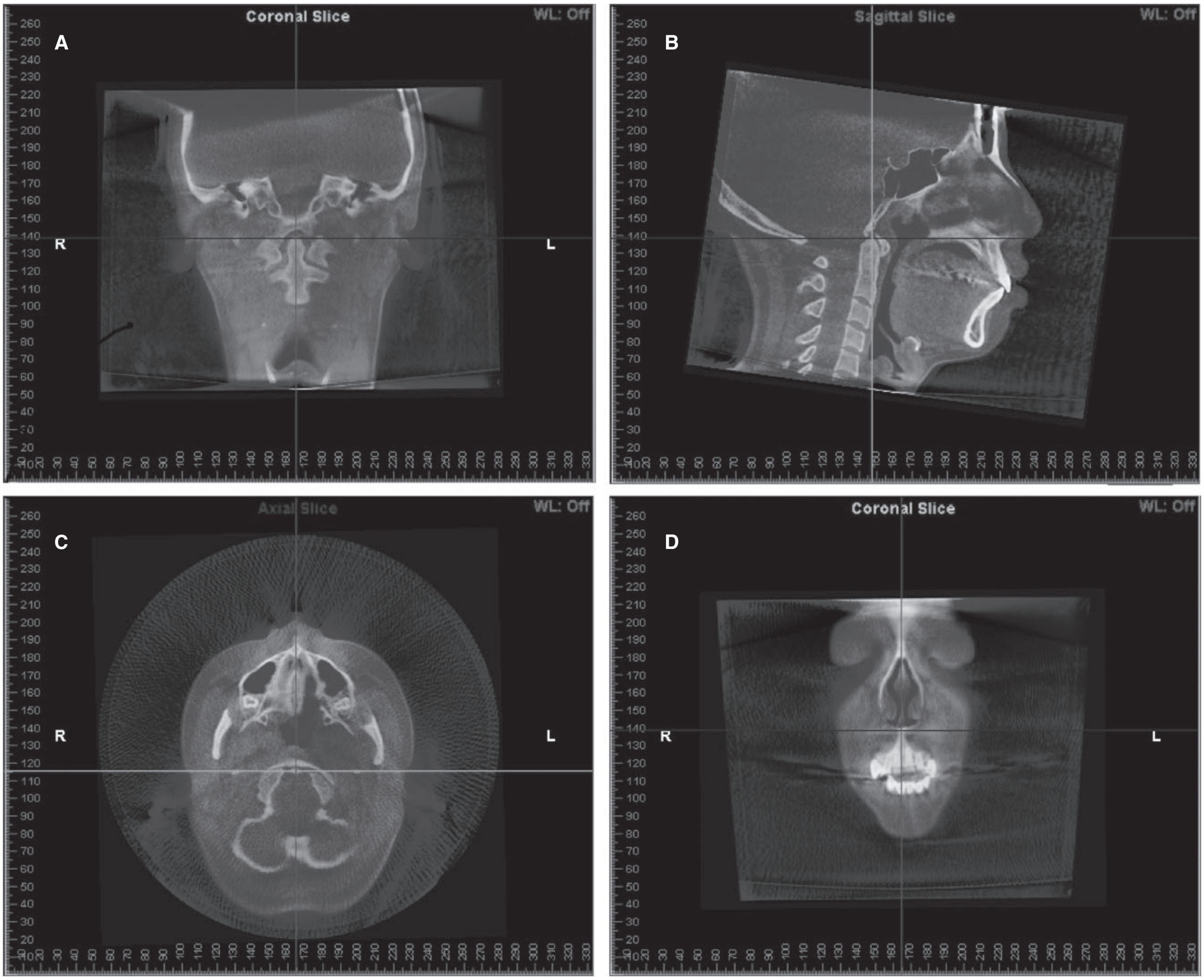

Fig. 1. Technique used to set the midsagittal plane as a reference plane for measurements. (A) In the coronal slice, the axial (horizontal) and sagittal (vertical) lines are set to intersect in the Dent point. (B) The sagittal slice is rotated until the axial line passes through ANS. (C) The axial slice is rotated until the sagittal line passes through ANS. (D) The coronal slice is rotated until the sagittal line passes through the N point.

and T2 were tested for statistical significance using independent samples *t*-tests and paired samples *t*-tests, respectively, after the data had been tested for normality (Kolmogorov–Smirnov test) and equality of variances (Levene's test). To quantify the relationship between the buccolingual inclination of mandibular canines and their linear distance, Pearson's correlation coefficients were calculated, separately for each group at T1 and T2, after the right and left angular measurements of each patient had been averaged. Statistical analyses were performed using SigmaStat 3.5 (Systat Software Inc., Point Richmond, CA, USA) and Stata 13 (StataCorp LP, College Station, TX, USA). For all tests, $p < 0.05$ was considered statistically significant.

Results

All measurements had intraclass correlation coefficients >0.95 indicating excellent repeatability. Bland-Altman comparisons of the buccolingual inclination of mandibular canines and their linear distance assessed at two different time points yielded a mean difference of 0.301° (95% confidence interval: −0.145 to 0.746) with limits of agreement (LoA) of −4.630 to 5.232° for the

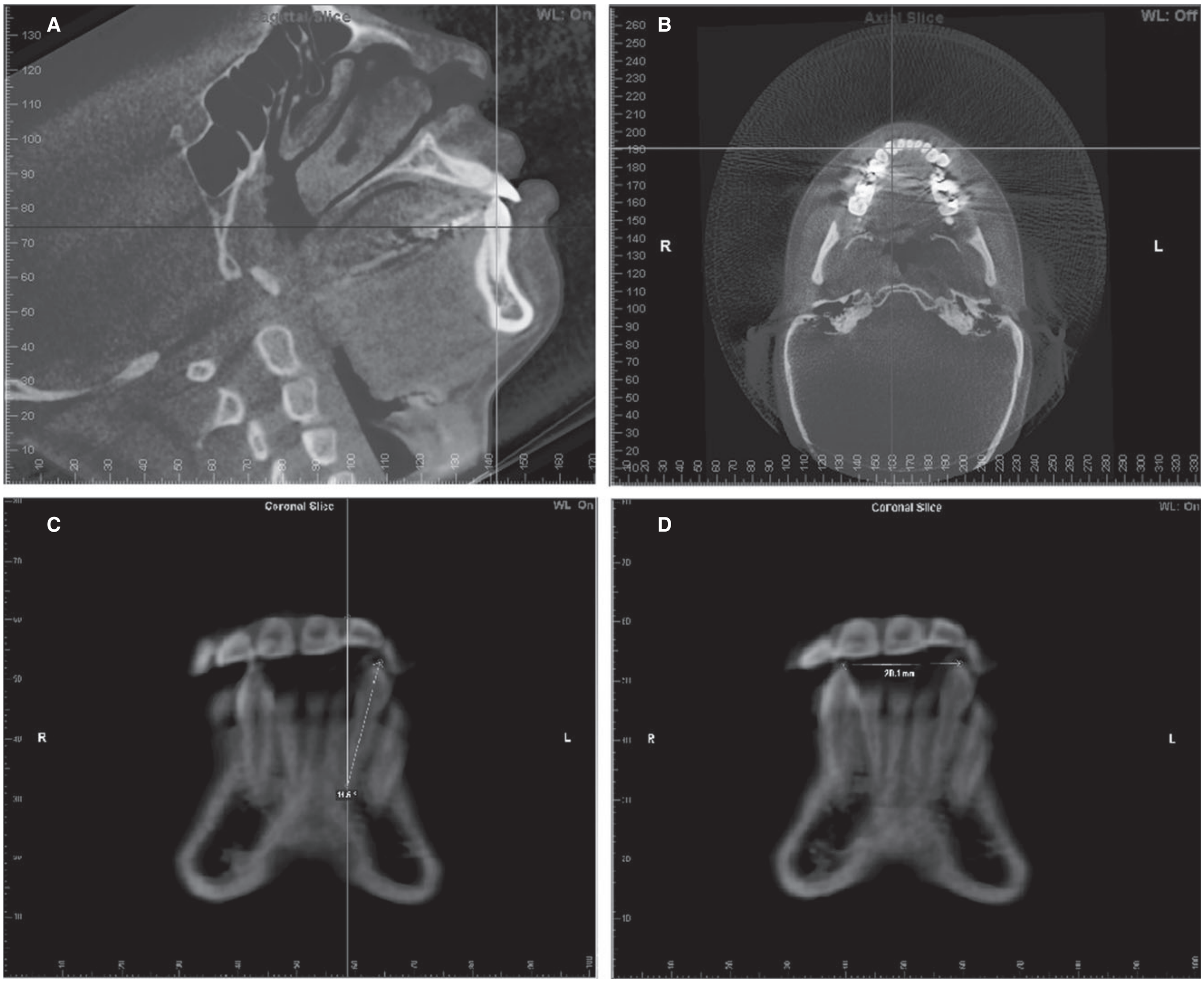

Fig. 2. Techniques used to measure the buccolingual inclination of mandibular canines and the intercanine distance. (A) The sagittal slice is rotated until the coronal (vertical) line is superimposed on the long axis of the canine. (B) The sagittal (vertical) and coronal (horizontal) lines are set to intersect in the center of the canine. (C) Measuring the buccolingual inclination 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) Measuring intercanine distance in the coronal slice: The canine cusp tips are selected to measure the linear distance between them.

buccolingual inclination, and a mean difference of −0.086 mm (95% confidence interval: −0.264 to 0.092) with LoA of −2.058 to 1.886 mm for the intercanine distance.

Mean values, standard deviations, and COVs of the buccolingual inclination of mandibular canines are shown in Table 2. The majority of the canines had positive buccolingual inclinations; that is, their crowns were lateral to their roots, both before (53 of 60 in the extraction group; 55 of 60 in the non-extraction group) and after treatment (41 of 60 in the extraction group; 52 of 60 in the non-extraction group). Differences between the groups were statistically significant as follows: The buccolingual inclination was greater in the non-extraction group than in the extraction group at T2 ($p = 0.015$). In the extraction group, the buccolingual inclination decreased over the course of the treatment, leaving the teeth more lingually inclined at T2 ($p < 0.001$). Furthermore, in both groups the COVs were greater at T2, indicating greater variability in the buccolingual inclinations after treatment.

Mean values, standard deviations, and COVs of the mandibular intercanine distance are shown

Table 2. **Buccolingual inclination of mandibular canines before and after orthodontic treatment**

	Before treatment (T1)		After treatment (T2)	
Group	Inclination (°)	COV	Inclination (°)	COV
Non-extraction (n = 30)	7.0 (4.7)	0.67	4.9 (4.9)*	1.00
Extraction (n = 30)	6.0 (4.7)†	0.78	1.9 (4.2)*†	2.21

Results are mean values (standard deviation).
COV, coefficient of variation.
*Statistically significant differences between groups (independent samples *t*-test, $p < 0.05$).
†Statistically significant differences between T1 and T2 (paired samples *t*-test, $p < 0.05$).

Table 3. **Mandibular linear intercanine distance before and after orthodontic treatment**

	Before treatment (T1)		After treatment (T2)	
Group	Distance (mm)	COV	Distance (mm)	COV
Non-extraction (n = 30)	24.7 (2.3)	0.09	24.2 (1.7)*	0.07
Extraction (n = 30)	24.4 (2.6)†	0.11	25.6 (1.6)*†	0.06

Results are mean values (standard deviation).
COV, coefficient of variation.
*Statistically significant differences between groups (independent samples *t*-test, $p < 0.05$).
†Statistically significant differences between T1 and T2 (paired samples *t*-test, $p < 0.05$).

in Table 3. While the intercanine distances were very similar in the two groups at T1, the intercanine distance at T2 was statistically significantly larger in the extraction group than in the non-extraction group ($p = 0.002$). The extraction group also showed a statistically significant increase in the intercanine distance over the course of treatment ($p = 0.031$), whereas the intercanine distance in the non-extraction group did not change significantly ($p = 0.385$). In both groups, the COVs were smaller at T2, indicating less variability in intercanine distance after orthodontic treatment.

Pearson's correlation coefficients calculated for buccolingual inclination and mandibular intercanine distance are shown in Table 4. The correlation was highest in the extraction group before treatment. While there was a statistically significant positive correlation between the buccolingual inclination of mandibular canines and their linear distance in both groups at T1 (non-extraction group $p = 0.003$; extraction group $p = 0.014$), at T2 this correlation was significant only in the non-extraction group (non-extraction group $p = 0.027$; extraction group $p = 0.192$).

Discussion

The present study explored changes in the buccolingual inclination of mandibular canines with orthodontic treatment on CBCT scans. CBCT, while providing proven diagnostic and therapeutic benefits, also exposes patients to a higher level of radiation than conventional 2D digital radiography (16). For this reason, the use of CBCT in orthodontic imaging is an area of intense discussion among clinicians. Opinions range from advocating its routine use for all patients to limiting its use to specific cases, in which conventional radiography cannot supply satisfactory diagnostic information (17–21). It is recognized that using CBCT to obtain objective diagnostic information in all 3 planes of space may not be consistent with regulations or guidelines outside the United States.

Table 4. **Pearson's product-moment correlation (*r*) between buccolingual inclination of mandibular canines and linear intercanine distance before and after orthodontic treatment**

Group	Before treatment (T1)	After treatment (T2)
Non-extraction (n = 30)	0.441*	0.403*
Extraction (n = 30)	0.516*	0.245

*Statistically significant positive correlation ($p < 0.05$).

Using this technology, the principal finding of the present study was that orthodontic treatment generally results in more lingually inclined mandibular canines together with greater variability in their buccolingual inclination. In the patient sample studied, there were no significant differences in the buccolingual inclination between the groups before treatment; however, there was greater variation in the extraction group than in the non-extraction group. A possible explanation for this finding may be that patients requiring premolar extraction as part of their orthodontic treatment typically have more anterior crowding, and in turn more irregularity in the position, inclination and angulation of anterior teeth.

Interestingly, orthodontic treatment led to more lingually inclined mandibular canines, especially in the extraction group, in which this increase in lingual inclination was accompanied with an increase in intercanine distance. This coupling of change in buccolingual inclination and increase in intercanine distance is noteworthy as it has been suggested that it may lead to decreased buccal bone thickness in some cases, thereby predisposing mandibular canines to gingival recession and bony defects (22, 23). Comparison of pre- and post-treatment CBCT scans yielded that the apices of the mandibular canines were distalized and lateralized more than their cusp tips. This finding was more pronounced in the extraction group. It is conceivable that the angulation of the bracket influenced this type of tooth movement. As the angulation of the mandibular canines was changed and distal root tipping was added, their roots were also moved into a wider part of the arch, which made them appear to be more lingually inclined in the frontal plane. As a primary aim of treatment involving the extraction of first premolars is typically to distalize the canines into the extraction space to allow alleviation of crowding in the anterior segment, it can be understood why this type of tooth movement was more pronounced in the extraction group.

Interestingly, treatment with preadjusted appliances led to more, not less, variation in the buccolingual inclinations of mandibular canines among patients. This finding may suggest that orthodontists tend to focus on achieving good alignment and root parallelism on panoramic radiographs, while not necessarily scrutinizing the buccolingual inclination of teeth at the end of treatment. It may also have to do with the angular placement of brackets and the influence of the angulation on the buccolingual inclination in the frontal plane as discussed above. It has been known that there is substantial interoperator variability in bracket placement with the greatest angular variation in maxillary and mandibular canines (24). This, together with the play of the arch wires in the bracket slot, which probably left some of the prescribed torque information unexpressed, as well as the anatomical variations of teeth, especially the degree of convexity of the labial surface, which has a profound influence on torque expression (25), may explain the increased variation in post-treatment buccolingual inclination.

The mandibular intercanine distances determined in the present study are in accordance with average mandibular intercanine distances of 24–26 mm reported elsewhere (12, 26). While there was only minimal change in the intercanine distance over the course of treatment in the non-extraction group, the intercanine distance increased significantly in the extraction group. This change is consistent with our understanding of orthodontic treatment (27): The unraveling of mandibular anterior crowding after extraction of first premolars leads to an increase in intercanine distance (15). Moreover, as indicated by the reduced COVs in both groups, the intercanine distance became less variable among patients after orthodontic treatment, most likely due to the fact that mandibular incisor widths tend to fall within a narrow range of variation in the general population (28, 29).

The post-treatment mandibular intercanine distance was significantly larger in the extraction group than in the non-extraction group. A difference in intercanine distance between two orthodontically aligned arches is most likely due to wider anterior teeth in one of these arches, in this case the arch that required first premolar extractions (30, 31). To a lesser extent, the difference may be attributed to treatment procedures performed in the non-extraction group to aid with space creation, such as interproximal enamel reduction, which may have left the mandibular anterior teeth slightly narrower, or a difference in archform between the groups. It is conceivable that, as the canines were distalized into the extraction space, the mandibular arch in the extraction group became broader and shorter than in the non-extraction group. As the intercanine distance was measured as the linear distance between the canine cusp tips, and not along the arch, this difference in archform may have contributed to the intergroup difference in intercanine distance.

A few comments must be made on the methodology used. While previous studies have used the mandibular border as a reference to assess tooth inclinations (32), the present study used the MSP. To validate this approach, all measurements were obtained in quadruplicate, that is, two data sets using each reference plane. When the measurements obtained using the MSP were compared with those obtained using the mandibular border method (32), no statistically significant differences were found. This may be due to the fact that the patient sample in the present study had no facial deformities or significant mandibular border irregularities, which could have created disagreement between the measurements obtained using the different reference planes. Although the two methods yielded no statistically significant differences in buccolingual canine inclination, the reference planes might not in every patient be perpendicular to each other, which makes the methods susceptible to different influences. For instance, it is conceivable that a method that uses the MSP as a reference plane may be able to detect mandibular asymmetry expressed in strong right–left differences in buccolingual canine inclination, while the same mandibular asymmetry may be masked when a tangent on the mandibular border is used. It should also be noted that the present data strictly describe the angle between the long axis of mandibular canines and the MSP, that is, the buccolingual inclination in the frontal plane. This angle may not represent the ‘true’ buccolingual inclination perpendicular to the line of the mandibular arch. Further, it needs to be understood that the plane in which the long axis of a mandibular canine lies in relation to the axial plane may change over the course of treatment.

Although more research is warranted to fully understand the 3D positional changes of teeth during treatment with preadjusted edgewise appliances, the present findings may aid in correcting a widely held conception that mandibular canines are typically tipped buccally during orthodontic treatment. They may also draw the attention of orthodontists and bracket manufacturers to root movement, especially because the significant root movements may not have been readily perceivable to many clinicians.

Conclusions

Orthodontic treatment with preadjusted edgewise appliances may lead to more lingually inclined mandibular canines together with increased variability in the buccolingual inclinations of these teeth. In patients whose treatment involves the extraction of mandibular first premolars, these changes are associated with a larger mandibular intercanine distance after treatment.

Clinical relevance

The findings of this study contradict the widely held opinion that preadjusted appliance treatment leads to more buccally inclined mandibular canines after treatment.

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