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Transverse and torque dental changes after passive self-ligating fixed therapy: A two-year follow-up study

Alessandra Lucchese,[a,b] Maurizio Manuelli,[a,b,c] Paolo Albertini,[a,d] and Luis Huanca Ghislanzoni[a,b,e,f]
Milan, Pavia, Bologna, Albino, and Reggio Emilia, Italy, and Geneva and Lausanne, Switzerland

Introduction: Self-ligating appliances are purposed to expand the arches, but evidence on stability of the result is lacking. We measured the width of maxillary and mandibular arches and torque changes after treatment with the use of passive self-ligating appliances and assessed stability at the 2-year follow-up. **Methods:** Maxillary and mandibular 3-dimensional (3D) models from 32 subjects (mean initial age 14.9 ± 0.9 years), consecutively treated with the use of self-ligating appliances, were obtained before, immediately after, and 2 years after treatment. Dental arches were examined with the use of 3D software to evaluate differences in transverse arch dimensions and torque values. **Results:** An incremental increase of arch widths was recorded, especially regarding maxillary and mandibular premolars. The increase in the transverse diameters was associated with a significant positive torque gain. No significant changes in arch perimeter and depth were recorded. In the retention period, slight significant changes in transverse diameters were recorded, and a transverse diameter constriction detected. Torque values remained almost unchanged in the follow-up period. **Conclusions:** Transverse arch dimensions, along with torque values, increased significantly after treatment with the use of a passive self-ligating appliance. In the 2 years following treatment, a tendency to transverse diameter restriction, especially for the maxillary and mandibular premolars, was observed. (Am J Orthod Dentofacial Orthop 2019;156:94-103)

Treatment with the use of passive self-ligating brackets has been claimed to be able to expand dental arches in a stable way.[1,2] This topic has triggered some controversies in the literature. Certain papers have provided data about expansion after the initial leveling and alignment phase.[3,4] Many papers report values at the end of the therapy,[5-8] and only 2 report transverse values after a period of retention.[9,10]

[a]School of Dentistry, Department of Orthodontics, Department of Orthodontics, Vita-Salute San Raffaele University, Milan, Italy.
[b]Unit of Dentistry, Division of Orthodontics, Research Area in Dentofacial Orthopedics and Orthodontics, IRCCS San Raffaele Scientific Institute, Milan, Italy.
[c]Private Practice, Milan, Pavia, and Bologna, Italy.
[d]Private Practice, Reggio Emilia, Italy.
[e]Department of Orthodontics, University of Geneva, Geneva, Switzerland.
[f]Private Practice, Albino, Italy, and Lausanne, Switzerland.
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Address correspondence to: Alessandra Lucchese, Dental Office Orthodontics Passion, Strada Maggiore 17\d, 40125 Bologna, Italy; e-mail, lucchese.alessandra@hsr.it; lucchese.orthopassion@gmail.com.
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Comparing treatment with passive self-ligating and conventional brackets, Jiang and Fu[11] and Vajaria et al[5] found a statistically significant difference between the 2 groups at the level of intermolar width only (wider in the self-ligating cases). Mikulencak[12] compared his patients treated with the use of Damon self-ligating brackets and those treated with the use of palatal expanders and fixed appliances. He found statistically significant changes in arch width dimensions in the premolar areas (+3.6 and +4.3 mm for first and second premolars, respectively) and molar areas (+1.8 mm) similar to those obtained with a rapid maxillary expander and fixed appliance. More recent studies have analyzed the transverse effects of self-ligating appliances with the use of measurements performed on virtual models. Lineberger et al[13] analyzed the variations of maxillary and mandibular arches in patients treated with the use of Damon self-ligating brackets compared with untreated subjects. They found an increase of +1.9-2.2 mm at the premolar level for both the maxillary and the mandibular arch. In the maxillary arch, the torque gain for premolars was 5.5° on average, and in the mandible it was +3.0°. However, that study did not provide any information on the stability of the expansion after the end of the therapy. Basciftci et al[9] described average expansions of +3.2 and +1.9 mm, respectively, for maxillary and mandibular molars, which remained stable 2 years after the end of the orthodontic therapy. That study, however, did not analyze the torque component of the expansion.

The present study aimed to analyze any eventual effects on transverse dimension of passive self-ligating appliances in a nonextraction sample including a follow-up period of 2 years. Changes in transverse dimensions were analyzed on virtual models in terms of both classic linear measures and angular measures of torque change.

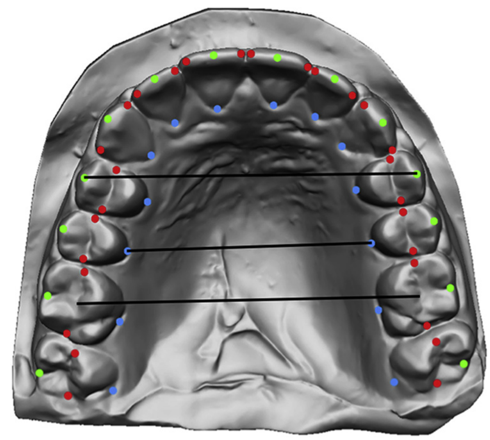

Fig 1. Transverse arch width measured at the cusp, lingual, and centroid levels for every tooth.

MATERIAL AND METHODS

The study sample consisted of 32 white subjects (19 female and 13 male) with a mean age of 14.9 years (SD = 0.9 years). They were consecutively treated in private practice with a passive self-ligating appliance (Ormco, Glendora, Calif), by the same operator (M.M.), who had 25 years' experience with self-ligating appliances.

The inclusion criteria for this retrospective study were: patients (white ancestry) with a full natural permanent dentition (excluding third molars extracted or not erupted) with at least a visible half crown of permanent second molars; patients with a Class I or mild Class II Angle classification (Class II relationship no more than head to head); absence of previous orthodontic treatment or tooth extraction; and absence of sucking habits, craniofacial syndromes, cysts, cleft lip or palate, and multiple or advanced caries. Exclusion criteria were: patients with prosthetic rehabilitation; patients who need corrective jaw surgery; and patients with incomplete or imperfect records. A panoramic radiograph, lateral cephalograms, and dental casts were obtained for all subjects.

At T0, 13 patients presented bilateral Class I and 19 patients unilateral or bilateral mild Class II. Mean age at T0 was 14.9 ± 0.9 years, at T1 16.9 ± 0.9 years, and at T2 18.9 ± 1.0 years.

All subjects were treated in both arches with a passive self-ligating bracket with Damon Q standard values for tip and torque and 0.022-in slots (Ormco, Glendora, Calif).

The treatment consisted of a standard archwire sequence: an initial upper and lower 0.014-inch round followed by a 0.014 × 0.025-inch rectangular and a 0.018 × 0.025-inch rectangular copper nickel-titanium alloy (Ormco Corporation, Glendora, Calif.)

After alignment and leveling, a 0.019 × 0.025-in stainless steel archwire, as working wire, was used in the maxillary and mandibular arch, and then a 0.019 × 0.025-in rectangular beta-titanium alloy was used for the finishing phase.

No extractions were needed, and Class II elastics were mainly used as early elastics in the first phase of the treatment. No interproximal reduction was performed.

The retention appliances were the same for every patient: a twisted-wire fixed retainer 0.0195-inch round dead soft-respond alloy (Ormco) bonded on 1.2 to 2.2 with an Essix retainer in the maxillary arch and a twisted-wire fixed retainer bonded on 3.3 to 4.3 in the mandibular arch.

For every patient, maxillary and mandibular dental casts were collected before treatment (T0), immediately after treatment (T1), and 2 years, on average, after the end of treatment (T2). A total of 192 dental casts were collected, and every cast was associated with a number to protect their identity and blind them to the operator who was digitizing the casts.

To perform the 3-dimensional (3D) dental analysis, study casts of the maxillary and mandibular arches of all subjects were scanned with the use of an intraoral 3D scanner (3D Vision Blue; Orodent, Castelnuovo del Garda, Italy) with a reported accuracy of 30 μm. The scanning of the maxillary and mandibular dental casts with the use of the intraoral scanner was performed in a predetermined order: beginning with the most distal tooth in the first quadrant, continuing to the anterior teeth, and then to the second quadrant. Each tooth was scanned from its buccal and lingual sides (placing the camera at an angle of <45° to the tooth axis). All models were exported in a standard tesselation language (STL) digital file.

A total of 74 points were digitized by the same operator (P.A.) on every virtual model (total 14,208 points), following the protocol described by Huanca Ghislanzoni et al[14] and using VAM software (Vectra; Canfield

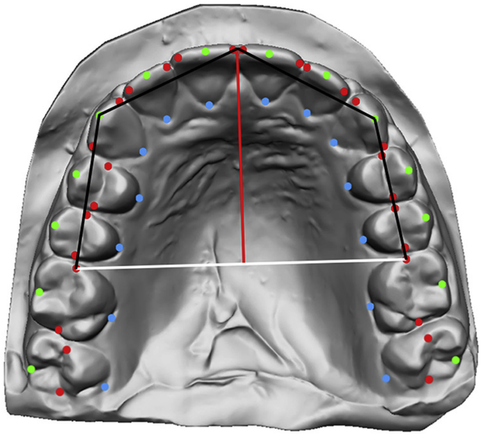

Fig 2. Arch perimeter (sum of the black lines) and arch depth (red line).

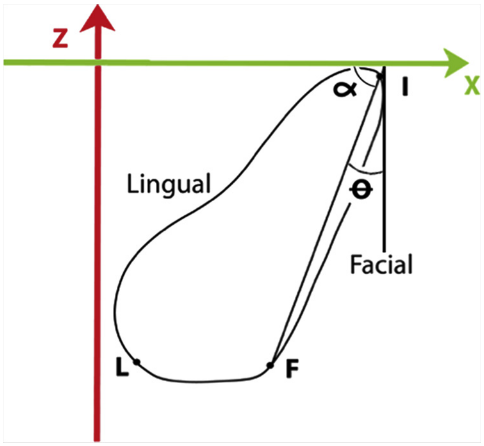

Fig 3. Illustration showing the angle of crown torque of a lower incisor: X represents the occlusal plane described by Andrews, FI represents the facial axis of the clinical crown, Θ represents the inclination of crown as the angle between FI and the perpendicular line of the occlusal plane.

Scientific, Fairfield, NJ). The correct sequence and the correct positioning of the points were doublechecked by a second expert operator (A.L.).

The virtual models at the 3 time points were superimposed on the T1 with a best-fit procedure on the digitized points, and the coordinates were exported as a set of x, y, z numbers. The impressions at T1 were used as a reference to establish a common "Andrews-like" reference plane to calculate angular measurements. The choice of T1 as a reference was due to the flat occlusal plane that is regularly achieved after orthodontic treatment, whereas the occlusal plane at T0 could eventually impair some torque measures. The following linear and angular measurements were analyzed.

Transverse arch widths were assessed for the canines, first and second premolars, and first and second molars by means of transverse intercusp distance, transverse centroid distance, and transverse lingual distance (Fig 1).

The transverse intercusp distances were evaluated as the linear distance from the cusps of the canine, from the vestibular cusps of the first and second premolars, and from the mesiovestibular cusps of the first and second molars.

The transverse centroid distances were obtained as the linear measurement of the distance between the centroid point of each tooth, which consists of the midpoint between mesial and distal points and the midpoint between the gingival point of the facial axis of the clinical crown and the gingival point of the lingual side.

The transverse lingual distances were calculated as the linear distance between the gingival lingual points in 2 analogous teeth.

Arch perimeter was assessed as the sum of 4 segments (2 per quadrant) extending from the mesial point of the first molar to the canine cusp tip and from the canine cusp tip to the mesial contact point of the central incisors (Fig 2).

Arch depth was measured as the length of a perpendicular line constructed from a line connecting the mesial points of the first molars to the mesial contact point of the central incisors (Fig 2).

Torque was measured as the labiolingual inclination of the facial axis of the clinical crown with respect to the reference plane as described by Andrews (Fig 3).[15]

The sign of the angular measurement has the same meaning as the conventional bracket prescriptions: Positive values are associated with buccal crown inclination and negative values are associated with lingual crown inclination.

The Little irregularity index was calculated to verify the homogeneity of the sample, to know the crowding entity, and to know how much an expansion is related to this entity.[16]

The virtual models were observed in occlusal view (perpendicular to the occlusal plane) and, starting from the mesial point of the canine, 10 points were placed, ending at the mesial point of the contralateral canine.

Statistical analysis

The Kolmogorov-Smirnov test was applied to verify the normal distribution of the sample. The hypothesis that the data were normally distributed could not be rejected for any variable. Descriptive analyses were

Table I. Maxillary transverse dimensions (mm) before treatment (T0), immediately after treatment (T1), and 2 years (on average) after the end of treatment (T2)

		T0		*T1*		*T2*	
Segment		*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
3-3	Intercusp	34.4	2.4	36.3	2.0	36.0	2.2
	Lingual	25.5	2.6	25.4	1.9	24.8	2.0
	Centroid	32.0	1.8	33.0	1.8	33.8	2.0
4-4	Intercusp	40.3	3.1	44.1	2.4	43.2	2.6
	Lingual	25.4	2.2	27.7	1.8	27.1	2.0
	Centroid	34.1	2.5	36.7	2.0	35.9	2.2
5-5	Intercusp	45.5	3.6	49.1	2.8	48.4	3.1
	Lingual	30.0	2.7	32.2	2.2	31.7	2.6
	Centroid	38.3	2.4	41.4	2.4	40.8	2.7
6-6	Intercusp	50.5	3.4	52.4	3.0	52.4	3.5
	Lingual	33.6	2.5	34.0	2.3	34.0	2.6
	Centroid	44.3	2.9	45.2	2.5	45.2	2.7
7-7	Intercusp	56.4	3.0	57.4	2.8	58.0	2.8
	Lingual	40.4	3.8	39.8	3.1	40.0	3.2
	Centroid	49.3	2.8	49.7	2.8	50.2	3.0

evaluated before the treatment (T0), immediately after the treatment (T1), and 2.0 years, on average, after the end of treatment (T2).

The variations between the 3 time points were tested with the use of a 1-way analysis of variance test, and any eventual difference was analyzed with the use of a Scheffé post hoc test.

The level of significance was set at $P \leq 0.05$ for all statistical analyses.

Method error was assessed by means of repeated digitization of 10 randomly selected study casts by the same investigator at a 14-day interval. No significant systematic errors were found between the measurement sessions. The method error turned out to be 0.7° for the angular measurement and 0.2 mm for the linear measurement.

A paired-sample *t* test was applied to compare the left and right crown torque values for the different teeth in both the maxilla and the mandible at T0. No statistically significant differences were found in the mean measurements between the teeth on the left and on the right sides at any time point, and therefore the angular measurements were grouped for analogous teeth.

All of the statistical analyses were performed with the use of the same statistical software (Statplus Pro, version 6; AnalystSoft, Walnut, Calif).

RESULTS

A general increment of the arch widths was recorded, especially for upper and lower canines and premolars (Tables I-IV). The increase in the transverse diameters was generally associated with a significant positive torque gain. In the maxillary arch, only first and second premolars showed a significant torque gain (+6.7° on average; Fig 4), together with central and lateral incisors (Tables V and VI).

In the mandibular arch, all teeth, except for central incisors, showed significant torque changes, with particular emphasis for first and second premolars (+8.5° and +9.6°, respectively; Fig 5; Tables VII and VIII).

No significant changes of arch width and arch perimeter were found (Tables IX-XII).

Though no statistically significant changes were found in the 2-year follow-up after treatment, a tendency to transverse diameter restriction was observed, especially for the upper and lower premolars. This tendency was not accompanied by any torque change. A torque gain, that was not statistically significant, was detected, also from T1 to T2, in particular for the mandibular incisors (+2.2° for the laterals and +1.8° for the centrals).

Little irregularity index decreased during the treatment and recorded stability from T1 to T2 (Table XIII).

No statistically significant differences were found regarding arch perimeter and arch depth; the arch perimeter was increased during the treatment (T0-T1) by 1 mm and 1.2 mm in the maxillary and mandibular arches, respectively.

DISCUSSION

The expansion of the dental arch has a role of primary importance for the resolution of nonextraction orthodontic treatments combined with missing spaces. Proper diagnosis and case selection remains essential to following the correct therapy solution. In examining the available literature, it is possible to find some controversies regarding the possible benefits of therapy with the use of passive self-ligating appliances. The only proven advantages are faster management of wire changes[17] and minor plaque accumulation.[18] Incidentally, one of clinicians' main concerns is the nature (bodily movement, dentoalveolar inclination) and stability of the claimed expansion potential of self-ligating treatments.

In the present study, we measured transverse effects of self-ligating appliances on virtual models by means of the method described by Huanca Ghislanzoni et al.[14] We decided to measure linear distances at the cusp, lingual, and centroid levels to allow a better understanding of the nature of the expansion. In fact, a bodily movement of the teeth would provide a similar extent of expansion at each level, whereas an expansion that consists of dentoalveolar inclination toward vestibular would have a stronger linear expansion at the cusp/occlusal level with respect to the lingual (gingival) reference points.

Table II. Statistical comparison between maxillary transverse dimensions (mm) at T0, T1 and T2

		1-way ANOVA	T1-T0				T2-T0				T2-T1			
Segment		*Sig*	*Value*	*Sig*	*LCI*	*UCI*	*Value*	*Sig*	*LCI*	*UCI*	*Value*	*Sig*	*LCI*	*UCI*
3-3	Intercusp	*	1.8	*	1.3	2.4	1.6	*	1.0	2.2	−0.2	NS	−0.4	0.0
	Lingual	NS	−0.1	NS	−0.6	0.4	−0.7	NS	−1.3	0.0	−0.6	NS	−0.8	−0.3
	Centroid	NS	1.0	NS	0.7	1.4	0.7	NS	0.4	1.1	−0.3	NS	−0.5	−0.1
4-4	Intercusp	NS	3.8	†	2.9	4.3	2.9	†	2.0	3.2	−0.9	NS	−1.3	−0.6
	Lingual	†	2.3	†	1.6	2.6	1.7	†	1.0	2.0	−0.6	NS	−0.8	−0.4
	Centroid	†	2.6	†	1.9	2.9	1.8	NS	1.1	2.0	−0.8	NS	−1.0	−0.6
5-5	Intercusp	†	3.6	†	2.9	4.2	2.9	†	2.3	3.4	−0.7	NS	−1.0	−0.5
	Lingual	†	2.2	*	1.7	2.6	1.7	NS	1.3	2.2	−0.5	NS	−0.6	−0.3
	Centroid	†	2.6	†	2.1	3.1	2.0	*	1.5	2.4	−0.6	NS	−0.8	−0.4
6-6	Intercusp	NS	1.9	NS	1.9	2.7	1.9	NS	1.4	2.3	0	NS	−0.7	−0.2
	Lingual	NS	0.4	NS	0.2	0.9	0.4	NS	0.1	0.9	0	NS	−0.3	0.1
	Centroid	NS	0.9	NS	0.9	1.5	0.9	NS	0.6	1.2	0	NS	−0.4	−0.1
7-7	Intercusp	NS	1.0	NS	0.6	1.5	1.7	NS	1.2	2.1	0.6	NS	0.4	0.9
	Lingual	NS	−0.6	NS	−1.1	−0.1	−0.3	NS	−0.9	0.3	0.3	NS	0.0	0.5
	Centroid	NS	0.4	NS	−0.1	0.9	0.9	NS	0.4	1.4	0.5	NS	0.3	0.7

LCI, lower limit of 95% confidence interval; *NS*, not significant; *Sig*, significance; *UCI*, upper limit of 95% confidence interval.
*$P < 0.05$; †$P < 0.01$.

Table III. Mandibular transverse dimensions (mm) before treatment (T0), immediately after treatment (T1), and 2 years (on average) after the end of treatment (T2)

		T0		T1		T2	
Segment		*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
3-3	Intercusp	27.0	1.7	28.5	1.2	28.1	1.9
	Lingual	19.8	1.8	20.5	1.3	20.4	1.9
	Centroid	25.3	1.3	25.6	1.3	25.9	1.9
4-4	Intercusp	33.0	3.0	37.2	1.7	36.1	3.1
	Lingual	24.8	2.2	27.4	1.7	27.2	2.2
	Centroid	30.3	2.3	33.1	1.7	32.5	2.2
5-5	Intercusp	38.4	3.1	42.5	1.8	41.3	3.2
	Lingual	28.8	2.6	31.0	2.1	30.7	3.6
	Centroid	35.3	2.0	37.9	2.0	37.2	2.5
6-6	Intercusp	44.5	3.2	46.3	2.3	45.8	3.2
	Lingual	32.8	3.0	33.7	2.6	33.9	4.1
	Centroid	41.3	3.0	42.4	2.6	42.0	3.0
7-7	Intercusp	49.6	2.9	51.8	2.5	51.3	3.1
	Lingual	39.1	2.4	39.7	2.4	39.7	3.9
	Centroid	46.9	2.2	48.0	2.2	47.6	2.5

This concept was further investigated by measuring the torque of all the elements. Arch perimeter and arch depth also were evaluated to assess the overall effects on each dental arch. A limitation of this study was the absence of a control group. We assumed that the lack of a control group would not influence the interpretation of results, because in a previous study[14] a control group with similar characteristics showed no changes in both transverse distances and torque changes. We thus compared the effect of a therapy with expansion potential with the absence of spontaneous changes.

The increase of cusp transverse diameters was observed, on average, for all sectors analyzed, but was found to be more significant for maxillary premolars (T1-T0 changes 3.8 mm for first, 3.6 mm for second premolars) and for mandibular premolars (T1-T0 changes 4.2 mm for first, 4.1 mm for second premolars). Therefore, 2 analytical considerations have been hypothesized: First, because the transverse diameter variations were similar for maxillary and mandibular arches, the use of the same arch (for size and shape) for the maxillary and mandibular arches may have played a major role in obtaining the same range of effects; and second, the Damon system arch form, which is more expanded in the premolar segments with the aim of preventing black corridors while smiling, was able to have a significant impact on the premolar area.[2] Lineberger et al[13], who measured the lingual transverse diameters with the use of the same method, obtained similar results: from −0.6 mm for maxillary canines to +2.2 mm for maxillary first premolars, and inferiorly from +1.3 mm for mandibular first molars to +2.0 mm for the mandibular first premolars in their research; we found −0.1 mm for maxillary canines and +2.3 mm for maxillary first premolars, and inferiorly values from +0.6 mm for mandibular second molars to +2.6 mm for mandibular first premolars. However, Lineberger et al's research lacked a follow-up evaluation. In our opinion, it is important to reevaluate the results at a certain point after the end of treatment to understand whether expansion and torque effect of the self-ligating appliances are

Table IV. Statistical comparison between mandibular transverse dimensions (mm) at T0, T1, and T2

Segment		1-way ANOVA	T1-T0				T2-T0				T2-T1			
		Sig	Value	Sig	LCI	UCI	Value	Sig	LCI	UCI	Value	Sig	LCI	UCI
3-3	Intercusp	†	1.5	†	1.1	1.8	1.1	†	0.7	1.5	−0.4	NS	−0.7	−0.1
	Lingual	*	0.7	NS	0.3	1.1	0.6	NS	0.1	1.1	−0.1	NS	−0.6	0.4
	Centroid	†	1.1	†	0.9	1.4	0.6	NS	0.1	1.1	−0.5	NS	−1.0	−0.2
4-4	Intercusp	†	4.2	†	3.5	5.1	3.1	†	2.1	4.0	−1.1	NS	−2.0	−0.5
	Lingual	†	2.6	†	2.1	3.2	2.4	†	1.8	2.8	−0.2	NS	−0.9	0.1
	Centroid	†	2.8	†	2.4	3.5	2.3	†	1.6	2.8	−0.6	NS	−1.2	−0.3
5-5	Intercusp	†	4.1	†	3.4	4.9	2.9	†	1.9	3.6	−1.2	NS	−2.3	−0.7
	Lingual	*	2.1	*	1.7	2.7	1.9	NS	1.1	2.6	−0.2	NS	−1.1	0.3
	Centroid	†	2.8	†	2.2	3.2	2.3	NS	1.3	2.3	−0.6	NS	−1.4	−0.4
6-6	Intercusp	NS	1.9	NS	1.4	2.5	1.3	NS	0.6	1.9	−0.6	NS	−1.4	−0.1
	Lingual	NS	0.8	NS	0.6	1.2	1.0	NS	0.2	1.8	0.2	NS	−0.7	0.9
	Centroid	NS	1.1	NS	0.9	1.6	0.7	NS	0.1	1.3	−0.4	NS	−1.1	0.0
7-7	Intercusp	NS	2.2	NS	1.7	2.7	1.7	NS	1.1	2.2	−0.5	NS	−1.1	0.1
	Lingual	NS	0.6	NS	0.2	1.0	0.6	NS	−0.3	1.5	0	NS	−0.7	0.7
	Centroid	NS	1.1	NS	0.8	1.5	0.7	NS	0.2	1.1	−0.5	NS	−0.9	0.0

LCI, lower limit of 95% confidence interval; *NS,* not significant; *Sig,* significance; *UCI,* upper limit of 95% confidence interval.
$^*P < 0.05$; $^\dagger P < 0.01$.

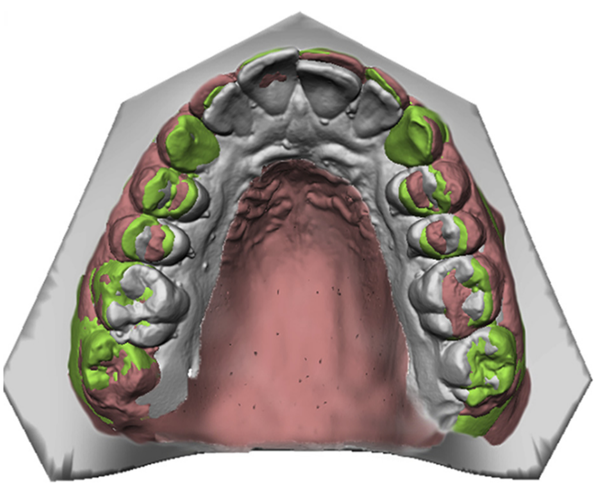

Fig 4. Digital models of maxillary arches in a representative case superimposed at T0 (*gray*), at T1 (*red*), and at T2 (*green*).

Table V. Maxillary torque values (°) before treatment (T0), immediately after treatment (T1). and 2 years (on average) after the end of treatment (T2)

Teeth	T0		T1		T2	
	Mean	SD	Mean	SD	Mean	SD
11-21	6.4	7.7	10.2	4.3	11.2	4.9
12-22	4.9	9.6	8.6	5.5	9.8	6.4
13-23	−0.7	4.9	0.3	4.9	1.5	5.5
14-24	−11.5	8.2	−4.7	6.3	−4.2	6.2
15-25	−13.8	8.5	−7.1	5.9	−6.3	5.8
16-26	−15.3	6.5	−14.1	7.4	−13.2	7.4
17-27	−13.7	10.4	−12.1	8.8	−8.8	6.8

stable or present a significant relapse. Basciftci et al[9] measured the transverse cusp diameters on digital models; they obtained similar results, although their work presented, on average, higher variations for maxillary arches and lower variation for mandibular arches. In particular, the cusp transverse diameters variation of maxillary arches ranged from +2.2 mm to +5.1 mm, whereas in our study they ranged from +1.8 mm to +3.8 mm. The mandibular variations were included from +0.8 mm to +3.3 mm in Basciftci et al's study, whereas in our study they ranged from +1.5 mm to +4.2 mm. However, in Basciftci et al's research only the distance variation between cusps of analogous teeth was evaluated, not allowing one to distinguish whether the expansion was determined by bodily movement or dental inclination.

According to our study, arch expansion by means of self-ligating appliances, previously described as transverse diameter increase, follows a very similar expression both superiorly and inferiorly and is combined with torque increase. Torque augmentation was proportional to the linear expansion values.

The elements that, during the overall observation period (T0-T2) gained, on average, more torque degrees were the first and second premolars, in particular +6.7° superiorly and +8.5° and +9.6° inferiorly. Lineberger et al[12] obtained lower values (+5.8° and +5.1°, respectively, superiorly and +2.4° and +3.6° inferiorly) but proportionally similar, because the linear changes that

Table VI. Statistical comparison between maxillary torque values (°) at T0, T1, and T2

	1-way ANOVA	*T1-T0*				*T2-T0*				*T2-T1*			
Teeth	*Sig*	*Value*	*Sig*	*LCI*	*UCI*	*Value*	*Sig*	*LCI*	*UCI*	*Value*	*Sig*	*LCI*	*UCI*
11-21	†	3.9	†	1.7	6.7	4.9	†	2.8	7.3	1.0	NS	−0.2	1.8
12-22	†	3.6	†	1.2	6.9	4.9	†	2.4	7.7	1.2	NS	−0.3	2.3
13-23	NS	1.0	NS	−0.6	3.0	2.1	NS	0.5	3.9	1.0	NS	0.1	1.7
14-24	*	6.7	†	5.6	9.1	7.2	*	6.0	9.1	0.5	NS	−1.1	1.4
15-25	†	6.7	†	5.3	9.2	7.5	†	6.1	9.6	0.8	NS	−0.6	1.8
16-26	NS	1.1	NS	−0.7	2.8	2.0	NS	0.6	3.4	0.9	NS	−0.4	2.2
17-27	NS	1.6	NS	−1.2	5.7	4.9	NS	0.0	6.5	3.3	NS	0.0	2.1

LCI, lower limit of 95% confidence interval; *NS*, not significant; *Sig*, significance; *UCI*, upper limit of 95% confidence interval.
$^{*}P < 0.05$; $^{\dagger}P < 0.01$.

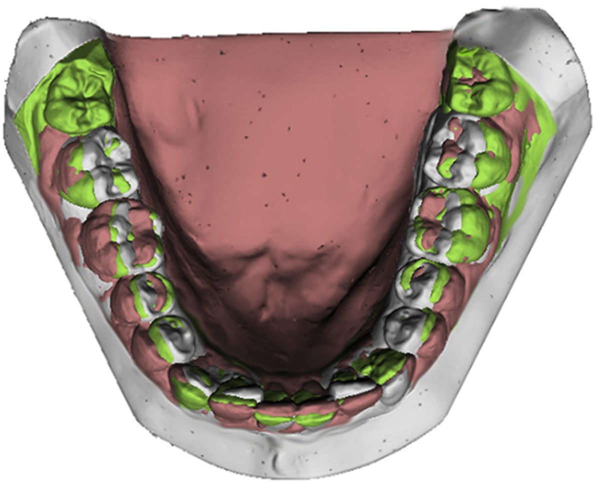

Fig 5. Digital models of mandibular arches in a representative case superimposed at T0 (*gray*), at T1 (*red*), and at T2 (*green*).

Table VII. Mandibular torque values (°) before treatment (T0), immediately after treatment (T1), and 2 years (on average) after the end of treatment (T2)

	T0		*T1*		*T2*	
Teeth	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
31-41	−0.4	10.2	4.1	8.7	5.9	11.0
32-42	−6.2	11.3	−0.2	8.4	2.0	8.2
33-43	−13.3	7.7	−7.0	7.7	−6.8	7.9
34-44	−22.6	7.7	−14.0	7.0	−14.6	8.6
35-45	−31.5	11.8	−22.0	7.9	−21.9	8.6
36-46	−38.6	8.7	−34.6	8.0	−34.5	7.4
37-47	−51.2	12.1	−44.7	11.2	−42.1	10.0

they found were lower than the ones that we found in this study. Cattaneo et al[7], despite a completely different torque calculation method, obtained values of torque variation for premolars even higher than those that we obtained: first premolar increase on average of +11.7° and second premolars +13.5°. In their study they also presented data showing possible reduction of buccal bone thickness. Such a biologic reaction can be a consequence of transverse expansion and can be investigated only with the use of cone-beam computed tomographic imaging. Overall, self-ligating bracket treatment determines, on average, an expansion of dental arches, coupled with an inclination of the same elements, in direct correlation with the increase entity of transverse diameters. In the case of premolars, this is probably due to the use of an archwire of a specific shape and size (Damon arch form).

As already noted, our work analyzed dental movements at follow-up, after the end of the orthodontic treatment with self-ligating brackets. Only Basciftci et al[9] have analyzed this period, a fundamental one in understanding the potential stability of the therapy. In their study, they found average variations of −0.5 mm maximum. In our study, the transverse constriction during the follow-up period (T1-T2) was higher (max value −1.1/−1.2 mm for mandibular first and second premolars), though not statistically significant. It is important to note that no special protocol for transversal retention was used, because patients were bonded a lingual wire, 12 to 22 superiorly and 33 to 43 inferiorly, wearing an upper Essix retainer for the first 6 months of the retention period. Thus, the occlusion had time to freely settle and adapt laterally. It emerged from our study that, as an alternative to the usual Essix, it is preferable to use an upper/superior plate with a central screw to control the tendency to transverse diameter restriction observed in our sample at the 2-year follow-up after treatment.

When analyzing torque changes in the same period, a slight increase was seen for the maxillary lateral incisors (+1.2°), the maxillary second molars (+3.3°), and the

Table VIII. Statistical comparison between mandibular torque values (°) at T0, T1, and T2

	1-way ANOVA	T1-T0				T2-T0				T2-T1			
Teeth	Sig	Value	Sig	LCI	UCI	Value	Sig	LCI	UCI	Value	Sig	LCI	UCI
31-41	†	4.5	NS	2.3	7.4	6.3	†	3.8	9.4	1.8	NS	0.0	3.5
32-42	†	6.0	†	3.7	9.2	8.2	†	5.6	11.6	2.2	NS	1.2	3.2
33-43	NS	6.3	†	5.5	8.1	6.5	†	5.2	8.2	0.2	NS	−1.1	0.9
34-44	†	8.5	†	6.8	11.2	8.0	†	5.9	10.6	-0.6	NS	−2.0	0.6
35-45	†	9.6	†	7.7	12.3	9.7	†	7.7	12.1	0.1	NS	−1.5	1.3
36-46	†	4.0	*	1.9	6.4	4.1	*	2.3	5.3	0.1	NS	−1.5	0.9
37-47	†	6.5	†	4.4	10.3	9.1	†	4.8	10.3	2.6	NS	−1.1	1.5

LCI, lower limit of 95% confidence interval; *NS*, not significant; *Sig*, significance; *UCI*, upper limit of 95% confidence interval.
*$P < 0.05$; †$P < 0.01$.

Table IX. Maxillary arch depth and arch perimeters (mm) before treatment (T0), immediately after treatment (T1), and 2 years (on average) after the end of treatment (T2)

	T0		T1		T2	
Variable	Mean	SD	Mean	SD	Mean	SD
Depth	29.3	2.5	29.2	2.0	29.2	2.2
Perimeter	70.8	4.6	71.8	4.1	71.3	4.5

Table X. Statistical comparison between maxillary arch measurements (mm) at T0, T1, and T2

	1-way ANOVA	T1-T0				T2-T0				T2-T1			
Variable	Sig	Value	Sig	LCI	UCI	Value	Sig	LCI	UCI	Value	Sig	LCI	UCI
Depth	NS	−0.1	NS	−0.7	0.6	−0.1	NS	−0.6	0.5	0	NS	−0.3	0.3
Perimeter	NS	1.0	NS	0.1	1.8	0.5	NS	−0.3	1.2	−0.5	NS	−0.8	−0.1

LCI, lower limit of 95% confidence interval; *NS*, not significant; *Sig*, significance; *UCI*, upper limit of 95% confidence interval.
*$P < 0.05$; †$P < 0.01$.

Table XI. Mandibular arch depth and arch perimeters (mm) before treatment (T0), immediately after treatment (T1), and 2 years (on average) after the end of treatment (T2)

	T0		T1		T2	
Variable	Mean	SD	Mean	SD	Mean	SD
Depth	24.2	2.4	24.6	1.9	25.8	5.4
Perimeter	62.1	3.8	63.4	3.6	62.5	9.2

mandibular central and the lateral incisors (+1.8° and +2.2°, respectively). This was an unexpected change, which was consistent with an increase in lower arch depth (+1.1 mm) in the same period. All of the other teeth, for both maxillary and mandibular arches, showed almost no changes (values between +1° and −1°; Tables VI and VIII).

Germane et al[19] demonstrated that the excessive inclination at incisor levels contribute more significantly to space creation in relation to medium and posterior sectors. By applying this assumption to the present research, we may assume that, because the arch perimeter remained essentially the same, the transverse diameter relapses were compensated by a slight increase of arch depth. This was particularly evident in the mandibular arch, where positive torque gain in the T1-T2 period was also evident. This can be considered to be a form of torque redistribution, mainly at the anterior level, where it is possible to gain the greatest space with the minimum movement.

Table XII. Statistical comparison between mandibular arch measurements (mm) at T0, T1, and T2

	1-way ANOVA	T1-T0				T2-T0				T2-T1			
Variable	*Sig*	*Value*	*Sig*	*LCI*	*UCI*	*Value*	*Sig*	*LCI*	*UCI*	*Value*	*Sig*	*LCI*	*UCI*
Depth	NS	0.5	NS	−0.1	1.1	1.6	NS	−0.3	3.5	1.1	NS	−0.5	2.8
Perimeter	NS	1.2	NS	0.8	1.7	0.4	NS	−1.8	2.5	−0.9	NS	−3.1	1.4

LCI, lower limit of 95% confidence interval; *NS,* not significant; *Sig,* significance; *UCI,* upper limit of 95% confidence interval.
*$P < 0.05$; †$P < 0.01$.

Table XIII. Little irregularity index before treatment (T0), immediately after treatment (T1), and 2 years (on average) after the end of treatment (T2)

	T0		T1		T2	
Little index	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Maxillary (mm)	8.23	3.22	2.92	1.2	3.08	1.18
Mandibular (mm)	6.2	2.85	1.03	0.91	1.4	0.5
	T1-T0		*T2-T0*		*T2-T1*	
Variation	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Maxillary (mm)	−5.31	3.19	−5.15	3.67	0.16	1.38
Mandibular (mm)	−5.17	2.8	−4.8	2.54	0.37	0.58

Little irregularity index was consistently reduced by 5 units, on average, in both maxillary and mandibular arches during the therapy. It was stable during the post-treatment period. Because the expansion in the canine region was only 2 mm, the slight torque gain at the level of upper and lower incisors probably helped to achieve a correct alignment.

The retention protocol (maxillary fixed retention on lateral and central incisors, mandibular fixed retention from canine to canine) may explain the stability of the results after 2 years. During this period, the maxillary intercanine distance lost 0.1 mm and the mandibular distance was reduced by 0.5 mm.

CONCLUSIONS

This study measured the width of the maxillary and mandibular dental arches and the torque changes after treatment with the use of passive self-ligating appliances. A 2-year follow-up was carried out to assess the stability of the therapy. The findings were as follows:

1. Dental expansion, as previously reported for the self-ligating appliances, was observed in all of the analyzed segments, mainly at the premolar level, for both maxillary and mandibular arches.
2. Torque values were significantly increased, in particular for the maxillary and mandibular premolars, showing that the expansion was determined mainly by a vestibular inclination component.
3. The follow-up analysis showed that transverse expansion did not show any statistically significant relapse, though showing a tendency to restriction, especially for the premolars, and a slight tendency to anterior torque gain.

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