A. Scribante, M. F. Sfondrini, D. Fraticelli, M. Malfatto, P. Gandini

Unit of Orthodontics and Paediatric Dentistry, Section of Dentistry, Department of Clinical, Surgical, Diagnostic and Paediatric Sciences, University of Pavia, Pavia, Italy

email: andrea.scribante@unipv.it

DOI: 10.23804/ejpd.2017.18.03.04

Adhesive systems for CAD-CAM customised lingual orthodontic brackets: which one is better?

ABSTRACT

Aim *Aesthetic orthodontic treatment demand is constantly increasing also for patients in adolescent age. New orthodontic protocols with CAD-CAM customised bracket bases have been introduced for lingual orthodontic therapy. The aim of the present study was to compare the shear bond strength (SBS) and Adhesive Remnant Index (ARI) scores of customised lingual brackets bonded with different adhesive systems.*

Materials and methods *Study design: Customised CAD-CAM lingual bracket bases were tested for shear bond strength and adhesive remnant index scores using three different adhesive systems.*

Sixty human permanent premolars were extracted for orthodontic reasons and embedded in resin blocks. Customised CAD-CAM lingual bracket bases were prepared and bonded using a pre-mix chemical cure adhesive (Transbond IDB), a chemical cure adhesive system (Maximum Cure) and a dual-cure self-adhesive resin cement (RelyX Unicem 2). All samples were tested in shear mode on a Universal Testing Machine. SBS and ARI scores were calculated. Statistics: Statistical analysis included ANOVA and Tukey tests for SBS and Chi squared for ARI Scores.

Results *Dual-cure self-adhesive resin cement showed significantly higher SBS values than pre-mix chemical cure adhesive and chemical cure adhesive system that showed no significant difference between them. No significant differences in ARI Scores were found among various groups.*

Conclusions *Dual-cure self-adhesive resin cement (RelyX Unicem 2) provides higher SBS values than pre-mix chemical cure adhesive (Transbond IDB) or chemical cure adhesive (Maximum Cure) and can be recommended to obtain higher adhesion performances of CAD-CAM lingual brackets.*

Keywords *Adhesive; Bond strength; CAD-CAM; Customised; Lingual bracket; Orthodontics.*

Introduction

The request for orthodontic treatment is constantly increasing in both adult and paediatric patients [Giannattasio et al, 2015]. Lingual orthodontics has been introduced for its high aesthetics compared with conventional vestibular orthodontic technique. In fact it allows treatment with a fixed orthodontic appliance without being visible on the facial, exterior aspect of the teeth. Lingual appliances have been developed in response to increasing interest of adult and paediatric patients in recent years. In orthodontic multibracket fixed therapy, bond failure is a common complication [Vicente et al., 2004]. This is a serious concern especially when using lingual appliances [Lombardo et al., 2011]. Bond failure can influence chair time, treatment duration, and total costs [Ziebura et al., 2014]. Shear bond strength (SBS) can be modified by bracket base design [Scribante et al., 2013], adhesive system used [Attar et al., 2007] and unwanted water [Sfondrini et al., 2013], saliva [Brauchli et al., 2010] or blood [Prasad et al., 2014] contamination before bonding. Also, adhesive remnant index (ARI) score is an important factor to be considered in the selection of orthodontic adhesive, as less adhesive remnant on the tooth has been advocated for easier and safer removal of residual resin after debonding [Montasser and Drummond, 2009].

SBS and ARI Scores of conventional [Bahnasi et al., 2013], self ligating [Sfondrini et al., 2011, aesthetic [Iijima et al., 2010] buccal brackets has been widely investigated, and some studies have been conducted also for conventional lingual brackets [Lombardo et al., 2011]. However, because of the wide variation in the morphology of the lingual surface, the fabrication of an individualised custom base for each lingual bracket has been proposed to increase treatment precision and minimize wire bending [Sung et al., 2013]. Recently, various computer technologies have been applied and tested. A new protocol with CAD-CAM customised bracket bases has been introduced for

lingual orthodontic therapy [Knösel et al., 2014]. These customised lingual brackets with an extended base area are manufactured by gold alloy casting based on computer-aided design using the 3D scanned data of a tooth model.

In the literature only one study tested these new customised brackets, investigating SBS using a single orthodontic adhesive system [Sung et al., 2013]. To the best of our knowledge there is no report that evaluated SBS of Incognito customised lingual brackets testing different adhesive systems.

Accordingly, the purpose of the present investigation was to measure and compare the SBS and adhesive remnant index (ARI) scores of CAD-CAM customised brackets with three different adhesive systems. The null hypothesis of the study was that there are no significant differences in SBS values and debond locations among the various groups.

Materials and methods

The present study was approved by the Unit Institutional Committee Board. The research was conducted in full accordance with the World Medical Association Declaration of Helsinki. Authors obtained written consent from all participants involved in the study. The consent was written and approved by the Unit Institutional Committee Board.

Sixty freshly human permanent premolars extracted for orthodontic reasons were collected and stored in a solution of 0.1 % (wt/vol) thymol. The criteria for tooth selection included intact buccal enamel with no cracks caused by extraction and no caries [Abu Alhaija et al., 2012]. The teeth were cleansed of soft tissue and randomly divided into three groups of 20 specimens each according to the three different adhesives tested. The teeth were aligned and inserted in alginate impressions were taken to construct working models, which allowed the teeth to be embedded in cold-curing resin (ProBase Cold, Ivoclar Vivadent, Schaan, Liechtenstein). The working models were sent to the laboratories for the fabrication of Incognito customised lingual brackets (TOP-Service für Lingualtechnik GmbH, 3M company, Bad Essen, Germany). These brackets were produced with CAD-CAM customised bases, which were manufactured by gold alloy casting based on computer-aided design using the 3D scanned data of a tooth model. As shown in Figure 1, during production, bracket slot and wings were replaced with a cylindrical pylon in order to standardise debonding procedure and shear force application.

Subsequently the specimens were placed into transfer trays to facilitate bonding procedure. Brackets were divided into three groups (n=20 each) and bonded with three different adhesive systems (Group 1 Transbond IDB; 3M Unitek, Monrovia, California, USA; Group 2, Maximum Cure, Reliance Orthodontic Products, Itasca, Illinois, USA; Group 3: RelyX Unicem 2 Automix; 3M Unitek, Monrovia, California, USA) bonded according to manufacturers' instructions.

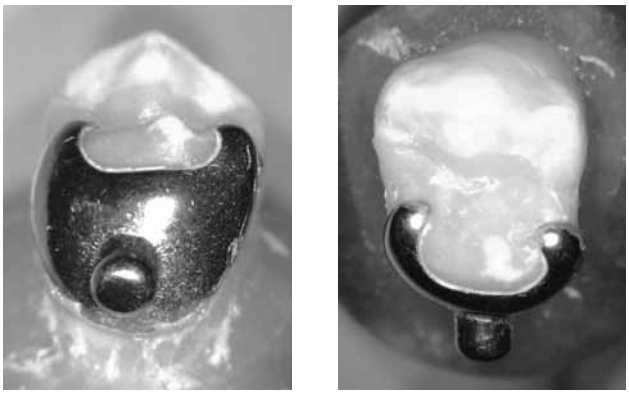


FIG. 1 Customised lingual bracket base modified for shear testing.

For all the groups, before bonding, the labial surface of each incisor was cleaned for 10 seconds with a mixture of water and fluoride-free pumice in a rubber polishing cup with a slow-speed handpiece. The enamel surface was rinsed with water to remove pumice or debris and then dried with an oil-free air stream. The teeth were sandblasted (27 µm aluminium oxide powder) and then etched with 37% phosphoric acid gel (Orthophosphoric acid gel, 3M Unitek, Monrovia, California, USA) for 30 seconds, followed by thorough washing and drying.

In Groups 1 (Transbond IDB) and 2 (Maximum Cure) self-curing adhesive systems were applied both onto bracket bases and to tooth surfaces. The transfer trays with the brackets were then seated on teeth with firm pressure for three minutes. Subsequently transfer trays were removed.

In Group 3 (RelyX Unicem 2) dual curing adhesive system was applied onto bracket bases. The transfer trays with the brackets were then seated on teeth and each specimen was light cured (Ortholux XT, 3M Unitek, Monrovia, California, USA) for 10 seconds from the mesial and distal side (total curing time: 20 seconds). Subsequently transfer trays were removed.

After bonding, all samples were stored in distilled water at room temperature for 24 hours and then tested in a shear mode on a Universal Testing Machine (Model 3343, Instron Industrial Products, Grove City, PA USA). The specimens were secured in the lower jaw of the machine so that the bonded bracket base was parallel to the shear force direction.

The specimens were stressed in an occlusogingival direction at a crosshead speed of 1 mm per minute, as in previous studies [Sung et al., 2013; Abu Alhaija et al., 2013]. The maximum load necessary to debond or initiate bracket fracture was recorded in newtons and

Group	Adhesive system	Product	n	Mean	SD	Min	Mdn	Max	Tukey*
1	Dual-cure self-adhesive resin cement	Transbond IDB	20	114,44 (3.53)	31,74 (0.96)	67,70 (2.37)	101,98 (3.42)	189,35 (6.06)	A
2	Pre-mix chemical cure adhesive	Maximum Cure	20	94,74 (3.05)	28,69 (0.64)	48,67 (1.95)	89,69 (3.12)	159,83 (4.31)	A
3	Chemical cure adhesive	RelyX Unicem 2	20	290,41 (9.52)	133,99 (5.14)	87,28 (3.51)	330,88 (9.53)	592,68 (26.94)	B
*: Tukey grouping. Means with the same letters are not significantly different.									

TABLE 1 Descriptive statistics of shear bond strength of the three groups tested measured in newtons (megapascal).

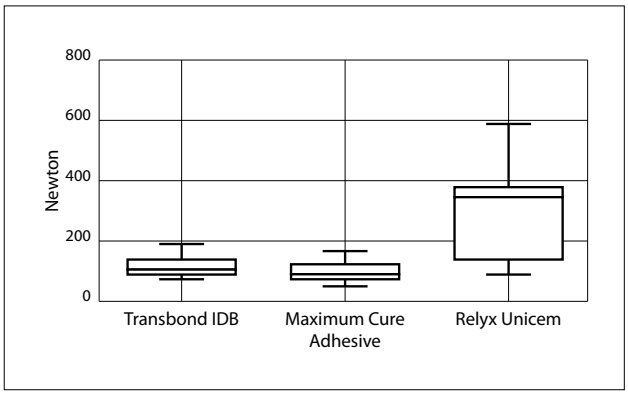


FIG. 2 Box plot of shear bond strength (MPa) of the different groups.

Groups	Adhesive system	n	ARI=0	ARI=1	ARI=2	ARI=3	EF*
1	Transbond IDB	20	0	17	0	0	3
2	Maximum Cure	20	0	15	4	0	1
3	RelyX Unicem 2	20	2	12	0	0	6
*: EF - Enamel Fracture.							

TABLE 2 Frequency of distribution of Adhesive Remnant Index scores (%).

then converted into megapascals as a ratio of newtons to surface area of the bracket [Sfondrini et al., 2013]. After bond failure, the bracket bases and the enamel surfaces were examined under an optical microscope (Stereomicroscope SR, Zeiss, Oberkochen, Germany) at 20 x magnification. The ARI was used to assess the amount of adhesive left on the enamel surface [Liu et al., 2014]. This scale ranges from 0 to 3. A score of 0 indicates no adhesive remaining on the tooth; 1 indicates less than half of the adhesive remaining on the tooth; 2 indicates more than half of the adhesive remaining on the tooth; and 3 indicates all adhesive remaining on the tooth with a distinctive mesh imprint remaining. The ARI scores were used as a more complex method of defining bond failure site among the enamel, the adhesive, and the bracket base.

Statistical analysis was performed with R Software (R version 3.1.3, R Development Core Team, R Foundation for Statistical Computing, Wien, Austria). Descriptive statistics, including the mean, standard deviation, median, and minimum and maximum values were calculated for all groups.

The normality of the data was calculated using the Kolmogorov-Smirnov test. Analysis of variance (ANOVA) was applied to determine whether significant differences in debond strength values existed among the groups. Tukey's test was used as post-hoc. The chi-square test was used to determine significant differences in the ARI scores among the different groups. Unpaired t test was pairwise applied to assess significant differences in fracture scores frequency among various groups.

Significance for all statistical tests was predetermined at $P < 0.05$.

Results

Shear bond strength values were recorded in newtons and then converted into Megapascals. Descriptive statistics are presented in Table 1. ANOVA showed the presence of significant differences among the various groups ($P < 0.0001$). Post-hoc Tukey testing showed that Groups 1 and 2 showed no significant difference in shear bond strength values between them ($P>0.05$). Both groups exhibited significantly lower shear strength values than Group 3 ($P < 0.05$) (Fig. 2).

The results of ARI scores are presented in Table 2. The chi-squared test showed a higher frequency of ARI score of "1" for all the groups tested. No significant differences were reported among various groups ($P>0.05$). When comparing fracture rates, Group 3 showed a significantly higher fracture rate than Group 2 ($P<0.05$). No significant difference in failure rate between Groups 1 and 2 was reported ($P>0.05$).

Discussion

The null hypothesis of the study was rejected. As showed in Figure 2, dual-cure self-adhesive resin cement

(Group 3 - RelyX Unicem 2) showed significantly higher shear bond strength values than pre-mix chemical cure adhesive (Group 1 - Transbond IDB) and chemical cure adhesive (Group 2 - Maximum Cure). This is probably due to the different composition of the three adhesive systems tested. In fact during orthodontic treatment, bonding between the bracket base and the enamel surface must be strong enough to withstand stresses and shear forces. Failure of the bonding technique, lack of retention of the bracket base and masticatory forces also contribute for displacement of orthodontic accessories, which creates a common problem in orthodontic clinical practice that causes disturbance, delays the treatment and increases its costs [Årtun and Bergland, 1984].

CAD-CAM customised lingual brackets have been previously tested evaluating torque expression [Tavares et al., 2006], microstructural and mechanical characterisation [Lossdörfer et al., 2014] and root control [Zinelis et al., 2013]. Only one study evaluated shear bond strength of customised lingual brackets, evaluating one single adhesive system [Sung et al. 2013] showing similar shear bond strength values.

In the present investigation three different adhesive systems were tested: pre-mix chemical cure adhesive (Group 1 - Transbond IDB), chemical cure adhesive (Group 2 - Maximum Cure) and dual-cure self-adhesive resin cement (Group 3 - RelyX Unicem 2).

Maximum Cure is a chemical cure adhesive system used for indirect orthodontic bonding. This mix adhesive, the most popular of the chemical cure systems [Lossdörfer et al., 2013], requires the mixing of two liquids (bonding resin). A thin coat of the mixed adhesive has been applied both to each custom resin base in the indirect bonding tray and to tooth surface. Previous authors showed bond strength of 180 - 220N when bonding orthodontic brackets [Cal-Neto et al., 2011].

Also Transbond IDB is a pre-mix chemical cure adhesive and its resin consists of the dimethacrylate monomers Bis-GMA and TegDMA. Transbond IDB has not been tested in literature for indirect orthodontic bonding yet.

RelyX Unicem 2 is a dual cure self-adhesive resin cement, so the acidic nature of the phosphorylated methacrylate allows for demineralisation of the tooth surface and penetration of the cement into the tooth surface. The polymerisation reaction can be begun by exposure to light or using an oxidation-reduction self-cure mechanism, and proceeds in the same way as those for composite materials. Once polymerised, micromechanical retention is achieved between the cement and the tooth [Cal-Neto et al., 2011].

Previous studies evaluated RelyX Unicem 2 for direct bonding in orthodontics [Hikita et al., 2007], indirect restorations [Correr et al., 2013], fibre post application [Lefever et al., 2012]. In literature, to our knowledge, there are no studies that evaluated RelyX Unicem 2 for indirect orthodontic bonding.

The different composition of the adhesives tested in the present investigation can partially explain the significant variation reported in shear bond strength values among the three groups. Both Maximum Cure and Transbond IDB are chemical cure adhesives, whereas RelyX Unicem 2 is a dual cure adhesive. In fact the organic matrix of this self-adhesive universal resin cement is made of multifunctional phosphoric acid methacrylate. This leads to a high degree of polymerisation and cross-linking. In addition, phosphorylated units condition the tooth structure and allow for self-adhesion [Mancebo et al., 2010].

Finally, in the present investigation ARI Scores were analysed. An ARI score of 0 means a higher adhesion of the bonding system more to the bracket base than to the tooth upon removal. This involves less time to remove adhesive from the tooth. In contrast, an ARI score of 3 indicates failure between the bracket and adhesive, with less risk of enamel fracture during the debonding process [Sung et al. 2013]. The results of the present investigation demonstrated a higher frequency of ARI score "1" for all the groups tested showing a mixed adhesion modality. Some enamel fractures were reported. These are probably due to the presence of pad wings in the occlusal part of the bracket, so the application of a vertical force can induce enamel cracks. Chemical cure adhesive (Group 3 - RelyX Unicem 2) showed a significantly higher fracture rate than pre-mix chemical cure adhesive (Group 2 – Maximum Cure). No significant difference in failure rate between pre-mix chemical cure adhesive (Group 2 – Maximum Cure) and dual-cure self-adhesive resin cement (Group 1 – Transbond IDB) was reported in the present investigation. Previous studies in literature indicated events of enamel fractures after SBS tests. Specimens fractured were reported while testing ceramic brackets [Gittneret al., 2012] or conventional brackets bonded with Bis-GMA/TEGDMA resin [Durrani et al., 2012] and dimethacrylate-based resin [Kim et al., 2015]. In the present report the dual cure adhesive (Group 3) presented significantly higher fracture rate than other chemical-cure adhesives (Groups 1 and 2). As for shear bond strength values, this could be due to the high degree of polymerisation and cross-linking of dual-cure adhesives [Lefever et al., 2012]. On the other hand other authors pointed out that the risk of enamel fracture may depend on the individual debonding procedure [31. Holberg et al., 2014]. Moreover one last factor has to be considered. In fact no studies that evaluated conventional lingual brackets reported enamel fractures [Lombardo et al., 2011] and the lack of studies with CAD-CAM customised brackets does not allow a direct comparison with previous results about this concern. However it is possible to hypothesise a relation between the presence of occlusal pads

(present only in CAD-CAM customised brackets and not in conventional lingual brackets) and the increased enamel fracture risk.

As the requests for lingual orthodontics is increasing in patients of all ages, future investigations are needed to conduct more tests about CAD-CAM customised brackets with different adhesive systems in order to confirm the present results. Moreover also long-term clinical studies are needed to evaluate the influence of other factors affecting bond strength such as saliva, masticatory forces and blood contamination of enamel surface that could reduce final bond strength efficacy.

Conclusions

This study demonstrated that when testing CAD-CAM customised lingual brackets:

1. Dual-cure self-adhesive resin cement showed significantly higher SBS values than pre-mix chemical cure adhesive and chemical cure adhesive system, that showed no significant difference between them.

2. No significant difference in debond locations were reported among various groups.

3. Higher enamel fracture frequency has been reported with dual-cure self-adhesive resin cement.

Acknowledgements

The authors wish to thank 3M/Unitek and Reliance Orthodontic Products for providing the materials tested in this study and Dr. Carolin Wiedig for excellent scientific assistance.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Financial support

None.

References

› Abu Alhaija ES, Irshaid SM, Alwahadni AM. Shear bond strength of orthodontic brackets bonded to deciduous teeth with different etching times. Eur J Paediatr Dent 2012;13:203-8.
› Årtun J, Bergland S. Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. Am J Orthod 1984;85:333-340.
› Attar N, Taner TU, Tülümen E, Korkmaz Y. Shear bond strength of orthodontic brackets bonded using conventional vs one and two step self-etching/adhesive systems. Angle Orthod 2007;77:518-23.
› Bahnasi FI, Abd-Rahman AN, Abu-Hassan MI. Effects of recycling and bonding agent application on bond strength of stainless steel orthodontic brackets. J Clin Exp Dent 2013;5:e197-202.
› Brauchli L, Eichenberger M, Steineck M, Wichelhaus A. Influence of decontamination procedures on shear forces after contamination with blood or saliva. Am J Orthod Dentofacial Orthop 2010;138:435-41.
› Cal-Neto JP, Castro S, Moura PM, Ribeiro D, Miguel JA. Influence of enamel sandblasting prior to etching on shear bond strength of indirectly bonded lingual appliances. Angle Orthod 2011;81:149-52.
› Correr AB, Costa AR, Lucato AS, Vedovello SA, Valdrighi HC, Vedovello Filho M, Correr-Sobrinho L. Effect of activation mode on shear bond strength of metallic brackets. Braz Dent J 2013;24:513-6.
› Durrani OK, Bashir U, Arshad N. Fabrication and evaluation of Bis-GMA/TEGDMA resin with various amounts of silane-coated silica for orthodontic use. Eur J Orthod 2012;34:62-6.
› Giannattasio A, Poggi E, Migliorati M, Mondani PM, Piccardo I, Carta P, Tomarchio N, Alberti G. The efficacy of Italian guidelines in promoting oral health in children and adolescents. Eur J Paediatr Dent 2015;16:93-8.
› Gittner R, Müller-Hartwich R, Engel S, Jost-Brinkmann PG. Shear bond strength and enamel fracture behavior of ceramic brackets Fascination® and Fascination®2. J Orofac Orthop 2012;73:49-57.
› Hikita K, Van Meerbeek B, De Munck J, Ikeda T, Van Landuyt K, Maida T, Lambrechts P, Peumans M. Bonding effectiveness of adhesive luting agents to enamel and dentin. Dent Mater 2007;23:71-80.
› Holberg C, Winterhalder P, Holberg N, Wichelhaus A, Rudzki-Janson I. Orthodontic bracket debonding: risk of enamel fracture. Clin Oral Investig 2014;18:327-34.
› Iijima M, Yasuda Y, Muguruma T, Mizoguchi I. Effects of CO(2) laser debonding of a ceramic bracket on the mechanical properties of enamel. Angle Orthod 2010;80:1029-35.
› Kim YK, Park HS, Kim KH, Kwon TY. Effect of adhesive resin flexibility on enamel fracture during metal bracket debonding: an ex vivo study. Eur J Orthod 2015;37:550-5.
› Knösel M, Klang E, Helms HJ, Wiechmann D. Lingual orthodontic treatment duration: performance of two different completely customized multi-bracket appliances (Incognito and WIN) in groups with different treatment complexities. Head Face Med 2014;10:46.
› Lefever D, Gregor L, Bortolotto T, Krejci I. Supragingival relocation of subgingivally located margins for adhesive inlays/onlays with different materials. J Adhes Dent 2012;14:561-7.
› Liu D, Pow EH, Tsoi JK, Matinlinna JP. Evaluation of four surface coating treatments for resin to zirconia bonding. J Mech Behav Biomed Mater 2014;32:300-9.
› Lombardo L, Kaplan A, Lapenta R, Bratti E, Pera C, Scuzzo G, Siciliani G. A comparative study of lingual bracket bond strength. Orthodontics (Chic.) 2011;12:178-87.
› Lossdörfer S, Bieber C, Schwestka-Polly R, Wiechmann D. Analysis of the torque capacity of a completely customized lingual appliance of the next generation. Head Face Med 2014;10:4.
› Lossdörfer S, Schwestka-Polly R, Wiechmann D. Control of lower incisor inclination with a completely customized lingual appliance for dentoalveolar compensation of class III malocclusion. J Orofac Orthop 2013;74:381-96.
› Mancebo JC, Jiménez-Castellanos E, Cañadas D. Effect of tooth type and ferrule on the survival of pulpless teeth restored with fiber posts: a 3-year clinical study. Am J Dent 2010;23:351-6.
› Montasser MA, Drummond JL. Reliability of the adhesive remnant index score system with different magnifications. Angle Orthod 2009;79:773-6.
› Prasad M, Mohamed S, Nayak K, Shetty SK, Talapaneni AK. Effect of moisture, saliva, and blood contamination on the shear bond strength of brackets bonded with a conventional bonding system and self-etched bonding system. J Nat Sci Biol Med 2014;5:123-9.
› Scribante A, Sfondrini MF, Fraticelli D, Daina P, Tamagnone A, Gandini P. The influence of no-primer adhesives and anchor pylons bracket bases on shear bond strength of orthodontic brackets. Biomed Res Int. 2013;2013:315023. Epub 2013 Aug 4.
› Sfondrini MF, Fraticelli D, Gandini P, Scribante A. Shear bond strength of orthodontic brackets and disinclusion buttons: effect of water and saliva contamination. Biomed Res Int 2013;2013:180137. Epub 2013 May 15.
› Sfondrini MF, Gatti S, Scribante A. Shear bond strength of self-ligating brackets. Eur J Orthod 2011;33:71-4.
› Sung JW, Kwon TY, Kyung HM. Debonding forces of three different customized bases of a lingual bracket system. Korean J Orthod 2013;43:235-41.
› Tavares SW, Consani S, Nouer DF, Magnani MB, Nouer PR, Martins LM. Shear bond strength of new and recycled brackets to enamel. Braz Dent J. 2006;17:44-48. Epub 2006 May 2.
› Vicente A, Bravo LA, Romero M, Ortíz AJ, Canteras M. Bond strength of brackets bonded with an adhesion promoter. Br Dent J 2004;196:482-5.
› Ziebura T, Hohoff A, Flieger S, Stamm T. Accidental debondings: Buccal vs fully individualized lingual multibracket appliances. Am J Orthod Dentofacial Orthop 2014;145:649-54.
› Zinelis S, Sifakakis I, Katsaros C, Eliades T. Microstructural and mechanical characterization of contemporary lingual orthodontic brackets. Eur J Orthod 2014;36:389-93. Epub 2013 Nov 14.