A comparative study of lingual bracket bond strength

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Aim: *To compare the adhesive potential, the mechanics implicated in adhesive failure, and the effect on the enamel of four brands of lingual brackets.* **Methods:** *One hundred sixty premolars and four types of commercially available lingual brackets (STB, ORG, Magic, and Stealth) were selected. Forty brackets per manufacturer were used, half bonded directly and half indirectly. Each of these bonding groups was further subdivided: 10 brackets were bonded without treatment, while the other 10 were sandblasted. Thus, a total of four groups were created for each type of bracket: (a) sandblasted and directly bonded, (b) sandblasted and indirectly bonded, (c) not sandblasted and directly bonded, and (d) not sandblasted and indirectly bonded. Immediately after bonding, each bracket was tested for adhesion strength, and each appliance was then examined via electron microscopy to calculate the ARI.* **Results:** *Statistical analysis showed a significant difference among the four bracket types; a general improvement in lingual appliance mechanical features provoked by sandblasting, albeit with some exceptions; and no significant effect of bonding method on the degree of bond strength. The ARI revealed that the most common area of adhesion crisis was at the adhesive-bracket interface.* **Conclusion:** *Overall, STB brackets performed better, and sandblasting proved to be an efficient way of improving the mechanical features of lingual brackets. Bonding technique, on the other hand, did not seem to exert a great influence on bonding success, and the bracket-adhesive interface was identified as the area most prone to failure.* ORTHODONTICS (CHIC) 2011;12:178–187.

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Bracket failure is a serious complication in orthodontic treatment, especially when using lingual appliances.[1,2] High bond strength is desirable and an essential requirement for successful lingual orthodontics.[2]

Bracket loss is greatly influenced by the orthodontic material employed, but proper clinical procedure may be an even more crucial factor. Indeed, successful bonding requires clean and neat tooth surfaces, and the area involved must be strictly isolated, maintaining good surveillance of both tongue and saliva to avoid accidental contamination.[3] Another relevant procedural aspect affecting the success of orthodontic treatment is bracket positioning, especially if the lingual side is involved. Indeed, the morphology of lingual surfaces is highly variable and differs greatly from its labial counterpart. Thus, even small changes in bracket position could induce strong shifts in dental movements. This is the main reason why many authors[1,3] emphasize the extreme significance of precise positioning. Unfortunately, direct bonding easily leads to inaccurate adhesion due to the inherent difficulties in lingual bracket visibility and positioning, often resulting in treatment failure. In contrast, indirect bonding is a more accurate means of bracket positioning and has thus been accepted as standard in lingual orthodontics.[1,3] Indirect bonding does entail longer laboratory preparation times, but this is largely counterbalanced by simpler and faster chairside bonding. Bracket loss is therefore a less complex issue since it can easily be managed in the dental clinic.

When loss occurs, it is common practice to reuse the failed bracket after reconditioning its base by means of sandblasting,[4] which permits complete and damage-free removal of residual adhesive. Interestingly, sandblasting yields adhesion values comparable to or even higher than those offered by a new bracket,[5] and many studies[6,7] have described this increase in adhesive forces to the generation of a microretentive topography, giving a larger contact surface area on the bracket base.

The aim of the present study was to compare four different brands of lingual brackets by focusing on their adhesive potential, the mechanics implied in their adhesive failure, and their influence on enamel after debonding. To better understand the causes of the observed results, two of many factors were chosen as functional variables due to their clinical relevance: adhesive base conditioning means (with or without sandblasting) and bonding technique (direct or indirect).

Fig 1a Tooth-base assembly.

Fig 1b Items needed for indirect bonding.

METHODS

One hundred sixty human premolars, extracted for orthodontic or restorative reasons, were selected and stored in distilled water at 37°C. Tooth selection criteria were as follows:

- Complete tooth soundness (absence of dental caries, cracks, or pigmentation)
- No previous orthodontic treatment
- No previous lingual or vestibular restorative treatment
- No previous endodontic therapy
- Lack of both plaque and calculus

Each premolar was cut horizontally using a low-speed refrigerated carborundum disk to isolate the crowns from the roots and then vertically to separate the lingual and the labial sides. The former were then inserted into numbered cylindric silicon test tubes (thermal gun and thermoplastic silicon bars). The enamel was then subjected to prophylactic cleaning treatment and polished with a curette (no. 11/12, Hu-Friedy), rubber cups (Microdont), and low-velocity irrigated pumice paste for 10 seconds (Kavo Dental), after which it was cleaned and dried for another 10 seconds.

The lingual brackets evaluated in the present study are sold under the names STB (0.18-inch slot, Ormco), ORG (0.18-inch, Hangzhou ORJ Medical Instrument & Material), Stealth (0.18-inch, American Orthodontics), and Magic (0.020-inch, Dentaurum). All these brackets are made of stainless steel, and, except for Magic, which is laser etched, all feature a single-mesh base. Forty brackets of each type were tested: 20 of each type bonded directly, while the remainder were applied indirectly (Figs 1a and 1b). Each of these groups was then subdivided to evaluate the influence of base conditioning on the resultant adhesive strength: 10 brackets were bonded without treatment, while the other 10 brackets were previously sandblasted using aluminium oxide particles (90 μ, 60 PSI) applied at a distance of 10 mm for 3 seconds (BIO ART).

Therefore, four study groups (Table 1) comprising 10 brackets were created for each brand as follows: *(a)* sandblasted and directly bonded (SD), *(b)* sandblasted and indirectly bonded (SI), *(c)* not sandblasted and directly bonded (NSD), and *(d)* not sandblasted and indirectly bonded (NSI).

Table 1 No. of tested brackets for each study group

	Bracket name			
	STB	ORG	Stealth	Magic
Base conditioning*				
SD	10	10	10	10
SI	10	10	10	10
NSD	10	10	10	10
NSI	10	10	10	10

*See text for explanation of acronyms.

Following prophylactic treatment and laboratory preparation of indirect bonding appliances, the following protocol[3] was employed:

- Alginate cast creation (Phase Plus, Zhermack)
- Plaster cast creation (plaster type 3) (Durguix, Protechno)
- Application of a thin insulation layer (Subident, Subiton Laboratorios), subsequently left to dry for 2 hours
- Application of the bracket onto the cast by the means of an adhesive resin (Ormco), followed by excess resin removal and halogen polymerization (Optilux 501, Ormco) for 20 seconds on all bracket sides (mesial, distal, above, and underneath)
- Preparation of resin cubes

To obtain the required adhesion, the enamel lingual surface was etched with a 37% orthophosphoric acid gel (Sci Pharm) for 30 seconds, rinsed with water, and dried for 10 seconds. After enamel conditioning, in indirect bonding cases, a primer was applied to the lingual surface and the polymerized resin. In direct bonding cases, the primer was first applied to the enamel and the sandblasted bracket. Adhesive was then applied to the bracket and polymerized for 20 seconds.

Once adhesion was complete, each tooth was stored in a numbered test tube containing distilled water for 24 hours at 37°C prior to the adhesion strength test. The tensile strength test was carried out using a mechanical traction machine (Instrom 1011, Cantom) with a crosshead speed set at 1 mm/min. The applied traction force direction was kept strictly perpendicular to the bracket with respect to its adhesive-enamel interface.

Immediately after the tensile test, every bracket, together with the respective dental element, was thoroughly examined under an electron microscope at 10× magnification (scanning electron microscope [SEM], Zeiss Evo 40, Carl Zeiss). This permitted evaluation and classification of the residual adhesive on the dental surface according to an Adhesive Remnant Index (ARI). Such an index has been used in several previous studies,[8,9] although scoring has been rather arbitrary. In the present study, the ARI was calculated according to the following coding: 0, no adhesive left on the tooth; 1, less than 50% on the tooth; 2, more than 50% on the tooth; and 3, all the adhesive on the tooth.

The ARI score was calculated to obtain a tool to classify the type of bonding crisis: bracket-adhesive or adhesive-enamel interface.

Table 2 Descriptive statistics of the tensile strength tests (in Newtons)

	SD	SI	NSD	NSI
ORG				
Mean	182.8	168.4	113.0	109.4
SD*	53.29	55.16	31.51	49.86
SEM	16.85	17.44	9.96	15.77
STB				
Mean	229.5	208.1	160.1	162.4
SD*	59.20	38.72	72.73	46.99
SEM	18.72	12.25	23.00	14.86
Magic				
Mean	166.1	181.0	121.6	112.8
SD*	11.33	56.78	51.55	54.43
SEM	3.58	17.96	16.30	17.21
Stealth				
Mean	167.0	172.7	130.0	118.3
SD*	34.85	72.15	46.34	56.90
SEM	11.02	22.82	14.65	17.99

SD*, standard deviation; SEM, standard error of mean. See text for explanation of remaining acronyms.

The overall interpretation of the observed results was assisted by statistical analysis of the tensile strength values recorded on the tested brackets. In detail, the differences in resistance observed among the different groups were studied by means of two-way analysis of variance (ANOVA), using bracket brand and the type of application (ie, the combination of bonding technique and base conditioning) as explanatory variables. Finally, the Bonferroni post hoc test was used as a further analysis.

RESULTS

The results of the shear strength test are shown in Table 2, which reports the mean values of the tensile forces that caused bracket detachment in Newtons, along with the respective standard deviations (SDs) and standard errors of the mean (SEM) to show test implementation was accurate.

The results obtained were statistically analyzed by the use of the ANOVA method, which permitted inspection of the strength of the tooth-adhesive-bracket system as a function of two relevant factors: the brand and the type of base conditioning and bonding methodology. The results of the analysis of variance are displayed in Fig 2.

Bracket brand was significant in explication of variance to a degree of 10.47% ($P < .0001$), and a difference in the performance of the four product types was observed (Table 3). However, the combination of bonding method and base conditioning type showed an even greater involvement in determining the variability of the recorded strengths over the four groups, succeeding in explaining a statistically significant 21.88% of the observed variance ($P < .0001$).

Nevertheless, the statistical analysis clearly demonstrated a negligible influence of bonding system on adhesive performance. The statistical significance of the differences observed in the strength values shown by direct or indirect techniques was insignificant, regardless of the manufacturer ($P > .05$, Table 4).

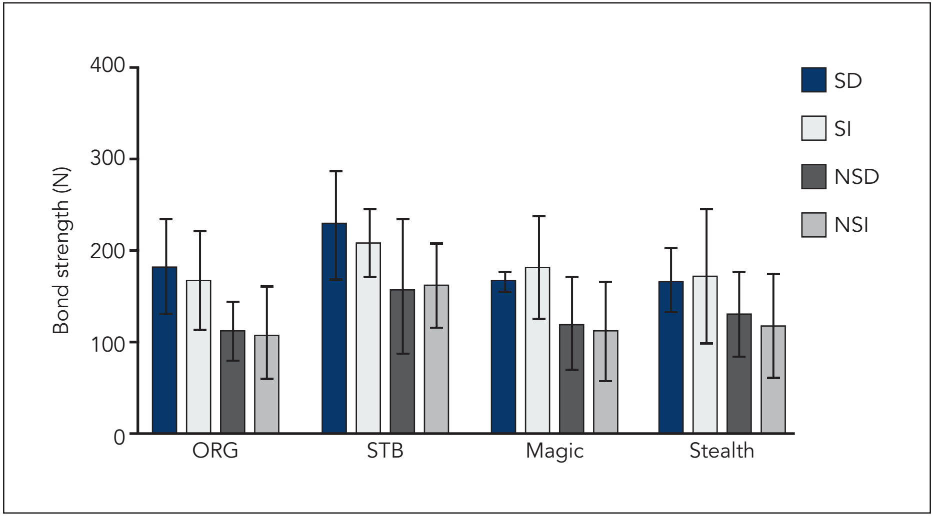

Fig 2 ANOVA results. Mean strength values and standard deviations.

Table 3 Results of the two-way ANOVA

Source of variation	% total variation	*P* value
A) Methodology	21.88	< .0001
B) Manufacturer	10.47	< .0001
Interaction between A and B	1.15	.9798

Table 4 Results of the Bonferroni post hoc tests

Manufacturer	Difference of the means	Student *t* test	*P* value	Summary
Sandblasted bases: Direct vs indirect bonding				
ORG	–14.47	.6268	> .05	NS
STB	–21.38	.9261	> .05	NS
Magic	14.87	.6441	> .05	NS
Stealth	5.61	.2430	> .05	NS
Nonsandblasted bases: Direct vs indirect bonding				
ORG	–3.53	.1528	> .05	NS
STB	2.34	.1012	> .05	NS
Magic	–8.73	.3779	> .05	NS
Stealth	–11.64	.5040	> .05	NS

NS, not significant.

On a qualitative basis, however, it can be noted that not all the bracket brands gave the same performance with respect to bonding technique. Stealth and Magic seemed to be more effective with indirect bonding when base sandblasting was performed, while the opposite pattern was found when no sandblasting was employed. ORG devices consistently gave better results when directly bonded, whereas STB appliances offered stronger resistance when directly bonded on sandblasted bases or indirectly bonded if no sandblasting had been carried out.

Table 5 Descriptive statistics of the ARI

	SD	SI	NSD	NSI
ORG				
Mean	2.6	2.6	2.9	2.8
SD*	0.52	0.52	0.32	0.42
SEM	0.16	0.16	0.10	0.13
STB				
Mean	2.7	2.6	2.9	2.8
SD*	0.48	0.52	0.32	0.42
SEM	0.15	0.16	0.10	0.13
Magic				
Mean	2.5	2.6	2.8	2.7
SD*	0.53	0.52	0.42	0.48
SEM	0.17	0.16	0.13	0.15
Stealth				
Mean	2.6	2.7	2.7	2.6
SD*	0.52	0.48	0.50	0.52
SEM	0.16	0.15	0.17	0.16

SD*, standard deviation; SEM, standard error of mean. See text for explanation of remaining acronyms.

> *“. . . the statistical analysis clearly demonstrated a negligible influence of bonding system on adhesive performance.”*

Following tensile tests, each sample was scored according to the ARI to analyze the failure patterns of the adhesive system. In no case was the ARI value smaller than 2, meaning that the amount of adhesive remaining on the tooth was consistently greater than 50%. As shown in Table 5, the mean of ARI for each group ranged between 2.5 and 2.9, regardless of the bracket brand or type of conditioning and bonding technique used. A marked tendency for failure in the bracket-adhesive interface was noted.

Figure 3 plots the values reported in Table 5, and the scarce variability in the ARI means for the four groups is evident. Differences in bracket performance were not appreciable, except for in type of base conditioning, bonding technique, and manufacturer brand. Visual inspection of the graph alone might suggest a dependence of the ARI value on the presence or absence of base sandblasting, but given the standard deviation of the data, together with the small range of variability of the ARI itself, such a conclusion cannot be drawn.

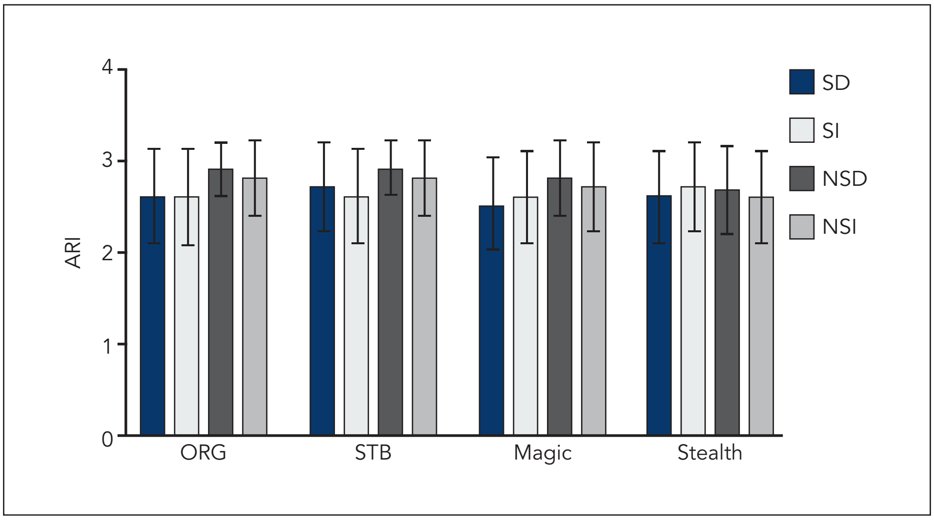

Fig 3 Mean ARI values of the four groups, with observed standard deviations.

DISCUSSION

The scientific literature has thoroughly documented the importance and main features of adhesion between brackets and enamel surface. Sorel et al[8] investigated the dependency of adhesive forces on the type of bracket base, determining the effects on the adhesive failure area and enamel behavior after debonding. Bishara et al[9] and Wang et al[10] conducted research aimed at explaining the relevance of bracket base mesh type in determining the entity of the forces that the adhesive system can produce. Knox et al,[11] on the other hand, also analyzed the type of resin used to join the orthodontic appliances to the dental surface.

The experimental research carried out in the present study focused on evaluation of the adhesive performance of lingual brackets as opposed to determination of any peculiarity with respect to common labial appliances.[12] The objective was to emphasize the dependency of the adhesive performance on factors such as base conditioning procedures and bonding techniques. While a comparison between labial and lingual appliances would be of great interest, the technical performance of lingual brackets is as of yet fairly undocumented. Therefore, it seems appropriate to further investigate lingual devices, postponing comparative studies until a later date.

Four different commercial bracket types (ORG, STB, Magic, and Stealth) were tested. The bond strength tests demonstrated that sandblasting is a key factor in determining bracket adhesive resistance to traction forces. Analysis of directly bonded ORG brackets, for example, showed sandblasted brackets experienced crisis when mean traction force reached 182.8 ± 53.29 N (mean ± SD), a significantly better performance than nonsandblasted brackets, which on average reached adhesive crisis at forces equal to 113.0 ± 31.51 N. Similarly, when indirect bonding was taken into account, the resistance offered by sandblasted and normal ORG brackets was 168.4 ± 55.16 and 109.4 ± 49.86 N, respectively. On average, sandblasting yielded an increase in adhesion capacity of 69.8 N for directly bonded and 59.0 N for indirectly bonded brackets, with a mean overall increase of 64.4 N. The same pattern could be found for all the other bracket brands, with a mean increase of 57.6, 56.3, and 45.7 N for STB, Magic, and Stealth brackets, respectively. It should be noted, however, that the increase in strength observed for the Magic and Stealth brackets did not prove significant in statistical terms ($P > .05$), possibly due to the magnitude of the variance of the recorded data.

These results consistently agree with those cited in other scientific studies[5,13] and can be explained by the fact that the sandblasting process creates an increase in adhesive microretention on the bracket base, since the contact area is enlarged by this treatment. As a consequence, a greater force is needed to break the bond established between the orthodontic device and adhesive resin.

Concerning bonding technique, the superiority of indirect over direct bonding with regard to better lingual bracket placement has been well documented.[1,3] Hence, this study was aimed at an in-depth investigation of the hypothesis that the choice of method could influence the degree of adhesive resistance. However, our findings indicate that bonding technique does not seem to be a decisive factor in terms of adhesion. In fact, the observed differences in resistance never reached statistical significance and may have been due to sampling variability. However, the plot of the mean resistances did evidence qualitative differences among the bracket brands used. Figure 1 shows that direct bonding gave higher resistances when ORG and STB devices were used, while indirectly bonded Magic and Stealth appliances seemed to perform better. Nevertheless, the bonding methodology did lead to significant differences in performance. This result might have been caused by the fact that the test was carried out in vitro, thus eliminating many environmental (presence of saliva) and methodologic interferences. It was not possible to choose an in vivo methodology, as the mechanical tests necessary to ascertain the performance of the lingual brackets clearly needed to be performed outside the oral environment. Furthermore, it should be emphasized that the clinical performance of the studied lingual devices could not be evaluated in vivo by these means, although this was beyond the scope of the current study, whose main focus was a technical examination of specific appliances.

The results discussed above were observed in all of the four commercial brands tested. This means the conclusions are valid, as they apply to different types of devices. Nonetheless, the manufacturer proved to be a significant factor in explaining the variation of the recorded results. Indeed, as can be seen in Fig 1, while the pattern of behavior as a function of base conditioning and bonding technique was fundamentally the same for the four brands, STB brackets did tend to offer higher adhesive strength values. This result might be explained in terms of differences in base design, which could play a role in determining the entity and distribution of the tensions consequent to the applied traction forces, and the type of mesh used to make the base. A better understanding would be obtained by carrying out further tests, which are beyond the scope of this study.

After determining bond strength, the brackets were examined to describe the breakage behavior of the tooth-resin-bracket system. Consequently, following a widely accepted methodology, an ARI was calculated, allowing definition of a scoring system for quantification of adhesive remnants on the tooth or bracket surface after debonding, thus establishing the most frequent location of bonding crisis. No great variation in ARI was seen: All brackets studied had an index of 2 or 3, meaning that more than 50% or 90%, respectively, of the adhesive was found on the tooth surface. This demonstrates that the failure area was mostly confined to the bracket-resin interface, thereby confirming the results of other authors.[8,9,14]

CONCLUSION

The observed results seem to show that STB brackets performed better overall and displayed higher adhesive bond strengths compared to the other brackets. Furthermore, sandblasting was found to be an efficient method of improving the mechanical features of the base by increasing its adhesion capacity. However, it was observed that when the tooth-adhesive-bracket system led to mechanical crisis, the failure zone mainly tended to be the bracket-adhesive interface.

REFERENCES

1. Wiechmann D. Lingual orthodontics (part 1): Laboratory procedure. J Orofac Orthop 1999;60:371–379.
2. Wiechmann D. Lingual orthodontics (part 3): Intraoral sandblasting and indirect bonding. J Orofac Orthop 2000;61:280–291.
3. Scuzzo G, Takemoto K. Invisible Orthodontics. Current Concepts and Solutions in Lingual Orthodontics. Chicago: Quintessence, 2002:15–17.
4. Ozer M, Arici S. Sandblasted metal brackets bonded with resin-modified glass ionomer cement in vivo. Angle Orthod 2005;75:406–409.
5. Sharma Sayal SK, Rossouw PE, Kulkarni GV, Titley KC. The influence of orthodontic bracket base design on shear bond strength. Am J Orthod Dentofacial Orthop 2003;124:74–82.
6. Guan G, Takano-Yamamoto T, Miyamoto M, et al. An approach to enhance the interface adhesion between an orthodontic plastic bracket and adhesive. Eur J Orthod 2001;23:425–432.
7. Kern M, Thompson VP. Sandblasting and silica-coating of dental alloys: Volume loss, morphology, and changes in the surface composition. Dent Mater 1993; 9:151–161.
8. Sorel O, El Alam R, Chagneau F, Cathelineau G. Comparison of bond strength between simple foil mesh and laser-structured base retention brackets. Am J Orthod Dentofacial Orthop 2002;122:260–266.
9. Bishara SE, Soliman MMA, Oonsombat C, Laffoon JF, Ajlouni R. The effect of variation in mesh-base design on the shear bond strength of orthodontic brackets. Angle Orthod 2004;74:400–404.
10. Wang WN, Li CH, Chou TH, Wang DD, Lin LH, Lin CT. Bond strength of various bracket base designs. Am J Orthod Dentofacial Orthop 2004;125:65–70.
11. Knox J, Hubsch P, Jones ML, Middleton J. The influence of bracket base design on the strength of the bracket-cement interface. J Orthod 2000;27:249–254.
12. Wang WN, Tarng TH, Chen YY. Comparison of bond strength between lingual and buccal surfaces on young premolars. Am J Orthod Dentofacial Orthop 1993;104: 251–253.
13. Faltermeier A, Behr M. Effect of bracket base conditioning. Am J Orthod Dentofacial Orthop 2009;135:12.e1–e5.
14. Algera TJ, Kleverlaan CJ, Prahl-Andersen B, Feilzer AJ. The influence of different bracket base surfaces on tensile and shear bond strength. Eur J Orthod 2008;30:490–494.