Assessment of three-dimensional changes after orthodontic treatment of low-complexity cases, using self-ligating brackets, conventional brackets or bracketless fixed system

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» Patients displayed in this article previously approved the use of their facial and intraoral photographs.

Abstract

OBJECTIVE: The aim of this study was to compare crown angulation, inclination, and arch dimension changes after orthodontic treatment across three bracket systems: self-ligating, conventional, and bracketless fixed systems. **METHODS:** Pre and posttreatment digital models from 114 patients aged 16 to 44 years, classified as low complexity cases, who had similar skeletal and dental pretreatment parameters and underwent orthodontic treatment, were divided into three groups: Group 1 ($n = 40$), treated with conventional brackets; Group 2 ($n = 40$), treated with self-ligating brackets; Group 3 ($n = 34$), treated with a bracketless fixed system. Upper and lower final crown angulation (tipping), inclination (torque), and arch dimension were measured using Dolphin software (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA) by a calibrated operator. The statistical analysis was carried out with the chi-square test, an ANOVA/Kruskal-Wallis test, the paired-sample t test/Wilcoxon matched-pairs signed-rank test, and a multinomial regression model. **RESULTS:** No statistically significant differences across the groups were found after orthodontic treatment. However, in the comparison of pre- and posttreatment intragroup changes, statistically significant differences ($p < 0.0014$) were found in some of the studied variables. The multinomial regression model showed a statistically significant association ($p < 0.05$) between self-ligating brackets and the maxillary interpremolar (first) width (OR = 1.58, 95% CI = 1.09–2.30) and the mandibular arch perimeter (OR = 0.77, 95% CI = 0.61–0.98) after orthodontic treatment, compared with conventional brackets. **CONCLUSIONS:** Pre- and posttreatment crown angulation, inclination, and arch dimension values across the three orthodontic appliance types showed no statistically significant differences in this sample of orthodontic low complexity cases.

Keywords: Orthodontic appliances. Orthodontic brackets. Torque. Dental arch. Dental models.

INTRODUCTION

In 1972, Andrews proposed the "six keys to normal occlusion" that were found in a study of 120 casts of non-orthodontic patients with normal occlusion; since then, orthodontists have acknowledged the importance of these keys for successful orthodontic treatment. Clinical crown angulation (mesiodistal tip) and inclination (labiolingual or buccolingual inclination or torque) are two of these key characteristics that affect not only the position of the teeth but also all types of occlusion and orthodontic treatment stability.[1] The straight-wire appliance that was also developed by Andrews included all three dimensions built into the bracket, and this appliance led to a new era in orthodontics involving the use of preadjusted appliances.[2]

Other important features in normal occlusion include the transverse arch dimension, the arch perimeter, and the arch depth. During the orthodontic treatment of nonextraction cases, the correction of the crowding depends mostly on the modification of these arch characteristics.[3] Self-ligating systems promote the use of broad archwires to achieve arch expansion for the alignment and leveling of crowded teeth. Different studies[4–6] have found that nonextraction orthodontic treatment with self-ligating brackets leads to the proclination of the anterior teeth and transverse expansion of the arches due to buccal tipping.[7]

The use of bracketless fixed systems has been reported in the literature by many authors[8–12] as a more comfortable, hygienic, and esthetic alternative to orthodontic brackets. These systems usually use mini-tubes that are covered by a flowable bonding material allowing the insertion of round superelastic nickel-titanium wires. These are used to correct low complexity cases with mild to moderate crowding in nonextraction cases with arch expansion and interproximal reduction.[12,13] The mini-tubes are smaller than 1 mm caliber, with different cross-sectional shapes (round, oval, and d-shaped). The mini-tubes can be used with different arch shapes and alloys. The combination of these shapes of tubes and arches and the application of fluid material to fix the tubes to the tooth in the bonding stage according to the diagnosis and treatment objectives give the system a special versatility to provide tooth movements in a minimally invasive manner.

Differences not only in the bracket prescriptions in terms of the torque and tip values but also in the arch forms and archwire sequences used lead to a better final position and three-dimensional control of the teeth for each of the orthodontic systems proposed. Most of the studies that compared different prescriptions with conventional brackets, self-ligating brackets, or aligners did not find statistically significant differences in the final values of inclinations or angulations of the tooth crowns or even in the transverse arch dimensions.[5,14,15] However, the facts that in an edgewise bracket, a rectangular wire can be inserted and produce torque and that in a bracketless fixed system, usually only round wires are used support the hypothesis that there are differences in the final crown angulation, inclination, and arch dimension of teeth between patients treated with orthodontic brackets and those treated with a bracketless fixed system.

To the best of our knowledge, no studies have been conducted to compare preadjusted appliances with a bracketless fixed system. The purpose of this study was to compare the crown angulation, inclination, and arch dimension changes after orthodontic treatment across three bracket systems: self-ligating, conventional, and bracketless fixed systems.

METHODS

This retrospective study was approved by the ethics committee of Fundación Universitaria CIEO-UniCIEO in Bogotá, Colombia. All the participants gave written informed consent for the use of their orthodontic data for research. This research followed the principles of the World Medical Association Declaration of Helsinki.

Pretreatment (T1) and posttreatment (T2) dental casts from 114 patients (16 to 44 years) who completed orthodontic treatment were distributed into three groups (G). In G1 (n = 40), the patients were treated with conventional preadjusted brackets [Gemini (3M Unitek, Monrovia, CA)]. In G2 (n = 40), the patients were treated with passive self-ligating brackets [Smartclip (3M Unitek, Monrovia, CA) and Carriere SLX (Ortho Organizer, USA); MBT Prescription, 0.022-in slot]. In G3 (n = 34), the patients were treated with a bracketless fixed system (FlowJac®, Bogotá, Colombia)[16-19] (Fig 1). The arch sequence were: for G1 and G2 NiTi 0.014-inch, NiTi 0.016-inch, NiTi .017X.025-inch and stainless steel .019x.025-inch and for G3 NiTi 0.013-inch, NiTi 0.014-inch. Patients with conventional preadjusted brackets and self-ligating brackets were selected among the patients who completed orthodontic treatment between May 2012 and December 2018 at the orthodontic postgraduate clinic at Fundación Universitaria CIEO-UniCIEO, and patients treated with the bracketless fixed system were selected among patients who completed orthodontic treatment between September 2007 and August 2017 at a private orthodontic office. The sample size was calculated based on a previous study[20] with the software Epidat 4.2 [Xullo 2016, Consellería de Sanidade, Xunta de Galicia, España; Organización Panamericana da saúde (OPS-OMS); Universidade CES, Colombia]. Considering a confidence level of 95% and a power of 90%, at least 34 subjects were required for each group to detect a 1.5 mm mean difference in the transverse width of the upper canines (standard deviations of 2.1 and 1.6 between the intervention and control groups). The inclusion criteria were patients with full permanent dentition up to the second molars without any prosthetic rehabilitation; low complexity cases treated with a nonextraction protocol; skeletal Class I malocclusion with a Class I, mild Class

Figure 1: A) Conventional brackets; **B)** Self-ligated Brackets; **C)** Bracketless Fixed System.

II, or mild Class III molar relationship; cases of overjet from 0 to 4 mm; and mild to moderate crowding (1–6 mm) according to Little's irregularity index. Patients with incomplete or poor records or with craniofacial syndromes and cases requiring the complex biomechanics of mini-implants or the prolonged use of Class II or Class III elastics were excluded.

For G1 and G2, several operators treated the patients, but the archwires were standardized within the orthodontic department. Patients in G3 were all treated by the same clinician (JA).

All the collected cast models were converted into a digital format using an Imetric 3D-dental scanner (IScan D103i, Imetric, Courgenay, Switzerland). All the variables of the study were measured by the same previously calibrated operator (SV) using the Dolphin software digital model interface (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA).

The maxillary and mandibular transverse arch widths, arch perimeter, and arch depth were measured according to the method used by Lineberger et al.[20] The transverse arch widths of the maxillary and mandibular canines, first and second premolars, and first molars were measured from the points of greatest convexity along the gingival cervical margin (Supplementary files, Fig 2A). Arch depth was defined as the distance of a perpendicular line from a line connecting the mesial points of the first molars to the central incisors (Supplementary files, Fig 2B).

Crown labiolingual or buccolingual inclination (torque) and mesiodistal angulation (tip) for all the teeth (excluding the second and third molars) were measured following the method reported by Herrera Sanches et al.[21] The occlusal plane in the digital model (disto-buccal cusp tips of the first molars and the contact point between the central incisors at the occlusal level) was rotated until it was parallel to the horizon-

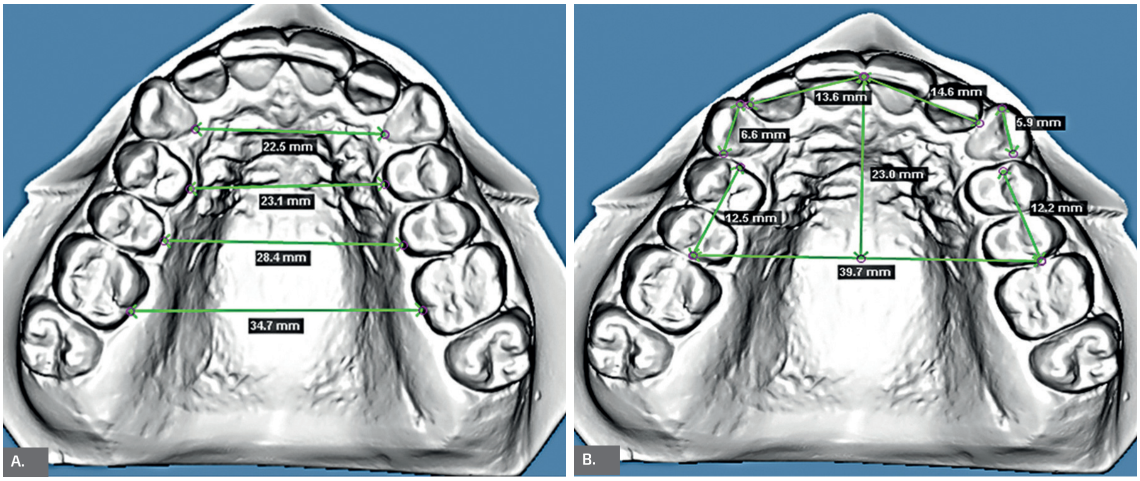

Figure 2: Linear measurements transverse width (**A**) and Arch length measurements (**B**).

tal plane. Andrews' facial axis of the clinical crown (FACC) was traced and used to perform the crown inclination and angulation measurements.[1] The buccolingual inclination was measured between the union of the FACC and a line parallel to the occlusal plane (Supplementary files, Fig 3A). Values greater than 90° indicated that the crown was buccally inclined (positive torque), and values smaller than 90° indicated that the crown was lingually/palatally inclined (negative torque). The torque value was determined by subtracting 90° from the measured angle.

The mesiodistal angulation was measured in the middle of the crown as the angle formed by the intersection of the FACC and a line perpendicular to the occlusal plane (Supplementary files, Fig 3B). It was considered positive when the occlusal portion of the FACC was more mesial at the gingival portion and negative when it was more distal. Additionally, demographic (sex, age) and clinical variables (pretreatment molar relationship, caliber and alloy of the final working archwire) were collected from the clinical records of the patients.

All variables were measured before (T1) and after (T2) orthodontic treatment, and their changes over the treatment period were assessed. Thirty randomly selected models (10 for each group) were measured by the same operator twice within a 2-week interval. Bland-Altman plots were used to assess the intraoperator reliability, and the method error was measured with a paired t test (systematic error) and the Dahlberg formula (random error). Both the operator who measured the variables and the researcher who performed the statistical analysis were blinded to which system was used for treating each patient.

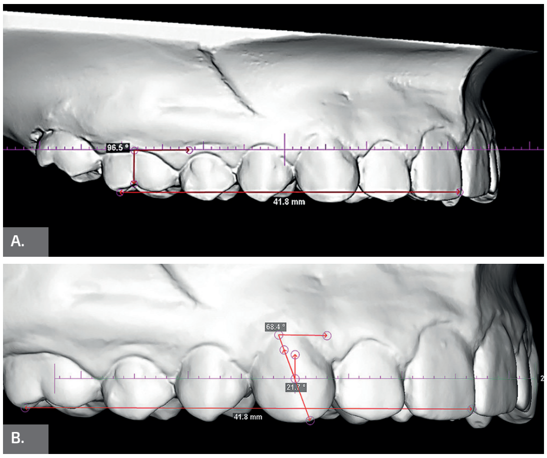

Figure 3: Torque measurement (A). Tip measurements (B).

STATISTICAL ANALYSIS

All statistical analyses were performed with Stata software (version 14; StataCorp, College Station, TX). The normality of the data was tested using Kolmogorov-Smirnov tests and q-q plots. The intergroup comparisons at T1 were performed by the chi-square test for the qualitative variables and by ANOVA or the Kruskal-Wallis test for the quantitative variables, depending on the data distribution. The intergroup comparisons of the differences pre- and posttreatment were performed by ANOVA or Kruskal-Wallis tests. The comparisons between T1 and T2 in each group were performed with a paired-sample t test for the normally distributed variables and the Wilcoxon matched-pairs signed-rank test for the nonnormally distributed variables. The significance level was set to be $p < 0.05$. The

Bonferroni correction for multiple tests was applied, and the significance level was adjusted to $p < 0.0014$. Additionally, ordinal multinomial logistic regression analysis was performed to evaluate the association between the groups and the changes in the linear arch measurements during orthodontic treatment. The quality of the models' adjustments was analyzed by the log of likelihood ratio and Akaike information criterion (AIC). The model with the lowest value of the log-likelihood ratio and AIC were selected.

RESULTS

The random errors were within acceptable limits, varying from -0.004 mm to 0.046 mm for the linear measurements and from -0.038° to 0.086° for the angular measurements. There were no statistically significant systematic errors ($p > 0.10$). The Bland–Altman plots indicated high intraobserver agreement, with an average error between -0.001 and 0.095°/mm (95% CI = -0.07 – 0.086).

The descriptive statistics and the comparison of the pretreatment variables (T1) across the groups are shown in Table 1. The three groups showed similar characteristics: G1 (n = 40; 21 females, 19 males; age: 24 ± 8.1); G2 (n = 40; 23 females, 17 males; age: 25.1 ± 7.1); and G3 (n = 34; 20 females, 14 males; age: 23.6 ± 6.7). No statistically significant differences ($p < 0.0014$) were observed between the groups in any of the variables at baseline.

For the intragroup changes from before to after the orthodontic treatment (T2–T1), statistically significant changes were observed in some of the measured variables in all the groups, mostly in the arch linear measurements (Table 2).

Table 1: Descriptive statistics and comparison of variables at baseline (T1) in the three bracket type groups (G1, G2, G3).

	BRACKET TYPE			
	CONVENTIONAL (G1)	SELF-LIGATING (G2)	MINI-TUBES (G3)	
QUALITATIVE VARIABLES	n (%)	n (%)	n (%)	*p*
Sex				0.842^Δ^
Female	21 (32.81)	23 (35.94)	20 (31.25)	
Male	19 (38.00)	17 (34.00)	14 (28)	
Right Molar Relationship				0.102^Δ^
Class I	20 (30.30)	25 (37.88)	21 (31.82)	
Class II	7 (26.92)	9 (34.62)	10 (38.46)	
Class III	13 (59.09)	6 (27.27	3 (13.64)	
Left Molar Relationship				0.342^Δ^
Class I	23 (23.86)	28 (40.00)	19 (27.14)	
Class II	8 (30.77)	7 (26.92)	11 (42.31)	
Class III	9 (50.00)	5 (27.78)	4 (22.22)	

Statistical significance with Bonferroni correction for multiple test at *P<0.0014. ^Δ^ Chi-square test. ^Ŧ^ ANOVA test. ^Ⱡ^ Kruskal Wallis test.

Table 1: (**Continuation**) Descriptive statistics and comparison of variables at baseline (T1) in the three bracket type groups (G1, G2, G3).

	BRACKET TYPE						
	CONVENTIONAL (G1)		SELF-LIGATING (G2)		MINI-TUBES (G3)		
QUANTITATIVE VARIABLES	Median (min-max)	Mean (SD)	Median (min-max)	Mean (SD)	Median (min-max)	Mean (SD)	*p*
Age	22 (12–53)	24 (8.1)	25 (13–43)	25.1 (7.1)	21 (16–35)	23.6 (6.7)	0.6186ᵀ
Maxillary arch linear measurements (mm)							
Intercanine width	26 (21.2–29)	29 (25.9)	25.4 (22.4–30.6)	25.7 (2.1)	31.8 (22.2–31.8)	25.6 (2.1)	0.7569ᵀ
Interpremolar (1st) width	28.9 (24.5–33.1)	28.9 (2.1)	28.7 (24.8–34.7)	28.75 (2.3)	27.8 (24.5–34.4)	27.9 (2.3)	0.8860ᵀ
Interpremolar (2nd) width	34.2 (29.5–38.1)	34.1 (2.5)	33.6 (29.7–40.9)	33.8 (2.5)	32.5 (27.9–37)	32.4 (2.2)	0.0153ᵀ
Intermolar width	37.5 (31.9–45)	37.7 (3.1)	37.5 (32.1–45.2)	37.1 (2.7)	36.2 (30.2–41.4)	36.2 (2.2)	0.0630ᵀ
Arch depth	26.3 (22.3–30.7)	26.6 (2.1)	26.3 (23.2–28.8)	26.1 (1.5)	26.3 (22.7–28.5)	26.1 (1.5)	0.3689ᵀ
Inclination measurements of the maxillary arch (degrees)							
Maxillary central incisor torque	4.3 (-2.8–13.8)	4.75 (3.74)	4.35 (-5.1–17.4)	4.61 (5.06)	5.25 (-3.6–18)	5.15 (4.22)	0.8628ᵀ
Maxillary lateral incisor torque	12.05 (-10.06–33.6)	11.98 (8.94)	9.85 (2.9–28.5)	11.48 (6.33)	8.10 (-3.8–25.1)	8.34 (5.07)	0.0121ᵏ
Maxillary canine torque	12.1 (-6.2–36.5)	13.13 (11.66)	12.5 (-3.9–47.4)	16.33 (12.68)	7.85 (-3.4–39.1)	9.74 (8.59)	0.0794ᵏ
Maxillary premolar (1st) torque	4.85 (-12.8–30)	5.86 (8.51)	3.5 (-12.4–15.9)	4.11 (6.01)	5.85 (-6.30–28.3)	6.47 (7.29)	0.4875ᵏ
Maxillary premolar (2nd) torque	6.05 (-17.2–32)	6.47 (8.90)	5.4 (-10.1–20.7)	5.78 (7.32)	5.85 (-17–32.5)	6.53 (9.13)	0.9162ᵏ
Maxillary first molar torque	0.95 (-26.5–9.3)	-1.53 (5.99)	-2.9 (-18.1–8.3)	-2.76 (6.19)	-2.65 (-16.6–10.5)	-3.10 (5.27)	0.2672ᵀ
Angulation measurements of the maxillary arch (degrees)							
Maxillary central incisor tip	3.05 (-10.4–16.5)	2.65 (4.99)	0 (-20.7–21.9)	2.17 (5.99)	1.25 (-6.8–20.3)	3 (4.69)	0.6650ᵏ
Maxillary lateral incisor tip	13.55 (-24.5–34.6)	11.36 (10.52)	8.25 (0–28.5)	8.84 (6.86)	5.95 (0–25.4)	7.22 (5.75)	0.0105ᵏ
Maxillary canine tip	11.9 (-18–40)	12.07 (12.93)	9.75 (0–51.7)	15.63 (14.15)	9 (-6–44.1)	10.51 (10.70)	0.4122ᵏ
Maxillary premolar (1st) tip	7.75 (-11.8–30.5)	7.50 (8.53)	3.65 (0–16.8)	4.62 (5.31)	5.2 (-6.1–22.7)	5.78 (6.60)	0.2410ᵏ
Maxillary premolar (2nd) tip	7.2 (-15.2–28.7)	7.38 (8.01)	6.05 (0–20.7)	7.42 (5.97)	5.8 (0–35.3)	8.93 (8.49)	0.9116ᵏ
Maxillary first molar tip	0 (0–8.7)	1.29 (4.33)	0 (0–9.7)	1.29 (2.50)	0 (0–13.9)	2.02 (3.54)	0.7130ᵏ

Statistical significance with Bonferroni correction for multiple test at *P<0.0014. ᐞ Chi-square test. ᵀ ANOVA test. ᵏ Kruskal Wallis test.

Table 1: (**Continuation**) Descriptive statistics and comparison of variables at baseline (T1) in the three bracket type groups (G1, G2, G3).

	BRACKET TYPE						
	CONVENTIONAL (G1)		SELF-LIGATING (G2)		MINI-TUBES (G3)		
QUANTITATIVE VARIABLES	Median (min-max)	Mean (SD)	Median (min-max)	Mean (SD)	Median (min-max)	Mean (SD)	*p*
Mandibular arch linear measurements (mm)							
Intercanine width	20.4 (16.6–23.8)	20.4 (1.8)	20.2 (17.1–23.7)	20.3 (1.6)	20.4 (16.9–24.4)	20.3 (1.7)	0.9896₮
Interpremolar (1st) width	26.9 (23.7–31.6)	26.9 (1.7)	27.1 (22–30.5)	26.9 (2.1)	26.3 (21.1–29.8)	26.1 (2.1)	0.1880₮
Interpremolar (2nd) width	30.4 (27–36.4)	30.8 (2.1)	31.3 (26.1–37.1)	31.3 (2.6)	30.2 (25.4–35.8)	30.2 (2.6)	0.2243₮
Intermolar width	34.9 (30.5–40.2)	34.6 (2.5)	35.8 (29.2–42.7)	35.2 (2.8)	34.5 (29.4–38.9)	34.2 (2.3)	0.3065₮
Arch depth	21.7 (18.9–25.3)	21.7 (1.5)	21.7 (18.1–24.7)	21.6 (1.6)	21.4 (18.2–24.1)	21.4 (1.3)	0.6224₮
Mandibular inclination measurements (degrees)							
Mandibular anterior incisor torque	-7.35 (-54.1–33.8)	-9.35 (10.78)	-7.9 (-43–11.9)	-9.36 (10.78)	-5.95 (-28.7–11)	-6.15 (7.75)	0.4029₺
Mandibular canine torque	5.55 (-20.3–35.4)	7.45 (12.65)	5.55 (-18.7–37.7)	6.08 (10.37)	14.3 (-24.3–45.6)	13.50 (14.26)	0.0209₮
Mandibular premolar (1st) torque	6.7 (-12–52.7)	8.49 (11.68)	9.6 (-5.4–36.3)	10.16 (9.57)	9.15 (-3.5–38.6)	13.18 (10.21)	0.0209₺
Mandibular premolar (2nd) torque	11.35 (-5.3–29.5)	11.91 (9.05)	9.25 (-7.8–23.6)	8.46 (8.11)	11.75 (-4–29.1)	12.04 (8.31)	0.1149₮
Mandibular first molar torque	15.15 (1.1–36.4)	15.5 (8.85)	14.4 (-2.1–44.2)	14.48 (10.25)	15.55 (-6.6–39)	16.97 (9.96)	0.5443₺
Mandibular angulation measurements (degrees)							
Mandibular anterior incisor tip	7.3 (-40.5–60.6)	5.02 (17.40)	3.4 (-22–38.2)	2.20 (13.07)	0 (-22.9–13.7)	-0.7 (9.06)	0.0439₺
Mandibular canine tip	6.55 (-17.5–51.7)	11.6 (13.35)	4.9 (-20.5–31.8)	5.08 (8.54)	11.6 (-21.6–43.1)	11.46 (13.35)	0.0446₺
Mandibular premolar (1st) tip	8.55 (-10.4–44.4)	10.01 (10.33)	5.7 (-7.9–37.64)	7.59 (9.77)	8.5 (-3.4–34.5)	10.32 (9.56)	0.2410₺
Mandibular premolar (2nd) tip	12.85 (-6.2–15.9)	12.92 (8.24)	6.05 (0–21.7)	7.23 (5.92)	7.7 (0-28.3)	9.70 (8.05)	0.9124₮
Mandibular first molar tip	10.85 (-6.9–26.1)	11.4 (8.43)	10.5 (0–36.7)	10.64 (10.08)	8.65 (0–30.5)	11.13 (9.29)	0.7643₺

Statistical significance with Bonferroni correction for multiple test at *P<0.0014. ᐞ Chi-square test. ₮ ANOVA test. ₺ Kruskal Wallis test.

Table 2: Comparison of the post-treatment differences of the studied variables (T2-T1) in each group according to bracket type and comparison between groups.

VARIABLE NAME	CONVENTIONAL (G1)			SELF-LIGATING (G2)			MINI-TUBES (G3)			P-value inter-group
	MEAN OF DIFFER-ENCES T2-T1 (SE) (EP)	95% CI	p (G1)	MEAN OF DIFFER-ENCES T2-T1 (SE)	95% CI	p (G2)	MEAN OF DIFFER-ENCES T2-T1 (SE)	IC 95%	p (G3)	
Maxillary arch linear measurements (mm)										
Intercanine width	0.09 (0.17)	-0.24/0.43	0.5676§	0.72 (0.21)	0.29/1.15	0.0014§	-0.02 (0.25)	-0.54/0.49	0.3915ǂ	0.0286Ł
Interpremolar (1st) width	0.57 (0.22)	0.12/1.03	0.0149§	1.17 (0.20)	0.76/1.59	<0.0001*§	0.99 (0.20)	0.58/1.40	< 0.0001*§	0.1111Ŧ
Interpremolar (2nd) width	0.82 (0.21)	0.39/1.25	0.0004*§	1.11 (0.19)	0.71/1.51	<0.0001*§	1.21 (0.18)	0.84/1.57	< 0.0001*§	0.3686Ŧ
Intermolar width	-0.17 (0.25)	-0.70/0.33	0.5037§	0.01 (0.18)	-0.37/0.38	1§	0.11 (0.13)	-0.16/0.39	0.4147§	0.6382Ł
Arch depth	0.36 (0.21)	-0.06/0.78	0.0939§	0.26 (0.21)	-0.17/0.70	0.4177ǂ	0.69 (0.20)	0.27/1.10	0.0017§	0.4786Ł
Maxillary inclination measurements (degrees)										
Maxillary central incisor torque	1.21 (0.81)	-0.43/2.85	0.6297§	0.5 (1.03)	-1.58/2.58	0.1439§	-1.38 (0.92)	-3.2/0.49	0.1438§	0.1413Ŧ
Maxillary lateral incisor torque	-1.32 (1.30)	-3.96/1.32	0.5542ǂ	-1.43 (1.51)	-4.49/1.63	0.3191§	0.43 (1.25)	-2.12/2.98	0.7648ǂ	0.7659Ł
Maxillary canine torque	-4.39 (1.44)	-7.31 / -1.46	0.0005*§	-7.31 (1.93)	-11.21 / -3.40	0.0043§	-2.78 (1.63)	-6.11/0.54	0.0183ǂ	0.3550Ł
Maxillary premolar (1st) torque	-2.68 (1.31)	-5.3 / -0.04	0.3889§	-0.85 (0.98)	-2.83/1.13	0.0469§	-3.39 (1.29)	-6.02 / -0.76	0.0130§	0.2375Ł
Maxillary premolar (2nd) torque	0.38 (1.27)	-2.19/2.96	0.0151§	-2.93 (1.15)	-5.26/0.60	0.7572ǂ	0.77 (1.15)	-3.13/1.58	0.3514ǂ	0.4844Ł

Statistical significance with Bonferroni correction for multiple test at *P<0.0014; Intra-group tests: § Paired t-test. § Wilcoxon matched-pairs signed-rank test; Intergroup-tests: ǂ ANOVA test. Ł Kruskal Wallis test.

Table 2: (**Continuation**) Comparison of the post-treatment differences of the studied variables (T2-T1) in each group according to bracket type and comparison between groups.

VARIABLE NAME	CONVENTIONAL (G1) MEAN OF DIFFERENCES T2-T1 (SE) (EP)	CONVENTIONAL (G1) 95% CI	p (G1)	SELF-LIGATING (G2) MEAN OF DIFFERENCES T2-T1 (SE)	SELF-LIGATING (G2) 95% CI	p (G2)	MINI-TUBES (G3) MEAN OF DIFFERENCES T2-T1 (SE)	MINI-TUBES (G3) IC 95%	p (G3)	*P-value inter-group*
Maxillary first molar torque	0.84 (1.09)	-1.38/3.06	0.7873§	-0.28 (1.05)	-2.41/1.83	0.4161ƚ	1.42 (1.05)	-0.71/3.56	0.1842§	0.7504Ł
Maxillary angulation measurements (degrees)										
Maxillary central incisor tip	2.75 (0.86)	1.01/4.51	0.0029§	0.64 (0.88)	-1.14/2.43	0.2147ƚ	-0.69 (1.03)	-2.80/1.40	0.7167ƚ	0.0709Ł
Maxillary lateral incisor tip	-1.30 (1.49)	-4.31/1.71	0.2162ƚ	-0.23 (1.35)	-2.97/2.51	0.8189ƚ	0.24 (1.23)	-2.27/2.74	0.6878ƚ	0.4922Ł
Maxillary canine tip	-2.95 (1.96)	-6.92/1.01	0.1403§	-6.96 (2.05)	-11.11 / -2.82	0.0047ƚ	-3.27 (2.06)	-7.46/0.92	0.0262ƚ	0.7646Ł
Maxillary premolar (1st) tip	-2.61 (1.32)	-5.28/0.05	0.0543§	-1.75 (1.03)	-3.83/0.34	0.0568ƚ	-1.83 (1.47)	-4.83/1.16	0.2208§	0.8642Ŧ
Maxillary premolar (2nd) tip	-0.21 (1.33)	-2.92/2.50	0.4235ƚ	-4.15 (1.18)	-6.55 / -1.76	0.0011*ƚ	-4.45 (1.08)	-6.66 / -2.25	0.0005*ƚ	0.0731Ł
Maxillary first molar tip	1.17 (0.96)	-0.78/3.12	0.5015ƚ	0.74 (0.78)	-0.83/2.31	0.6748ƚ	-0.87 (0.83)	-2.57/0.83	0.2298ƚ	0.4385Ł
Mandibular arch linear measurements (mm)										
Intercanine width	0.27 (0.17)	-0.07/0.62	0.011§	0.63 (0.18)	0.27/0.99	0.1168§	-0.03 (0.16)	-0.35/0.30	0.8556§	0.0678Ł
Interpremolar (1st) width	0.79 (0.21)	0.36/1.22	0.0011*§	0.76 (0.21)	0.32/1.19	0.0006§	0.93 (0.26)	0.40/1.47	0.0011*§	0.8497Ŧ
Interpremolar (2nd) width	1.38 (0.22)	0.94/1.82	0.0001*§	1.06 (0.24)	0.58/1.55	< 0.0001*§	1.15 (0.27)	0.59/1.71	0.0002*§	0.6249Ŧ
Intermolar width	0.20 (0.21)	-0.22/0.62	0.5768§	0.11 (0.20)	-0.29/0.52	0.3380§	-0.97 (0.18)	-0.46/0.26	0.5924§	0.5717Ŧ

Statistical significance with Bonferroni correction for multiple test at *P<0.0014; Intra-group tests: § Paired t-test. § Wilcoxon matched-pairs signed-rank test; Intergroup-tests: ƚ ANOVA test. Ł Kruskal Wallis test.

Table 2: (**Continuation**) Comparison of the post-treatment differences of the studied variables (T2-T1) in each group according to bracket type and comparison between groups.

VARIABLE NAME	CONVENTIONAL (G1) MEAN OF DIFFER-ENCES T2-T1 (SE) (EP)	CONVENTIONAL (G1) 95% CI	*p* (G1)	SELF-LIGATING (G2) MEAN OF DIFFER-ENCES T2-T1 (SE)	SELF-LIGATING (G2) 95% CI	*p* (G2)	MINI-TUBES (G3) MEAN OF DIFFER-ENCES T2-T1 (SE)	MINI-TUBES (G3) IC 95%	*p* (G3)	*P-value inter-group*
Arch depth	1.13 (0.22)	0.69/1.57	0.0011*ǂ	0.70 (0.36)	0.25/1.15	< 0.0001*§	1.01 (0.24)	0.51/1.50	0.0002*§	0.3755Ŧ
Mandibular inclination measurements (degrees)										
Mandibular anterior torque	6.29 (2.49)	1.25/11.33	0.0010*§	6.35 (1.78)	2.74/9.95	0.01557§	8.47 (1.83)	4.74/12.20	0.0002*ǂ	0.7176Ŧ
Mandibular canine torque	-3.35 (1.75)	-6.89/0.19	0.3678ǂ	-1.31 (1.43)	-4.20/1.59	0.0636§	-7.10 (2.13)	-11.43/-2.76	0.0022§	0.0647Ł
Mandibular premolar (1st) torque	-3.38 (1.66)	-6.75 / -0.01	0.0005*§	-4.46 (1.17)	-6.83/ -2.09	0.0513ǂ	-6.07 (1.36)	-8.84/-3.31	0.0001*§	0.3225Ł
Mandibular premolar (2nd) torque	0.19 (1.51)	-2.86/3.24	0.4089§	0.95 (1.13)	-1.35/3.24	0.8991§	-0.61 (1.33)	-3.31/2.10	0.6516§	0.7221Ŧ
Mandibular first molar torque	-2.78 (1.47)	-5.74/0.19	<0.00001*§	-7.41 (1.40)	-10.25/ -4.57	0.0657§	-7.49 (1.57)	-10.68/-4.30	< 0.0001*§	0.0364Ŧ
Mandibular angulation measurements (degrees)										
Mandibular anterior tip	-0.89 (2.80)	-6.56/4.78	0.5955ǂ	-0.69 (1.98)	-4.71/3.32	0.0299ǂ	4.84 (1.75)	1.27/8.41	0.0123§	0.0434Ł
Mandibular canine tip	-4.38 (1.83)	-8.09 / -0.67	0.0589ǂ	-2.88 (1.41)	-5.73/ -0.03	0.0190ǂ	-6.34 (2.07)	-10.55/ -2.13	0.0043§	0.5511Ł
Mandibular premolar (1st) tip	-5.67 (1.53)	-8.77/ -2.58	0.0010*ǂ	-4.65 (1.48)	-7.66/-1.64	0.0012*ǂ	-5.63 (1.41)	-8.50/-2.76	0.0006*ǂ	0.9278Ł

Statistical significance with Bonferroni correction for multiple test at *P<0.0014; Intra-group tests: § Paired t-test. § Wilcoxon matched-pairs signed-rank test; Intergroup-tests: ǂ ANOVA test. Ł Kruskal Wallis test.

Table 2 also shows the results of the comparisons between the pre- (T1) and posttreatment (T2) time points across the groups. No statistically significant differences were found.

The final multinomial logistic regression with the arch linear measurements (Table 3) showed statistically significant differences in the odds ratio (OR) of the maxillary interpremolar (1st) width (OR = 1.58, 95% CI = 1.09;2.30) after orthodontic treatment in G2 (self-ligating brackets) compared with G1 (conventional brackets).

The distributions of the clinical variables during orthodontic treatment in the studied groups are shown in Table 4. Statistically significant differences were observed in the maximum archwire caliber used [G1: 0.019 + 0.025-in (90%), G2: 0.019 + 0.025-in (87.50%), G3: 0.014-in (67.65%)] and archwire alloy used [G1: stainless steel (75%), G2: stainless steel (75.50%), G3: nickel-titanium (100%)].

Table 3: Multinomial regression.

VARIABLE	OR CRUDE		OR FULL MODEL		OR FINAL REGRESSION MODEL	
	OR (95%CI)	*p*	OR (95%CI)	*p*	OR (95%CI)	*p*
G2 (SELF-LIGATING BRACKETS)						
Mandibular arch linear measurements (mm)						
Intercanine width	1.19 (0.69–2.05)	0.514				
Interpremolar (1st) width	1.57 (0.85–2.91)	0.144	1.71 (1.03–2.85)	0.038*	1.58 (1.09–2.30)	0.015*
Interpremolar (2nd) width	1.11 (0.62–1.98)	0.722	1.07 (0.63–1.82)	0.789		
Intermolar width	1.01 (0.61–1.67)	0.959				
Arch length	1.17 (0.69–2.00)	0.546				
Mandibular arch linear measurements (mm)						
Intercanine width	1.51 (0.82–2.79)	0.183	1.42 (0.85–2.36)	0.181		
Interpremolar (1st) width	1.01 (0.55–1.83)	0.978	1.02 (0.57–1.81)	0.940		
Interpremolar (2nd) width	0.73 (0.42–1.25)	0.256	0.66 (0.40–1.09)	0.109		
Intermolar width	0.96 (0.55–1.66)	0.885				
Arch length	1.25 (0.68–2.30)	0.456				

Statistically significant at *P < 0.05.

Table 3: (**Continuation**) Multinomial regression.

VARIABLE	OR CRUDE		OR FULL MODEL		OR FINAL REGRESSION MODEL	
	OR (95%CI)	*p*	OR (95%CI)	*p*	OR (95%CI)	*p*
G3 (MINI-TUBES)						
Maxillary arch linear measurements (mm)						
Intercanine width	1.01 (0.62–1.67)	0.956				
Interpremolar (1st) width	1.16 (0.65–2.06)	0.622	1.57 (1.02–2.42)	0.039*	1.32 (0.91–1.91)	0.142
Interpremolar (2nd) width	1.49 (0.84–2.65)	0.170				
Intermolar width	1.25 (0.74–2.08)	0.395				
Arch length	1.22 (0.71–2.07)	0.464				
Mandibular arch linear measurements (mm)						
Intercanine width	0.64 (0.34–1.19)	0.162	0.69 (0.43–1.12)	0.138		
Interpremolar (1st) width	1.57 (0.85–2.92)	0.145				
Interpremolar (2nd) width	0.60 (0.34–1.05)	0.074	0.76 (0.53–1.09)	0.148		
Intermolar width	0.75 (0.44–1.30)	0.313				
Arch length	0.82 (0.44–1.53)	0.541				

Statistical significant at * $P < 0.05$

Table 4: Descriptive statistics and comparison between different groups according to the type of bracket in clinical variables.

QUALITATIVE VARIABLES	CONVENTIONAL (G1)	SELF-LIGATING (G2)	MINI-TUBES (G3)	*p*
	n (%)	n (%)	n (%)	
Caliber of final working archwire used				
0.019" x 0.025"	36 (90)	35 (87.50)	0	
0.018" x 0.025"	0	4 (10)	0	
0.017" x 0.025"	0	1 (2.50)	0	*p* < 0.0001*
0.018"	4 (10)	0	0	
0.016"	0	0	11 (32.35)	
0.014"	0	0	23 (67.65)	
Alloy used in final working archwire				
Stainless Steel	30 (75)	29 (75.50)	0	
Australian Wire	4 (10)	0	0	*p* < 0.0001*
Titanium-molybdenum	0	4 (10)	0	
Nickel-titanium	6 (15)	7 (17.50)	34 (100)	

Statistically significant at *$P < 0.05$. Fisher Exact test.

DISCUSSION

Over the years, the development of different orthodontic systems has led to better tri-dimensional control of teeth. Nevertheless, the results of the present study did not show statistically significant differences across the three studied orthodontic systems. Similar results were found by Mittal et al,[22] who compared the achieved torque in the anterior teeth at the end of the orthodontic treatment between the Roth and MBT prescriptions, and by Fleming et al,[5] who compared the arch dimensional and inclination changes between self-ligating and conventional brackets during alignment.

In this study, no significant differences between groups were found in the bivariate analysis in the changes of the linear measurements after orthodontic treatment. However, in the multinomial regression, significant differences were found, with a higher increase of the maxillary interpremolar (1st) width in the self-ligating group compared with the conventional group. Similar results were found by other authors.[5] Conversely, no differences across bracket types and transverse width changes at the end of orthodontic treatment were found in other studies.[4,7,23]

For the intragroup changes in the arch dimensions, we found statistically significant ($P < 0.0014$) higher values at T2 than at T1 in maxillary interpremolar (2nd) width, mandibular interpremolar (1st and 2nd) width, and mandibular arch depth in the conventional group; in maxillary interpremolar (1st and 2nd) width, mandibular interpremolar (2nd) width, and mandibular arch depth in the self-ligating group; and in maxillary and mandibular interpremolar (1st and 2nd) width and mandibular arch depth in the bracketless fixed system group. In this study, only 0.014-inch or 0.016-inch nickel-titanium archwires were used in all patients treated with the bracketless fixed system, while mostly rectangular wires (0.019 + 0.025-inch) were used as the final arch in the other two groups. These results are similar to those of Fleming et al,[24] who found early arch dimension changes with nickel-titanium archwires; these results seem to suggest that if a clinician only aims to expand the arches, small nickel-titanium round archwires are sufficient to achieve this goal irrespective of the orthodontic system used.

On the other hand, in the present study, an increase in the mandibular arch depth after orthodontic treatment was found for all three groups, and this finding may indicate proclination of the mandibular incisors in all the groups. Additionally, none of the groups showed significant changes in the posttreatment mandibular intercanine width. Likewise, Fleming et al[5] found no difference in the mandibular intercanine width or inclination changes during alignment between conventional and either active or passive self-ligation brackets. In contrast, Lineberger et al[20] found increases in the arch widths with self-ligating brackets but no changes in the arch depths. Some evidence in the literature has shown that variations in the mandibular intercanine width can be considered particularly unstable and may be an important factor in long-term treatment stability.[25] Lucchese et al[6] found an increase in transverse arch dimensions, along with torque values, after treatment with a passive self-ligating appliance but a tendency toward transverse diameter restriction at 2 years after the treatment.

Our study did not show significant differences across groups in any of the studied variables. Intragroup changes from T1 to T2 were noted in all of the groups in some of the variables in the present study, and the differences in both the tooth crown tip and torque were similar. These results are similar to those of Tong et al,[26] who found distinctive trends in the intra-arch fluctuations of the mesiodistal angulation and the faciolingual inclination from the anterior to the posterior teeth. Few differences in the final results in the tip and torque between self-ligating brackets and preadjusted conventional brackets are expected because prescriptions often differ by only a few degrees.[22,27] Tooth crown angulation is mainly the result of the bracket prescription and its axial placement; if a bracket or a bracketless fixed system is placed in the correct position, similar mesiodistal angulation must be obtained.[28] On the other hand, the resulting torque is affected by variables related to the properties of the archwire alloys, such as the inability to fill the slot because of a size difference between the archwires and bracket slot, irregularities caused by the manufacturing process of the brackets, and differences in the stiffnesses of the wire alloys and ligation modes.[29] Therefore, differences in the torque between the bracket systems that use rectangular steel wires and the bracketless fixed systems that only use round nickel-titanium wires are expected, but in this study, these differences were not found. One of the reasons for these findings might be that there are many other variables that affect the resulting torque, such as the facial contour convexity of the clinical crown and the height of bracket placement, which can induce large inter-individual variations in the final torque value of the teeth.[30] Multiple authors[31-33] have found that the nominal dimensions of the bracket slots and rectangular archwires could differ from the real dimensions where slot heights are usually oversized and archwire heights are usually undersized. This slot/archwire combination results in a torsional play that may affect the amount of torque expression. Also, self-ligating brackets seem to deliver lower torque expression than conventional brackets as has been reported by Al-Thomali et al[34] in a systematic literature review. Another reason for our findings in torque values between the study groups could be that in low complexity cases where teeth are not significantly displaced before treatment, the small amount of tooth movement does not allow the perception of the differences in torque expression between the three orthodontic appliances. Torque delivery is very important in producing stable outcomes, particularly where teeth are significantly displaced before or during the orthodontic treatment. A quick interpretation of the results of the present study may lead to the conclusion that the use of rectangular wires is not necessary in orthodontic treatment. However, the use of rectangular wires enables torque to be generated during the leveling and working stages of orthodontic treatment. Rectangular steel archwires are essential tools for placing teeth in the proper buccolingual or palatal positions and for counteracting the loss of torque generated, which occurs due to space closure mechanics in extraction cases. Therefore, these findings should be interpreted with caution because they do not consider the individual variations that can occur for each patient. Another important consideration is that the statistical tests were performed with group means, and individual changes could not be detected.

One of the limitations of this study is the retrospective manner in which the data were collected and manner in which the operators and clinical procedures were standardized. Another limitation could be a possible selection bias by individual differences in the amount of crowding between groups at baseline. Additional randomized clinical trials with random and more strict selection criteria of the cases need to be conducted to confirm these findings.

CONCLUSIONS

The results of this study show that there is insufficient evidence to reject the null hypothesis and that there are no difference in the final values of the transverse width, mesiodistal angulation, or buccolingual or palatal inclination in patients treated with either self-ligating, conventional, or bracketless systems.

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