Journal of the World Federation of Orthodontists 8 (2019) 51–56

Contents lists available at ScienceDirect

Journal of the World Federation of Orthodontists

journal homepage: www.jwfo.org

Research Article

# Use of the WALA ridge to evaluate mandibular molar inclination measured to American Board of Orthodontics standards

Chad M. Rasmussen [a,*], Peini Zhu [b], Christine M. Lohse [c], John E. Volz [d], Thomas J. Salinas [e]

[a] Senior Associate Consultant, Department of Dental Specialties, Mayo Clinic, Rochester, Minnesota
[b] Private Practice, Apple Valley, Minnesota
[c] Statistician, Department of Biomedical Statistics and Informatics, Mayo Clinic, Rochester, Minnesota
[d] Consultant and Assistant Professor, Department of Dental Specialties, Mayo Clinic, Rochester, Minnesota
[e] Consultant and Professor, Department of Dental Specialties, Mayo Clinic, Rochester, Minnesota

ARTICLE INFO

*Article history:*
Received 16 December 2018
Received in revised form
28 January 2019
Accepted 14 February 2019
Available online 16 March 2019

*Keywords:*
ABO standards
Mandibular molar inclination
WALA ridge

ABSTRACT

*Objective:* Evaluation of mandibular molar inclination provides valuable information to the orthodontist when evaluating posterior functional occlusal relationships, diagnosing and treating transverse skeletal and dental relationships, and assessing the quality of orthodontic treatment finishing. Traditional evaluation methods rely on radiographs or diagnostic dental models. Identification of a clinical anatomic landmark that can be evaluated chairside and reliably produces desired treatment results would prove valuable to the clinician.

*Materials and Methods:* Plaster dental casts of 60 posttreatment patients were evaluated for mandibular molar inclination by American Board of Orthodontics (ABO) Cast-Radiograph evaluation standards and compared with the mandibular anatomic landmark the WALA ridge.

*Results:* Mandibular first molars conforming to ABO standards with a vertical difference in buccal and lingual cusp heights $\leq$1.0 mm had an average horizontal WALA-facial axis (FA) distance of 2.56 mm, which was significantly smaller than the 3.11 mm found when molars were ABO nonconforming with vertical cusp height differences of $>$1.0 mm to $\leq$2.0 mm ($P < 0.001$). Mandibular first molars with WALA-FA distances of $\leq$2.5 mm were not significantly more likely to be ABO conforming than those with WALA-FA distances of $>$2.5 mm.

*Conclusions:* Mandibular molars with vertical differences in buccal and lingual cusp heights meeting the ABO standards for inclination have significantly smaller horizontal tooth to mandibular bone distances (WALA-FA).



## 1. Introduction

Establishing a functional occlusion is a hallmark of successful orthodontic treatment. Molar inclination is essential to establishing optimal function [1] and load distribution [2]. A mild curve of Wilson has been associated with increased masticatory muscle activities [3] and increased periodontal breakdown [4,5]. It is equally important that the teeth are kept within their bony housing with respect to the lateral boundaries for periodontal and osseous stabilities [6].

Andrews has described optimal buccolingual molar inclination [7] and its effect on the diagnosis and treatment of the transverse dimension [8]. The Andrews 6-Elements diagnostic method uses an intraoral landmark designated as the WALA ridge from which to evaluate mandibular molar inclination. This ridge is a landmark immediately superior to the mucogingival junction, the shape of which reflects each individual's basal bone [8] for which there is a defined horizontal distance to each mandibular tooth's facial axis (FA) point [9]. The FA point is a dental landmark that represents the midpoint on the facial axis of the clinical crown separating the tooth into occlusal and gingival halves. On the molars it

Funding: The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.
Competing interest: Authors have completed and submitted the ICMJE Form for Disclosure of potential conflicts of interest. None declared.
Provenance and peer review Not commissioned; internally peer reviewed.
* Corresponding author: Department of Dental Specialties, Mayo Clinic, 200 First Street SW, Rochester, MN 55905.
*E-mail address:* rasmussen.chad@mayo.edu (C.M. Rasmussen).

2212-4438/$ – see front matter © 2019 World Federation of Orthodontists.
https://doi.org/10.1016/j.ejwf.2019.02.003

**Table 1**
Patient demographics

| Demographics | n | Mean, y | SD | Range, y |
|---|---|---|---|---|
| Age | | | | |
| Age at final records | 60 | 17.2 | 7.0 | 13–44 |
| Sex | | | | |
| Male | 24 | 17.1 | 5.6 | 13–42 |
| Female | 36 | 17.2 | 7.8 | 13–44 |
| Race | | | | |
| White | 48 | 17.0 | 6.6 | 13–43 |
| Asian | 10 | 18.4 | 9.2 | 13–44 |
| African American | 1 | 15 | NA | NA |
| Other | 1 | 17 | NA | NA |

SD, standard deviation.

corresponds to the buccal pit on the buccal surface [1]. Andrews [9] defined the horizontal distance between the WALA ridge and FA point at the mandibular first molar to be 2.0 mm. There have been recent investigations into use of the WALA ridge as an appropriate landmark from which to individualize arch shapes [10] and to maintain posttreatment stability [11].

The objective of this investigation was to identify whether the WALA ridge is a reliable intraoral anatomic landmark from which to evaluate mandibular molar inclination as measured to the American Board of Orthodontics (ABO) standard. Thus far, no studies have compared the validity of using a horizontal anatomic-based measure (WALA to FA distance) to a vertical dental-based measure (ABO buccal-lingual cusp discrepancy). The hypothesis is that a correlation exists between the WALA-FA distance and molar inclination, and that the WALA ridge can serve as an anatomic landmark to make clinical decisions and produce treatment outcomes conforming to ABO standards.

## 2. Materials and Methods

Institutional review board approval was granted for retrospective chart review. As the ABO Cast-Radiograph Evaluation (CRE) is a posttreatment assessment, inclusion criteria consisted of patients of any age or race who presented with a full permanent dentition (second molar to second molar) at the time of final orthodontic records. Sixty consecutive patients who completed comprehensive fixed-appliance treatment were selected regardless of their pretreatment skeletal or dental presentation and were evaluated by a single examiner (PZ). Exclusion criteria included patients with craniofacial syndromes; cleft lip and palate; congenitally missing, unerupted, or extracted mandibular permanent dentition; evidence of trauma; excessive wear of cusp tips (either in situ or damaged plaster models); plaster models in which the location of the WALA ridge was not clearly captured or able to be identified; periodontal disease; buccal dental restorations on permanent first molars (verified with models or clinical photographs); and/or any patients treated by the examiner.

The patient cohort consisted of 36 female and 24 male individuals with a mean age of 17.2 years (range 13–44) at the time of final orthodontic records. Forty-eight patients were white (80%), 10 were Asian (17%), 1 African American (2%), and 1 of mixed heritage (2%). Demographic features for all 60 patients are summarized in Table 1.

Plaster models were scanned with a 3shape D2000 desktop model scanner and 3shape ScanItManager software, then analyzed with 3shape Ortho Analyzer software (3shape A/S, Copenhagen, Denmark). All measurements were made according to the same protocol. First, a vertical plane is constructed (Figs. 1 and 2). The FA point of the mandibular left and right first molars and the corresponding WALA ridge are identified. The horizontal distance paralleling the model base is digitally measured and recorded as WALA left and WALA right (Fig. 3).

Second, a method of digitally reproducing the ABO step gauge was needed. To simulate the straight portion of the gauge, a point was selected on the mesiobuccal cusp tips of the right and left first molars. Anatomically, the mesiolingual cusps of the mandibular first molar are generally located distal to the mesiobuccal cusps. Displacement of the lingual cusp tips also may occur depending on the amount of rotation of each molar. Measurement from the mesiolingual cusps to the line connecting the mesiobuccal cusp tips thus contained a horizontal component and was deemed

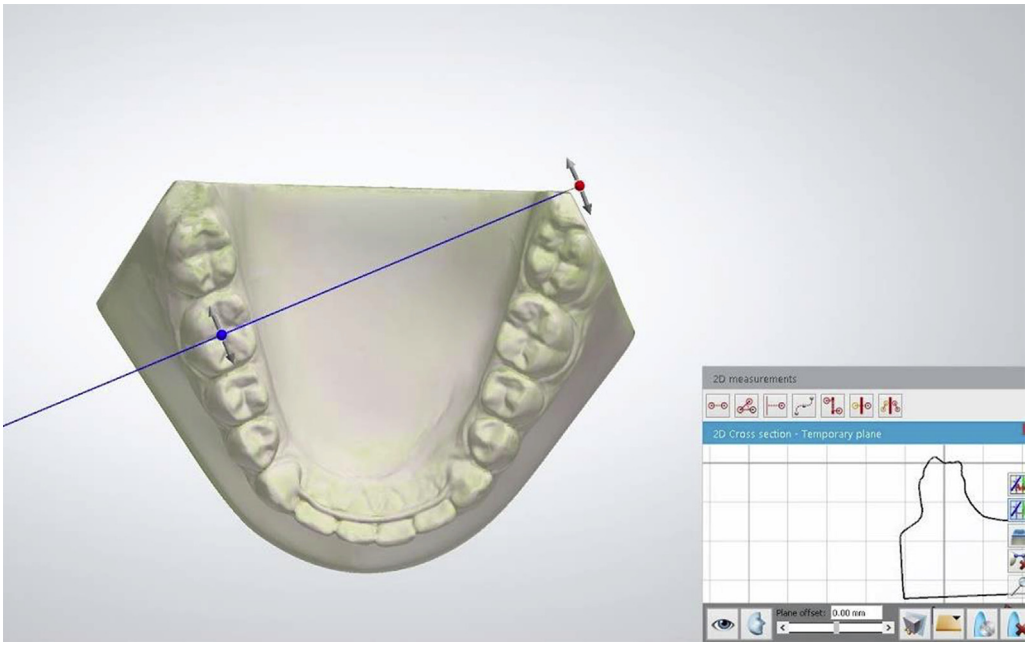


**Fig. 1.** Top-down view of the constructed measurement plane for WALA-FA measurements. The plane is adjusted to align with the buccal and lingual grooves of the mandibular first molar.

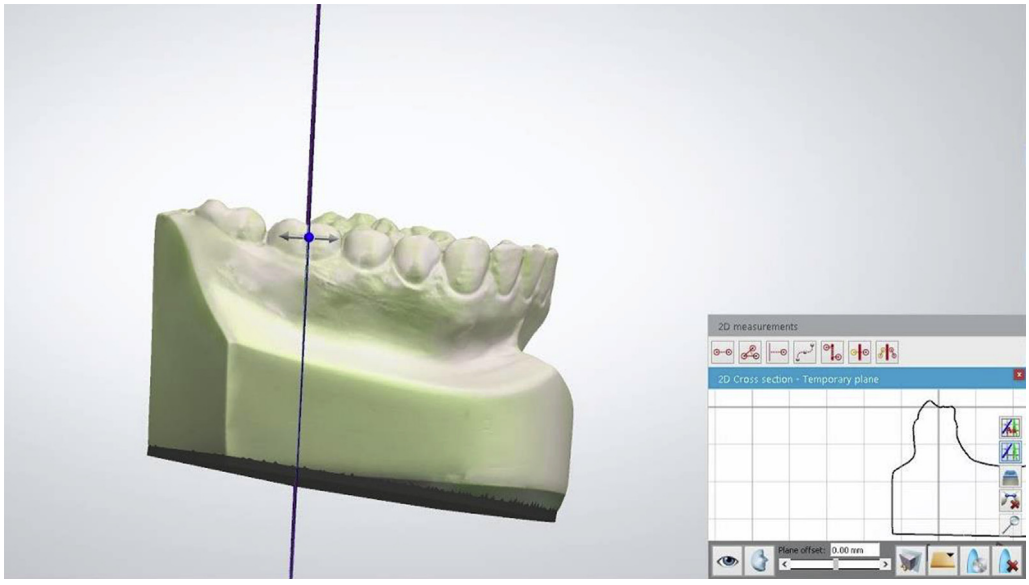


**Fig. 2.** Lateral view of the constructed measurement plane for WALA-FA measurements. The plane is adjusted mesiodistally to align with the buccal groove of the mandibular first molar.

inaccurate. To overcome this shortcoming in measurement, a simulated occlusal plane was constructed. The third point for plane construction was selected to reproduce an occlusal plane, using a point on the incisors as close to the midline as possible without being placed in the embrasure. Digital measurement from the mesiolingual cusp to the constructed plane could then be made with a pure vertical vector, and was recorded as vertical left and vertical right (Fig. 4).

Continuous features were summarized with means, standard deviations (SDs), and ranges; categorical features were summarized with frequency counts and percentages. Differences in the two sets of measurements to evaluate intrarater reliability were evaluated using one-sample *t* tests. Reliability was also measured using Lin's concordance correlation coefficients, which range from 0 to 1 with higher values indicating a greater degree of agreement. Associations between WALA and vertical measurements were evaluated using Pearson correlation coefficients and two-sample *t*-tests. Statistical analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC). *P* values $<0.05$ were considered statistically significant.

To evaluate intrarater reliability, 18 models were randomly selected and measured a second time 2 weeks after the first measurement. The mean difference in the two sets of WALA left measurements was 0.00 (SD 0.09; range −0.15 to 0.16), which was not statistically significantly different from zero ($P = 0.96$). The mean differences in vertical left, WALA right, and vertical right measurements were 0.01 (SD 0.05; range −0.13 to 0.09; $P = 0.56$), 0.05 (SD 0.12; range −0.24 to 0.23; $P = 0.12$), and 0.02 (SD 0.05;

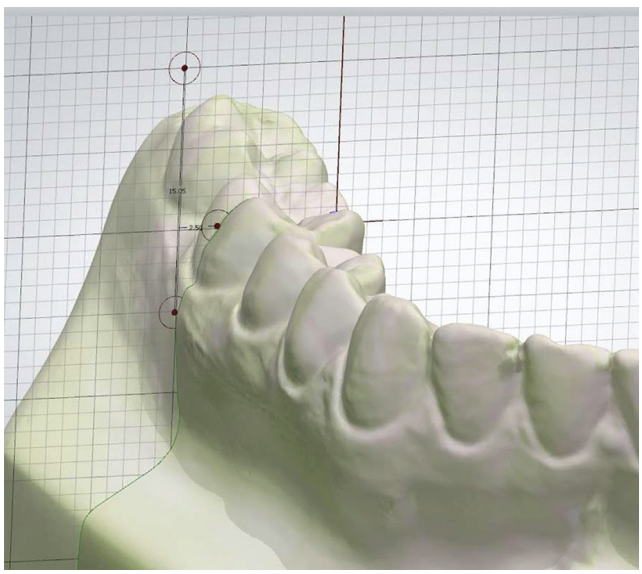

**Fig. 3.** Example measurement of WALA-FA distance. The FA and WALA points are identified on the surface of the scanned model. To measure a point in space, the constructed measurement plane (Figs. 1 and 2) is oriented from right to left so a vertical gridline corresponds to the WALA point. A line is superimposed on the grid to create a vertical extension of WALA point. Measurement is made by 3shape Ortho Analyzer software from the FA point to the vertical extension of the WALA point.

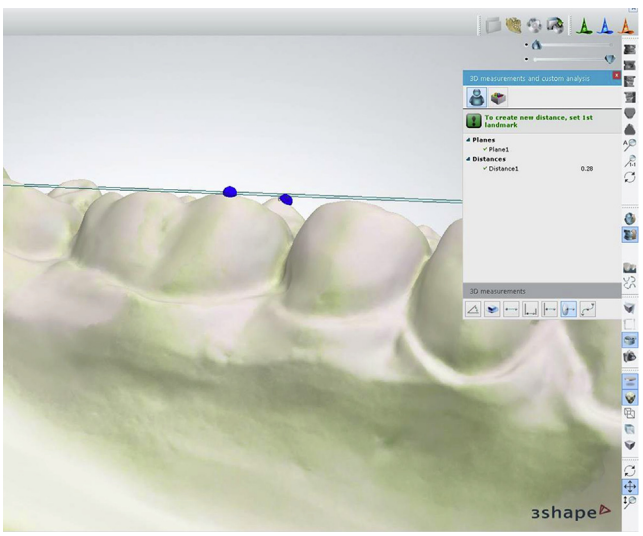


**Fig. 4.** Example of a vertical measurement simulating the ABO step instrument evaluation taken at the mesiolingual cusp of the mandibular right first molar.

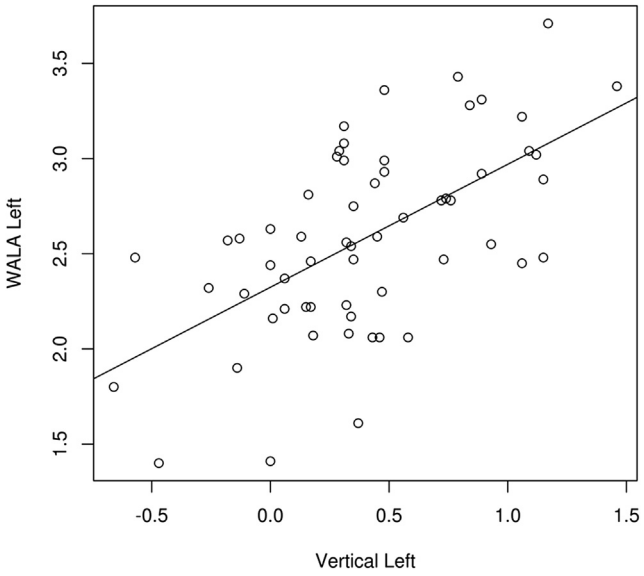


**Fig. 5.** Correlation between vertical left and WALA left (correlation coefficient = 0.59, $P \leq 0.001$).

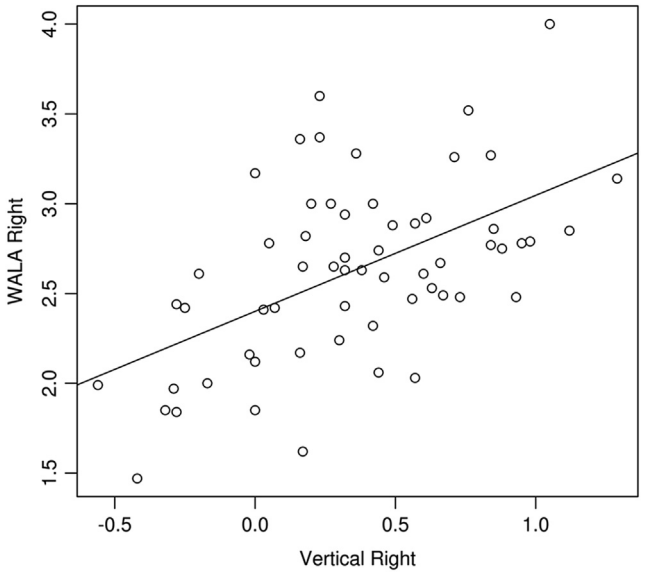


**Fig. 6.** Correlation between vertical right and WALA right (correlation coefficient = 0.53, $P \leq 0.001$).

range −0.06 to 0.15; $P = 0.16$), respectively. Lin's concordance correlation coefficients for WALA left, vertical left, WALA right, and vertical right were 0.98, 0.99, 0.96, and 0.99, respectively, indicating almost perfect agreement.

## 3. Results

The correlation coefficient ($R$) for the association between WALA left and vertical left was 0.59 ($P < 0.001$; Fig. 5), and the correlation coefficient ($R$) for the association between WALA right and vertical right was 0.53 ($P < 0.001$; Fig. 6).

Table 2 displays measurements when sorted by groups according to vertical differences between buccal and lingual cusps. Molars meeting ABO standards whose vertical cusp height difference measured ≤1.0 mm (ABO conforming) numbered 52 (87%) on the left and 57 (95%) on the right. The corresponding mean horizontal WALA-FA distances were 2.52 mm (SD 0.47; range 1.40–3.43) on the left and 2.59 mm (SD 0.47; range 1.47–3.60) on the right.

When the vertical cusp height difference measured >1.0 mm to ≤2.0 mm (ABO nonconforming), 8 (10%) molars on the left and 3 (5%) molars on the right were identified. The corresponding mean horizontal WALA-FA distances increased to 3.02 mm (SD 0.43; range 2.45–3.71) on the left and 2.85 mm, 3.14 mm, and 4.00 mm on the right.

Separated by vertical cusp height differences, Figure 7 illustrates the differences between the two groups of left-sided molars ($P = 0.006$) and Figure 8 the differences in the two groups of right-sided molars ($P = 0.012$), both indicating statistically significant differences.

As the number of ABO nonconforming molars was small, analysis was made with both right and left groups combined to total 11 molars (9%). ABO conforming molars thus totaled 109 (91%). The mean horizontal WALA-FA measurement was 2.56 mm (SD 0.47; range 1.40–3.60) for the ABO conforming group and increased to 3.11 mm (SD 0.47; range 2.45–4.00) in the ABO nonconforming group. These groups are illustrated in Figure 9, again demonstrating statistically significant differences ($P < 0.001$).

A goal of this study was to provide the orthodontist with a clinical tool to make chairside decisions. A reasonable expectation is for a practitioner to be able to judge the horizontal WALA-FA to within 0.5 mm from the optimal 2.0 mm. Using this parameter, the data were divided into two further groups by horizontal WALA-FA distances ≤2.5 mm and those >2.5 mm.

This grouping identifies 51 (43%) molars with a WALA-FA distance of ≤2.5 mm; 49 of these 51 molars (96%) were ABO conforming and 2 molars (4%) were ABO nonconforming. Sixty-nine (57%) molars measured a WALA-FA distance >2.5 mm. Of these, 60 (87%) molars were ABO conforming, and 9 (13%) were ABO nonconforming. There was no statistically significant difference between the number of ABO conforming molars when the WALA-FA distance was ≤2.5 mm, versus those whose WALA-FA was >2.5 mm ($P = 0.087$).

## 4. Discussion

Digital cast measurement was used to evaluate the buccolingual inclination of mandibular first molars using the horizontal distances from a mandibular anatomic landmark at the WALA ridge to the dental FA point, and comparing with the ABO standard, which measures vertical height discrepancies from buccal to lingual cusps. A moderate correlation is observed between the horizontal and vertical measurements. As the vertical difference between buccal and lingual cusps increases, the horizontal WALA-FA distance also increases to a significant degree. The correlation between the horizontal and vertical measurements is 0.59 ($P < 0.001$) and 0.53 ($P < 0.001$) for the left and right sides, respectively.

This study was sufficiently powered to illustrate the significance of the measurements between the right and left vertical and horizontal measurements (Figs. 7 and 8). The difference between horizontal WALA-FA distances in ABO conforming and ABO nonconforming groups of molars is statistically significant ($P < 0.001$). The authors strongly felt it important to include only posttreatment records in this study in order to conform to the definition of the ABO CRE, which is specifically designed for posttreatment analysis. A limitation of this study lies in the small number of ABO nonconforming molars. None of the posttreatment subjects scored a deduction of 2 ABO points (vertical cusp height difference >2.0 mm). In future studies, applying the ABO CRE to pretreatment occlusions would yield a larger variation in the number of ABO nonconforming teeth scoring points.

**Table 2**
Differences in horizontal WALA-FA distances when grouped by vertical cusp height differences (*$P \leq 0.05$; **$P \leq .01$; ***$P \leq 0.001$)

| | n | Vertical cusp height differential, mm | | Horizontal WALA-FA distance | | | *P* |
|---|---|---|---|---|---|---|---|
| | | | | Mean, mm | SD | Range, mm | |
| Left | 52 | ≤1.0 | ABO conforming | 2.52 | 0.47 | 1.40–3.43 | 0.006** |
| | 8 | >1.0 to ≤2.0 | ABO nonconforming | 3.02 | 0.43 | 2.45–3.71 | |
| Right | 57 | ≤1.0 | ABO conforming | 2.59 | 0.47 | 1.47–3.60 | 0.012* |
| | 3 | >1.0 to ≤2.0 | ABO nonconforming | 3.33 | NA | 2.85, 3.14, 4.00 | |
| Combined | 109 | ≤1.0 | ABO conforming | 2.56 | 0.47 | 1.40–3.60 | <0.001*** |
| | 11 | >1.0 to ≤2.0 | ABO nonconforming | 3.11 | 0.47 | 2.45–4.00 | |

ABO, American Board of Orthodontics; FA, facial axis; SD, standard deviation.

When mandibular molar vertical cusp height differences meet the ABO standard, the mean horizontal WALA-FA distance is 2.52 mm for the left side, 2.59 mm for the right side, and 2.56 mm for the two sides combined. These values are higher than those reported by Andrews (2.0 mm) [9], Triviño et al. (2.21 mm) [12], and Kong-Zárate et al. [13] (2.12 mm) in their studies of populations with normal occlusions. Although those studies consisted of nontreated occlusions, the WALA-FA distances in this study's posttreatment sample would certainly be affected by orthodontic treatment mechanics.

Wire archform shapes used in treatment of this patient sample were preformed by the manufacturer and not customized to the shape of the WALA ridge, as has been advocated [14,15]. From clinical experience, the manufacturer-formed archwires are narrower in the posterior region before customization. When orthodontically uprighting a lingually inclined mandibular molar, use of an archwire expanded in the posterior to the shape of the WALA ridge would tip the crown buccally and decrease the posttreatment WALA-FA distance. In contrast, use of a narrower full-size rectangular archwire would leave the crown displaced to the lingual and place a lingual root torque couple in the slot of the bracket. This force system would produce a larger WALA-FA distance. Using preformed narrower archforms may explain the larger WALA-FA distance in this posttreatment population sample.

The amount of lingual tipping present before initiating treatment will also play a role in posttreatment WALA-FA distances based on the force system applied. Molars that begin treatment with severe lingual inclination could be expected to show either a large (with buccal tipping) or small (with lingual root torque) WALA-FA distance change based on the treatment mechanics selected. Teeth with optimal inclinations before treatment would not be expected to show much WALA-FA distance change, as they would be less affected by uprighting mechanics. This may help to explain the large variation in WALA-FA distances for ABO conforming molars seen in this sample.

Further investigation into the clinical implications between these two methods of molar uprighting is evident from this study. Anatomically, the lingual surface of the mandible is characterized by a depression to accommodate the position of the submandibular gland. Three-dimensional evaluation of uprighting mechanics is needed to determine if differences are produced in root position within the alveolus and in root position relative to the submandibular fossa. Excessive lingual root torque could potentially have a negative effect on periodontal stability, external root resorption, and rate of tooth movement. Ong and Wang [6] state that as long as the tooth is moved within the envelope of the alveolar process, the risk of harmful periodontal side effects is minimal. In a systematic review by Brezniak and Wasserstein [16], contact of root surfaces with the lingual cortical plate is implicated in external root resorption of incisors; however, additional investigation is needed in evaluating cortical contact and molar root resorption. Ricketts

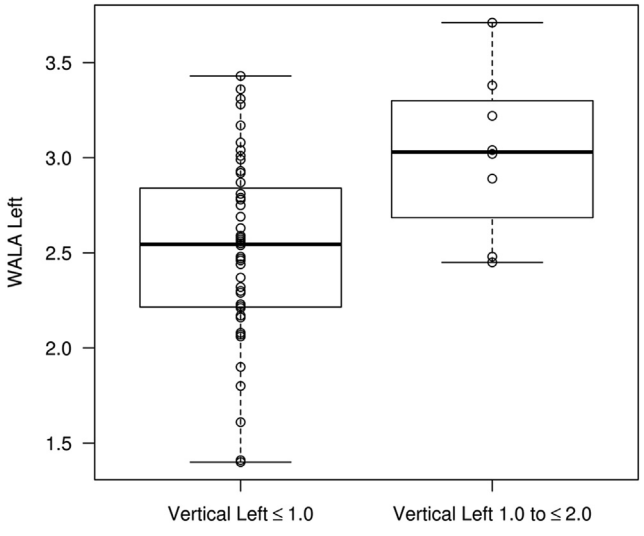


**Fig. 7.** Comparison of WALA-FA distance on the left side based on vertical differences. The group of points on the left are molars with vertical cusp height differences ≤1.0 mm. The group of points on the right are molars with vertical cusp height differences >1.0 to ≤2.0 mm. The vertical axis shows the range of WALA-FA distances for both groups. The heavy horizontal line represents the median. The box represents 25% of the sample above and 25% of the sample below the median.

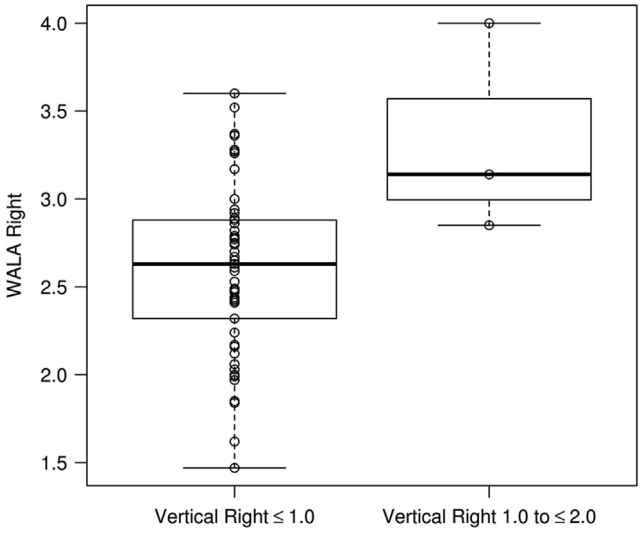


**Fig. 8.** Comparison of WALA-FA distance on the right side based on vertical differences. The group of points on the left are molars with vertical cusp height differences ≤1.0 mm. The group of points on the right are molars with vertical cusp height differences >1.0 to ≤2.0 mm. The vertical axis shows the range of WALA-FA distances for both groups. The heavy horizontal line represents the median. The box represents 25% of the sample above and 25% of the sample below the median.

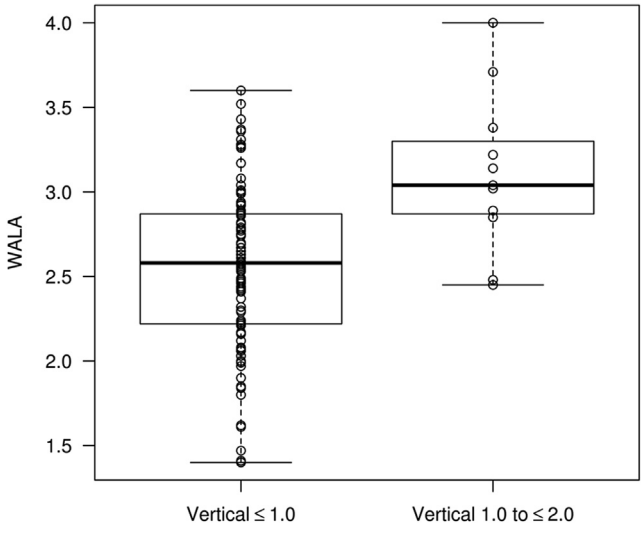


**Fig. 9.** Comparison of WALA-FA distance for the entire sample based on vertical differences. The group of points on the left are molars with vertical cusp height differences ≤1.0 mm. The group of points on the right are molars with vertical cusp height differences >1.0 to ≤2.0 mm. The vertical axis shows the range of WALA-FA distances for both groups. The heavy horizontal line represents the median. The box represents 25% of the sample above and 25% of the sample below the median.

[17] proposed intentional contact between root surfaces and cortical bone to increase anchorage and slow the rate of posterior tooth movement.

Differences in treatment mechanics also may be key to identifying a horizontal measurement that shows a statistically significant difference in WALA-FA distances for ABO conforming and ABO nonconforming molars. Molars with WALA-FA distances measuring ≤2.5 mm were not significantly more likely to be ABO conforming than WALA-FA distances measuring >2.5 mm ($P = 0.087$), although the number of ABO nonconforming molars increased from 2 in the ≤2.5-mm group to 9 in the >2.5-mm group. All molars treated to the optimal WALA-FA distance of 2.0 mm were ABO conforming. This may suggest that the closer the posttreatment results approach what is found in naturally occurring optimal occlusions, the better chance of meeting treatment goals established by the ABO.

## 5. Conclusions

Horizontal WALA-FA distances are significantly smaller (2.56 mm vs. 3.11 mm) when discrepancies in the posttreatment vertical heights between the buccal and lingual cusps of mandibular first molars conform to ABO standards (≤1.0 mm) than when the ABO standard is not met (>1.0 mm to ≤2.5 mm).

## References

[1] Andrews LF. Straight wire: the concept an appliance. San Diego, CA: L.A. Wells; 1989.
[2] Okeson JP. Management of temporomandibular disorders and occlusion. St. Louis, MO: Mosby Elsevier; 2013.
[3] Okano N, Baba K, Igarashi Y. Influences of altered occlusal guidance on masticatory muscle activity during clenching. J Oral Rehabil 2007;34:679–84.
[4] Ishigaki S, Kurozumi T, Morishige E, Yatani H. Occlusal interference during mastication can cause pathological tooth mobility. J Periodontal Res 2006;41:189–92.
[5] Harrell SK. Occlusal forces as a risk factor for periodontal disease. Periodontol 2000 2003;32:111–7.
[6] Ong MM, Wang HL. Periodontic and orthodontic treatment in adults. Am J Orthod Dentofacial Orthop 2002;122:420–8.
[7] Andrews LF. The six keys to normal occlusion. Am J Orthod 1972;62:296–309.
[8] Andrews LF. Syllabus of the Andrews Orthodontic Philosophy. San Diego, CA: The Lawrence F. Andrews Foundation; 2001.
[9] Andrews LF. The six elements of orofacial harmony. Andrews J 2000;1:13–22.
[10] Ball RL, Miner RM, Will LA, Arai K. Comparison of dental and apical base arch forms in Class II division 1 and Class I malocclusions. Am J Orthod Dentofacial Orthop 2010;138:41–50.
[11] Conti MR, Filho MV, Vedovello SAS, Valdrighi HC, Kuramae M. Longitudinal evaluation of dental arches individualized by the WALA ridge method. Dental Press J Orthod 2011;16:65–74.
[12] Triviño T, Siqueira DF, Andrews WA. Evaluation of distance between the mandibular teeth and the alveolar process in Brazilians with normal occlusion. Am J Orthod Dentofacial Orthop 2010;137:308. e1–e8.
[13] Kong-Zárate CY, Carruitero MJ, Andrews WA. Distances between mandibular posterior teeth and the WALA ridge in Peruvians with normal occlusion. Dental Press J Orthod 2017;22:56–60.
[14] Ronay V, Miner RM, Will LA, Arai K. Mandibular arch form: the relationship between dental and basal anatomy. Am J Orthod Dentofacial Orthop 2008;134:430–8.
[15] Triviño T, Siqueira DF, Scanavini MA. A new concept of mandibular dental arch forms with normal occlusion. Am J Orthod Dentofacial Orthop 2008;133:10. e15–e22.
[16] Brezniak N, Wasserstein A. Root resorption after orthodontic treatment: part 2. Literature review. Am J Orthod Dentofacial Orthop 1993;103:138–46.
[17] Ricketts RM. Bioprogressive therapy as an answer to orthodontic needs. Part II. Am J Orthod 1976;70:359–97.