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Original Article

Effects of a ceramic active self-ligating bracket on retraction/tipping/rotation of canine, premolar mesialization, and transverse arch dimensions: A preliminary single-blind split-mouth randomized clinical trial

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ABSTRACT

Background: There is no clinical study on ceramic self-ligating brackets (SLBs). Therefore, this preliminary study was conducted for the first time to address its effects.
Materials and Methods: This split-mouth randomized trial was performed on 32 quadrants in 16 orthodontic patients needing extraction of maxillary premolars and distalization of canines. In each blinded patient, right/left sides were randomized into control (ceramic bracket) and experimental (ceramic SLB) groups. Dental stone models were taken before canine retraction and 3 months into retraction. Models were digitized as three-dimensional models. Changes were measured on superimposed models. Groups were compared using Wilcoxon signed-rank test ($\alpha = 0.05, \beta = 0.1$).
Results: Both bracket types caused significant changes after 3 months in terms of all assessed clinical outcomes ($P \leq 0.002$). Compared to conventional ceramic brackets (control), ceramic SLBs reduced retraction rate ($P = 0.001$), canine rotation ($P = 0.001$), canine tipping ($P = 0.002$), and arch expansion at the canine site ($P = 0.003$). However, the extents of anchorage loss ($P = 0.796$) and arch constriction in the premolar area ($P = 0.605$) were not statistically different between the bracket types.
Conclusion: Compared to conventional metal-lined ceramic brackets, active ceramic SLB can increase the duration of canine distalization, while reducing canine rotation and tipping (inducing more bodily movements). The loss of anchorage with ceramic SLB was similar to that of conventional ceramic bracket after 3 months of treatment (considering the lower rate of SLB canine retraction during that time). Both brackets similarly constricted the arch at the premolar site. In the canine area, they expanded the arch, with the SLB causing smaller extents of expansion.

Key Words: Corrective orthodontics, bodily tooth movement, tooth rotation

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INTRODUCTION

Dental extractions performed in orthodontics are followed by space closure, which can be done either with the older frictionless approach (using closing loops that exert light continuous force but are difficult to fabricate and use) or with the friction-based method that uses sliding mechanics, and despite wasting energy and anchorage, it is highly predictable, convenient, and common.[1-8]

However, friction is usually undesirable and can compromise treatment and cause complications.[9-11] Friction is suggested to be associated with factors such as the cross-section of arch wire, bracket design, angulation of wire with bracket, materials used in arch wires and brackets, and the type of ligation.[9-13] Regarding materials, although stainless steel (SS) brackets have usually higher practical qualities, they are not esthetic;[14] this is crucial to many patients nowadays,[15] leading to the introduction of ceramic brackets.[11,15] Albeit these brackets look appealing, they have higher coefficients of friction and cause greater frictions and induce slower tooth movements in comparison with SS brackets.[9-12,15-18] The effect of ligation method (elastomeric/steel ligatures, active/passive self-ligating brackets [SLBs]) on friction[19-21] influences tooth movement rate.[22,23] SLBs are suggested to reduce friction and overall treatment time, improve plaque control, deliver forces in more biological levels, enhance patient comfort, and increase clinical efficacy.[13,23-29] Besides, in comparison to conventional ceramic brackets, metal slot ceramic brackets and self-ligating ceramic brackets might give improved clinical performance, resembling that of conventional metal bracket systems.[10] However, controversy exists over many of these claims,[6,23,24,26,30,31] and a 2018 systematic review concluded that SLBs might not act better than conventional brackets (CBs) in terms of space closure, expanding transversal dimensions, or orthodontic efficiency.[31] Another issue with SLBs that will affect the sliding is binding which is the contact angle of the wire and the wings or the clit of the brackets.[3]

Compared to metal SLBs, ceramic SLBs are relatively new to orthodontic practice, and literature on their efficacy is scarce and limited to merely *in vitro* studies. They may have advantages such as their esthetic look while producing lower frictions.[32,33] This study was conducted since (1) clinical studies on SLBs are scarce and highly controversial, (2) since the few clinical trials are mostly concerned with the speed of retraction and not the other aspects of treatment such as rotation control, (3) because studies on bodily movement of canine during retraction with SLBs are very scarce or nonexistent, (4) since studies on transverse arch changes following canine retraction using SLBs are nonexistent, and finally (5) since there is no clinical study regarding ceramic SLBs. We aimed to comparatively assess the retraction speed, anchorage loss, rotation control, and tipping control of ceramic self-ligating and conventional ceramic brackets for the first time. In addition, for the first time, we used precision three-dimensional (3D) digital measurements for this purpose. The null hypotheses were (1) the lack of any effect of either bracket type on five treatment outcomes, as well as (2) the lack of any significant difference between ceramic CB and ceramic-active SLB types in terms of the amounts of changes over 3 months in the case of five clinical measurements.

MATERIALS AND METHODS

Trial design

This is a preliminary, parallel-arm, single-blind split-mouth randomized clinical trial. Protocol ethics were approved before commencement, by both the Ethics Committee of the University (ethical code: IR.AJUMS.REC.1397.254) as well as an International Online Review Body (RCT code: IRCT20180710040414N1) in accordance with the Declaration of Helsinki. Patients could leave the study anytime they wanted to and treatments would be completely delivered anyways.

Participants, eligibility criteria, and setting

Patients were included from the attendees to the Department of Orthodontics, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran, in 2018–2019. The intervention began on September 6, 2018, treatment for all patients finished on November 17, 2018, and all follow-ups finished on March 17, 2019. The inclusion criteria were the indication for extraction of maxillary first premolars followed by canine retraction, alignment of maxillary central incisors in the leveling and alignment stage, absence of any systemic diseases and any history of using medications that could interfere with orthodontic treatment, absence of any periapical lesions and root anomalies before treatment as confirmed by panoramic radiography, and consent of patients or their parents to participate in the study. The exclusion criteria were debonding of brackets from canines or anchorage teeth, removal of retracting coil springs during treatment, and irregular follow-up visits of patients. Patients with asymmetrical arches were excluded from the study.

Preintervention treatment

This step was carried out to control for confounding variables that could affect canine rotation on both sides. The teeth were bonded using MBT slot 22 brackets (G&H, USA), and attachments were placed on the first and second maxillary molars. The first and second maxillary molars and the second maxillary premolar were connected on each side using ligature wires. The leveling and alignment stage continued up to 18" nickel titanium wires (NiTi, Gestenco, Göteborg, Sweden). The order of NiTi wires depended on the patient: some patients needed more steps and some others needed only 18" wires. Afterward, bilateral maxillary first premolars were extracted. To prevent possible rotation and retraction of maxillary central teeth, due to the presence of transseptal fibers during canine retraction, bilateral aligned maxillary central teeth were attached to each other using a steel wire, and a stop was placed between the maxillary centrals. This stop also prevents wire movement within brackets and maintains the similarity of the arch on both sides.

Randomization and blinding

Randomization was done by a third person using an online random number generator: To remove the nonselection error of the ceramic and ceramic self-adhesive bracket in the right or left canine teeth, a simple randomization method was used to extract random numbers by a third person using the website www.randomizer.org. The patients and statistician, but not the operating orthodontist, were blinded to the treatment allocations. The statistician and patients did not have any access to random assignments. The analyst received coded data. Although the SLB and CBs were not exactly the same, the patients were not aware that which bracket shape is SLB or CB.

Interventions

Canine brackets were replaced with the experimental brackets (active ceramic SLB with a 22" metal slot and a ceramic clip [Quicklear, Forestadent, Germany]) and control brackets (metal-lined ceramic bracket [Encore, Ortho-technology, USA]). Brackets of other teeth were not replaced. The control bracket was attached to the wire using an O-ring (clear, YahongOrtho, Beijing, China). NiTi wires remained for a month until the intervention. Before beginning the intervention [Figure 1], alginate templates were taken from the maxilla to record the initial condition and rotation of canines. The impression was poured with dental stone. NiTi wires were replaced with 18" SS wire (Ortho-Technology, USA). Canine retraction was performed using a NiTi closed coil spring (G&H, USA) 9 mm in length that exerted a moderate 150-g force. The force was assessed and adjusted each month. After 3 months of canine distalization [Figure 2], a second alginate impression was taken. During this period, patients were visited each month to make sure that the appliances were intact, and the coil forces were appropriate.

Since both bracket types and brands were commonly used in orthodontic practice, no harms were identified with this study.

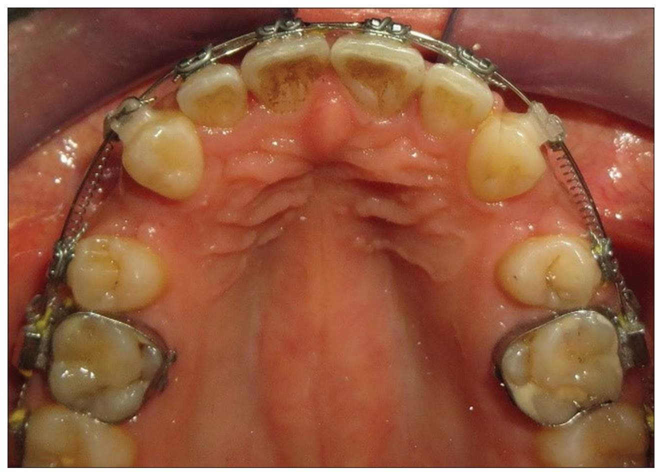

Figure 1: The occlusal view of the maxilla before beginning the retraction of the canine.

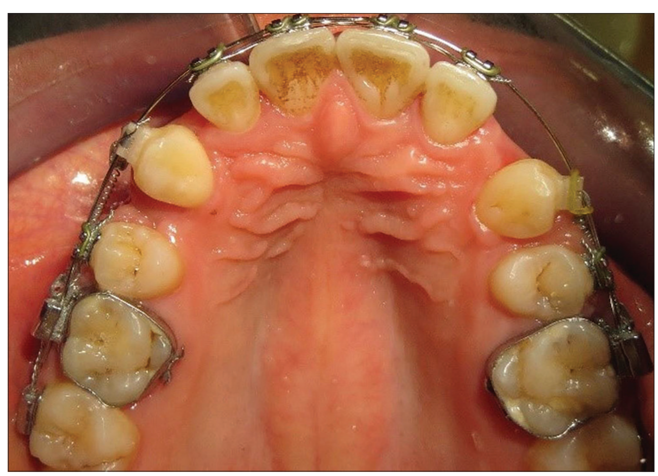

Figure 2: The occlusal view of the maxilla after 3 months of canine retraction.

Clinical outcomes

Dental models were 3D-scanned and digitized (3Shape-trios, 3Shape Dental System, Copenhagen, Denmark) by an expert operator. Using OrthoAnalyzer software on digital 3D models, the rugae (especially the medial end of the third one as the most stable one) on pre- and post-treatment models were identified and used along with the palate to superimpose the before-and-after models on each other [Figure 3].[34,35]

Canine retraction and anchorage loss

On the superimposed model, the extent of distalization happened to the position of the image of the canine cusp tips on the raphe midline before and after the study period was recorded as the extent of canine retraction; a similar procedure was done for premolar mesialization as the anchorage loss [Figure 4].

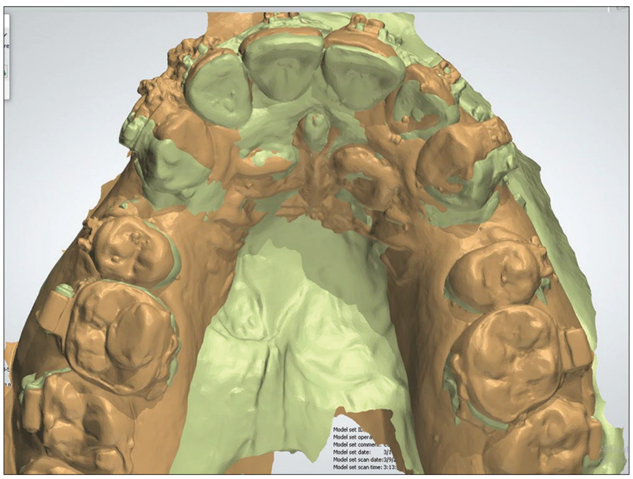

Figure 3: Two superimposed three-dimensional models shown within the OrthoAnalyzer software's environment.

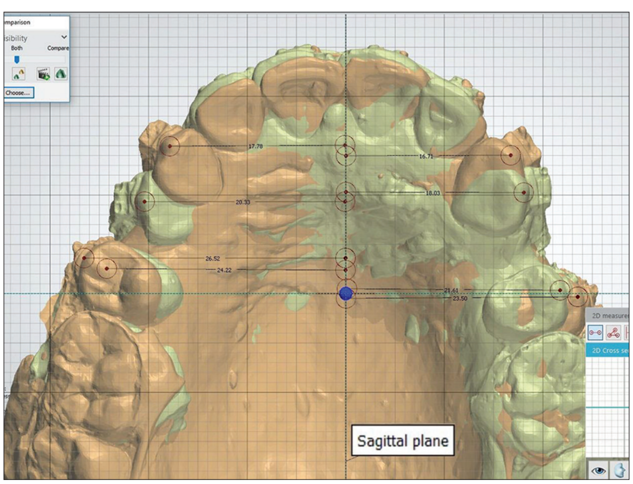

Figure 4: An example of measuring the images of cusp tips of canines and premolars on the midline to measure canine retraction and anchorage loss as well as arch expansion.

Canine rotation was measured by first taking a snapshot of the palatal aspect of the superimposed digital 3D model, while the point of view was perpendicular to the occlusal plain. Afterward, two points were determined on mid-mesial and mid-distal aspects of the canine. The line passing through these points (indicating the direction of mesiodistal dimension of the canine) also passed through a line parallel to the raphe midline. The angle between these two lines was measured. Changes in this angle after 3 months indicated the rotation of canine [Figure 5].

Bodily movement

For measuring the tipping of the canine, on the superimposed model, the center of the canine bracket in each of the superimposed two models was connected to the two cusp tips pertaining to different time points of the same canine, drawing two different lines that made an angle. The angle between these two lines was recorded as the extent of tipping [Figure 6].

Changes of transverse arch dimensions

Looking perpendicular at the occlusal plane, the midline passing the mid-palatal raphe was

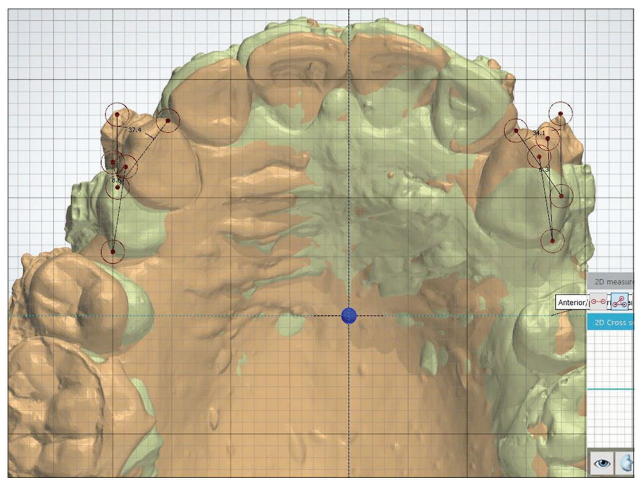

Figure 5: An example of measuring canine rotation.

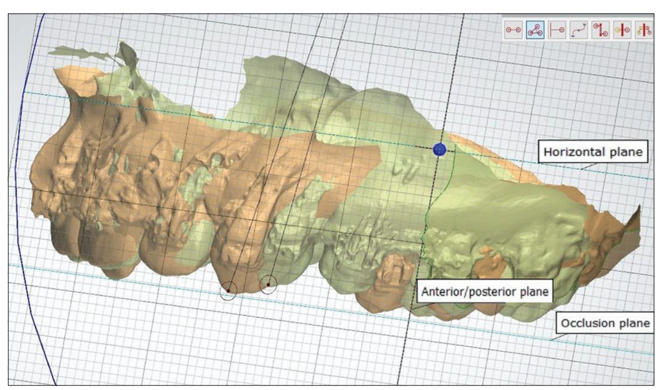

Figure 6: Measuring the tipping of the canine.

drawn when the models were viewed from above, i.e., the direction of camera was perpendicular to the occlusal plane. The distance between the canines on both sides with this line was measured before and after the treatment period; this was repeated for premolars [Figure 4].

All measurements were assessed for two times, and their averages were considered as the main values. All the outcomes were primary. There were no interim analyses. Interventions would be stopped after 3 months or if one of the two spaces in a patient closed before 3 months. In the latter case, the patient would be excluded. No patients met this criterion.

Statistical analysis

The sample size was predetermined as 32 quadrants in 16 patients, based on the following formula:

$$N = \frac{(Z1-\alpha 22+Z1-\beta)^2\ (S1^2+S2^2\ )}{(X1-X2)^2}$$

Where S1 = 0.38/S2 = 0.3, X1 − X2 = 0.6, and Z = 1.28.[36,37] To offset for dropouts, it was later increased to 38 quadrants in 19 patients. We also calculated the *post hoc* power for all primary outcome tests, using the paired *t*-test formula (differences were normally distributed).

Inter-observer agreement was determined by evaluating all pre- and post-treatment angular measurements taken in a pilot study on all the angular measurements of the same sample, on both sides by another observer. It showed excellent inter-observer agreements (all the 4 Cronbach alpha values ≥0.956, all the 4 $P = 0.000$). Descriptive statistics and 95% confidence intervals (CIs) were calculated for pre- and post-treatment measurements and also for the extents of changes (i.e., delta values).

Primary outcome

Delta values indicating the 3-month changes were calculated for each measurement as posttreatment minus baseline. The Kolmogorov–Smirnov test showed that some of groups of delta values were not distributed normally. Comparisons between the effects of two bracket types on measurements (indicated by the delta values) were done using a Wilcoxon signed-rank test for matched data. The software in use was SPSS 25 (IBM, Armonk, NY, USA). The differences between delta values of CB and SLB followed a normal distribution (all Kolmogorov–Smirnov $P > 0.1$). Therefore, 95% CIs were reported for them along with other descriptive statistics.

Secondary outcome

We assessed if either of bracket types had any before–after effects on each of the evaluated parameters. Not all groups were normally distributed according to the Kolmogorov–Smirnov test. Parameters with both the before- and after-treatment measurements available (i.e., the angle of canine with the midline, the distance of canine and premolar from midline) were compared with each other using a Wilcoxon signed-rank test for paired data to assess the effect of treatment on these parameters. For parameters with only the extent of change measured (canine retraction, anchorage loss, and canine tipping), the extent of change was compared with the value zero using a one-sample Wilcoxon signed-rank test, to test if the treatment had any effects above zero on these variables over time. The level of significance was set at 0.05.

RESULTS

Participant flow

About 320 patients were originally screened before reaching the desired sample size. During the study, three patients who had been originally included were dropped out, all due to a failure in an orthodontic appliance in one of the sides (i.e., bracket hook and coil spring); they were replaced by three new patients (with randomized maxilla sides) [Figure 7].

Baseline data

Due to the split-mouth nature of the study, both groups were identical in terms of demographics. Of the 16 patients, 13 were females and 3 were males. Their mean age was 22.8 ± 5.9 years (range: 15–35). For the three variables, both baseline and 3-month values were measured separately. Their baseline measurements are presented in Table 1. Other variables were not calculated using baseline values.

Primary outcome

The raw data pertaining to all 3-month changes (delta values) are presented as Table 2. Canine retraction after 3 months in the conventional ceramic bracket group was about twice faster than that in the SLB group (Wilcoxon signed-rank test, $P = 0.001$). Anchorage loss extents were rather similar in both groups ($P = 0.796$) noting that in the same time period, the extent of retraction in the SLB group was about half of that in the conventional group. Canine rotation in CBs was more than twice as that in SLBs ($P = 0.001$). Canine tipping in the SLB group was about half of that in the conventional group (P = 0.002). The arch was expanded much more in the conventional group compared to the SLB group (P = 0.003). However, the arch constrictions observed at the premolar sites after 3 months of treatment were rather similar for both groups [P = 0.605, Tables 2-4]. Most *post hoc* powers were above 90% [Table 3].

Secondary outcome

All 3-month changes were statistically significant: canines rotated to become more parallel with the midline in either group (their distal side becoming "in"); in either group, the arch was expanded at the canine site but was constricted at the premolar site [Wilcoxon signed-rank test, $P \leq 0.002$, Table 1]. In either bracket group, the extents of canine distalization, premolar mesialization, and canine tipping within 3 months were all significantly greater than zero (one-sample Wilcoxon signed-rank test, all P = 0.000). *Post hoc* powers were 1.0 for canine distalization caused by either bracket type, ≥0.997 for anchorage loss in either group, and 1.0 for canine tipping in either of bracket types. The rest of *post hoc* powers are presented in Table 1.

Table 1: Descriptive statistics for all available before and after measurements, as well as the results of Wilcoxon signed-rank test comparing pre- and post-treatment measurements

Measurement	Bracket	Time	Mean	SD	Minimum	Maximum	Percentiles			P
							25th	Median	75th	
Canine rotation (°)	Conventional	Pretreatment	34.55	7.28	22.40	47.60	29.13	36.15	41.00	0.000
		Posttreatment	4.14	10.90	−17.20	18.30	−5.05	4.75	13.88	
	Self-ligating	Pretreatment	35.22	8.34	17.30	52.30	28.96	35.90	39.13	0.000
		Posttreatment	22.79	10.95	6.30	42.40	15.93	21.85	32.58	
Canine expansion (mm)	Conventional	Pretreatment	16.72	1.16	14.77	19.90	16.09	16.42	17.27	0.001
		Posttreatment	18.59	1.07	16.49	20.33	17.83	18.67	19.65	
	Self-ligating	Pretreatment	16.46	0.94	14.69	17.70	15.47	16.80	17.34	0.002
		Posttreatment	17.43	1.45	14.06	19.23	16.48	17.86	18.50	
Premolar expansion (mm)	Conventional	Pretreatment	23.68	1.93	20.88	26.99	22.30	23.32	25.69	0.001
		Posttreatment	22.05	2.35	16.06	25.72	20.76	22.25	23.31	
	Self-ligating	Pretreatment	23.35	1.71	20.00	26.26	22.14	23.47	24.74	0.000
		Posttreatment	22.02	1.70	18.28	25.13	21.18	22.32	23.00	

SD: Standard deviation

Table 2: The raw data pertaining to 3-month change extents (delta values) as well as pretreatment canine angles in both sides of all patients

Patient	Sex	Age	Baseline canine angle		Canine distalization		Premolar mesialization		Canine rotation		Canine angulation		Arch expansion (at canine)		Arch expansion (at premolar)*	
			C	SL	C	SL	C	SL	C	SL	C	SL	C	SL	C	SL
1	Female	20	35.20	17.30	8.92	3.34	1.95	3.70	−40.40	−10.60	2.90	0.40	3.04	2.32	−3.93	−0.69
2	Female	26	42.00	39.50	5.55	3.67	0.78	1.18	−23.99	−4.80	12.30	6.60	2.18	0.80	−0.93	−0.14
3	Female	35	38.03	33.04	2.18	3.34	0.27	0.31	−29.03	−11.98	3.30	4.90	2.01	0.80	−0.13	−0.40
4	Female	21	37.10	52.30	6.41	2.57	1.54	0.51	−23.00	−9.90	5.00	2.50	1.40	1.22	−1.91	−0.57
5	Female	20	37.40	34.10	5.67	3.68	1.33	0.99	−28.80	−27.80	3.20	1.50	2.55	1.32	−2.30	−1.89
6	Female	17	28.90	36.30	4.61	2.15	1.17	0.69	−24.60	−13.50	4.10	2.50	2.90	2.72	−0.50	−0.11
7	Female	23	29.80	37.20	4.81	2.20	1.07	0.63	−24.60	−13.50	3.90	2.20	1.84	1.32	−0.50	−0.11
8	Female	32	30.40	26.10	3.77	2.03	1.96	2.07	−26.90	−7.10	7.70	2.70	2.22	0.13	−0.71	−0.90
9	Male	19	41.90	38.00	4.92	2.28	0.86	0.97	−28.70	−8.20	1.50	2.20	−0.18	1.06	−4.02	−3.45
10	Female	15	30.30	36.80	4.92	4.81	1.05	0.71	−26.80	−17.00	2.50	3.40	2.20	1.53	−2.13	−3.08
11	Female	17	42.70	45.50	3.00	1.72	1.54	1.42	−56.80	−6.80	8.00	2.20	0.84	0.63	−1.12	−3.38
12	Female	23	38.30	43.90	6.72	1.31	1.03	3.22	−43.40	−10.40	3.50	0.60	0.86	−0.63	−4.88	−1.72
13	Female	28	47.60	35.50	4.11	2.33	0.69	1.52	−32.50	−13.00	3.90	1.90	2.01	−0.49	−2.01	−2.02
14	Male	16	26.10	27.20	5.92	2.12	0.85	1.06	−43.30	−19.60	3.70	3.00	3.29	0.43	0.03	−0.90
15	Male	29	22.40	33.20	2.04	1.47	0.69	0.12	−4.10	−12.00	3.00	1.20	1.16	0.94	−0.26	−0.68
16	Female	24	24.60	27.60	4.26	3.65	1.69	1.03	−29.50	−12.70	6.10	2.20	1.54	1.36	−0.75	−1.26

All measurements are in mm except canine angle, canine rotation, and canine tipping which are in degrees. *Negative values related to "arch expansion" at the premolar site denote arch contraction. C: Conventional bracket; SL: Self-ligating bracket

Table 3: Descriptive statistics for delta values (posttreatment minus pretreatment measurements), as well as the results of the Wilcoxon signed ranks test comparing bracket types

Measurement	Bracket	Mean	SD	Minimum	Maximum	Percentiles			P
						25th	Median	75th	
Canine distalization (mm)	Conventional	4.86	1.74	2.04	8.92	3.86	4.87	5.86	0.001
	Self-ligating	2.67	0.97	1.31	4.81	2.05	2.31	3.57	
Anchorage loss (mm)	Conventional	1.15	0.48	0.27	1.96	0.80	1.06	1.54	0.796
	Self-ligating	1.26	0.99	0.12	3.70	0.65	1.01	1.50	
Canine rotation (°)	Conventional	−30.40	11.62	−56.80	−4.10	−38.43	−28.75	−24.60	0.001
	Self-ligating	−12.43	5.55	−27.80	−4.80	−13.50	−11.99	−8.63	
Canine tipping (°)	Conventional	4.66	2.70	1.50	12.30	3.05	3.80	5.83	0.002
	Self-ligating	2.50	1.53	0.40	6.60	1.60	2.20	2.93	
Arch expansion at canine (mm)	Conventional	1.87	0.91	−0.18	3.29	1.22	2.01	2.47	0.003
	Self-ligating	0.97	0.88	−0.63	2.72	0.48	1.00	1.35	
Arch expansion at premolar (mm)*	Conventional	−1.63	1.51	−4.88	0.03	−2.26	−1.03	−0.50	0.605
	Self-ligating	−1.33	1.15	−3.45	−0.11	−1.99	−0.90	−0.44	

*Negative values related to 'arch expansion' at the premolar site indicate arch constriction. SD: Standard deviation

Table 4: Descriptive statistics and 95% confidence interval for differences between delta values of both methods (calculated as $Delta_{SLB}$ - $Delta_{CB}$)

Outcome	Mean	SD	Minimum	Median	Maximum	95% CI
Canine distalization	−2.20	1.82	−5.58	−1.94	1.16	−3.17-−1.23
Anchorage loss	0.10	0.86	−1.03	−0.04	2.19	−0.35-0.56
Canine rotation	17.97	13.12	−7.90	18.12	50.00	10.98-24.96
Canine tipping	−2.16	2.20	−5.80	−1.90	1.60	−3.33-−0.99
Arch expansion (canine)	−0.90	1.03	−2.86	−0.70	1.24	−1.45-−0.35
Arch expansion (premolar)	0.30	1.41	−2.26	0.19	3.24	−0.45-1.05

Linear measurements (canine retraction, anchorage loss, and arch changes) are in mm. The rest of variables are angular and in degrees. SD: Standard deviation; CI: Confidence interval

DISCUSSION

The findings of this study indicated that both methods caused canine distalization, anchorage loss, canine rotation, canine tipping, arch expansion at the canine site, and arch constriction at the premolar site during canine retraction. However, compared to conventional ceramic brackets, self-ligating ceramic brackets would cause slower canine retraction, less rotation, less tipping, and less arch expansion at the canine site. Both bracket types may have similar extents of anchorage loss and similar extents of arch constriction at the premolar site. Since there was no study on ceramic SLBs, we are limited to discuss our results in light of few studies available on metal SLBs.

Metal SLBs have been shown to have the lowest frictions *in vitro*,[13,38-43] which suggests a faster tooth movement, because less extents of force are wasted on friction and more is available to the tooth movement. Nevertheless, clinical evidence was quite controversial in this regard. Sirinivas[44] observed faster canine retractions with SLBs compared to CBs. Similarly, Hassan *et al*. (using passive SLBs)[37] and Jayachandran *et al*. (using interactive brackets)[45] found significantly greater rates of canine retraction in their SLB groups. A reason for their result is suggested to be their methodology of assessing the canine tip, which can be also influenced by tilting,[23] because tilting can move the canine tip faster while the body of the tooth has not moved as much. On the other hand, da Costa Monini *et al*.[46] who had measured the distances between the canine tips, found no significant difference between metal SLB and CBs in terms of canine retraction. They published another study in 2017[29] on the same active SLB and again observed no significant differences between conventional and active SLB in terms of canine retraction.[29] Miles (using passive SLB)[47] as well found no significant difference in speeds of both methods while retracting the anterior teeth. Furthermore, DiBiase *et al*. (using passive SLBs)[48] and Deguchi *et al*.[49] did not detect a significant difference between SLB and CB in terms of treatment duration and number of visits. Mezomo *et al*.[23] found similar rates of retraction as well; they used passive brackets [although they had not stated this in their paper, the type/brand used implied being

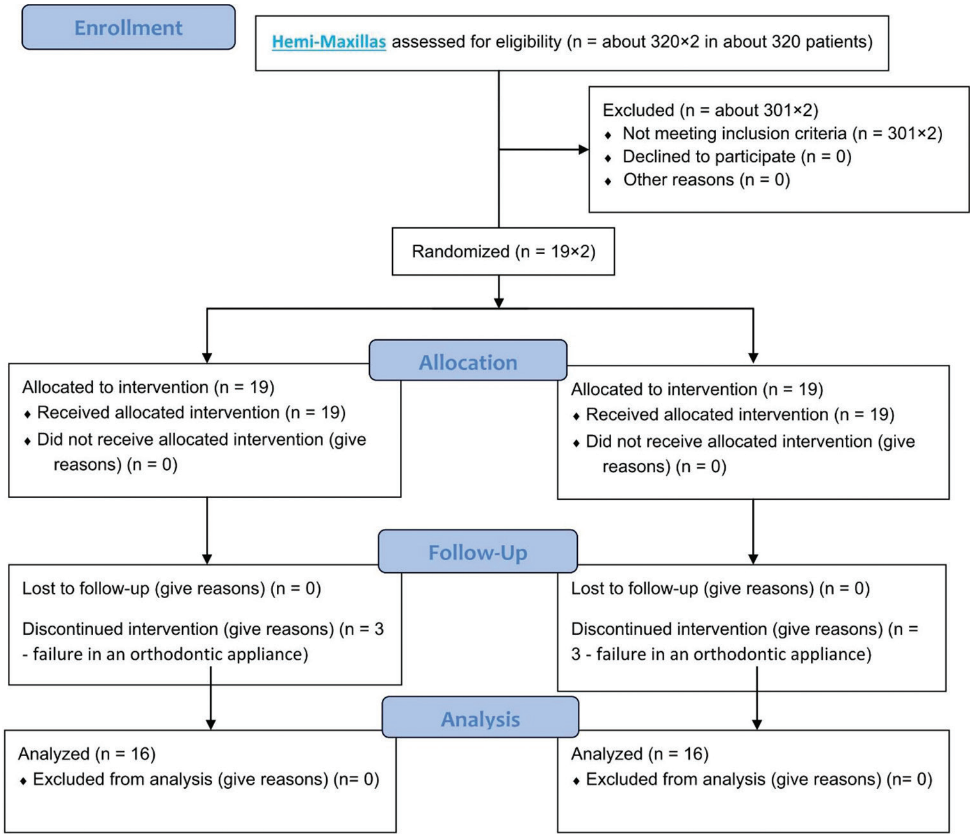

Figure 7: The flow diagram of the maxillary quadrants (and not the patients) in this study.

passive]. According to Wong *et al*.,[50] differences in the extent of space closure between CB and passive SLBs over 3 months were trivial and nonsignificant. There was also a study by Burrow[51] that, similar to our study, found a slower speed of retraction in their passive metal SLB group compared to CBs. The controversy might be attributed to the assessment of canine tip which can be affected by the tooth movement as well as its tipping; therefore, if tipping occurs, a greater range of movement will be detected. Moreover, different brands in use can differ in terms of quality and various physical and mechanical properties. This will lead to different results in various studies.

In addition, if SLB can exert a better control over tooth movement, the movement would be mostly bodily and hence less tipping would be expected, which translates into a shorter distance of canine tip movement within a fixed time frame. Our study showed that ceramic SLBs can induce bodily movement. The only two available studies on tipping of the canine during retraction have shown that passive and active SLBs may induce significant bodily movements.[46,52] Finally, not all *in vitro* studies agree that friction is less with SLBs. Some *in vitro* studies indicate that although there might be some significant differences between SLBs and CBs at lower extents of force, the resistance to sliding would be similar for SLBs and CBs at clinically relevant forces.[27] Another study found greater frictions in their passive SLB group compared to CBs.[52] Moreover, although SLBs have usually low friction rates,[38,39] active SLBs (which were used in this study) may have considerably higher friction rates than passive ones.[53]

The lower rates of friction are suggested to also contribute to a greater control over anchorage and reduce the loss of anchorage.[37,54] Our results in this regard were consistent with those of da Costa Monini *et al*.[29] who used active SLBs as well as Mezomo *et al*.[23] and Miles[47] who researched passive SLBs, and none found a significant difference between CB and SLBs in terms of anchorage loss. However, Hassan *et al*.[37] and Jayachandran *et al*.[45] reported smaller amounts of anchorage loss in their passive and interactive SLB systems, respectively. These differences can again be attributed to various methodological differences such as shape and size of wires. In earlier studies, SS wires of 18” or 0.025" × 0.019" or 0.025" × 0.017" had been used.[13,38,55] We used 18" SS wire because larger wires would press the clip of the active SLB and increase the friction; further, this wire size would improve rotation control when engaged within the 22" slot of the SLBs used in this study.[55] Another major source of discrepancy can be the limited time of many studies. For instance, in the 3-month course of this study, canines were retracted much more on the conventional side compared to the SLB side. In this situation with SLB canines moving less, the extent of anchorage loss was comparable in both groups. It is not known if we allowed the canine of the SLB side to move as much as the canine did during 3 months in the conventional side; it would be possible for the anchorage to become lost more on the SLB side.

Canine rotation during retraction is a result of the applied orthodontic forces passing not through the center of resistance of the tooth.[23] Two of the available clinical trials suggest that rotation control may be better with passive SLBs.[23,37] Moreover, Hassan *et al*.[37] found a significant improvement in rotation control with passive SLBs, similar to our results. They attributed their finding to their larger diameter of arch wires in comparison to the previous two trials.[37] The above-mentioned methodological issues such as the differences in physical properties of appliance parts can as well account for the dispute. Characteristic differences in brackets of both sides such as materials that used for their construction can affect the results of treatment as well.

Effects of canine distalization using SLBs have not been studied before. We found that SLBs can expand the arch at the canine site, but about half of the expansion caused by CBs. Both bracket types similarly constricted the arch at the premolar site. Our findings pertaining to the CB was similar to those of Aksakalli *et al*.[35] who observed an expansion of the arch after using CBs. However, they found also expansion in the premolar area, which was in contrast to our findings related to CB (or SLB). Still, in their study, the arch expansion at the premolar area was much smaller than that in the canine area, and even some patients had shown arch constriction like in this study.[35] These findings should be re-assessed for other SLB or CB types so that generalization can become possible.

This study was limited by some factors. The 32 quadrants in 16 patients might not look like a large sample; however, it was large enough: the sample size was predetermined to provide powers considerably >90%. The highly significant results and very high *post hoc* powers obtained in our study confirmed the adequacy of the sample size and the powers for most tests, which were above 90%. Some trials published recently had only 10 patients assessed over 2 months, still with sufficient powers obtained.[35]

This trial was powered only for the canine retraction, but there were other variables included. It was not known before commencement of the trial whether the study could be adequately powered for those as well. Still, the *post hoc* powers clearly show that almost all tests had powers above 90%.

The trial had a surrogate end point of how much space closure is achieved within a time frame. The actual clinical relevant end point would be the duration of space closure or even better the duration of the whole treatment. However, it was not possible to test such parameters in a split-mouth design.

One might argue that the age was not specified in the inclusion criteria and the study included both growing and nongrowing patients and that the rates of tooth movement are different between these groups and they might not be combined or assumed to produce similar results. Nevertheless, this study was a split-mouth trial, meaning that each patient was his or her own control. This intra-individual matching rules out the effect of age on the difference between experimental (SLB) and control (CB) sides. Choosing a broader age range (as done in this study) could also improve the generalizability which is favorable. Yet, the generalizability of results might be limited to the specific physicomechanical characteristics and brands of the materials used in this study as well as characteristics of the sample such as age range and ethnicity of patients. This limitation was something natural and shared by all previous investigations. Another potential concern of readers can be "not using the main SLB/CBs through the whole treatment and instead using a similar bracket for both sides before the beginning of intervention." Of course, the answer would be that the use of different brackets before beginning of the intervention would simply disrupt the baseline symmetry between the sides. Moreover, we needed the sides to be treated similarly until the intervention. Another argument could be the use of metal ligatures (instead of O-rings) to exert better control over rotation. We used O-rings since, unlike metal ligatures, they were standardized. Moreover, O-rings and metal ligatures might be both ineffective in controlling rotation.[55] Furthermore, it was better to adopt more than two types of brackets. However, a limitation of split-mouth designs is that they usually disallow the inclusion of more than two groups. Randomization concealment was not done in this study; however, given that both sides of a patient's mouth are matched, it might affect the results minimally.

CONCLUSION

Both bracket types succeeded to distalize the canine at the expense of its rotation and anchorage loss. Compared to the used conventional ceramic bracket with a metal slot, this particular brand of active ceramic SLB exerted a better control over canine rotation and its tipping. However, it reduced the speed of canine retraction compared to the CB, perhaps partly because of the bodily movement it caused. The extent of anchorage loss was similar for both groups during the fixed time of 3 months, and noting the lower extent of retraction occurred in the SLB group. The arch was expanded at the canine site, and this expansion was faster for CBs compared to SLBs. The arch was constricted in the premolar area at a rather similar rate for both bracket types.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

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