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Geometric morphometric evaluations of a randomized prospective split-mouth study on modes of ligation and reverse-curve mechanics

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Structured Abstract

Objectives – To evaluate tooth position after six and 9 months of orthodontics with conventional brackets on one side of the dentition and ligature-less brackets on the other.

Setting and sample population – Orthodontic Division, Vienna Medical University. Twenty patients aged 22.5 ± 5.7 years, symmetrical malocclusion and arch form, no premolar extraction.

Material and Methods – Prospective split-mouth study, 0.022-inch SmartClip self-ligating brackets assigned randomly to the left or right dentition, conventional 0.018-inch brackets on the other side. 52 dental landmarks, digitized on plaster casts, represented dental arches at baseline (t_0), 6 months and 9 months (t_1, t_2). During t_0–t_1, we used 0.016 and 0.014 x 0.025 inch superelastic wires, during t_1–t_2 connected reverse-curve hemiarch wires: 0.017 x 0.025 inch ß-titanium on the ligature-less side, and 0.016 x 0.022 inch Elgiloy multiloop wires on conventional brackets. Morphometric analyses were used to assess differences in dental arch shapes.

Results – Neither initial alignment nor the reverse-curve phase showed statistically significant differences between ligature-less and conventional brackets in moving teeth.

Conclusion – Morphometric shape analyses corroborated current evidence that self-ligating brackets were no more effective than conventional brackets with steel ligatures after 6-month initial alignment. From months 6–9 treatment with ß-titanium reverse-curve wires on 0.022-inch ligature-less brackets resulted in similar tooth positions as accomplished by Elgiloy multiloop wires on 0.018-inch steel-ligature-tied brackets.

Key words: geometric morphometrics; principal component analysis; reverse curve; self-ligation; split mouth

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Introduction

Self-ligating brackets (SLBs) reflect a trend of simplification in orthodontics focusing on easy engagement of arch wires. *In vitro* frictional tests and retrospective studies (1–4) supported claims that SLBs lead to higher treatment efficiency than conventional brackets (CBs). However, studies comparing groups treated with either CBs or SLBs brought limited prospective evidence and concluded that SLBs were no more effective than CBs (4–16). The results of these comparative studies may be influenced by the variation among individuals in their response to orthodontic treatment because compliance, medication, disease, bone metabolism and turnover can differ considerably across patients. Split-mouth studies that apply both bracket types to the same patient are an effective strategy against bias from inter-individual variation but have rarely been used to contrast SLBs and CBs (7, 17).

The aims of the present split-mouth study were to compare 1) tooth movement using 0.022-inch straight-wire SLBs with CBs from a multiloop concept, which is renowned for effective orthodontics without premolar extraction but using 0.018-inch slots (18–21), and 2) two different reverse-curve mechanics used after initial alignment in this SLB-CB set-up. We used geometric morphometric methods (22–29) for a comprehensive analysis of the dental arch geometries.

Material and methods

The institutional ethical committee approved this prospective clinical trial in accordance with the Helsinki Declaration (#536/2006). Over a period of 24 months, we invited patients, whose orthodontic treatment planning had revealed symmetric malocclusions and arch forms, to participate in this study. Further inclusion criteria encompassed a full permanent dentition without consideration of the third molars, and written informed consent.

Exclusion criteria comprised cleft lip and palate, asymmetric craniofacial growth, facial nerve paresis, inability to use intermaxillary elastics, unilateral cross-bite or mandibular lateral displacement, hypodontia, oligodontia, former orthodontic therapy, a current orthodontic treatment plan designating premolar extraction, orthognathic surgery, temporary anchorage devices, or extraoral traction. We omitted patients with more than one failed appointment or rebonding of bracket failures beyond 5 days.

Sample

We triaged the records for orthodontic treatment planning of 676 patients. Of 27 patients, who fulfilled the inclusion criteria, 21 volunteered and gave written informed consent. Four patients were male, aged from 11 to 25 years, and 17 were female, aged from 14 to 36 years. The treatment objectives envisioned extraction of third molars. Seven patients showed an Angle Class I occlusion with crowding and/or anterior open bite (AOB), five patients a Class II/1 (two of them with AOB) and nine patients a Class III malocclusion (three with AOB). Negative overbites ranged from −0.5 mm to −3.5 mm and averaged −1.9 mm. One patient showed buccally erupting maxillary canines.

The calculation of crowding, performed with a sliding caliper accurate to 0.1 mm, yielded -4.2 ± 2.6 mm in the maxillary and -5 ± 2.7 mm in the mandibular arches. We excluded one patient because of multiple missed appointments. The final sample thus comprised 20 individuals aged from 14 to 36 years (22.5 ± 5.7) at bracket placement (Fig. 1).

Brackets

By drawing lots, the treating orthodontist (KO) positioned 0.022 x 0.028 inch SLBs (SmartClip; 3M Unitek Orthodontic Products, Monrovia, CA, USA) on either the left or right side of the baseline plaster casts (t_0) with bonding resin (Transbond XT; 3M Unitek Orthodontic Products). He placed conventional twin brackets (0.018 x 0.025 inch Standard Edgewise; American Orthodontics, Sheboygan, CA, USA) on the other side.

The maxillary mesiodistal bracket dimensions were 4 mm (SLB) vs. 4.2 mm (CB) for central

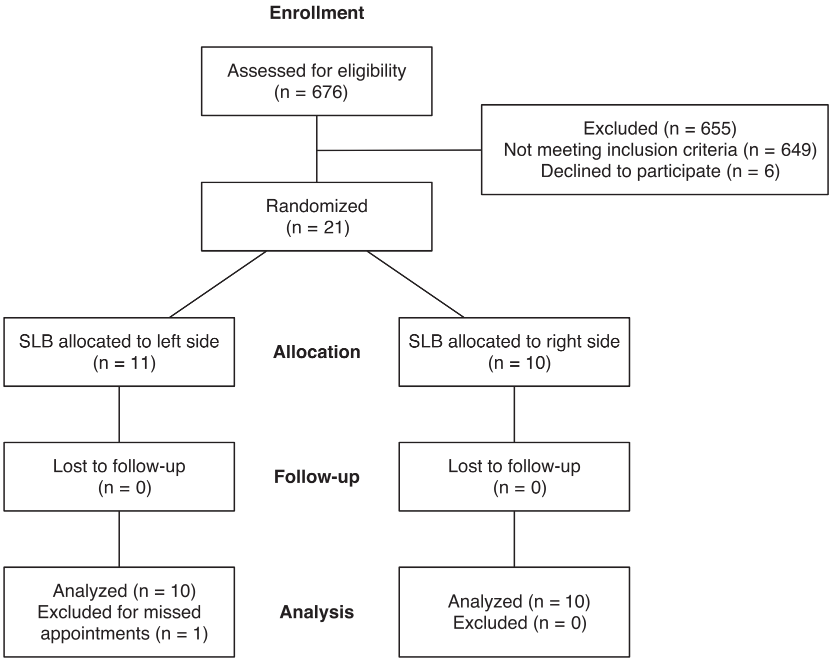

Fig. 1. CONSORT patient flow diagram.

incisors, 2.6 vs. 2.8 mm for lateral incisors, 3.5 vs. 3.8 mm (canines, premolars), 4 mm for both first molar bracket types and 4.5 vs. 5.5 mm for second molars. The mandibular mesiodistal bracket dimensions coincided for both types on incisors, first and second molars (2.6, 4 and 4.5 mm). Mandibular canine and premolar brackets were 3.5 mm (SLB) and 3.8 mm (CB) in mesiodistal size. The averaged differences were 0.32 mm in the maxilla and 0.13 mm in the mandible.

The distances between bracket base and slot bottom ranged from 1.2 to 1.5 mm on the maxillary SLBs (mean 1.39) vs. 1.3–1.4 mm (CBs, mean 1.33) and 1.3–1.7 mm on mandibular SLBs (mean 1.53) vs. 1.3–1.6 mm on mandibular CBs (mean 1.4).

Brackets were bonded indirectly to the patient's teeth using dual-layer transfer trays fabricated from soft and hard pressure foils (Bioplast Bleach 1 mm, Duran 0.75 mm, both Scheu-Dental GmbH, Iserlohn, Germany) and dual cure resin (Sondhi™ Rapid-Set; 3M Unitek, Landsberg, Germany). CBs were tied with 0.01-inch stainless steel ligatures.

Treatment phases

Phase I started with 0.016-inch nickel-titanium-levelling wires (Sentalloy; Dentsply GAC International, Bohemia, NY, USA) for 12 weeks and was continued with 0.014 x 0.025 inch copper-nickel-titanium wires (Damon; Ormco Corp., Glendora, CA, USA) for another 12–14 weeks. Patients were scheduled every 6 weeks. Alginate impressions for casts documented the stage t_1.

From months 6–9 (t_1–t_2), phase II included a compound reverse-curve arch wire. It consisted of a 0.017 x 0.025 inch ß-titanium wire (Beta III, 3M Unitek) on the SLB side, and a 0.016 x 0.022 inch nickel-chromium-cobalt multiloop arch wire for the CBs (Blue Elgiloy, Rocky Mountain Orthodontics, Denver, CO, USA). The latter had five boot loops between the CBs distal from the lateral incisors. A stainless steel clamp connected both hemiarch wires (Fig. 2).

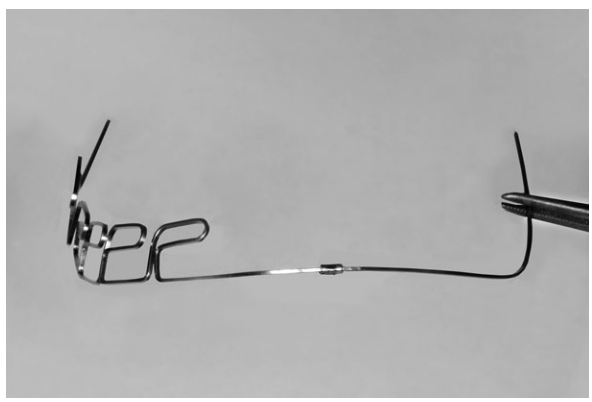

Fig. 2. Phase II (t_1–t_2): compound arch wire with stainless steel clamp.

Different arch wire dimensions accounted for comparable resilience of the Beta III and Elgiloy wires and the play in the bracket slot. We had quantified their forces and moments with an electronic 2D gauge (Hottinger Baldwin Messtechnik, Vienna, Austria). The reverse curves had an initial total tipback of 20 degrees (°), followed by 30° 4 weeks later, and 40° after another month. During t_1–t_2, patients used intermaxillary elastics on canines and premolars day and night. Six patients used short anterior vertical elastics, six patients short anterior class II elastics and eight patients short anterior class III elastics. The 3/16-inch and 6 oz. elastics counteracted anterior intrusive forces, whereupon molars were intruded and retracted for 12–14 weeks. Then, we documented stage t_2 by taking impressions.

Digital representation of dental arches

Operator EA marked 52 maxillary and 52 mandibular landmarks on all casts with a pencil: the mesial and distal edges, the highest point of the lingual tubercle on incisors and canines, the buccal and lingual cusp tips as well as the buccolingual mid-points of the mesial and distal marginal ridges on premolars and molars. She digitized the landmarks with a MicroScribe® 2GX digitizer (CNC Services, Amherst, VA, USA). For the visualization of statistical results, each tooth was represented as a polygon based on the corresponding landmarks (Figs 3 and 4). Because of three patients with designated extraction of root-filled maxillary second molars, we omitted these teeth when evaluating the maxillary arches.

Evaluations

A fourth investigator (MB) measured *unilateral irregularity scores* separately for the left and right sides of the dentition, summing the distances between the ideal contact points of incisors, canines, first and second premolars, and the first molar, respectively. The difference between left and right irregularity score at t_0 was used as a measure of dental arch asymmetry.

Geometric morphometrics required that SLBs appeared on the same side of the virtual dental arches and CBs on the other side in every patient. Therefore, the landmark configurations were mirrored where necessary so that SLBs were always on the right side and CBs on the left. The configurations were superimposed by Generalized Procrustes Analysis, a registration technique based on all landmarks without specification of a reference plane (27–29). This procedure standardized the overall position, size and orientation of the configurations by 1) translating

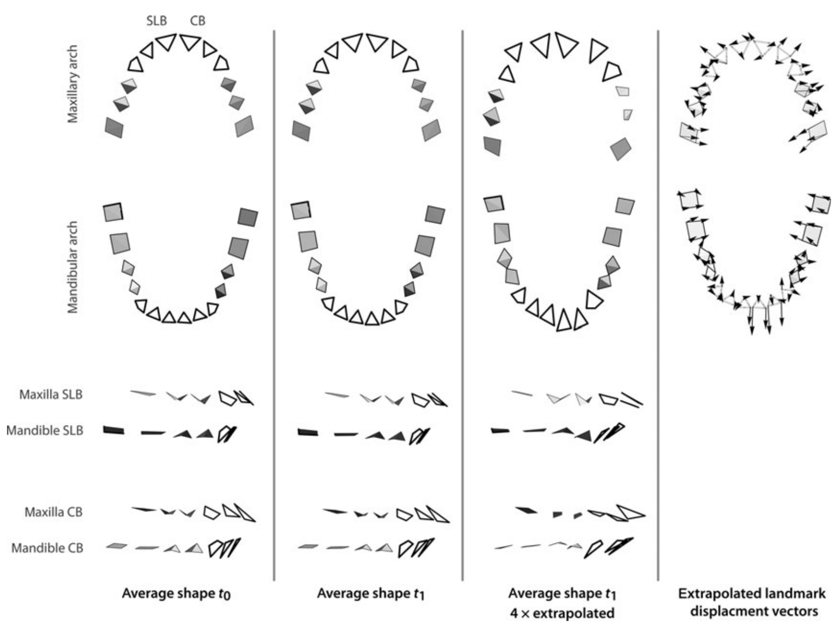

Fig. 3. The first two panels show average shapes at t_0 and t_1 (upper images are occlusal views, lower images lateral views). Differences between t_0 and t_1 are extrapolated by factor 4 in panel three to highlight the shape differences. Lingual surfaces of incisors and canines are visualized by empty polygons, occlusal surfaces of premolars and molars by grey polygons. Panel 4 illustrates shape changes by extrapolated landmark displacement vectors.

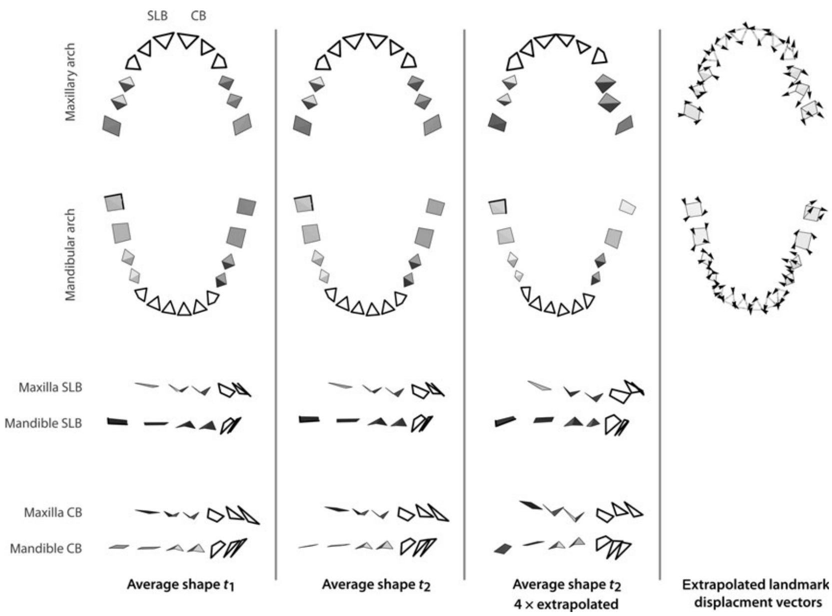

Fig. 4. Visualization of the average shape changes from t_1 to t_2 for maxillary and mandibular arches. Panels 1 and 2 present the average shapes at t_1 and t_2 in occlusal and lateral views. Panel 3 shows differences between t_1 and t_2 fourfold extrapolated. Panel 4 illustrates shape changes by extrapolated landmark displacement vectors.

them to the same centroid (average of the respective xyz coordinates), 2) scaling them to unit centroid size (square root of summed squared distances between the landmarks and their centroid) and 3) rotating the configurations to minimize the summed squared distances between the corresponding landmarks. Procrustes superimpositions were performed separately for the maxillary and mandibular landmark configurations. Additionally, we separated the left and right hemiarches and superimposed them instead of the full arches to avoid mutual influences between left and right hemiarch formations, which may result from a common superimposition.

A principal component analysis of the superimposed landmark configuration was computed to assess the variation of dental arch shape changes across individuals (also see Appendix). The amount of individual shape change (tooth displacement) was measured by Procrustes distances (Euclidean distance) between the corresponding superimposed landmark configurations of t_0, t_1 and t_2. If the patients' tooth displacements differ both in magnitude and direction, the computation of an average magnitude is ambiguous. We thus used two alternative estimates: first, the magnitude of the average shape differences, and second, the average of the individual magnitudes of shape differences. The first estimate was an average of both magnitude and direction (it would be zero if two patients had the same amount of tooth displacement in exactly opposite directions). The second one was an average of the amounts of individual tooth displacement regardless of direction. Mean treatment effects were visualized by 3D reconstructions of the average shapes at t_0, t_1 and t_2, along with fourfold linear extrapolations of the treatment effects to ease the exploration of the spatial pattern of average change.

The statistical significance of group mean differences was estimated by permutation tests with 5000 random re-samplings. Morphometric and statistical analyses were performed in Mathematica 8.0 (Wolfram Research, Inc., Champaign, IL, USA) and SPSS 19.0 (IBM SPSS Statistics, Armonk, NY, USA).

Results

Measurement error and interbracket distances

We measured maxillary and mandibular arches three times. Intraclass correlation coefficients (ICC) for the first three principal components of dental arch shape (accounting for 84% of total shape variance for maxillary and 98% for mandibular arches) were 0.98, 0.99 and 0.93 for the maxilla and 0.99 for all three mandibular arch components. Multivariate ICC measures based on

Table 1. **Mean, standard deviation (SD) and random error of unilateral irregularity scores (IS), intercuspid distances (ICD; mm) and absolute differences between sides (mm) on initial casts**

	SmartClip side		Conventional side			Absolute difference		SmartClip side			Conventional side		
	Mean	SD	Mean	SD	p	Mean	SD	Random error	−95% CI	+95% CI	Random error	−95% CI	+95% CI
IS mx	2.7	1.7	2.8	2.2	0.640	0.9	0.9	0.38	0.20	0.53	0.27	0.14	0.38
IS md	2.1	0.8	2.5	1.3	0.151	1.0	0.9	0.24	0.12	0.33	0.20	0.11	0.28
ICD mx 3–4	8.6	1.0	8.5	1.0	0.401	0.5	0.3	0.17	0.09	0.24	0.14	0.07	0.19
ICD mx 4–5	7.3	0.3	7.2	0.5	0.597	0.3	0.2	0.13	0.07	0.19	0.18	0.10	0.26
ICD mx 5–6	7.0	0.6	6.9	0.5	0.802	0.4	0.3	0.23	0.12	0.33	0.19	0.10	0.27
ICD md 3–4	6.8	0.9	7.1	0.9	0.060	0.5	0.4	0.21	0.11	0.30	0.18	0.10	0.25
ICD md 4–5	7.5	0.6	7.5	0.4	0.960	0.3	0.3	0.18	0.10	0.25	0.15	0.08	0.21
ICD md 5–6	7.2	0.6	7.1	0.6	0.938	0.4	0.2	0.17	0.09	0.23	0.21	0.11	0.29

mx, maxillary; md, mandibular; CI, confidence interval.

total shape variance yielded 0.95 and 0.98, respectively. Measurement error of irregularity scores ranged from 0.13 to 0.38 mm (Table 1). At t_1, the CB-SLB differences in interbracket distance were 1.9 ± 1.3% of the total maxillary arch length and 1.4 ± 0.8% of the mandibular arch length (sums of the hemiarch interbracket distances were 33.7 ± 2.6 mm for maxillary CBs, 35 ± 2.3 mm for maxillary SLBs, 31.3 ± 2.1 mm for mandibular CBs and 32.3 ± 2.6 mm for mandibular SLBs).

Baseline symmetry and failures

The unilateral irregularity scores at t_0 did not differ significantly between the left and right sides of the dentition, indicating absence of directional arch asymmetry. In the first 9 months of treatment, 16 patients encountered complications. Single bracket emergencies occurred in seven patients (four SLBs, 3 CBs). Four patients experienced bracket loosening twice (five SLBs, 3 CBS), another five patients thrice (10 SLBs, 5 CBs). Four times the clip between Elgiloy and ß-titanium became loose. All failures were corrected within 4 days. Six patients missed one appointment.

Shape analysis

Figures 3 and 4 visualize the average dental arch shapes at t_0, t_1, t_2 along with the extrapolated shape differences. From t_0 to t_1, the dental arches became more U-shaped, and the incisors and canines tipped forward. From t_1 to t_2, the curve of Spee became more pronounced in the maxilla with a reverse effect in the mandible. The molars tipped backward. All average changes were slightly more pronounced on the CB side than on the SLB side, but the differences were not statistically significant (Table 2).

Individual changes

In the principal component analysis, the individual shape changes differed considerably across the patients, both in direction and magnitude (see Appendix). When averaging the magnitudes of individual shape change regardless of its direction, the changes were larger on the CB side than on the SLB side, both from t_0 to t_1 and from t_1 to t_2 (except for t_0–t_1 in the mandible, where on both sides, the changes were about the

Table 2. **Magnitudes (Procrustes distances) of the average shape differences between t_0 and t_1, and between t_1 and t_2. In contrast to Table 3, these numbers are averages of both the magnitudes and directions of individual tooth displacement as illustrated in Figs 3 and 4. The upper two rows of the table show average shape differences of the entire dental arches, the bottom rows the changes after superimposition of all left and right hemiarches**

		Maxilla		Mandible	
		Conventional	SmartClip	Conventional	SmartClip
Superimposition of whole arches	$t_0 - t_1$	0.0193	0.0130	0.0219	0.0138
	t_1–t_2	0.0194	0.0109	0.0187	0.01124
Superimposition of hemiarches	t_0–t_1	0.0417	0.0246	0.0346	0.0236
	t_1–t_2	0.0278	0.0176	0.0317	0.0176

Table 3. **Means of the magnitudes of individual shape differences (Procrustes distances) between t_0 and t_1, and between t_1 and t_2, reflecting the amount of tooth displacement averaged over all patients *regardless of its direction*. Shape differences were computed from Procrustes superimposition of the entire dental arch (upper two rows) and from superimposition of all left and right hemiarches (bottom rows)**

		Maxilla		Mandible	
		Conventional	SmartClip	Conventional	SmartClip
Superimposition of whole arches	t_0–t_1	0.0434	0.0358	0.0416	0.0409
	t_1–t_2	0.0363	0.0275	0.0361	0.0324
Superimposition of hemiarches	t_0–t_1	0.0907	0.0724	0.0744	0.0763
	t_1–t_2	0.0697	0.0559	0.0635	0.0545

same). All differences were not significant (Table 3).

Discussion

Our prospective split-mouth study did not substantiate a superior performance of SmartClip SLBs relative to CBs. This result corroborates findings of former studies, which did not use a split-mouth approach or confined the split-mouth design to the anterior teeth (4–15). Also, some of these studies mixed the results of orthodontic therapies from residents with those of experienced orthodontists in different practices (3, 10, 11). Our data derived from the work of a single decidedly skilled clinician, who strictly followed consistent arch wire sequences under control of a second investigator.

Using geometric morphometric methods of the entire dental arch, we found that both bracket types increased the proclination of incisors, expanded the interpremolar width from t_0 to t_1, and decreased the transverse distance between the second premolars from t_1–t_2 and the intermolar widths from t_0–t_1 and t_1–t_2. The reduction in posterior width was a concomitant side effect of the arch expansion and seemed to spread forward at t_2 as intermaxillary elastics had been used. The posterior slightly inward orientation of the reverse-curve wires represents another explanation for this finding.

The proclination of incisors resembled previous comparisons of 0.022-inch SLBs and CBs (8, 9, 30). These studies reported a statistically non-significant increase in intercanine width and a reduction in arch length. A statistically significant finding pertained to intermolar expansion: Fleming et al. (30) reported 0.9 mm more intermolar width for the SLB group. As indicated by the landmark displacement vectors, our study did not support an average increase in the intercanine or intermolar widths. Different study designs, samples, mechanics, time points, and methods of evaluation may contribute to this disagreement.

In the present study, the extent of shape change as well as the average magnitude of individual shape change (neglecting different direction) was slightly more pronounced for CBs than SLBs. As these differences were not statistically significant, we do not have strong support for the superiority of CBs over SmartClip SLBs. Yet, we can clearly reject a superiority of SLBs. Increasing sample size may lead to statistically significant results but is unlikely to change the direction of our results. Less play of the wire and stronger effects of steel ligatures may account for our observation, which conforms to the reported difficulty in orthodontic finishing with SLBs (31, 32). Tying steel ligatures or elastomeric modules in a figure-8 shape also expressed small but statistically significant advantages in alignment for CBs over SLBs (7). The alleviation of crowding was reported to be faster with CBs than with SLBs in the first 4 weeks of treatment (14).

The t_1–t_2 phase investigated the effects of the reverse-curve arch wires. Multiloop wires on CBs were effective in treating pronounced malocclusions without orthognathic surgery and showed excellent results (18, 20, 33). Multiple tipback bends produced distal en masse movements of the dentition and obtained a Class I intercuspation in markedly short time (19, 21, 34). We coupled the multiloop wires with the originally used 0.018-inch CBs, and the Beta III titanium wires with commonly advocated 0.022-inch SLBs. The reverse-curve wires mostly opened one or two proximal contacts between molars or premolars. These spaces were on average 1 mm wider on the multiloop-CB side in 19 of 20 patients. We attributed this statistically not significant effect to the looped Elgiloy, which showed less wire deformation than the ß-titanium during engagement.

The split-mouth design avoided interindividual differences in the response of teeth to orthodontic therapy. A prerequisite of an effective split-mouth study is a sample of patients with approximately symmetric irregularities, which limited the sample of our study to 4% of new patients treated at that time. Some patients did not accept compromised aesthetics caused by unilateral loops. Patients also reported that cleaning the multiloop side was more difficult than the ß-titanium segment. Biohostability is clinically important and requires further studies.

A potential drawback of a split-mouth design is the mutual influence of the two treatment modes, particularly for incisors, which might mitigate differences in the direction or magnitude of tooth displacement. However, in Fig. 3, the average position and orientation of the incisors differ clearly between left and right sides, indicating that mutual influences of the treatment modalities were small.

Both bracket systems were largely similar in terms of mesiodistal dimension, bracket base thickness and interbracket distances. Even the mesial and distal clips resembled the position of a ligature as requested in former publications (13, 16). Given the symmetry of the dental arches, the horizontal orthodontic forces were not necessarily higher on one side.

Following Kim and Sato's concept, we adhered to 0.018-inch CBs for the multiloop side, whereas the claims of SLB superiority were attributed to the commonly used 0.022-inch braces. The vertical slot height requires some comments. Differences in vertical slot height were unlikely to influence most treatment effects because dental malpositions predominated in the horizontal plane. Only one patient showed high-erupting maxillary canines, where the larger slot might have produced less binding. During the first 6 weeks, the SLBs moved this maxillary canine 1 mm more downward, but the canine positions were the same after 12 weeks.

During the t_0–t_1 phase, both slot dimensions gave considerable leeway for 0.016 and 0.014 x 0.025 inch wires. We consider this clearance to have counteracted most differences between the pre-designed features of SLBs and CBs including torque. Torque effects can be fully applied only if the slot is filled (35). While 0.018-inch systems will reach this stage earlier, it did not happen within the initial 9 months of treatment.

Also the edge bevel of orthodontic wires, which depends on material properties, may affect torque (36). A lower amount of torque in 0.022-inch systems is not necessarily a clinical disadvantage because there is no consensus on optimum torque moments but rather a range from five to 20 Nmm (37). Further clinical research is necessary for determining the average amount of tooth movement resulting from this range of torsion (38). We simulated the reverse-curve mechanics by 3° tipback bends in our laboratory. The 0.016 x 0.022 multiloop Elgiloy and 0.017 x 0.025 non-loop ß-titanium wires showed moments from six to 18 Nmm. The 3° tipback indicated an average tipback, which should represent the fading action of the initial 5° bends over time. Yet without presence of saliva and periodontal ligament, any interpretation of *in-vitro* measurements requires caution.

Some authors considered the differences between 0.018 and 0.022-inch slots as clinically not significant in terms of quality of outcome (39). Although arch wires may align mandibular anterior teeth faster using 0.022-inch brackets (40), the total treatment time was longer with 0.022-inch brackets than with 0.018-inch brackets (41). Altogether, we cannot dismiss a potential effect of vertical slot dimension but do not expect a great influence on the results. However, the slot height represents a limitation of the study.

Binding and notching phenomena may also influence the effects of SLBs and CBs (42). Binding of arch wires is essential for space opening during levelling (43). *In vitro* experiments with parallel bracket wire alignments ignore binding and do not permit extrapolation of laboratory results to *in vivo* conditions (13). When laboratory settings considered binding, the frictional behaviour of CBs and SLBs was alike (42). Therefore, increasing dental arch irregularity questions the theoretical benefits of reduced friction as long as binding and notching occur.

In agreement with a systematic review (5), preference of SLBs over CBs for more efficient treatment is not warranted presently. Advantages of SLBs comprise modest reduction in chair time and assistance, and elimination of injuries from ligatures (6, 44, 45).

Conclusion

The present split-mouth study assessed shape changes of the maxillary and mandibular dental arches at six and 9 months of orthodontic treatment with conventional and self-ligating brackets. Morphometric analyses did not find significantly different effects on tooth movement between the two bracket types with different slot dimensions and reverse-curve mechanics. Using 0.017 x 0.025 inch Beta-III-titanium wires on 0.022-inch self-ligating brackets from month six to nine showed slightly but not significantly less distal movement of molars than 0.016 x 0.022 inch Elgiloy multiloop arch wires engaged contralaterally on 0.018-inch conventional brackets.

Within the limitations of sample size and bracket dimensions, the present study refutes claims of superior alignment including uprighting of mesially tipped teeth by a ligation-less bracket system within the first 9 months of non-premolar extraction therapy.

Clinical relevance

The present prospective split-mouth study investigated both dental arches using morphometric methods and could not detect different therapeutic effectiveness of 0.018-inch conventional and 0.022-inch ligature-less brackets during the initial 9 months.

Appendix

We present the results of principal component analyses for the maxillary and the mandibular arches. The first principal component is the linear combination with maximum variance in the data set. The second component is uncorrelated with the first one and accounts for the second-most variance. Figure 5 shows scatter plots of the first four principal components (PCs) for both analyses, accounting for 53% of total shape variation in the maxilla and for 58% in the mandible. An arrow, representing the patient's shape trajectory, connects the tooth configurations at t_0, t_1 and t_2 of every patient. The individual shape changes share a common pattern, mainly along PC 3, but are otherwise quite heterogeneous.

The shape patterns corresponding to the PCs are visualized in Figs 6 and 7. Both for the maxilla and for the mandible, PC 1 is a contrast between wide vs. narrow arch shapes. PC 3 largely represents the difference between a U-shaped and a V-shaped arch for the maxilla and PC 2 for the mandible. The other components mainly comprise variation in incisor size and orientation, the curve of Spee, and arch asymmetry.

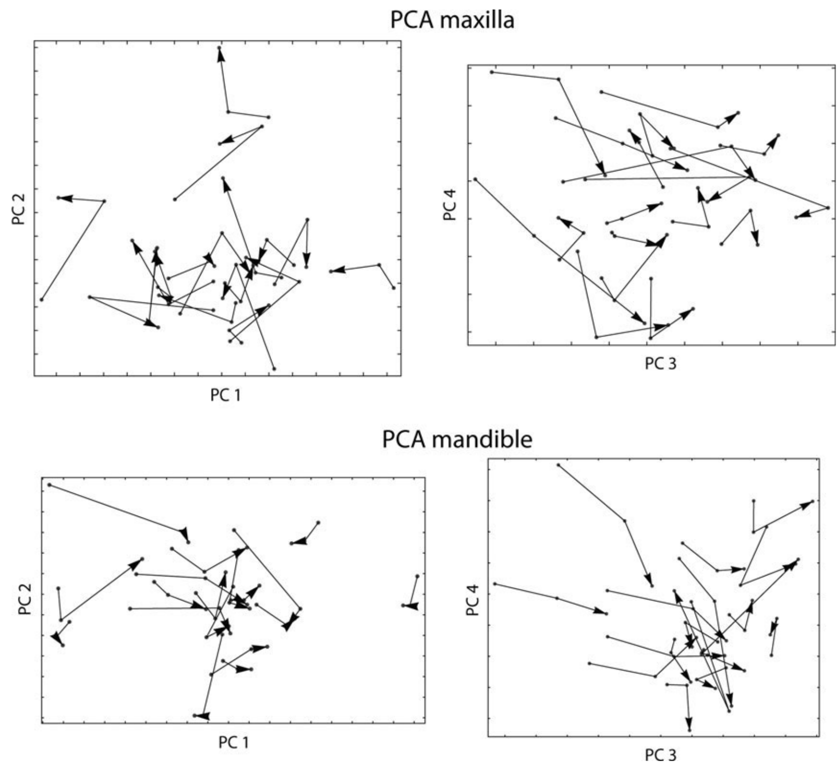

Fig. 5. Scatter plots of principal components 1–4.

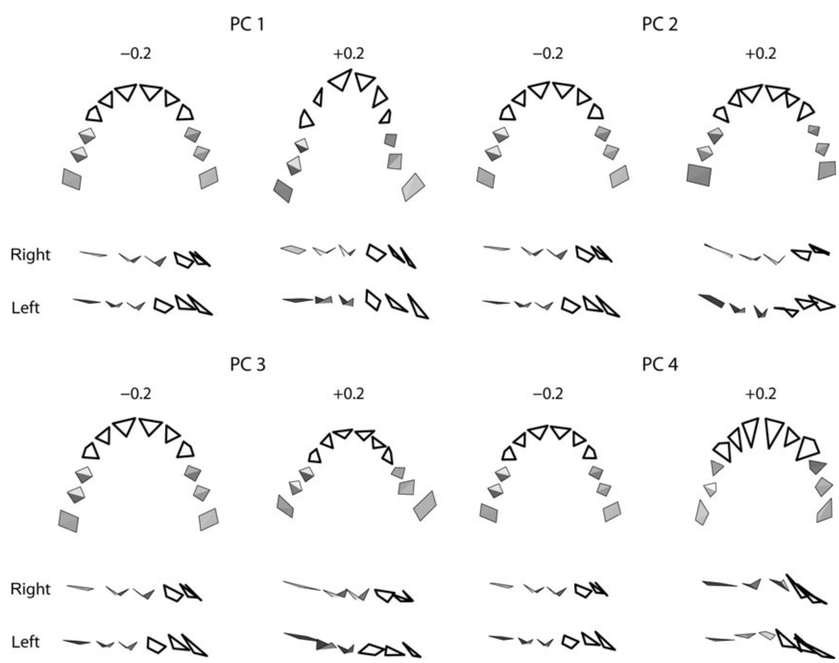

Fig. 6. Maxillary shape patterns from principle component (PC) 1 to PC 4.

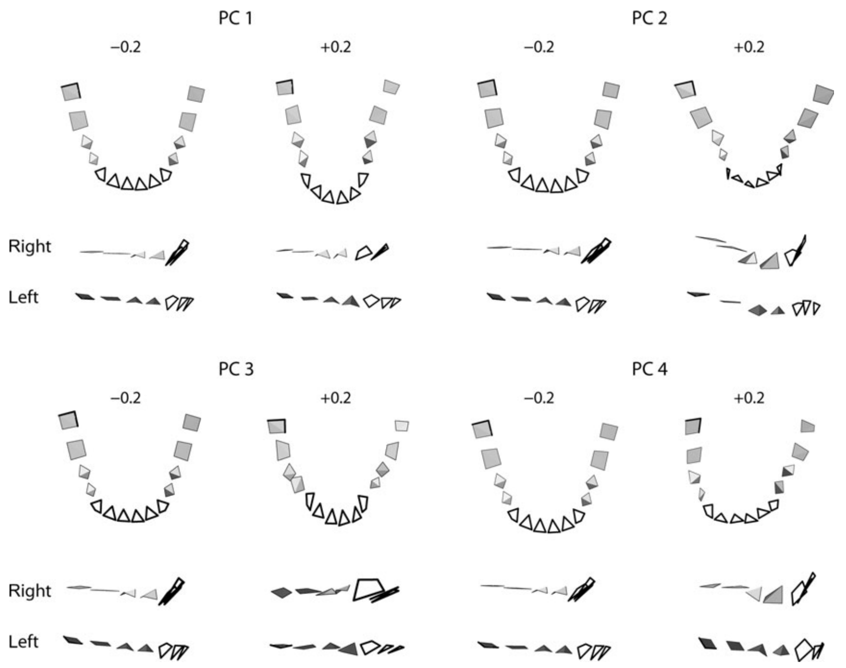

Fig. 7. Mandibular shape patterns from principle component (PC) 1 to PC 4.

References

1. Griffiths HS, Sherriff M, Ireland AJ. Resistance to sliding with 3 types of elastomeric modules. *Am J Orthod Dentofacial Orthop* 2005;127:670–5.
2. Harradine NW. Self-ligating brackets and treatment efficiency. *Clin Orthod Res* 2001;4:220–7.
3. Eberting JJ, Sraja SR, Tuncay OC. Treatment time, outcome, and patient satisfaction comparisons of Damon and conventional brackets. *Clin Orthod Res* 2001;4:228–34.
4. Hamilton R, Goonewardene MS, Murray K. Comparison of active self-ligating brackets and conventional pre-adjusted brackets. *Aust Orthod J* 2008;24:102–9.
5. Fleming PS, Johal A. Self-ligating brackets in orthodontics. A systematic review. *Angle Orthod* 2010;80:575–84.
6. Fleming PS, DiBiase A, Lee RT. Randomized clinical trial of orthodontic treatment efficiency with self-ligating and conventional fixed orthodontic appliances. *Am J Orthod Dentofacial Orthop* 2010;137:738–42.
7. Miles PG, Weyant RJ, Rustveld L. A clinical trial of Damon 2 vs conventional twin brackets during initial alignment. *Angle Orthod* 2006;76:480–5.
8. Pandis N, Polychronopoulou A, Eliades T. Self-ligating vs conventional brackets in the treatment of mandibular crowding: a prospective clinical trial of treatment duration and dental effects. *Am J Orthod Dentofacial Orthop* 2007;132:205–15.
9. Scott P, DiBiase AT, Sheriff M, Coburne MT. Alignment efficiency of Damon3 self-ligating and conventional orthodontic bracket systems: a randomized clinical trial. *Am J Orthod Dentofacial Orthop* 2008;134:470.e1-470.e8.
10. Ong E, McCallum H, Griffin MP, Ho C. Efficiency of self-ligating vs conventionally ligated brackets during initial alignment. *Am J Orthod Dentofacial Orthop* 2010;138:138.e1–138.e7.
11. Johansson K, Lundström F. Orthodontic treatment efficiency with self-ligating and conventional edgewise twin brackets. *Angle Orthod* 2012;82:929–34.
12. Chen SS-H, Greenie GM, Kim J-E, Smith CL, Huang GJ. Systematic review of self-ligating brackets. *Am J Orthod Dentofacial Orthop* 2010;137:726.e1-726.e18.
13. Marshall SD, Currier GF, Hatch NE, Huang GJ, Nah H-D, Owens SE et al. Self-ligating bracket claims. *Am J Orthod Dentofacial Orthop* 2010;138:128–31.
14. Wahab RMA, Idris H, Yacob H, Ariffin S. Comparison of self- and conventional-ligating brackets in the alignment stage. *Eur J Orthod* 2012;34:176–81.
15. DiBiase AT, Nasr IH, Scott P, Cobourne MT. Duration of treatment and occlusal outcome using Damon3 self-ligated and conventional orthodontic bracket systems in extraction patients: a prospective randomized clinical trial. *Am J Orthod Dentofacial Orthop* 2011;139:e111–6.
16. Miles PG, Weyant R. Porcelaine brackets during initial alignment: are self-ligating cosmetic brackets more efficient?. *Aust Orthod* 2010;26:21–6.
17. Miles PG. Self-ligating vs conventional twin brackets during en-masse space closure with sliding mechanics. *Am J Orthod Dentofacial Orthop* 2007;132:223–5.
18. Kim YH. Anterior openbite and its treatment with multiloop edgewise archwire. *Angle Orthod* 1987;57:290–321.
19. Sato S. Case report: developmental characterization of skeletal class III malocclusion. *Angle Orthodont* 1994;64:105–11.

20. Kim YH, Han UK, Lim DD, Serraon ML. Stability of anterior openbite correction with multiloop edgewise archwire therapy: a cephalometric follow-up study. *Am J Orthod Dentofacial Orthop* 2000;118:43–54.
21. Kim YH, Han UK. The versatility and effectiveness of the Multiloop Edgewise Archwire (MEAW) in treatment of various malocclusions. *World J Orthod* 2001;2:208–18.
22. Moyers RE, Bookstein FL. The inappropriateness of conventional cephalometrics. *Am J Orthod* 1979;75:599–617.
23. Bookstein F. Biometrics, biomathematics and the morphometric synthesis. *Bull Math Biol* 1996;58:313–65.
24. Halazonetis DJ. Morphometrics for cephalometric diagnosis. *Am J Orthod Dentofacial Orthop* 2004;125:571–81.
25. Zedlitch ML, Swiderski DL, Sheets DS. *Geometric morphometrics for biologists*. San Diego: Elsevier Academic Press; 2004.
26. Slice D. Geometric morphometrics. *Annu Rev Anthropol* 2007;36:261–81.
27. Mitteroecker P, Gunz P. Advances in geometric morphometrics. *Evol Biol* 2009;36:235–47.
28. Rohlf FJ, Slice DE. Extensions of the Procrustes method for the optimal superimposition of landmarks. *Syst Zool* 1990;39:40–59.
29. Weber GW, Bookstein FL. *Virtual Anthropology. A Guide to a New Interdisciplinary Field*. Wien – New York: Springer; 2011. pp. 190–230.
30. Fleming PS, DiBiase AT, Sarri G, Lee RT. Comparison of mandibular arch changes during alignment and leveling with 2 preadjusted edgewise appliances. *Am J Orthod Dentofacial Orthop* 2009;136:340–7.
31. Harradine NWT, Birnie DJ. The clinical use of Activa brackets. *Am J Orthod Dentofacial Orthop* 1996;109:319–28.
32. Prettyman C, Best AM, Lindauer SJ, Tufekci E. Self-ligating vs conventional brackets as perceived by orthodontists. *Angle Orthod* 2012;82:1060–6.
33. Rubin RM. Commentary: skeletal class III malocclusion. *Angle Orthod* 1994;64:111–111.
34. Beane RA. Nonsurgical management of the anterior open bite: a review of the options. *Semin Orthod* 1999;5:275–83.
35. Epstein MB. Benefits and rationale of differential bracket slot sizes: the use of 0.018-inch and 0.022-inch slot sizes within a single bracket system. *Angle Orthod* 2002;72:1–2.
36. Sebanc J, Brantley WA, Pincsak JJ, Conover JP. Variability of effective root torque as a function of edge bevel on orthodontic arch wires. *Am J Orthod* 1984;86:43–51.
37. Sifakakis I, Pandis N, Makou M, Eliades TH, Katsaros CH, Bourauel CH. Torque expression of 0.018 and 0.022 inch conventional brackets. *Eur J Orthod* 2012;35:610–4.
38. Archambault A, Lacoursiere R, Badawi H, Major PW, Carey J, Flores-Mir C. Torque expression in stainless steel orthodontic brackets. *A systematic review. Angle Orthod* 2010;80:201–10.
39. Detterline DA, Isikbay SC, Brizendine EJ, Kula KS. Clinical outcomes of 0.018-inch and 0.022-inch bracket slot using the ABO objective grading system. *Angle Orthod* 2010;80:528–32.
40. Cobb N, Kula K, Phillips C, Profit WR. Efficiency of multi-stranded steel, superelastic NiTi and ion-implanted NiTi archwires for initial alignment. *Clin Orthod Res* 1998;1:12–9.
41. Amiditis C, Smith LF. The duration of fixed orthodontic treatment: a comparison of two groups of patients treated using Edgewise brackets with 0.018” and 0.022” slots. *Aust Orthod J* 2000;16:34–9.
42. Burrow SJ. Friction and resistance to sliding in orthodontics. A critical review. *Am J Orthod Dentofacial Orthop* 2009;135:442–7.
43. Bantleon H-P. The mechanical background of binding in a three-bracket-relationship simulating a premolar, canine and lateral incisor in levelling. *Orthod Waves* 2011;70:53–8.
44. Shivapuja PK, Berger J. A comparative study of conventional ligation and self-ligation bracket systems. *Am J Orthod Dentofacial Orthop* 1994;106:472–80.
45. Turnbull NR, Birnie DJ. Treatment efficiency of conventional vs self-ligating brackets: effects of archwire size and material. *Am J Orthod Dentofacial Orthop* 2008;134:470.e1–470.e8.