Original Article

Wilson curve modification in permanent dentition: a retrospective comparison between clear aligners and continuous archwire treatment

Roberta Lione[a]; Francesca Chiara De Razza[b]; Francesca Gazzani[b]; Paola Cozza[c]; Chiara Pavoni[d]

ABSTRACT

Objectives: To evaluate leveling of the Curve of Wilson (COW) by two different treatment appliances (clear aligners [CA] and continuous archwire fixed appliances [FA]) in a permanent dentition sample of patients.

Materials and Methods: Digital casts of 40 patients (CA group = 20 patients; FA group = 20 patients) were collected. Angular values for COW, right and left vertical height difference of lower first molars, and linear distance between lower teeth and the WALA ridge were analyzed for pre- (T1), posttreatment (T2) and on final virtual (ClinCheck) models (T2-CC) of the CA group. An unpaired *t*-test was used to evaluate significant intergroup differences ($P < .05$), while a paired *t*-test was used for posttreatment CA intragroup comparison.

Results: FA group showed better control of second molar crown positions compared to CA group (47-WALA = −0.2 ± 0.1 mm, 37-WALA = −0.6 ± 0.3 mm). No significant difference was detected for linear distance of lower first molars and the WALA ridge or for vertical height difference. CA group showed a greater reduction of distance between lower premolars and the WALA ridge (mean difference: –0.5 mm for both 45-WALA and 35-WALA; mean difference: −0.5 mm for 44-WALA, −0.6 mm for 34-WALA). Predictability for the CA group was high for every measurement (87% Right COW, 89% Left COW, 88% 46 Vertical Diff, 87% 36 Vertical Diff).

Conclusions: Clear aligner and continuous archwire mechanics were effective in leveling COW. FA was more effective in changing crown position of lower second molars with respect to the WALA ridge, while CA provided a greater distance reduction between lower premolars and WALA ridges compared to FA. (*Angle Orthod*. 2024;00:000–000.)

KEY WORDS: Orthodontics; Biomechanics; Digital cast analysis

INTRODUCTION

An ideal and functional occlusal plane shows a curvilinear shape, modulated by two physiological curves: the Spee curve in the sagittal plane and the curve of Wilson in the frontal plane.[1]

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The curve of Wilson (COW) ideally passes through the first permanent molar buccal and palatal/lingual cusps. It can be seen as a concave curve in the lower arch and as a convex curve in the upper arch.[2]

The COW allows lateral dynamic jaw movements without occlusal interferences.[3] The mandibular dental arch curvature increases from adolescence to adulthood, especially in the molar region.[4] An enhanced lower COW displays lateral-posterior negative crown torque. This mandibular adaptation is a common response to a maxillary transverse deficit.[4,5] The American Board of Orthodontics (ABO) reported that a functional COW can be assessed when the lingual/palatal cusps are less than, or 1 mm lower, than the first permanent molar buccal cusps.[3] Therefore, the main goal of orthodontic therapy is to achieve proper coordination between dental arches, which improves occlusion and masticatory effectiveness, while positioning roots over supporting bones.[6,7]

Flattening of the COW with conventional fixed appliances has been extensively investigated,[8–10] but few studies focused on COW leveling using Clear Aligners (CA). A recent retrospective study by Goh et al. analyzed predictability of the COW correction with CA. The authors reported low predictability of COW flattening, especially in the mandibular first molar region, while significant cusp tip expansion and buccolingual crown inclination were found in lower premolars.[11]

Lim et al.[12] recently evaluated the predictability of CA in leveling only the maxillary COW and found an under-expression of upper arch expansion, except for second molars. These results were also supported by Bowman,[13] who measured the buccolingual inclination of the maxillary arch in patients treated with CA.

In addition to buccolingual crown inclination, WALA ridges are considered a good landmark for establishing arch morphology and detecting the orthodontic effects on COW depth.[14] WALA ridges are a soft-tissue band immediately superior to the mucogingival junction in the mandible, representing a stable anatomical structure that determines the ideal contour for the roots of teeth in the basal bone.[15]

The current retrospective study aimed to investigate the lower COW posttreatment modifications in patients with permanent dentition treated with CA, and to compare the lower COW leveling produced by CA with continuous archwire fixed appliance therapy (FA). Therefore, the null hypothesis was that COW leveling for patients in the permanent dentition who underwent treatment with clear aligners would not differ from patients with the same occlusal characteristics who underwent treatment with conventional fixed appliances.

MATERIALS AND METHODS

This project was approved by the ethical committee of the University of Rome "Tor Vergata" (Protocol Number 48/23). Each patient gave informed consent.

Two groups were selected retrospectively from the Department of Orthodontics of the Hospital of Rome "Tor Vergata." The first group (CA group) of 20 patients (8F, 12M, mean age of 14.5 $\pm$ 0.7 years) was treated with clear aligners (Invisalign System, Align Technology Inc., Santa Clara, CA, USA), while the second group (FA group) of 20 patients (15F, 5M, mean age: 14.8 $\pm$ 0.6 years) was treated with conventional fixed appliances (McLaughlin Bennet 5.0, Forestadent, Pforzheim, Germany).

Inclusion Criteria

The inclusion criteria were: Caucasian ancestry, Angle Class I molar or Class II edge-to-edge molar relationship, permanent dentition with fully-erupted second molars, increased COW, moderate or slight transverse discrepancy, and moderate dental crowding. A pretreatment evaluation of the molars according to ABO standards was also performed by measuring the height differences between buccal and lingual cusps on each lower first molar, grouped as ABO-nonconforming when the vertical cusp height difference was $>$1.0 mm to $\leq$2.0 mm.

Exclusion Criteria

Exclusion criteria were: incomplete second molar distobuccal cusp registration, crossbite, supernumerary teeth or tooth agenesis, need for extractions, cleft lip and/or palate history, any dental/periodontal disease.

The CA group was treated with a mean number of 20–40 aligners for each arch, with a maximum of three revision aligner sets. There were no limitations about the number/type of attachments. COW flattening was digitally planned following ABO guidelines: lower molar buccal cusps were positioned $<$ 1 mm higher than the lingual cusps on the digital grid, according to crown anatomy.[3] COW overcorrection was never prescribed, but a cusp-fossa relationship was digitally planned. Each patient was seen every 6 weeks and changed their aligners every week. Patient compliance was evaluated by a three-point Likert-type scale: compliance was good if patients wore aligners full time, moderate for 16–20 hours, and poor for less than 16 hours.[16]

The FA group was treated with full-fixed, conventional, preadjusted edgewise brackets and MBT prescription, with the following lower arch torque values: $-12°$ on first-premolars, $-17°$ on second premolars, $-20°$ on first molars, and $-10°$ on second molars. A tapered-form standard archwire sequence was used (0.016-inch round, 0.017 $\times$ 0.025-inch rectangular, 0.019 $\times$ 0.025-inch rectangular martensitic active nickel-titanium alloys, and 0.019 $\times$ 0.025-inch stainless steel, 0.021 $\times$ 0.025-inch beta-titanium). The complete arch sequence allowed for wire play reduction in the bracket slot.[17] Follow-up checks for each patient were performed before the finishing stage and the last archwire was inserted for about 4 months to allow for proper torque expression.

For the CA group, pretreatment (T1) and posttreatment (T2) lower digital dental casts were made using an intraoral scanner iTero Orthodontic (version 5.2.1.290, Align Technology). For the FA group, pr-treatment (T1) and posttreatment (T2) lower digital dental casts were obtained using an extra-oral scanner (OrthoXScan, Dentaurum GmbH and Co, Ispringen, Germany).

Lower digital casts were exported in stereolithography file format and analyzed using Viewbox4.0 (dHAL Software, Kifissia, Greece). A trained examiner (FCDR) performed all measurements.

Figure 1. Occlusal plane (OP).

On each lower digital-cast, three reference planes were established:[2]

- Occlusal Plane (OP): to construct this plane, 26 points were digitized on the digital casts (buccal and lingual cusp tips of first and second molars, buccal cusps of first premolars, second premolars, and canines, and incisal edges of lateral and central incisors). This defined the orientation and position of a three-dimensional best-fit occlusal plane including as many points as possible, as shown in Figure 1;
- Wilson right plane (WRP): plane passing through the lower right first molar buccal and lingual cusps;
- Wilson left plane (WLP): plane passing through the lower left first molar buccal and lingual cusps (Figure 2).

On each lower digital dental cast, Facial Axis midpoint (FA-midpoint) was digitized on the clinical crowns of mandibular first premolar to second molar as a reference point. FA point was chosen at the most prominent portion of the buccal surface of premolars and at the mesiobuccal groove of molars. WALA ridge was digitized in the region from first premolar to second molar, choosing the most prominent buccal portion immediately superior to the mucogingival junction on the lower digital cast.[18]

For each lower digital cast, 11 measurements were performed:[19,20]

- Right Wilson Curve (Right COW): angle assessed between WRP and OP;
- Left Wilson Curve (Left COW): angle assessed between WLP and OP (Figure 3);
- Right Vertical Height Difference (46-VerticalDiff): difference between the linear distance of the mandibular right first molar mesiobuccal cusp from the OP and the linear distance of the mesiolingual cusp from OP;
- Left Vertical Height Difference (36-VerticalDiff): difference between the linear distance of the mandibular right first molar mesiobuccal cusp from the OP and the linear distance of the mesiolingual cusp from OP;
- 47-WALA ridge (47-WALA): distance between the perpendicular projection of the lower right second molar FA-midpoint and the perpendicular projection of the lower right WALA ridge on OP;
- 37-WALA ridge (37-WALA): distance between the perpendicular projection of the lower left second molar FA-midpoint and the perpendicular projection of the lower left WALA ridge on OP;
- 46-WALA ridge (46-WALA): distance between the perpendicular projection of the lower right first molar FA-midpoint and the perpendicular projection of the lower right WALA ridge on OP;
- 36-WALA ridge (36-WALA): distance between the perpendicular projection of the lower left first molar FA-midpoint and the perpendicular projection of the lower left WALA ridge on OP;
- 45-WALA ridge (45-WALA): distance between the perpendicular projection of the lower right second premolar FA-midpoint and the perpendicular projection of the lower right WALA ridge on OP;
- 35-WALA ridge (35-WALA): distance between the perpendicular projection of the lower left second premolar FA-midpoint and the perpendicular projection of the lower right WALA ridge on OP;
- 44-WALA ridge (44-WALA): distance between the perpendicular projection of the lower right first premolar FA-midpoint and the perpendicular projection of the lower right WALA ridge on OP;

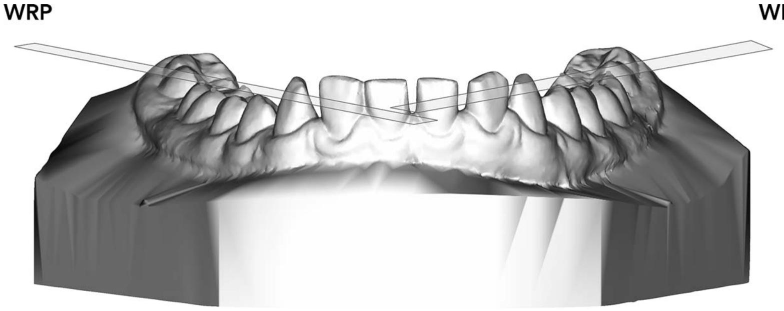

Figure 2. Wilson right plane (WRP); Wilson left plane (WLP).

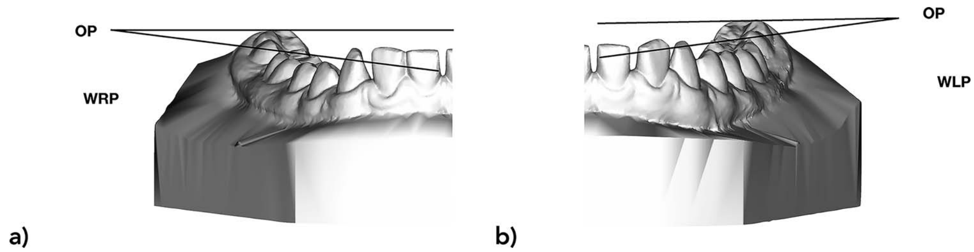

Figure 3. Angular measurements: (a) Right Curve of Wilson (Right COW); (b) Left Curve of Wilson (Left COW).

- 34-WALA ridge (34-WALA): distance between the perpendicular projection of the lower right first premolar FA-midpoint and the perpendicular projection of the lower right WALA ridge on OP (Figure 4).

Pretreatment and posttreatment evaluation using ABO standards was performed by measuring the height differences between buccal and lingual cusps on each lower first molar. Molars were grouped as "ABO-conforming" if the vertical cusp height difference measured $\leq$1.0 mm. Molars were sorted as "ABO-nonconforming" if the vertical cusp height difference was $>$1.0 mm to $\leq$2.0 mm.[20]

In a pilot study, 10 patients were used to calculate the reproducibility and the sample-size. 38 patients (19 for each group) were needed to estimate the COW angulation with a 95% confidence interval (CI), a minimum difference of 2° and a standard deviation (SD) of 1.5°, with a power of 80%. To reduce assessment bias, the examiner (FCDR) was blinded to the patient's name and treatment type.

Intra-examiner reproducibility was assessed by repeating measurements on 15 randomly selected models 2 weeks after the original data collection, using a paired *t*-test. The magnitude of the random error was

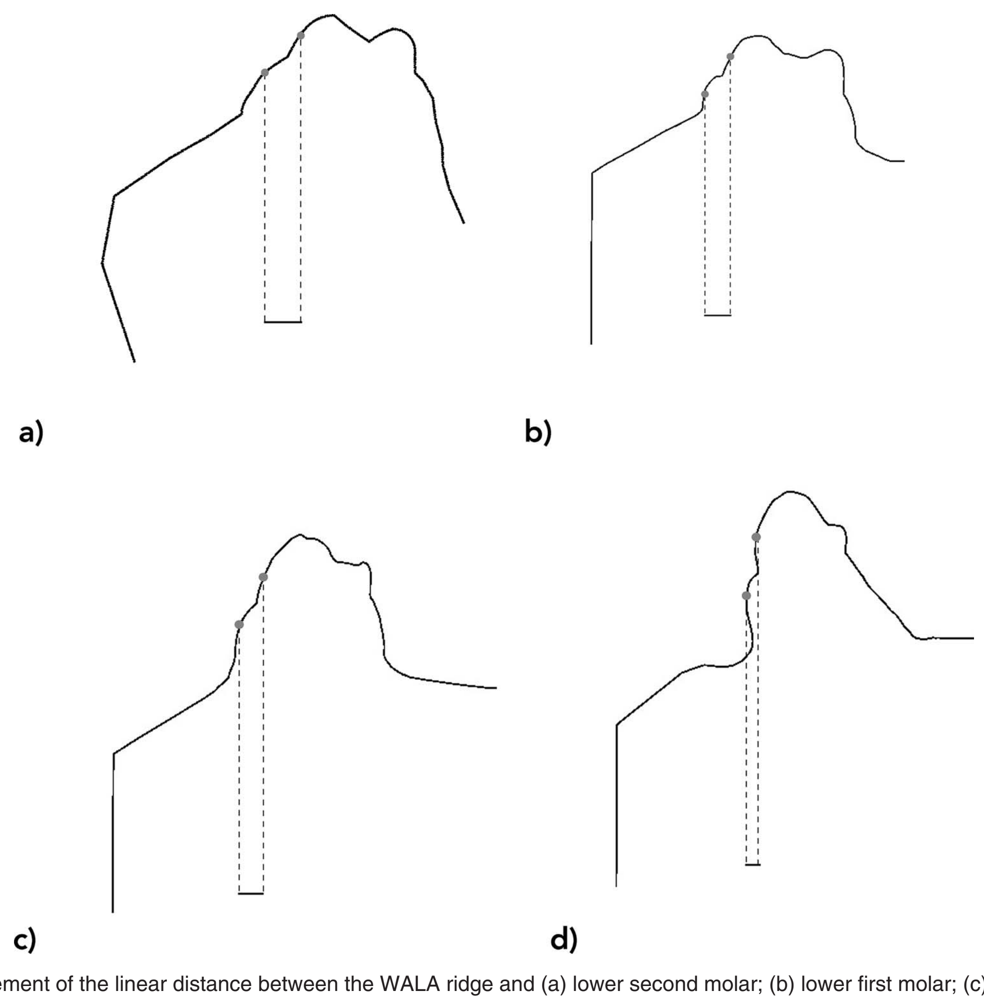

Figure 4. Measurement of the linear distance between the WALA ridge and (a) lower second molar; (b) lower first molar; (c) lower second premolar; (d) lower first premolar.

Table 1. Descriptive Statistics and Comparisons (Independent Sample *t*-Test) of the Starting Forms (Measurements at T1)[a]

	CA Group T1		FA Group T1				95% CI of the Difference	
	CA = 20	(F = 8, M = 12)	FA = 20	(F = 15, M = 5)				
Variables	Mean	SD	Mean	SD	Difference	*P* Value	Lower	Upper
Age (y)	14.5	0.7	14.8	0.6	0.3	NS	−25.3	24.7
Right COW (°)	20.9	2.1	22	2.2	1.1	NS	−2.4	0.2
Left COW (°)	21.2	2.4	21.9	1.6	0.3	NS	−2.1	0.6
46 Vertical Diff (mm)	2.0	0.6	1.9	0.4	−0.1	NS	−0.3	0.4
36 Vertical Diff (mm)	1.8	0.5	1.7	0.3	−0.1	NS	−0.2	0.3
47 WALA (mm)	1.4	0.2	1.8	0.6	0.4	NS	−1.5	0.7
37 WALA (mm)	1.6	0.5	1.7	0.3	0.1	NS	−1.4	1.2
46 WALA (mm)	2.5	0.5	2.4	0.7	−0.1	NS	−1.6	1.8
36 WALA (mm)	2.9	0.9	2.3	0.5	−0.6	NS	−1.7	2.9
45 WALA (mm)	1.9	0.8	1.9	0.4	−0.1	NS	−2.7	1.9
35 WALA (mm)	1.8	0.7	1.7	0.3	−0.1	NS	−1.7	1.9
44 WALA (mm)	1.6	0.8	1.1	0.5	−0.4	NS	−1.6	2.6
34 WALA (mm)	1.5	0.8	1.3	0.3	−0.2	NS	−1.8	2.2

[a] CA indicates clear aligners; CI, confidence interval; F, female; FA, fixed appliances; M, male; NS not significant; SD, standard deviation; * $P < .5$, ** $P < .01$, *** $P < .001$.

calculated by using a method of moments estimator (MME).[21]

An unpaired *t*-test was used to perform the starting form analysis and the statistical comparison of T2–T1 changes between CA and FA groups, while a paired *t*-test was used to compare the CA group differences between T2 and the ClinCheck prediction (T2–CC). Data were analyzed using SPSS (version26; IBM Corp, Chicago, IL, USA) Statistical significance was $P \leq .05$.

RESULTS

No systematic error was found between the repeated measurements. The random error varied from 0.25° (Wilson Right) to 0.34° (Wilson Left) for angular measurements and from 0.19 mm (46-WALA) to 0.22 mm (36-WALA) for linear measurements.

Treatment duration was similar for both groups (CA group: 15 ± 8 months; FA group:16 ± 6 months). CA group analysis showed that cooperation was good in 60% of patients: none had poor cooperation, eight had moderate cooperation, 12 patients had good compliance.

The starting form analysis showed no significant differences in lower arch characteristics and no significant differences for all the measurements (Table 1). The first molars showed the largest distance from WALA ridge, followed by second premolars.

In the analyzed sample, 17 patients presented with Class I molar relationship, while 23 patients showed a Class II edge-to-edge molar relationship with an equal distribution in the two groups. The transverse discrepancy (DT) was 2.7 mm ± 1 mm for the CA group, while the FA group had a DT mean value of 2.5 mm ± 1.5 mm. Crowding in the lower arch was also measured, showing a mean value of 3.2 mm ± 0.5 mm for the CA group and a mean value of 3.3 mm ± 1 for the FA group.

Pretreatment evaluation of the lower first molar ABO conformity according to vertical differences between buccal and lingual cusps showed that, of 80 analyzed teeth, 33 molars on the right, and 37 on the left, did not meet ABO standards (ABO nonconforming) while seven molars on the right and three molars on the left met ABO standards (ABO conforming).

Table 2 shows the T2–T1 statistical comparisons between the CA and FA groups. Both appliances were effective in COW flattening with no statistical difference on the right (−3.9° ± 5.9° for CA, −6.1° ± 4.7° for FA, mean difference: 2.2°) or on the left side (−3.4° ± 5.4° for CA, −5.1 ± 4.5° for FA, mean difference: −2.4°). The right vertical height difference (−1.2 mm ± 0.7 mm for CA, −1.4 mm ± 0.5 mm for FA, mean difference: −0.2) and the left vertical height difference (−1.1 mm ± 0.7 mm for CA, −1.2 mm ± 0.4 mm for FA, mean difference: −0.1) supported these findings.

FA group showed better control of the second molar crown position compared to the CA group, with a greater improvement of the buccal projection to the WALA ridge (mean difference: −0.2 ± 0.1 mm for 47-WALA, −0.6 ± 0.3 mm for 37-WALA).

No significant differences were found between the two groups for the linear distance of 46-WALA and 36-WALA. CA resulted in a greater reduction of the distance between the lower premolars and the WALA ridge (mean difference: –0.5mm for both 45-WALA and 35-WALA, mean difference: −0.5 mm and −0.6 mm for 44-WALA and 34-WALA) at T2.

CA group ClinCheck predictability was determined at the end of treatment (Table 3) by comparing post-treatment digital casts (T2) and the final virtual (ClinCheck)

Table 2. Descriptive Statistics and Comparisons (Independent Sample *t*-Test) of the T2-T1 Changes

	CA Group		FA Group				95% CI of the Difference	
	CA = 20	(F = 8, M = 12)	FA = 20	(F = 15, M = 5)				
Variables	Mean	SD	Mean	SD	Difference	*P* Value	Lower	Upper
Age (y)	1.2	1.1	1.7	0.5	0.5	NS	−1.5	0.5
Right COW (°)	−3.9	5.9	−6.1	4.7	2.2	NS	−1.4	5.7
Left COW (°)	−3.4	5.4	−5.1	4.5	1.7	NS	−1.8	5.3
46 Vertical Diff (mm)	−1.2	0.7	−1.4	0.5	−0.2	NS	−0.2	0.5
36 Vertical Diff (mm)	−1.1	0.7	−1.2	0.4	−0.1	NS	−0.3	0.4
47 WALA (mm)	−0.2	0.1	−0.6	0.2	0.4	*	−0.1	−0.3
37 WALA (mm)	−0.1	0.1	−0.6	0.3	0.5	*	−0.5	−0.1
46 WALA (mm)	−1	0.5	−0.7	0.4	−0.3	NS	−0.8	0.03
36 WALA (mm)	−1.1	0.6	−0.5	0.9	−0.6	NS	−0.7	0.04
45 WALA (mm)	−1.1	0.7	−0.6	0.3	−0.5	*	−1.1	−0.03
35 WALA (mm)	−1.1	0.7	−0.6	0.3	−0.5	*	−1.1	−0.003
44 WALA (mm)	−0.9	0.6	−0.4	0.6	−0.5	*	−1.2	−0.1
34 WALA (mm)	−1.2	0.7	−0.6	0.4	−0.6	*	−1.2	−0.1

[a] CA indicates clear aligners; CI, confidence interval; F, female; FA, fixed appliances; M, male; NS not significant; SD, standard deviation; * $P < 0.5$, ** $P < .01$, *** $P < .001$.

models T2-CC. All the measurements showed significant differences, meaning that the planned movement was different from the achieved clinical outcomes. Every measurement showed high predictability (87% for Right COW, 89% for Left COW, 88% for 46-vertical Diff, 86% for 36-vertical Diff).

Table 4 shows posttreatment evaluation of the lower first molar ABO conformity according to vertical differences between buccal and lingual cusps. Molars meeting ABO standards (ABO conforming) were 32 (80%) on the right and 34 (85%) on the left. Six molars on the right (20%) and eight on the left (15%) did not meet ABO standards (ABO nonconforming).

DISCUSSION

A harmonic COW reduces possible balancing interferences and improves functional intercuspation.[22] A proper vertical height difference between posterior buccal and lingual cusps provides a balanced occlusion and more ideal dental inclination.[23] No previous studies analyzed the clinical difference of COW flattening between clear aligners and conventional continuous archwires. The present study aimed to evaluate COW depth achieved at the end of treatment using both appliances. The results showed that CA and FA were both effective in COW flattening.

The FA group showed better control of the projection of lower second molars relative to the WALA ridge, even though a tight slot/archwire fit may be difficult to achieve due to differences between claimed slot sizes and wire dimensions, therefore usually resulting in excessive torsional play.[24] Similar differences between clear aligners and conventional appliances were noted in a recent review by Jaber et al.[25] With FA, the correct buccal lingual crown projection is achieved when a rectangular wire is engaged in the bracket. Conventional brackets are positioned on the buccal surface of teeth, and the angulation of the bracket slot provides the torque necessary to reach ideal tooth inclination. Torque is expressed only when the wire exhibits elastic deformation, as it tends to return to the original form, altering dental buccolingual inclination.[26–28]

On the other hand, the aligner structure can effectively move teeth during arch expansion but cannot produce good torque control in the absence of a specific force application point.[29] In particular, the reduced torque expression at the aligner distal ends could be due to aligner flexibility in the posterior segment, shorter crowns on the lingual aspect, larger root surfaces in thick cortical

Table 3. Descriptive Statistics and Comparisons (Independent Sample *t*−Test) of the Predicted (ClinCheck) CC−T2 Differences and Predictability (%)[a]

	Clear Aligners T2		Clear Aligners CC−T2				95% CI of the Difference		
	N = 20	(F = 8, M = 12)	n = 20	(F = 8, M=12)					
Variables	Mean	SD	Mean	SD	Difference	*P* Value	Lower	Upper	Predictability (%)
Right COW (°)	16.1	2.9	14.7	2.3	−1.4	*	0.04	2.7	87%
Left COW (°)	16.7	3.7	15.0	2.3	−1.7	*	0.2	3.5	89%
46 Vertical Diff (mm)	0.8	0.3	0.7	0.2	−0.1	*	0.01	0.3	88%
36 Vertical Diff (mm)	0.7	0.2	0.6	0.1	−0.1	*	0.01	0.2	86%

[a] CI indicates confidence of interval; NS, not significant; SD standard deviation; * $P < .5$, ** $P < .01$, *** $P < .001$.

Table 4. First Molars Grouped by Their Conformity to ABO Standards at Posttreatment (T2)[a]

	CA Group	FA Group	Combined	Vertical Cusp Height Differential (mm)	
n	20	20			
Right	15	17	32	≤1	ABO conforming
	5	3	8	>1.0 to 2.0	ABO not conforming
Left	16	18	34	≤1	ABO conforming
	4	2	6	>1.0 to 2.0	ABO not conforming

[a] ABO indicates American Board of Orthodontics.

bone requiring major anchorage, higher masticatory forces, and less predictable buccal cusp extrusion.[14] Additionally, CA have been shown to exhibit decreases in force, quite dramatic in the first few hours of use, indicative of material fatigue.[22]

These findings disagree with other previous studies[11–13] that reported CA provided a good amount of buccolingual inclination control in the mandibular second molar region during expansion. The differences may have been due to differences in the measurements performed. In the current study, the linear distances between the facial axes of posterior mandibular segments and the WALA ridge were used because it is difficult to determine an angular inclination of the tooth surface, which is often irregularly convex.[30,31] The WALA ridge is more easily detectable, indicating the bone base and the physiological border within which teeth can move.[31] Gupta et al. examined the mandibular arch form differences between adults and adolescents and stated that the WALA ridge represented a reliable reference point since there were no significant differences in dental and basal arch forms.[32]

CA exhibited significantly better results in the lateral segments compared to FA. This can be explained because simple crown tipping is the most easily achievable tooth movement using aligners. The interaction between the aligner geometry and the dental crown shape generates a three-dimensional force system distributed all over the tooth surface. Aligners transmit forces to a larger lingual surface tooth area,[25] while traditional fixed appliances exert orthodontic forces on a smaller buccal surface.[3]

A limitation of this study was that measurements were only performed on the crowns without evaluating root movement. The higher radiation dose of cone beam computed tomography compared to conventional radiographic examination was not justified in the context of these records for pre-and posttreatment. Other limitations of the study were its sample size, its retrospective nature, and the absence of long-term observation.

Further studies are needed to improve understanding of COW correction during orthodontic treatment with aligners and the differences between clear aligner and fixed appliance therapy.

CONCLUSIONS

- CA and continuous archwire mechanics were both effective in leveling the lower COW. Traditional FA were more effective in changing the crown position of the second lower molar relative to the WALA ridge, while CA provided a greater reduction of the distance between the lower premolars and WALA ridge compared to traditional continuous archwires.
- Of the 80 molars evaluated, 32 right and 34 left lower first molars met ABO standards, while six lower first molars on the right and eight on the left did not achieve ABO standards.

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