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Transversal maxillary dento-alveolar changes in patients treated with active and passive self-ligating brackets: a randomized clinical trial using CBCT-scans and digital models

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Structured Abstract

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Objective – To assess transversal tooth movements and buccal bone modeling of maxillary lateral segments achieved with active or passive self-ligating bracket systems in a randomized clinical trial.

Materials and Methods – Sixty-four patients, with Class I, II, and mild Class III malocclusions, were randomly assigned to treatment with passive (Damon 3 MX) or active (In-Ovation R) SLBs. Impressions and cone-beam CT-scans were taken before (T0) and after treatment (T1). Displacement of maxillary canines, premolars and molars, and buccal alveolar bone modeling were blindly assessed.

Results – Twenty-one patients in the Damon and 20 in the In-Ovation group completed treatment according to the prescribed protocol. Eight Damon and 10 In-Ovation patients were excluded as the treatment approach had to be changed because of deviation from the recommended initial plan, while three Damon and two In-Ovation patients did not complete the treatment. Transversal expansion of the upper arch was achieved by buccal tipping in all but one patient in each group. No statistical significant difference in inter-premolar bucco-lingual inclination was found between the two groups from T0 to T1. The bone area buccal to the 2nd premolar decreased on average of 20% in the Damon and 14% in the In-Ovation group. Only few patients exhibited widening of the alveolar process.

Conclusion – The anticipated translation and buccal bone modeling using active or passive SLBs could not be confirmed. Because of the large interindividual variation, a patient-specific analysis seems to be mandatory as individual factors like pre-treatment teeth inclination and occlusion influenced the treatment outcome of the individual patients.

Key words: cone-beam computed tomography; digital models; ligation; maxilla; orthodontics; treatment outcome

Introduction

The influence of the type of orthodontic appliance on the rate of tooth movement and the biological reaction has been a matter of constant discussion. Recently, self-ligating brackets (SLBs) have gained popularity among clinicians; however, the relationship between claims and facts related to SLBs is still not clarified. The SLB concept is not new (1). The Boyd band and the Ford lock bracket were introduced already in 1933. However, it was with the SPEED brackets in the 70s and later on with the In-Ovation bracket and the Damon SL, that the interest for SLBs increased (2), as they were promoted as a system rather than a bracket (3). This happened because of the claims of higher treatment efficiency and less chair time associated with SLBs (4, 5), although these allegations are not unanimously accepted (6, 7). The combination of SLBs with high-tech and high-resilient copper–nickel–titanium wires is supposed to deliver light forces and low friction (3, 8). Yet, from a clinical point of view, the actual force magnitude exerted by SLBs was found similar to conventional systems (9), while data about frictional resistance are not unanimous (10) as friction plays only a negligible role in sliding mechanics (11).

It has been alleged that by using '*light forces,*' the Damon system is able to create a new force equilibrium that allows the arch to reshape itself to accommodate the teeth, with the new form determined by the body and not by the clinician or the system applied (3). However, it is not clear how this 'system' can deliver such a fine-tuned balance given the fact that even extremely low forces were shown to be sufficient to displace teeth (12). It was also claimed that using a passive SLB system, the arch length gain is achieved by bodily movement of the teeth or at least with ''minimal'' tipping combined with alveolar bone and surrounding tissues reshaping with a Fränkel-like effect (3). The reshaping of the alveolar bone was illustrated by computed tomography (CT)-scans of few patients, and expansion without tipping was claimed to be related to bracket's design, wire sequence, and torque control; yet, wide variations in torque expression have been described (13–15).

Quantification of treatment outcome in two-dimensions (2D) by superimposing before- and after-treatment cephalograms raised some criticisms as its reliability was questioned (16). Indeed, to fully assess the dento-skeletal changes occurring during treatment, three-dimensional (3D) data sets are needed. These can be obtained from CT or cone-beam CT (CBCT), the latter rendering a significant lower effective radiation dose than medical CT (17, 18). By superimposing 3D data sets taken at different time-points, it is possible to assess treatment outcome in all planes as well as to visualize changes in 3D.

The aim of this study was to compare the outcome of treatments carried out using passive or active SLBs, in accordance with the relative prescription. Pre- and post-treatment digital dental casts and CBCT-scans were analyzed to assess: (1) the quantity and type of tooth movement for the maxillary canines, premolars, and molars; and (2) the thickness and modeling of the buccal bone in the premolars region of the maxilla.

Materials and methods

Sixty-four patients, from the Orthodontic Department, Aarhus University, Denmark, were enrolled and completed their treatment at this stage of this ongoing randomized clinical trial. Consent to undergo the CBCT radiographic examinations and to use the material for the present investigation was obtained from all patients. CBCT-scans were taken following the protocol approved by the Radiological Department, School of Dentistry, Aarhus University.

Patients were carefully selected in conformity with the guidelines for Damon® 3 MX brackets system (Ormco Corporation, Orange, CA, USA) and In-Ovation R (GAC International Inc., Bohemia, NY, USA). Patients with severe Class III, obvious need for extraction, with periodontal problems, and major skeletal discrepancies were excluded. A randomization sequence was created with a 1:1 allocation using random block size of 4. Based on this list, the patients were assigned to one of the two parallel treatment groups:

(1) Damon® 3 MX passive SLBs and Damon arch wires, treatment protocol according to the Damon Workbook;
(2) In-Ovation R active SLBs and medium AccuForm arch wires, treatment protocol based on the GAC recommendation.

Impressions were taken before the start of treatment (T0) and after treatment completion (T1), and digital study models were generated (O3DM; Ortolab, Częstochowa, Poland). The transversal distances between left and right canines, 1st and 2nd premolars, and 1st molars, were measured at the occlusal level on the digital models at T0 and T1, and the achieved expansion at the occlusal level (ΔE) was thus calculated. All patients had a 12″ CBCT-scan taken at T0 and at T1 (NewTom 3G; QR, Verona, Italy). All CBCT-scans were reconstructed with a 0.36-mm isotropic voxel dimension. One observer, who was blinded to the patient's group, performed all measurements.

Assessment of the inter-premolars bucco-lingual inclination

CBCT axial- and coronal-images were used to place markers at the apical part of the root canal of the 1st and 2nd premolars; in case of two-rooted premolars, the marker was placed on the buccal root canal. Likewise, markers were placed on the central fossa of the crowns. On cross-sections perpendicular to both the horizontal and sagittal plane, a first line was drawn through the markers on the crowns of the left and right 1st premolars. A second line was drawn passing through the markers of the crown and apex of the left 1st premolar. Angle α was defined as the angle between these two lines (Fig. 1). Angle β was calculated likewise on the contralateral site. The inter-premolars' bucco-lingual inclination λ was calculated as $\lambda = 180° - (\alpha + \beta)$. The change in the bucco-lingual inclination ($\Delta\lambda$) of the 1st premolars was calculated as: $\Delta\lambda = \lambda_{T1} - \lambda_{T0}$. The same was carried out for the 2nd premolars.

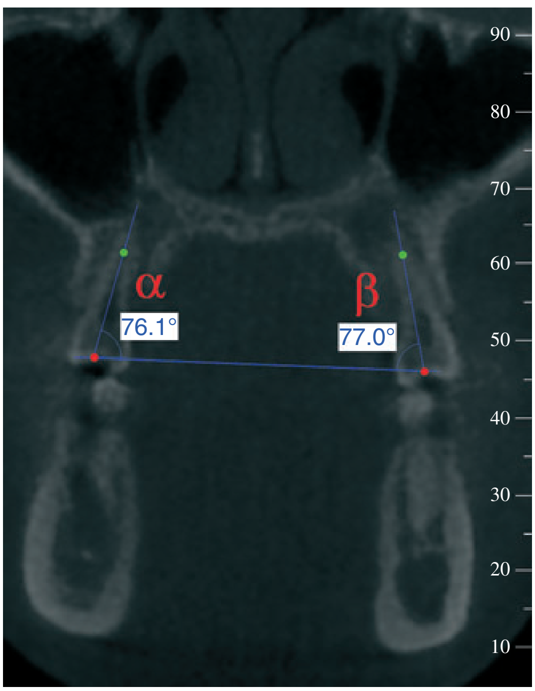

Fig. 1. Green markers (apical part of the root canal) and red markers (central fossa of the crowns) and angle α and β, where α and β were defined as the angles between the line passing through the central fossa of the crowns of the 1st premolars (red markers) and the long axis of left and right 1st premolars, respectively.

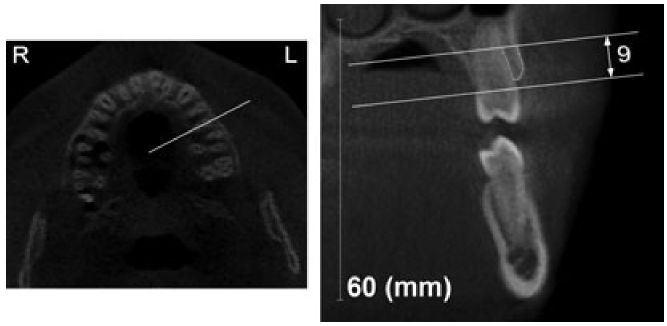

Fig. 2. A vertical plane is traced through the middle of the root(s) of the 2nd premolar and the buccal cortical bone -left-. On the corresponding cross-section (right), two lines are drawn: the 1st line through the buccal and lingual cemento-enamel junction and the 2nd line parallel to the 1st one, 9 mm (±0.1) apically. The bone area buccal to the 2nd premolar is outlined. For calibration purposes, a vertical line is traced.

Assessment of area of buccal bone

A vertical cross-section was generated passing through the center of the root canal of each premolar (in case of two-rooted premolars, the buccal root was chosen) and the point on the buccal cortical bone plate characterized by the shortest distance to the root canal (Fig. 2, left). On the cross-section, a first line was drawn through the buccal and lingual cemento-enamel junction of each premolar (CEJ). A second line was traced parallel to the first one at a distance of 9 mm (±0.1) apically to the CEJ line (Fig. 2, right). The outline of the bone delimited by these two lines, the root of the premolar and the external contour of the buccal bone plate, was traced. After images calibration, the area comprised within this perimeter was calculated (ImageJ, NIH, Bethesda, Maryland, USA).

Study definition for 3D bone modeling evaluation

The CBCT-scans were exported via the DICOM format and imported into ITK-SNAP open-source software (http://www.itksnap.org) (19), where 3D surface models of the maxilla were generated by three different investigators, previously calibrated for segmentation of CBCT-scans, following the protocol described by Cevidanes and coworkers (20, 21). The registration of the T1 model to the corresponding model at T0 was

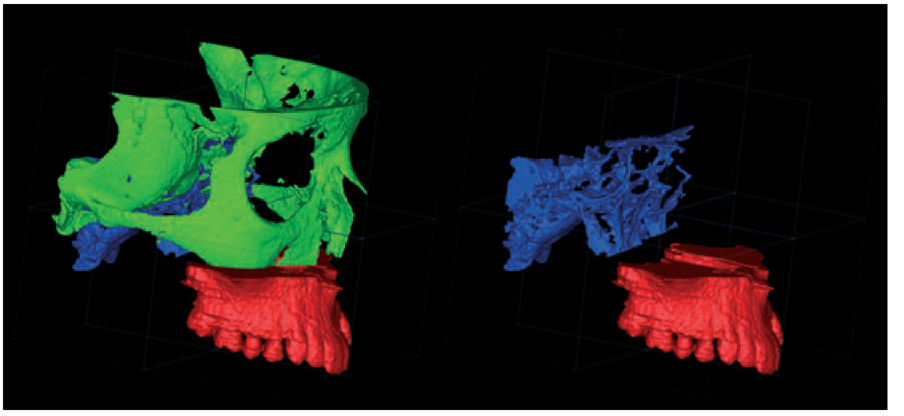

Fig. 3. The anterior cranial base and the upper-frontal structures of the skull (green and blue masks, left) were used for registering and superimposing cone-beam CT-scans at T0 and T1. In case of growing patients, only the anterior cranial base was used (blue mask, right).

performed using the maximization of mutual information algorithm applied to the anterior cranial base and the cranial upper-frontal structures in case of non-growing patients, and only on the anterior cranial base (22) in case of growing patients (20, 21, 23) (Fig. 3). The CMF-tool application software (M.E. Müller Institute, Bern, Switzerland) was used to overlay the 3D registered surface models, and color maps were used to visualize localization and amount of the changes that occurred during treatment at any location. Displacement of teeth and alveolar bone modeling could be depicted. Isolines were used to delimit the areas on the models at T1 that display a certain distance from the model at T0. To account for the spatial resolution, which can roughly assumed to be the double of the voxel size (24), the isoline was set at 0.7 mm (Fig. 4).

Statistical analysis

Statistical analysis was performed with SPSS version 13.0 for Windows (SPSS Inc., Chicago, IL, USA). In both groups, all variable were normally distributed.

Differences at baseline between the two groups were compared by independent-samples *t*-test. The same test was used to compare transversal expansion, bucco-lingual inclination, and bone area difference between the groups. Within the groups, the changes occurring from T0 to T1 were assessed by a paired *t*-test. The correlation between changes in buccal bone area and amount of expansion as well as between changes in buccal bone area and treatment time was assessed. The significance level was set at 0.05.

For all the measurements, the error of the method (s) was calculated on double measurements of 10 randomly selected measurements at T0 using the Dahlberg's formula ($s = \sqrt{\Sigma d^2/2n}$, where d = difference between the first and second measurements) (25). The coefficient of reliability was calculated as $CoR = 1 - s^2/SD^2$, where SD is calculated at T0.

Results

Sample

Enrollment started in December 2004 and was completed by November 2009. The CONSORT flow diagram is shown in Fig. 5. From the original 32 patients in the Damon group, 11 had to be excluded: five had to be reoriented toward premolar(s) extraction, three needed segmented appliance because of asymmetry, and three prematurely interrupted the treatment. In the In-Ovation group, 12 patients had to be excluded: three of them had premolar(s) extraction, one had severe slenderizing, two were reoriented toward surgery, four

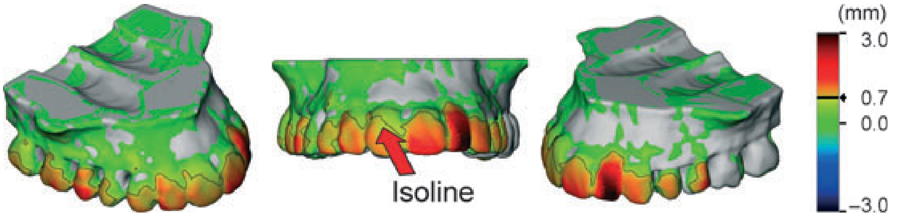

Fig. 4. Example of superimposed T1- over T0-models: the T0-model is depicted in gray, while the T1-model is shown using a color map (green = no changes; red = outward expansion). The *Isoline* delimits the areas on the T1-model that displays a distance from the T0-model ≥0.7 mm.

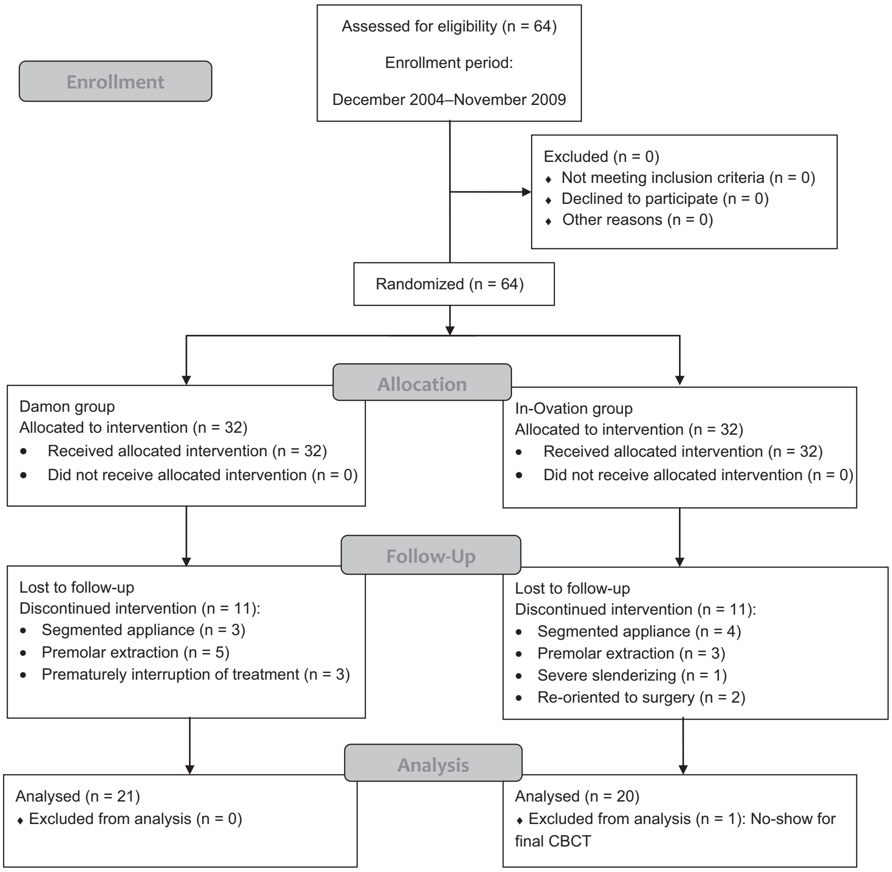

Fig. 5. CONSORT flow diagram of the patients through the study.

needed segmented appliance because of asymmetry, one dropped out before the end of the treatment, and one did not show up for the final CBCT-scan. The two groups were homogeneous regarding age and sex.

As many of the expected changes were unknown *a priori*, a *post-hoc* power-analysis was performed. The power of the study (PoS) for expansion for the Damon group was 0.987, $PoS_{In\text{-}Ovation} = 0.847$; for angulation, $PoS_{Damon} = 0.999$ and $PoS_{In\text{-}Ovation} = 0.995$.

Error of the method

The error of the method was found to be small for all measurements while the calculated CoRs confirm the validity of the method (Table 1).

***Table 1.* Error of the methods and Coefficient of Reliability (λ is defined as the angle between the long axes of the contralateral premolars; Bone Area R and L is the bone area buccal to the right and left 1st premolar roots, respectively)**

	Error of the Method (s)	Coefficient of reliability
Width 13–23 (mm)	0.37	0.970
Width 14–24 (mm)	0.36	0.988
Width 15–25 (mm)	0.46	0.987
Width 16–26 (mm)	0.47	0.973
λ 1st prem (°)	3.8	0.752
λ 2nd prem (°)	3.2	0.805
Bone Area R (mm^2)	0.98	0.970
Bone Area L (mm^2)		

Inter-premolars bucco-lingual inclination and expansion

At T0, no statistical significant differences in inter-teeth distance and inclination λ for both 1st and 2nd premolars were found between the two groups (Table 2). ΔE and $\Delta\lambda$ were statistically different both for the Damon group as well as in the In-Ovation group (except ΔE at canine level in the In-Ovation group). When comparing the achieved ΔE and $\Delta\lambda$ between the two groups, no statistically significant changes were found (Table 3).

Table 2. **Baseline and treatment outcome (λ is defined as the angle between the long axes of the contralateral premolars; Bone Area R and L is the bone area buccal to the right and left 1st premolar roots, respectively)**

	Damon							In-ovation							Ind. samples *t*-test
	T0		T1		Paired-samples *t*-test 95% CI			T0		T1		Paired-samples *t*-test 95% CI			Damon T0 vs. In-ovation T0
	Mean	SD	Mean	SD	*p*-value	Lower	Upper	Mean	SD	Mean	SD	*p*-value	Lower	Upper	*p*-value
Age (years)	16.0	5.7	–	–	–	–	–	15.0	3.3	–	–	–	–	–	0.475
Width 13–23 (mm)	34.3	2.2	35.6	1.4	0.002	−2.2	−0.6	34.8	2.2	35.5	1.6	0.076	−1.5	0.1	0.444
Width 14–24 (mm)	37.3	2.6	41.6	2.5	0.000	−5.0	−3.6	37.1	3.3	41.7	3.7	0.000	−5.3	−3.8	0.849
Width 15–25 (mm)	42.7	3.6	46.5	2.8	0.000	−4.9	−3.1	42.6	4.2	46.3	3.8	0.000	−4.2	−2.4	0.949
Width 16–26 (mm)	47.7	3.2	49.6	3.1	0.000	−2.4	−1.4	46.8	2.9	48.0	3.0	0.000	−1.9	−0.7	0.340
λ 1st prem (°)	−0.5	10.2	11.7	11.2	0.000	−16.1	−7.3	3.6	13.4	15.3	10.6	0.000	−17.5	−6.0	0.352
λ 2nd prem (°)	2.8	8.8	17.1	9.0	0.000	−17.3	−9.8	6.1	10.5	19.1	9.2	0.000	−17.2	−8.7	0.290
Bone Area R (mm^2)*	14.9	5.6	11.5	5.9	0.003	1.9	5.3	14.4	5.7	12.1	6.5	0.041	0.1	4.4	0.492
Bone Area L (mm^2)*	16.1	5.3	13.4	6.2	0.003	1.0	4.5	15.5	5.0	13.3	4.7	0.020	0.4	4.0	0.695

*Reported only for 1st premolar.

Table 3. **Treatment Outcome – Comparison (Δ is used to denote the changes between T0 and T1 in transversal dimension – ΔE – at the canine, 1st and 2nd premolars, and 1st molar levels; tipping – $\Delta\lambda$; and amount of bone buccal to the right and left 1st premolar)**

	Damon T1 – T0		In-Ovation T1 – T0		Independent-samples *t*-test 95% CI		
	Mean	SD	Mean	SD	*p*-value	Lower	Upper
Tx duration (months)	22.4	4.8	21.1	5.9	0.432	−2.1	4.7
ΔE 13–23 (mm)	1.4	1.7	0.7	1.7	0.251	−0.5	1.7
ΔE 14–24 (mm)	4.3	1.6	4.5	1.6	0.542	−1.3	0.7
ΔE 15–25 (mm)	4.0	1.9	3.3	1.8	0.253	−0.5	1.9
ΔE 16–26 (mm)	1.9	1.2	1.3	1.3	0.104	−0.1	1.4
$\Delta\lambda$ 1st prem (°)	11.7	9.7	11.8	12.4	0.980	−7.1	6.9
$\Delta\lambda$ 2nd prem (°)	13.5	8.1	13.0	9.1	0.832	−4.9	6.1
ΔBone area R (mm^2)*	−3.6	3.6	−2.3	3.5	0.303	−4.0	1.3
ΔBone area L (mm^2)*	3.8	0.8	−2.2	2.8	0.636	−3.0	1.9
ΔBone area R (%)*	−22.6	26.7	−16.7	28.2	0.504	−23.7	11.9
ΔBone area L (%)*	−17.9	26.3	−12.0	25.5	0.478	−22.5	10.7

*Reported only for 1st premolar.

In both groups, expansion was most pronounced in the premolar regions. Apart from one patient in the Damon group and two cases in the In-Ovation group, buccal tipping of the premolars occurred during treatment (Tables 4 and 5).

Buccal bone area

The bone buccal to the 1st premolar was so thin that the error of the method surpassed the mean measured value, for which reason only the bone in the

Table 4. **Damon group**

			Buccal bone modeling – 2D (%)*		Buccal bone apposition – 3D**	Expansion – ΔE (mm)				Inclination – Δλ (°)	
Patient #	Age (years)	Tx Length (months)	Right	Left		13–23	14–24	15–25	16–26	1st prem	2nd prem
1	31	24	8	−31	□	3.0	3.5	3.7	1.8	7	12
2	13	23	−3	−5	■	1.9	6.8	7.1	2.7	9	16
3	14	19	−22	−24	□	−2.0	4.0	2.3	−0.1	10	10
4	12	29	−9	−33	■	2.2	3.6	0.6	1.4	0	−2
5	11	19	−6	−4	■	3.2	5.7	6.4	2.6	15	18
6	17	24	33	−23	■	−0.4	1.1	0.7	1.8	14	14
7	13	26	−44	35	□	3.9	2.6	4.9	1.2	−5	21
8	16	19	−38	−15	■■	0.9	2.9	2.2	0.6	16	5
9	15	22	−3	3	□	1.5	3.2	2.6	1.7	15	14
10	16	16	−18	−20	□	0.8	2.1	5.7	2.4	15	14
11	33	21	−24	−9	■	2.4	6.1	3.0	0.7	18	2
12	14	19	−85	−88	□	Unerupted	3.5	3.1	2.5	12	6
13	12	16	−40	−15	■	1.4	4.9	3.6	1.4	13	14
14	15	24	−38	−57	□	2.5	5.7	3.8	1.5	19	41
15	18	21	−46	−58	■■	1.7	5.0	8.0	1.7	16	24
16	14	32	0	−8	■	3.4	6.2	4.9	5.4	11	11
17	18	16	−65	−6	■	1.4	4.6	4.5	0.8	40	17
18	13	29	−20	17	□	−1.0	6.6	4.8	2.2	21	19
19	12	30	n/a	3	□	−1.9	2.6	Extraction	1.5	14	–
20	15	24	−8	−18	■	1.4	4.8	4.3	3.7	16	13
21	14	17	−23	−1	■	0.5	4.1	3.3	3.0	20	16

*Calculated as percentage in comparison to the initial buccal bone, reported only for 1st premolar.
**□, no bone apposition (<0.5 mm); ■, mild bone apposition (≥0.5 mm & ≤0.7 mm); ■■, moderate bone apposition (> 0.7 mm); n/a, too thin to be measured.

2nd premolars region was evaluated. Here, at baseline, the buccal bone amount did not differ significantly between the two groups. In the Damon group, on average, the buccal bone decreased 23 and 18% on the right and left side, respectively, while in the In-Ovation group 17 and 12% (Table 3). The buccal bone area decreased on both sides in more than half the patients in both groups. Large variation in bone area both at T0 and T1 (range: 7.1–37.9 mm^2 at T0 and 1.6–35.8 mm^2 at T1) was seen (Tables 4 and 5).

The inter-premolars expansion was positively associated with buccal tipping, especially for the 2nd premolars; a negative tendency was noticed between expansion and bone area buccal to the 2nd premolar. However, none of the correlations were statistically significant. No correlation was found between changes in buccal bone and treatment duration.

3D evaluation of bone remodeling

The 3D analysis revealed a modest modeling of the buccal surface of the alveolar process in both Damon and In-Ovation groups (Tables 4 and 5). Indeed, in most cases, no alveolar bone apposition was seen, this being confirmed by the fact that the isoline was often located in proximity to the cervical bone level (Fig. 6).

Table 5. **In-Ovation group**

Patient #	Age (years)	Tx Length (months)	Buccal bone modeling – 2D (%)*		Buccal bone apposition – 3D**	Expansion – ΔE (mm)				Inclination – Δλ (°)	
			Right	Left		13–23	14–24	15–25	16–26	1st prem	2nd prem
1	27	10	−60	−68	■■	1.2	2.1	3.8	0.6	4	16
2	12	27	−8	−5	■	−0.5	4.4	4.2	1.9	7	7
3	11	24	42	25	□	0.1	6.8	2.4	2.9	21	16
4	18	22	12	−27	■	5.1	7.5	3.9	0.8	38	17
5	13	23	−22	2	□	1.5	5.2	6.0	2.4	26	20
6	16	23	−28	−18	■■	3.1	3.1	1.4	1.6	5	11
7	15	21	−54	15	□	0.1	2.5	0.2	−0.9	9	0
8	15	20	−31	42	■	0.4	3.4	2.7	1.2	8	12
9	13	18	−8	−11	□	0.1	3.2	3.0	0.8	9	10
10	15	18	n/a	n/a	□	0.7	4.6	4.9	1.7	23	17
11	16	10	13	11	□	1.0	1.9	1.4	0.2	5	11
12	15	25	24	4	■■	−0.4	4.2	0.1	0.6	15	−3
13	16	27	−48	−36	■	−0.4	5.6	2.0	−1.3	20	8
14	15	15	13	−33	■	0.1	1.9	1.0	−0.2	7	0
15	15	19	−12	−17	□	0.1	4.0	2.1	0.9	16	15
16	13	34	−50	−22	□	3.7	4.8	5.1	3.9	20	8
17	13	29	−12	9	■■	0.0	6.6	4.5	1.8	20	24
18	15	18	−56	−50	■	1.1	6.0	6.2	1.8	23	9
19	13	18	−17	−4	■■	−2.5	4.3	4.3	1.3	5	10
20	13	20	−32	−27	□	−1.3	6.1	4.5	0.3	13	9

*Calculated as percentage in comparison to the initial buccal bone, reported only for 1st premolar.
**□, no bone apposition (<0.5 mm); ■, mild bone apposition (≥0.5 mm & ≤0.7 mm); ■■, moderate bone apposition (>0.7 mm); n/a, too thin to be measured.

Discussion

Angle's idea of expanding the dental arches to accommodate all teeth was challenged by Tweed, who claimed that teeth should be placed over basal bone (26, 27). This lead to a high number of patients treated with four premolar extractions. Now, the pendulum has swung back: Damon's idea to achieve dental arch expansion follows the same rule proposed by Angle, the only difference being the use of super-elastic copper–nickel–titanium wires (28). The combination of thin CuNiTi wires and 'low-friction systems' is claimed to be advantageous when leveling crowded dental arches, although the evidence is still lacking (7, 29). Although it has been shown that extractions had little influence on stability (30), the question whether true expansion with SLBs and CuNiTi wires would be achieved together with the maintenance of alveolar buccal bone without the potential risk of bony dehiscences remains (31). The present study was undertaken to solve these questions.

Superimposition of 2D radiographic images cannot precisely describe treatment outcomes in 3D. Registration and superimposition of digital casts (32) allow for high-resolution 3D analyses. However, the registration process is fallible, as typically it is performed on not fully stable anatomical landmarks (33). Furthermore, this method is only capable to depict dental changes, while skeletal changes cannot be assessed. To overcome this issue, in this study, digital models and CBCT-scans were used to analyze dental and alveolar bone changes, respectively. Although CBCT-scans

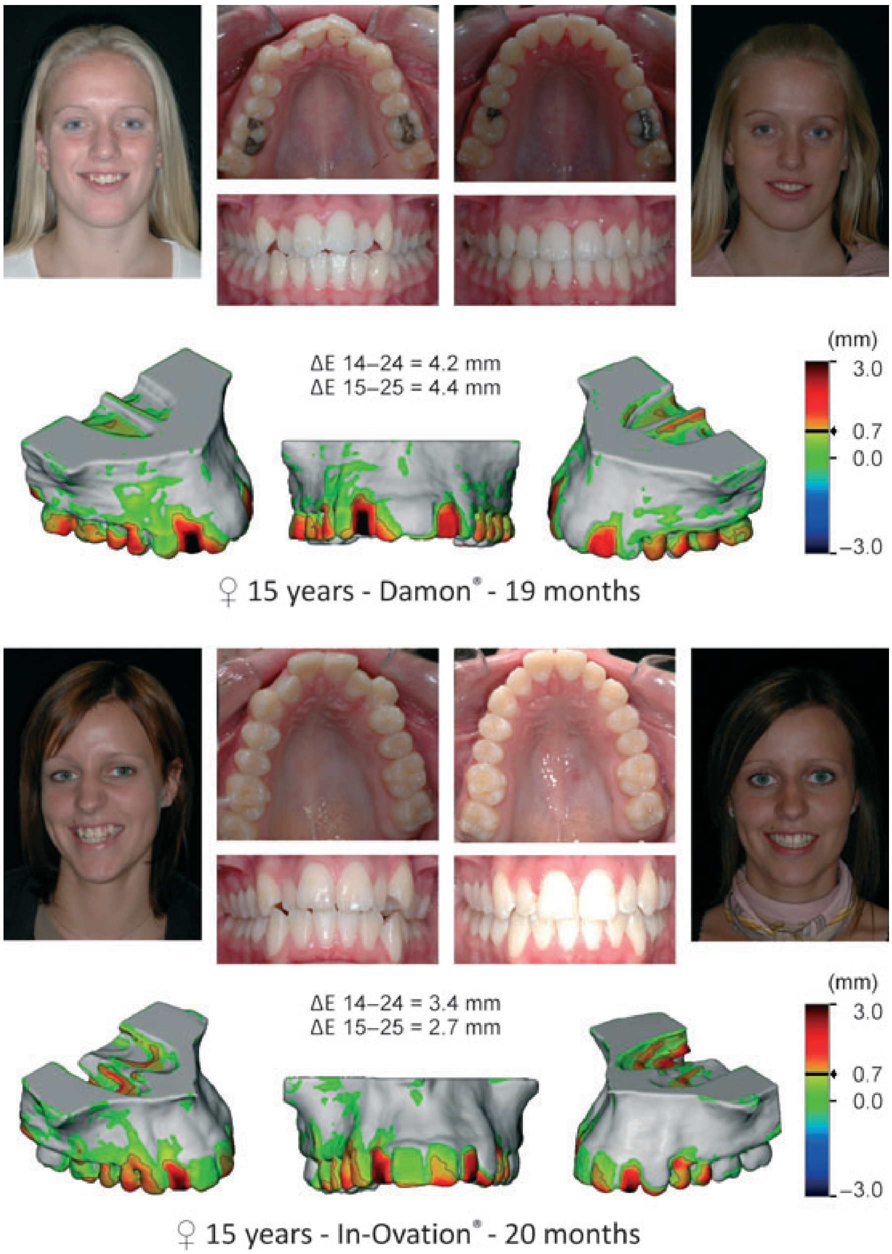

Fig. 6. Patient from the Damon group and the relative 3D analysis (top) and one from the In-Ovation group (bottom). The expansion achieved at occlusal level for the 1st and 2nd premolars is reported. Please note that in both cases, very little buccal bone modeling had happened.

allow for truly 3D evaluation and quantification of treatment outcome, still the authors are aware of the ethical concerns related to the increased ionizing radiation exposure associated with CBCT in comparison with conventional 2D radiograph (34). Nevertheless, a low-dose CBCT-scanner was used. Hence, the patients received only three times the effective dose of an average panoramic examination, yet at least ten times less than the dose for an equivalent examination performed with medical CT-scanner (17), as previously used to quantify bone apposition (3).

In the present study, no attempt was made to compare treatment outcomes of SLB-systems with conventional bracket systems. The reasons are twofold: First, we wanted to test the hypothesis that passive- and active-SLB have a different influence on the treatment outcome, as claimed by the companies; Second, we wanted to test whether arch widening would be achieved by bodily movement, with subsequent buccal bone modeling, as alleged especially in case of the passive SLB. For this reason, it was important to compare systems allowing for similar treatment

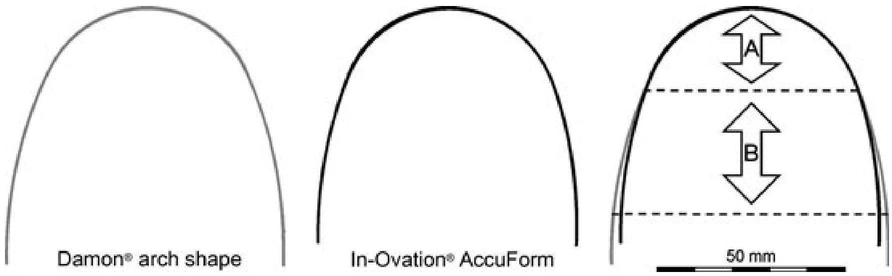

Fig. 7. Damon (right) and In-Ovation (center) arch wires. The two wires display the same shape in the front region -A-, while the Damon wire is wider in the region distal to the canines -B- (left).

modality (i.e., arch widening) where arches' expansion relies solely on arch wires and bracket interactions. With conventional brackets, space problems are usually handled differently than by expansion alone, making them unsuitable as control group.

Although patients' selection was preformed in conformity with the prescribed guidelines, a considerable number of patients had to be excluded. Indeed, as the treatment goal could not be achieved following the original plan, reevaluation of the treatment was necessary, resulting in extractions and surgery, as previously detailed. This raises the serious issue of the feasibility of the recommended treatment protocol. This confirms once more that the orthodontist, not the bracket philosophy, must take decisions regarding treatment advancement. Nevertheless, we are aware that the high dropout might raises some statistical issues, still we strongly believe that this information is highly valuable as it highlights the discrepancy between the case selection according to the manufacturer and the real treatment.

In the majority of the cases finished with the prescribed wire sequence, increased buccal tipping for both the active and the passive SLBs was seen. The claims regarding expansion without tipping had to be, therefore, rejected.

The Damon and In-Ovation wires share the same arch shape in the anterior segment, while the Damon arches are wider than the In-Ovation distally to the 1st premolar (Fig. 7). This could explain why the ΔE at the 2nd premolar and 1st molar was on average larger in the Damon group. Our results and the fact that the amount of expansion seems to be correlated with the arch wires' shape (35), thus raises some doubts about the concept of '*physiological determined tooth position*' and '*arch shape determined by the body and not by the clinician or the system applied*' alleged by Damon (3).

After orthopedic maxillary expansion, widening at premolar and molar crown level was shown to be closely related to bone width (36). On the other hand, the present 3D analyses showed that, despite dental expansion at the occlusal level, the claimed buccal bone augmentation could hardly be detected. Therefore, the hypothesis regarding the Fränkel-like effect should thus be rejected (37). In fact, the Fränkel functional-regulator appliance alters the conditions by releasing the pressure from the cheeks soft tissue and not by wire determined tooth movement.

This study showed that positive buccal bone modeling was not correlated with the length of treatment. Nevertheless, as in patients treated with rapid maxillary expansion, bone apposition was detected some months after treatment completion (38), it might be interesting to follow-up the patients at a suitable period after termination of treatment.

Conclusion

- The anticipated translation and buccal bone modeling using active or passive SLBs could not be confirmed in the majority of the cases.
- Individual pre-treatment factors, like initial teeth inclination and occlusion, seem to be important in determining the final outcome of the individual treatment.
- CBCT-technology combined with digital casts is all important to analyze 3D treatment outcomes both at dental and bone level in large study groups.

Clinical relevance

Self-ligating appliances have been alleged to have advantages in terms of true expansion, buccal bone apposition, and Fränkel-like effects. In a randomized clinical trial, these claims have been evaluated following treatment with passive and active self-ligating brackets (SLBs). This investigation evaluated type of tooth movement, amount of alveolar bone buccal to the 2nd premolar, and buccal bone augmentation before and after treatment with active and passive SLB in the maxilla. The results revealed that none of the above-mentioned claims could be verified.

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