eor.istanbul.edu.tr

Official Publication of Istanbul University Faculty of Dentistry

Eur Oral Res 2023; 57(2): 96-102

Original research

Comparison of the shear bond strength of new and recycled metallic brackets using different adhesive materials. An *in vitro* study

Nicole Ibarra R[1], **Mackarena Sáez**[1], **Victor Rojas**[1], **Rodrigo Oyonarte**[1]

Purpose

To evaluate and compare shear bond strength (SBS) of new and recycled metallic brackets bonded to conditioned and reconditioned enamel, using two different adhesive materials.

Material and Method

72 extracted sound human premolars were randomly divided into 6 groups. Transbond XT light cured composite (LCC) and Fuji Ortho LC resin-modified glass ionomer (RMGI), were used as adhesive materials. In groups 1 and 2 (control), new brackets were bonded to sound premolars using either LCC or RMGI, respectively. In Groups 3 and 4, new brackets were bonded to reconditioned enamel; and in groups 5 and 6, sandblasted recycled brackets were rebonded to reconditioned enamel. After 5.000 thermal cycles between 5ºC and 55ºC, SBS was evaluated and adhesive remnant on the enamel assessed using the ARI index. Statistical analyses included Shapiro-Wilk, ANOVA, Fligner-Killeen ANOVA and Tukey tests.

Results

The statistical analysis showed no significant difference in SBS comparing control and experimental groups for either new or recycled brackets ($p = 0.848$). The SBS was significantly higher in brackets bonded with LCC (15.7 MPa) than RMGI (11.6 MPa) ($p = 0.006$). Adhesive failure was the most frequent, with the adhesive remnant covering more than 50% of the bracket base.

Conclusion

No significant differences were observed in SBS using either new or recycled brackets, regardless of the dental surface treatment (conditioned or reconditioned). Significantly higher SBS values were obtained with LCC adhesive. Adhesive failure prevails in all groups.

Keywords: *Shear bond strength, Metallic brackets, Adhesive materials, Recycled brackets, Thermal cycling*

Introduction

Bracket bond failure is a frequent complication during orthodontic treatment, which can increase its duration and represents a challenge in clinical practice (1). The most popular bracket bonding systems include light-cured composite resins (Bis-GMA) (LCC) and the resin-modified glass ionomer (RMGI) (2,3).

The adhesion strength resists shear forces naturally occurring during chewing function and can be determined by the shear bond strength (SBS), which is "the amount of force required to produce a fracture at the interface of two materials, when parallel forces are applied in opposite direction" and it is measured in Mega Pascals (MPa) (2,4,5,6,7). SBS values

ORCID IDs of the authors: N.I.R. 0000-0002-4744-718X; M.S. 0000-0001-5608-2381; V.R. 0000-0001-7653-8681; R.O. 0000-0003-4517-6950

[1]*Department of Orthodontics, Faculty of Odontology, Universidad de los Andes, Santiago, Chile*

Corresponding Author: Rodrigo Oyonarte

E-mail: royonarte@miuandes.cl

Received: 17 September 2022
Revised: 24 October 2022
Accepted: 4 November 2022

DOI: 10.26650/eor.20231163180

How to cite: *Ibarra N, Sáez M, Rojas V, Oyonarte R. Comparison of the shear bond strength of new and recycled metallic brackets using different adhesive materials. An in vitro study. Eur Oral Res 2023; 57(2): 96-102.* DOI: 10.26650/eor.20231163180

between 6 and 8 MPa are considered clinically acceptable (2,5,8,9). Some studies suggest that values higher than 13-14 MPa may increase the risk of enamel fracture (4,10,11). On the other hand, lower adhesive forces may cause bracket debonding during normal functional conditions (1,4,9). Studies have reported bracket debonding rates between 4.7% and 6% for light-curing and self-curing adhesives respectively in a 6-month treatment period (12,13).

Bracket bond failure can increase both treatment time and costs. To solve this, clinicians must replace the debonded bracket. They usually choose between rebonding with a new bracket or carry on with the same debonded bracket after recycling (4,14). In both cases, the adhesive remnant should be removed from the enamel surface and a new adhesive protocol should be performed. This procedure would not affect the SBS using LCC, but evidence is inconclusive with RMGI in this regard (15,16). Bracket recycling consists of removing the adhesive material from the bracket base, allowing rebonding in optimal conditions (17).

In *in-vitro* settings, thermocycling allows an approximation to oral conditions by simulating the permanence of orthodontic adhesive in mouth for extended periods of time (18). The results regarding SBS using new and recycled metallic brackets are still controversial, especially if different adhesive systems are used (14). The present study was conducted in order to test the null hypothesis that there were no statistically significant differences in SBS between new and recycled metallic brackets bonded with light-cured composite resin (LCC) or resin-modified glass ionomer (RMGI) before and after a thermocycling process.

Materials and Methods

Ethical statement

The present study was approved by the Scientific Ethical Committee of Universidad de los Andes, Santiago, Chile.

Sample size estimation

The sample size calculation was carried out considering a 3x2 factorial design and was calculated with the G*Power 3.1 program, aiming at a statistical power of 80%, and an alpha level of 5%. The sample size for each group was 12 teeth, with a total of 72 teeth.

Study samples and experimental design

This *in-vitro* study was performed using human premolars extracted due to orthodontic reasons. The selection criteria for the teeth included: sound enamel without cracks or fractures, hypoplastic areas, chemical pretreatments or damage during extraction. The extracted teeth were stored in tap water at room temperature (20ºC to 25ºC), which was renewed once a week. Teeth were randomly divided into 6 groups. Group 1 (control): New bracket bonded with light-cured composite resin, Transbond XT (LCC) to conditioned enamel; Group 2 (control): New bracket bonded with resin-modified glass ionomer, Fuji Ortho LC (RMGI) to conditioned enamel; Group 3: Rebonding with a new bracket using LCC to reconditioned enamel; Group 4: Rebonding with a new bracket using RMGI to reconditioned enamel; Group 5: Rebonding with a recycled bracket using LCC to reconditioned enamel; Group 6: Rebonding with a recycled bracket using RMGI to reconditioned enamel.

Bonding protocol

Orthodontic stainless-steel brackets (Abzil Kirium, slot 0.022, MBT prescription with mesh-base size 80G, 3M, Brazil) were bonded to the teeth following a standardized protocol. Each tooth was cleaned using low speed brush and pumice stone, and then dried with oil- and moisture- free air. Brackets were bonded by one calibrated operator (NI), in the center of the buccal surface of each tooth following the longitudinal axis of the crown, either with LCC or RMGI.

For groups 1, 3 and 5 brackets were bonded with Transbond XT light-curing resin (3M Unitek, Monrovia, CA, USA). The procedure included acid etching with a 37% orthophosphoric acid gel (3M Espe Scotchbond Universal Etchant, Seefeld, Germany) for 30 seconds, followed by rinsing with water spray for 30 seconds, and drying for 15 seconds with oil-free compressed air. Adhesive primer (Transbond XT, 3M Unitek, Monrovia, Ca, USA) was then applied with a microbrush and light cured, and then the brackets were bonded with composite resin. Excess resin was removed with a Hollenbeck carver (Hu-Friedy, Chicago IL, USA). Light curing was performed with a 470 nm LED light (Bluephase Style, Ivoclar Vivadent) at 1,100 mW/cm2 for 20 seconds.

For groups 2, 4 and 6 brackets were bonded with dual polymerization resin-modified glass ionomer Fuji Ortho LC (GC, Tokyo, Japan). The enamel was etched with the same 37% orthophosphoric acid (3M Espe Scotchbond Universal Etchant, Seefeld, Germany) for 30 seconds, and rinsed with water keeping the surface moist, according to the manufacturer´s recommendations. Excessive RMGI material was removed with a Hollenbeck Carver. Light curing was performed according to the manufacturer´s instructions with the same light source as previously described for 40 seconds, 10 seconds per side of the bracket.

Thermocycling

24 hours after bonding, all groups were subjected to thermocycling between 5ºC and 55ºC for 5.000 cycles, simulating a 6 to 8 months intraoral natural aging process. The time of permanence at each temperature level was 30 seconds with 10 seconds of a transfer time between baths.

Bracket rebonding

After thermocycling, all brackets from the experimental groups were debonded with bracket removal pliers (Dentamax, Santiago, Chile). The enamel in groups 3, 4, 5 and 6 was reconditioned using a tungsten carbide bur with a low-speed hand piece (Jota C21R Right Angle 012, US-No. 1158, Switzerland) and followed by the same bonding protocol as in the first bond.

For groups 3 and 4, the debonded brackets were discarded and new brackets were bonded. For groups 5 and 6, the debonded brackets were reconditioned by sandblasting with 50 µm aluminum oxide particles powder (Zeta Sand, Zhermack, Germany) from a distance of 10 mm, under an air pressure of 5 bar, for 10 seconds or until no adhesive remained at the base of the bracket. Finally, the brackets were cleaned with acetone and dried with oil-free air. All the samples corresponding to the rebonding groups (3, 4, 5 and 6) were thermocycled again.

Shear bond strength test

The teeth were mounted in self-curing acrylic blocks (Marché®, Santiago, Chile) approximately 30 mm in diameter and 10 mm in height. Shear force was applied parallel to the bonding surface between the bracket base and enamel. A Bisco machine (Shear Bond Tester, Bisco Dental, Schaumburg, Illinois, USA) was used to determine the shear bond strength at a speed of 5 mm/min. Results were expressed in Mega Pascals (MPa). The SBS test was performed within 24 hours after the samples were removed from the thermocycling.

Bracket and enamel surface analysis

Bracket and enamel surface were examined using an optical microscope with 2.5x magnification (Leica Micosystems, Wetzlar, Germany) and photographed with a Canon DSLR 700D reflex camera attached to the microscope. The presence of enamel damage and adhesive remnant on the bracket base were recorded. The adhesive remnant was calculated as the area of the adhesive in relation to the area of the bracket base, using a morphometric Software (AmScope v3.7.13522, United Scope LLC, Irvine, CA, USA). (Figure 1). The area of adhesive remnant on the bracket base was expressed as a percentage of the total surface area, in each group, and the Adhesive Remnant Index (ARI) scale ranges from 0 to 3 was stablished (19) (Table 1).

Statistical analysis

Shapiro-Wilk test was applied to test the data for normality. The SBS data did not show a normal distribution, therefore the non-parametric Fligner-Killeen ANOVA test was used. The data on the amount of adhesive remnant was normally distributed and the ANOVA test was applied. Tukey post-hoc test was performed in case of finding statistically significant differences, and the Chi-square test was applied to the enamel damage analysis. The confidence interval was set to 95% and p values less than 0.05. The statistical analysis was performed using the RStudio statistical software (Rstudio Inc., Boston, MA, USA).

Results

There was no statistically significant difference in SBS ($p=0.848$) between new brackets bonded to conditioned enamel (13.1 MPa), new brackets rebonded to reconditioned enamel (14.1 MPa) and recycled brackets rebonded to reconditioned enamel (13.7 MPa). On the other hand, SBS of brackets bonded with LCC (15.7 MPa) was significantly higher than that of brackets bonded with RMGI (11.6 MPa) ($p=0.006$). (Table 2, Figure 2 and 3)

Regarding to the percentage of adhesive remnant on the bracket base, there was no statistically significant difference between a new bracket bonded to conditioned enamel, a new bracket bonded to reconditioned enamel and a recycled bracket rebonded to reconditioned enamel ($p= 0.078$). Statistically significant differences were found for the type of adhesive. The percentage of LCC remaining on the bracket base was significantly higher ($p= 0.00014$) than when RMGI was used (Table 3).

Table 3 shows the distribution of ARI scores and the presence of enamel fractures found during the shear bond strength test. In all groups, the most common failure was of the adhesive type located at the cement-enamel interface. Enamel fractures during the shear strength test were found

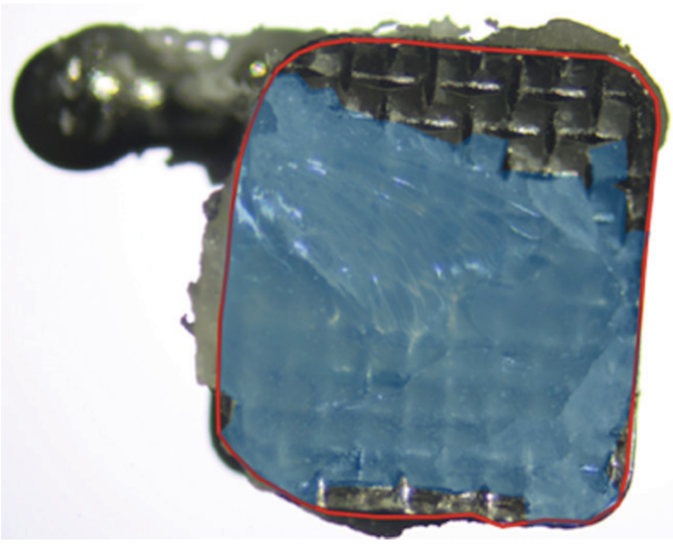

Figure 1. *Diagram of the adhesive area in relation to the bracket base.*

Table 1. *Adhesive Remnant Index score*

Score	Adhesive Remnant Index
0	0% adhesive on the enamel, 100% on the bracket. Adhesive failure
1	Less than 50% adhesive on the enamel, more than 50% on the bracket. Adhesive failure
2	More than 50% adhesive on the enamel, less than 50% on the bracket. Cohesive failure
3	100% adhesive on enamel, 0% on the bracket. Cohesive failure

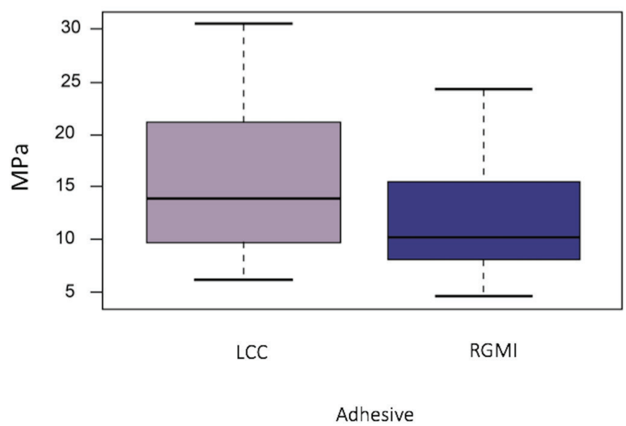

Figure 2. *Boxplot of the effect of adhesives on SBS.*

in 7 samples. Two samples belonged to group 1, one sample to group 2, three samples to group 5 and one sample to group 6 (Table 4 and Figure 4).

The Chi-square homogeneity analysis showed a homogeneous distribution among the combination of factors (type of bracket and type of adhesive), with no significant differences for the enamel fracture variable (p=0.947).

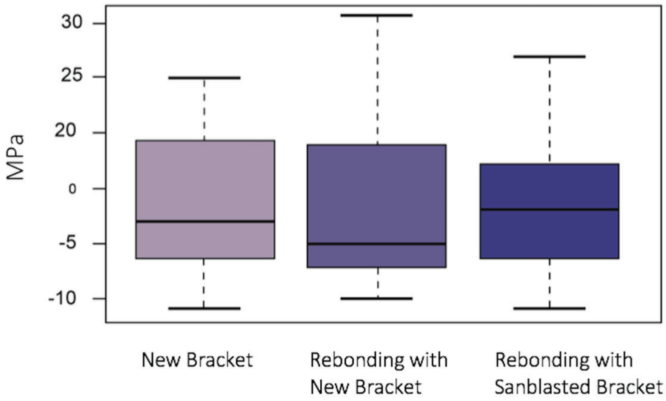

Figure 3. *Boxplot of the effect of new or recycled brackets on SBS.*

Discussion

Several authors have assessed the effects of using sandblasted recycled brackets on SBS, bonded with composite resin cement materials (17,20,21). These studies tested SBS including a thermocycling process, but the enamel was not reconditioned, as the present work did, in order to better emulate a clinical setting. Nevertheless, SBS values were similar to ours, and the mean SBS was higher than the minimum recommended for all groups.

The results of our study showed no significant difference on SBS using new or recycled brackets. Consequently, the null hypothesis of the study was accepted. Some authors reported higher SBS values with recycled brackets, which is attributed to the sandblasting process, that may increase

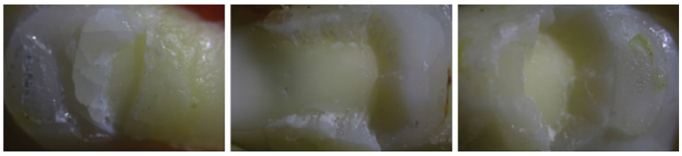

Figure 4. *Enamel fracture after SBS test.*

Table 2. *Effect of adhesives and new or recycled brackets on SBS*

Group	Adhesive	N	Mean (Mpa)	SD	Range (MPa)	*p-value*
1	LCC (Transbond XT)	36	15,7	6,7	6,1 – 30,6	0,00592
2	RMGI (Fuji Ortho LC)	36	11,6	5,3	4,5 – 24,4	
Group	**Bracket**	**N**	**Mean (Mpa)**	**SD**	**Range (Mpa)**	*p-value*
1	New Bracket	24	13,1	6,7	5,4 – 30,6	0,84803
2	Rebonding with New Bracket	24	14,1	6,5	4,5 – 26,9	
3	Rebonding with Sanblasted Bracket	24	13,7	6,2	4,5 – 24,4	

SD: Standard desviation *p-value* ≤ 0,05

Table 3. *Effect of adhesives and new or recycled brackets on the adhesive remnant in the bracket base*

Group	Bracket	N	ARI 0	ARI 1	ARI 2	ARI 3	Mean (%)	SD	Range (%)	*p-value*
1	New	24	2	22	0	0	75,7	14,4	56,1-100	0,07777
2	Rebonding with New Bracket	24	1	20	3	0	71,8	18,9	32,7 -100	
3	Rebonding with Sanblasted Bracket	24	0	19	5	0	65,2	19,6	35,8 -91,7	
Group	**Bracket**	**N**	**ARI 0**	**ARI 1**	**ARI 2**	**ARI 3**	**Mean (%)**	**SD**	**Range (%)**	*p-value*
1	LCC (Transbond XT)	36	2	32	2	0	78,6	16,3	35,2 - 100	0,00013
2	RMGI (Fuji Ortho LC)	36	1	29	6	0	63,3	16,6	32,7 - 100	

SD: Standard deviation *p-value* ≤ 0,05

Table 4. *Distribution of ARI scores and enamel fracture*

Group	Bracket	Adhesive	N	ARI 0	ARI 1	ARI 2	ARI 3	Mean Adhesive Percent (%)	SD	Range (%)	Enamel Fracture
1	New	LCC (Transbond XT)	12	2	10	0	0	82,7	13	63,1 - 100	2
2		RMGI (Fuji Ortho LC)	12	0	12	0	0	68,8	12,5	56,1 – 83	1
3	Rebonding with New Bracket	LCC (Transbond XT)	12	0	12	0	0	83,7	10,9	62,9 – 92,5	0
4		RMGI (Fuji Ortho LC)	12	1	8	3	0	59,9	17,9	32,7 – 100	0
5	Rebonding with Sanblasted Bracket	LCC (Transbond XT)	12	0	10	2	0	69,3	20,4	35,2 – 96	3
6		RMGI (Fuji Ortho LC)	12	0	9	3	0	61,1	18,7	35,8 – 91,7	1

SD: Standard deviation *p-value* ≤ 0,05

bracket bonding surface area (15,22,23). Conversely, several studies have reported a reduction in SBS in recycled brackets, but with values that are consistently higher than the minimum recommended SBS for bracket bonding (5,11,12,24). The variations between the studies could be explained by differences in the recycling procedure, instrumentation, storage solution and thermal cycling, among others. Despite subtle differences, the use of new or recycled brackets yields SBS values that are appropriate in a clinical setting (11,12,24,25).

It has been reported that enamel reconditioning could reduce SBS compared to when it is cemented to intact enamel conditioned for bracket bonding, which is attributed to the depth achieved by acid etching procedure, that does not allow the complete removal of the adhesive (12,24,25,26). In our study, however, no significant differences were observed in SBS neither at rebonding in reconditioned enamel nor using recycled or new brackets.

Our results did show significant differences in SBS between LCC and RMGI, which was lower in RMGI groups. Both groups, however, displayed SBS mean values higher than the acceptable limit. These results are consistent with previous studies reported in the literature (26-28). Both, LCC and RMGI appear to have appropriate adhesive properties for orthodontic bracket bonding, even on reconditioned enamel during a rebonding procedure, although RMGI could be more prone to failure if exposed to shear forces.

ARI index is frequently used for adhesive remnant assessment, but comparison between studies is difficult due to variations in their reporting methods (12,15,21,22). In the present study the adhesive remnant was first determined as a percentage of the area of the bracket base covered by the orthodontic cement after debonding. Then, the ARI index was established based on the afore mentioned percentage (19).

Some studies have reported higher adhesive remnant in the recycled brackets, because the sandblasted surface could increase the surface area for bonding, and thus the mechanical retention (9,10). It has also been suggested that bracket recycling has no apparent effect on ARI results when using LCC (12). In the present study no statistically significant difference was found between new or recycled brackets in reconditioned enamel on adhesive remnants. Most of the adhesive remaining on the base of the analyzed brackets covered more than 50% of the surface, suggesting that adhesion failure was at the adhesive-enamel interface in all groups. This can be clinically important because it would allow faster and easier reconditioning of the enamel surface. On the other hand, significant differences were found between the LCC and RMGI groups on adhesive remnant of the bracket, being higher in RMGI group.

A greater number of enamel fractures during bracket debonding has been described when SBS reaches values exceeding 13 Mpa (15). From the 7 samples with enamel fractures in the present study, 6 of them had SBS values higher than 13 Mpa. This suggests that enamel fractures are not exclusively related to shear strength and may be associated with individual variations in enamel structure or even bracket base design (29). Comparison of these results with other studies is especially difficult because most studies of bracket recycling did not report data of the presence or absence of enamel fractures (12,15,17,20-22,24,25).

During bracket bonding procedures, RMGI cements could be a better option in cases with high risk of caries and/or excessive salivation, because it releases fluoride and can be used in a humid environment. These aspects should be considered and contrasted with the more accessible pricing and the higher SBS achieved with LCC orthodontic cements (1). Both orthodontic cement systems provide the orthodontists with excellent bonding alternatives that can be selected according to clinical requirements.

Although the present article presents relevant information regarding the SBS of new and recycled metallic brackets bonded with different adhesive materials after a thermocycling process, this study was performed *in vitro*, using a specific experimental model. The limitations of this study are related to all the clinical variations that are relevant for the occurrence of bracket debonding and cannot be assessed *in vitro*. These clinical variations include masticatory force, interindividual behavioral, functional, anatomical, and intraoral factors, as well as variations in enamel thickness among individuals. All these factors can clinically define the tendency of a bracket to debond and could not be evaluated in our *in vitro* study. Nevertheless, the results presented in this study may be relevant for the design of *in vivo* clinical studies on this topic in the future.

Conclusion

No significant differences were found for SBS between new or recycled brackets bonded in conditioned or reconditioned enamel. SBS provided by LCC (Transbond XT) was significantly higher than that achieved using RMGI (Fuji Ortho LC). Neither enamel reconditioning nor bracket recycling presented a negative impact on SBS. On the other hand, the adhesive failure prevailed at the cement-enamel interface in LCC and RMGI groups, with the remaining adhesive material covering more than 50% of the bracket surface. The presence of enamel fractures following SBS test was not associated with any adhesive system.

Türkçe özet: *Farklı adeziv malzemeler kullanılarak yapıştırılan yeni ve geri dönüştürülmüş metalik braketlerin kesme bağ dayanımının karşılaştırılması. Bir in vitro çalışma. Amaç: Bu çalışmanın amacı yeniden işlem görmüş ve görmemiş mineye iki farklı adeziv malzeme kullanılarak yapıştırılan yeni ve geri dönüştürülmüş metalik braketlerin kesme bağlanma mukavemetini (SBS) değerlendirmek ve karşılaştırmaktır. Gereç ve Yöntem: 72 adet çekilmiş sağlam insan küçük azı dişi rastgele 6 gruba ayrıldı. Adeziv materyal olarak Transbond XT ışıkla sertleşen kompozit (LCC) ve Fuji Ortho LC reçine ile modifiye edilmiş cam iyonomer (RMGI) kullanıldı. Grup 1 ve 2'de (kontrol), sırasıyla LCC veya RMGI kullanılarak sağlam küçük azı dişlerine yeni braketler yapıştırıldı. Grup 3 ve 4'te, yeniden işlem görmüş mineye yeni braketler yapıştırıldı; ve 5. ve 6. gruplarda, kumlanmış geri dönüştürülmüş braketler, işlem görmüş mineye yeniden yapıştırıldı. 5ºC ile 55ºC arasında 5.000 termal döngüden sonra, SBS değerlendirildi ve mine üzerindeki adeziv kalıntı ARI indeksi kullanılarak değerlendirildi. İstatistiksel analizler Shapiro-Wilk, ANOVA, Fligner-Killeen ANOVA ve Tukey testlerini içermektedir. Bulgular: İstatistiksel analiz, yeni veya geri dönüştürülmüş braketler için kontrol ve deney gruplarını karşılaştıran SBS›de anlamlı bir fark göstermedi (p = 0.848). SBS, LCC (15,7 MPa) ile bağlanmış braketlerde RMGI›den (11,6 MPa) önemli ölçüde daha yüksekti (p = 0,006). Yapıştırıcı ayrılması, en sık braket tabanının %50'den fazlasını kaplayan yapışkan kalıntısı ile birlikte gözlendi. Sonuç: Mine yüzeyinin gördüğü işlemden bağımsız olarak, yeni veya geri dönüştürülmüş braketler kullanılarak SBS'de önemli bir fark gözlenmedi. LCC adeziv ile önemli ölçüde daha yüksek SBS değerleri elde edildi. Adeziv kopma tipi tüm gruplarda hakimdi. Anahtar Kelimeler: Kesme bağlanma dayanımı, metalik braketler, adeziv malzemeler, geri dönüşümlü braketler, termal döngü*

Ethics Committee Approval: The present study was approved by the Scientific Ethical Committee of Universidad de los Andes, Santiago, Chile.

Informed Consent: Participants provided informed constent.

Peer-review: Externally peer-reviewed.

Author contributions: NI, MS, VR, RO participated in designing the study. NI participated in generating the data for the study.NI, MS, RO participated in gathering the data for the study. NI, VR, RO participated in the analysis of the data. NI, MS, VR, RO wrote the majority of the original draft of the paper. NI, MS, VR, RO participated in writing the paper. NI, MS, VR, RO have had access to all of the raw data of the study. NI, MS, VR, RO have reviewed the pertinent raw data on which the results and conclusions of this study are based. NI, MS, VR, RO have approved the final version of this paper. RO guarantees that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

Conflict of Interest: The authors declared that they have no conflict of interest.

Financial Disclosure: The authors declared that they did not receive any financial support.

REFERENCES

1. Gange P. The evolution of bonding in orthodontics. Am J Orthod Dentofacial Orthop 2015; 47:56-63. [CrossRef]
2. Reicheneder CA, Gedrange T, Lange A, Baumert U, Proff P. Shear and tensile bond strength comparison of various contemporary orthodontic adhesive systems: an in-vitro study. Am J Orthod Dentofacial Orthop 2009;135:422-3. [CrossRef]
3. Ewoldsen N, Demke RS. A review of orthodontic cements and adhesives. Am J Orthod Dentofacial Orthop 2001;120:45-8. [CrossRef]
4. Gupta A, Kallury A, Sahu K. Influence of various factors affecting shear bond strength: A review. J Applied Dent Med Sci 2017;3:121-132.
5. Reynolds IR. A review of direct orthodontic bonding. Br J Orthod 1975;2:171-8. [CrossRef]
6. Bishara SE, Ostby AW. Bonding and debonding from metal to ceramic: research and its clinical application. Seminars in Orthodontics 2010;16:24–36. [CrossRef]
7. Finnema KJ, Ozcan M, Post WJ, Ren Y, Dijkstra PU. In-vitro orthodontic bond strength testing: a systematic review and meta-analysis. Am J Orthod Dentofacial Orthop 2010;137:615-622.e3. [CrossRef]
8. Bakhadher W, Halawany H, Talic N, Abraham N, Jacob V. Factors affecting the shear bond strength of orthodontic brackets - a Review of In Vitro Studies. Acta Medica (Hradec Kralove) 2015;58:43-8. [CrossRef]
9. Faltermeier A, Behr M. Effect of bracket base conditioning. Am J Orthod Dentofacial Orthop 2009;135:12-3. [CrossRef]
10. Eminkahyagil N, Arman A, Cetinşahin A, Karabulut E. Effect of resin-removal methods on enamel and shear bond strength of rebonded brackets. Angle Orthod 2006 Mar;76:314-21.
11. Bishara SE, Fehr DE, Jakobsen JR. A comparative study of the debonding strengths of different ceramic brackets, enamel conditioners, and adhesives. Am J Orthod Dentofacial Orthop 1993;104:170-9. [CrossRef]
12. Wendl B, Muchitsch P, Pichelmayer M, Droschl H, Kern W. Comparative bond strength of new and reconditioned brackets and assessment of residual adhesive by light and electron microscopy. Eur J Orthod 2011;33:288-92. [CrossRef]
13. Read M J F, O'Brien K D. A clinical trial of an indirect bonding technique with a visible light-cured adhesive. Am J Orthod Dentofacial Orthop 1990; 98: 259–262. [CrossRef]
14. Montero M, Vicente A, Alfonso-Hernández N, Jiménez-López M, Bravo-González LA. Comparison of shear bond strength of brackets recycled using micro sandblasting and industrial methods. Angle Orthod 2015;85:461-7. [CrossRef]
15. Rüger D, Harzer W, Krisjane Z, Tausche E. Shear bond strength after multiple bracket bonding with or without repeated etching. Eur J Orthod 2011;33:521-7. [CrossRef]
16. Kilinc D, Sayar G. Comparison of the shear bond strength of treated and untreated brackets on treated and untreated enamel surfaces in rebonding. J Orofac Sci 2018;10:69. [CrossRef]
17. 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;5:197-202. [CrossRef]
18. Sung EC, Chan SM, Mito R, Caputo AA. Effect of carbamide peroxide bleaching on the shear bond strength of composite to dental bonding agent enhanced enamel. J Prosthet Dent 1999;82:595-9. [CrossRef]
19. Bishara SE, Gordan VV, VonWald L, Jakobsen JR. Shear bond strength of composite, glass ionomer, and acidic primer

adhesive systems. Am J Orthod Dentofacial Orthop 1999;115:24-8. [CrossRef]
20. Sonis AL. Air abrasion of failed bonded metal brackets: a study of shear bond strength and surface characteristics as determined by scanning electron microscopy. Am J Orthod Dentofacial Orthop 1996;110:96-8. [CrossRef]
21. Al Maaitah EF, Alomari S, Abu Alhaija ES, Saf AA. The effect of different bracket base cleaning method on shear bond strength of rebonded brackets. J Contemp Dent Pract 2013;14:866-70. [CrossRef]
22. Salama F, Alrejaye H, Aldosari M, Almosa N. Shear bond strength of new and rebonded orthodontic brackets to the enamel surfaces. J Orthod Sci 2018;7:12. [CrossRef]
23. Montasser MA, Drummond JL, Evans CA. Rebonding of orthodontic brackets. Part I, a laboratory and clinical study. Angle Orthod 2008;78:531-6. [CrossRef]
24. Eslamian L, Borzabadi-Farahani A, Tavakol P, Tavakol A, Amini N, Lynch E. Effect of multiple debonding sequences on shear bond strength of new stainless steel brackets. J Orthod Sci 2015; 4: 37–41. [CrossRef]
25. Chacko PK, Kodoth J, John J, Kumar K. Recycling stainless steel orthodontic brackets with Er:YAG laser - An environmental scanning electron microscope and shear bond strength study. J Orthod Sci 2013;2:87-94. [CrossRef]
26. Bishara SE, Laffoon JF, Vonwald L, Warren JJ. The effect of repeated bonding on the shear bond strength of different orthodontic adhesives. Am J Orthod Dentofacial Orthop 2002;121:521-5. [CrossRef]
27. Movahhed HZ, Ogaard B, Syverud M. An in vitro comparison of the shear bond strength of a resin-reinforced glass ionomer cement and a composite adhesive for bonding orthodontic brackets. Eur J Orthod 2005;27:477-83. [CrossRef]
28. Summers A, Kao E, Gilmore J, Gunel E, Ngan P. Comparison of bond strength between a conventional resin adhesive and a resin-modified glass ionomer adhesive: an in vitro and in vivo study. Am J Orthod Dentofacial Orthop 2004;126:200-6. [CrossRef]
29. Ahangar Atashi MH, Sadr Haghighi AH, Nastarin P, Ahangar Atashi S. Variations in enamel damage after debonding of two different bracket base designs: An in vitro study. J Dent Res Dent Clin Dent Prospects 2018;12:56-62. [CrossRef]