Shear bond strength of metal brackets and ceramic brackets with monocrystalline and polycrystalline alumina bonded to provisional polymethyl methacrylate crowns

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Author Contributions

All authors have made substantial contributions to the conception and design of the study. NS and AG were involved in sample preparation and data collection. NS was involved in the data analysis. AG was involved in data interpretation and drafting of the manuscript. All authors revised the manuscript critically. All authors have given final approval for this version to be published.

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ABSTRACT

Purpose:

This study aimed to assess how the material and base design of orthodontic brackets affect the shear bond strength (SBS) when bonded to a provisional polymethyl methacrylate PMMA crown.

Methods:

Fifty provisional PMMA maxillary crowns were fabricated and divided into five groups based on the orthodontic brackets used: Group 1: Bionic®, Group 2: Discreet™, Group 3: Radiance™, Group 4: Symetri®, and Group 5: Translux®. After surface treatment with 9.6% hydrofluoric acid, brackets were bonded. Each study group was subdivided into three subgroups according to artificial water ageing protocols used: baseline (24 h), 5000 thermocycles and 10000 thermocycles. SBS was tested and failure mode was analyzed. Statistical analysis included two-way ANOVA, and Tukey's post-hoc test ($P < 0.05$).

Results:

Radiance™ exhibited the highest SBS values under all aging conditions. Bionic® showed the second-highest SBS. Discreet™, Symetri™, and Translux® showed significant decreases in SBS values after ageing. ARI scores indicated that “Index 0” and “Index 1” significantly increased after ageing particularly for Discreet™, Symetri®, and Translux® orthodontic brackets.

Conclusion:

Radiance™ demonstrated superior SBS and durability compared to other brackets. However, caution is advised when using Radiance™ on PMMA crowns, as their SBS exceeds the clinically acceptable range.

Keywords: Provisional PMMA crown; orthodontic bracket; bracket base; shear bond strength

INTRODUCTION

Due to an increase in adults seeking orthodontic treatment with heavily restored dentition, orthodontists are confronted with the need to bond orthodontic brackets to them [1]. In some cases, a collaborative approach involving a restorative specialist is employed where a restorative specialist opts to administer a provisional crown mainly to capitalize on the sequential advantage of deferring the placement of final restoration until optimal dental realignment has been achieved [2]. Additionally, the bonding and debonding processes used to place orthodontic brackets have the potential to harm permanent prostheses [3]. Therefore, bonding between a bracket and a provisional crown needs to be optimal.

For the fabrication of provisional crowns, a variety of materials are available on the market, including polymethyl methacrylate (PMMA), polycarbonate, composite resin, and bisacryl composite resin. PMMA is a popular material nonetheless because of its esthetic, ease of fabrication, durability, and strength [4]. Despite the advantages, the PMMA resin surface exhibits lower bond strength with orthodontic brackets, falling below clinically acceptable standards [4]. Therefore bonding of an orthodontic bracket with a provisional crown made of PMMA is critical and presents a high bonding failure rate [4]. Additionally, the bonding of an orthodontic bracket with a provisional crown is challenging compared to a natural tooth [5,6].

Amongst the factors influencing the shear bond strength (SBS) are the size, shape, and surface treatment of the bracket bases [7]. Due to esthetic demands, the manufacturers have decreased the size of the bracket bases [8]. A huge array of bracket systems is available in the market that can be categorized based on materials used such as metal, ceramic, plastic, *etc.,* and type of base used such as foil mesh, laminated mesh, Quad Matte®, laser etched, *etc.*

It has been reported that the bracket base-cement interface is the weakest point in orthodontic bonding [7,9,10]. With the vast array of orthodontic bracket base designs that are currently on the market, it's critical to determine which bracket design is clinically practical for the provision of adequate SBS. Therefore, the primary objective of this laboratory was to evaluate the influence of the bracket's base design on the SBS to the provisional PMMA crown. A secondary objective was to identify the bonding failure mode. The null hypotheses for the objectives were that the SBS and bonding failure mode are not significantly influenced by the material/base design and the aging effect.

MATERIALS AND METHODS

A prepared maxillary upper right central incisor (Nissin Dental Products Inc., Kyoto, Japan) was selected and the impression was taken with a silicone material (Fusion II, GC, Tokyo, Japan) according to the manufacturer's instructions. After the setting of

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the silicone material, the mould was removed. For the fabrication of PMMA provisional crowns, auto-polymerizing acrylic resin (Bosworth Trim Plus; Bosworth Company, Skokie, USA) was selected and the powder and liquid ratio was mixed following the manufacturer's instructions. When the dough-like consistency was achieved, it was poured into the silicone mould for 10 min. Next, the fabricated crown was removed from the mould and stored for 24 h to allow complete polymerization. A total of 120 provisional PMMA crowns were fabricated and equally divided into 5 study groups. All crowns were fabricated by a single operator to eliminate the inter-operators' discrepancies. All crowns were ground and polished under water cooling using a polishing machine (Isomet 5000, Buehler Ltd., Lake Bluff, IL, USA). The process involved using three types of silicon carbide papers (800, 1000, and 1500 grit), followed by a final polishing with a cloth and polishing paste (Abraso-Starglanz ASG; Bredent, Senden, Germany).

Next, the individual crown was embedded in auto-polymerizing resin (Palapress™, Heraeus Kulzer, Hanau, Germany) and decanted into the PVC mold with a 10 cm diameter in such a way that the labial surface was free from interaction with resin acrylic. The specimens were randomly divided into five equal groups according to orthodontic brackets used (n=8): Group 1: Bionic® (10.9 mm^2; Ortho Technology, USA), Group 2: Discreet™ (Adanta®, Germany), Group 3: Radiance™ (13.94 mm^2; American Orthodontics, USA), Group 4: Symetri™ (Ormco, USA), and Group 5: Translux® (Aditek, Brazil).

Before bonding of bracket with adhesive, the labial surface of the provisional crown was surface treated with 9.6% hydrofluoric acid for 30 s and then rinsed off with water and air-dried. Next, a single coat of Transbond XT primer was applied on the surface, and Transbond XT paste was applied to the bracket base. The bracket was then pressed firmly onto the crown. The excess adhesive was removed from around the bracket, and the adhesive was light cured (Elipar 2500, 3M ESPE, St Paul, MN, USA) by positioning the light guide on each side for 10 seconds.

Artificial aging

Before testing to determine the baseline SBS values, eight specimens, or one-third of the specimens from each bracket group (n = 8), were stored in a desiccator for 24 h. The other two thirds of the specimens underwent artificial water ageing using thermocycler (Model 1100, SD Mechatronik, Feldkirchen-Westerham, Germany), which involved 5,000 and 10,000 thermocycles in distilled water at temperatures between 5 and 55°C. Ten seconds was the dwell period at each bath, and ten seconds was the transfer time between the water baths.

Shear test

A universal testing machine (Model no. 3369 Instron, Canton, MA, USA) was used for the shear test of the study specimens. The specimens were fastened to the holder consisting of a metal frame with screws that ensured the specimens remained stable and properly aligned during the testing. The bracket base was kept parallel to the tip of the chisel (Fig. 1). Shear tests were performed with a load cell of 5 kN at a speed of 0.5 mm/min. The SBS (in MPa) was calculated by proprietary software (Bluehill ver. 2.4) associated with the testing machine.

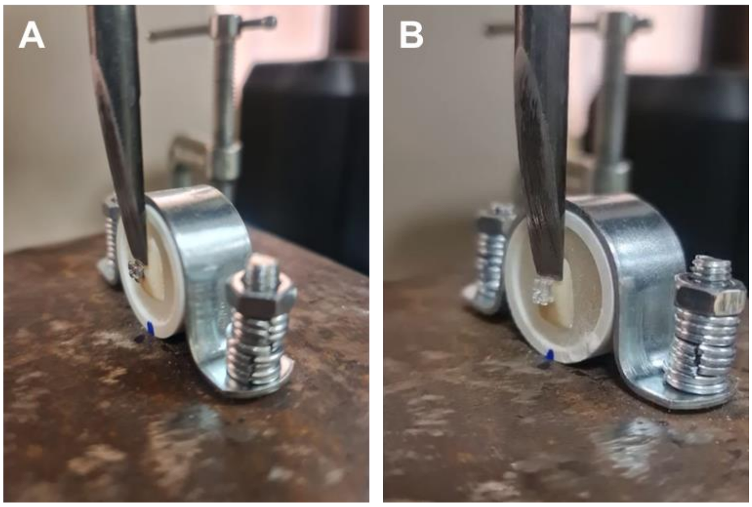

Fig. 1: Chisel positioned against the adhesive interface of orthodontic bracket bonded with PMMA provisional crown: (A) Bionic® bracket and (B) Radiance™ bracket.

Failure mode analysis

At 20× magnification, the bases of the brackets were examined after SBS test using a light stereomicroscope (Nikon SM2-10, Tokyo, Japan). The scoring of failure was performed according to the adhesive remnant index (ARI) where 0% of adhesive remaining in the bracket base was scored as “Index 0”; with less than 50% of remaining adhesive on the bracket base was considered as “Index 1”; with more than 50% of remaining adhesive on the bracket base was counted as “Index 2”; and “Index 3- adhesive failure” represented a bracket–adhesive interface failure where there is 100% of adhesive left on the bracket base.

Statistical analysis

The normality in distribution and homogeneity of variance were determined with the Levene test and Shapiro-Wilk test, respectively. The SBS values acquired from the experimental groups underwent analysis via a two-way analysis of variance (ANOVA), where the bracket type and ageing condition served as independent variables. Group comparisons were conducted using Tukey's *post hoc* multi-comparison tests, with a significance level set at 5%.

RESULTS

Table 1 displays the SBS of the study groups. Under all aging conditions, the Radiance™ consistently exhibited the highest SBS values, starting at 20.21 MPa (at baseline) and falling to 16.79 MPa (after 5000 thermocycles) and 11.80 MPa (after 10,000 thermocycles). With a baseline SBS of 14.02 MPa, Bionic® had the second highest SBS, but after 5000 and 10,000 thermocycles, SBS dropped to 12.38 MPa and 8.36 MPa, respectively. While the Discreet™, Symetri™, and Translux® showed decreased SBS values. After 10,000 thermocycles, Discreet™ showed a notable decrease from 12.32 MPa at baseline to 4.16 MPa. The SBS values of Symetri™ and Translux® were comparable; they began at around 10.7 MPa at baseline and dropped to about 5 MPa after 10,000 thermocycles.

Table 1: Descriptive and inferential statistics for the shear bond strengths (SBS) of the study groups.

Group	Shear bond strength (MPa) (mean ± SD)		
	Baseline	5000 thermocycles	10000 thermocycles
Bionic®	$14.02\pm1.73^{A}_{a}$	$12.38\pm1.48^{E,F,G,H}_{b}$	$8.36\pm0.68^{L,M,N,O}_{a,b}$
Discreet™	$12.32\pm2.77^{B}_{c,d}$	$07.61\pm0.75^{E,I}_{c,e}$	$4.16\pm1.30^{L,P}_{d,e}$
Radiance™	$20.21\pm2.33^{A,B,C,D}_{f}$	$16.79\pm1.73^{F,I,J,K}_{g}$	$11.80\pm1.95^{M,P,Q,R}_{f,g}$
Symetri™	$10.74\pm1.41^{C}_{h,i}$	$6.13\pm0.85^{G,J}_{h}$	$5.08\pm1.73^{N,Q}_{i}$
Translux®	$10.76\pm1.13^{D}_{j,k}$	$6.31\pm1.29^{H,K}_{j}$	$4.28\pm1.40^{O,R}_{k}$

Note: The same uppercase superscript alphabets show significant differences between the groups. The same lowercase subscript alphabets show significant differences between the group

Table 2 shows the summary of ARI scores among the groups. At baseline, most groups exhibited a range of ARI scores, with adhesive failures (Index 3) being rare. The scores suggested that as aging progresses, there's a tendency for less adhesive to remain on the bracket. In particular, Discreet™, Symetri™, and Translux® shifted towards lower ARI scores (Indices 0 and 1) after 10000 thermocycles, implying less adhesive left on the bracket. This could indicate a change in the failure mode from cohesive within the adhesive to more adhesive failures at the bracket-adhesive interface. Visual analysis of ARI scores can be seen in Fig. 2.

Table 2: Adhesive Remnant Index (ARI) Scores for various bracket groups before and after thermocycling

Group	ARI score [n]											
	Baseline				5000 thermocycles				10000 thermocycles			
	0	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**
Bionic®	0	5	2	1	0	4	4	0	0	2	6	0
Discreet™	0	4	4	0	1	6	1	0	3	5	0	0
Radiance™	0	1	6	1	0	4	4	0	0	5	3	0
Symetri™	0	5	3	0	1	7	0	0	3	5	0	0

Translux®	0	5	3	0	0	8	0	0	3	5	0	0

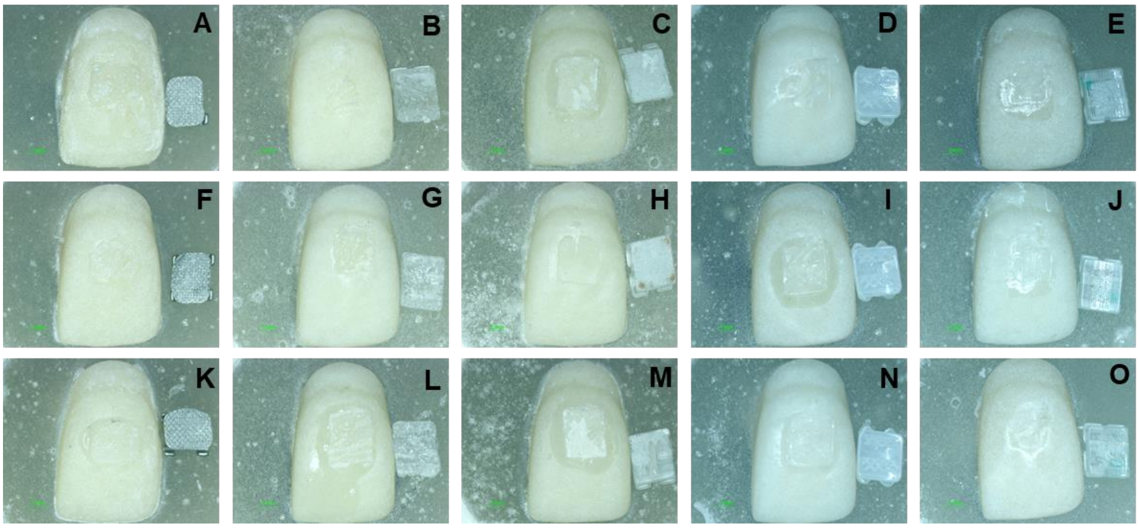

Fig. 2: Representative images of provisional PMMA crown after debonding of orthodontic brackets under varying conditions: From A-E, debonding of Bionic®, Discreet™, Radiance™, Symetri™, and Translux®, respectively at baseline evaluation; from F-J, debonding of Bionic®, Discreet™, Radiance™, Symetri™, and Translux®, respectively at 5000 thermocycles evaluation; and from K-O, debonding of Bionic®, Discreet™, Radiance™, Symetri™, and Translux®, respectively at 10000 thermocycles evaluation.

DISCUSSION

The null hypotheses were rejected: the first hypothesis that SBS was significantly influenced by the material/base design is accepted and the second hypothesis that bonding failure mode was significantly influenced by bracket base design is also accepted. Among the brackets used, Radiance™ displayed a significantly higher SBS compared to other study groups.

A single type of adhesive was utilized to certify that any observed variations in bond strength were solely attributable to differences in mesh design. Radiance™ is a monocrystalline ceramic bracket that has been fabricated using patented Quad Matte™ technology [11], with Al_2O_3 particles only on the center of the base. Additionally, the retentive features protrude above the ceramic that forms the bracket base. This technology creates a unique surface texture by increasing the surface area available for bonding, therefore helping to enhance the mechanical interlocking with the PMMA-based material. Additionally, this technology increases the roughness of the bracket’s base, allowing for improved micro-mechanical retention. Monocrystalline ceramic has superior adhesion properties and has compatible surface chemistry with dental adhesives such as dimethacrylate [12].

The available literature suggests that a minimum required SBS of 6 to 8 MPa is necessary to preserve the bond between the orthodontic brackets and the temporary crown material [6]. The control group exhibited SBS of 14.02 MPa at baselines and decreased to 12.38 MPa after 5000 thermocycles and further to 8.36 MPa after 10000 thermocycles. The higher SBS could be attributed to the chemical treatment of provisional crown with Transbond™ XT primer containing bisphenol A diglycidyl ether dimethacrylate (MW = 512.59 g/mol) and triethylene glycol dimethacrylate (MW = 286.32 g/mol) monomers. Due to the dissolution ability of these monomers and the formation of a secondary semi-interpenetrating polymer network (IPN) on the PMMA crown surface, diffusion of cross-linking monomers, i.e., Transbond XT paste into the acrylic provisional crown' surfaces occurred [13,14] and produced higher bonding. Whereas, the 80-gauge foil mesh of Bionic brackets provided increased surface area and better penetration of the adhesive into the mesh.

We observed that Symetri™, a polycrystalline ceramic with multiple fused Al_2O_3 particles did not produce higher SBS. Although the manufacturer claims reliability of bonding due to laser etched base [15]. Unlike monocrystalline ceramic brackets, they are more prone to having impurities and structural flaws, which can result in lower retention and bonding with acrylic surfaces. Additionally, the smooth, flat areas in combination with laser-etched base areas might not help aid the bond. Unlike monocrystalline alumina which has fewer grain boundaries and defects, polycrystalline alumina may not chemically bond well with the acrylic surface because of increased grain boundaries and defects.

Translux® brackets, fabricated through machining processes are polycrystalline ceramic brackets that have gained popularity and increased usage recently due to their cost-effectiveness and ease of production. The lower SBS of these brackets with provisional acrylic tooth surface might be attributed to a fine mesh pattern on the base of the central region of the bracket only that could not help to increase the surface area for adhesive bonding. The mesh design may not allow the adhesive to flow into the small spaces, nor may it create a stronger mechanical lock with the restorative surface.

The findings suggest that bases may feature micro-etching, mesh patterns, or retentive grooves to enhance mechanical retention. Bases may come with a fine-brazed mesh or have a milled undercut or are sandblasted, chemically etched, or sintered with porous metal powder [16]. These features increase the surface area for adhesive bonding, allowing the adhesive to flow into small spaces and create a strong mechanical lock [16]. Effective base contouring distributes stress evenly across the adhesive interface, reducing the risk of bond failure and enhancing the overall durability and stability of the orthodontic treatment, hence preventing unwanted tooth movements and improving treatment outcomes.

We observed that all the groups exhibited reduced SBS after artificial ageing in thermocycling. This is due to adhesive components that may hydrolyze and degrade when water seep through the adhesive interface. Over time, this process weakens the adhesive bond by dissolving the polymer chains in the adhesive [17]. According to some investigators, acceptable SBS values should be in the range of 5.9-7.8 MPa [18,19] while others think that 8-16 MPa is ideal [20]. Although Radiance™ exhibited higher SBS at baseline and the end of 5000 thermocycles, which clearly exceeded the suggested range. This may have deleterious effect on the orthodontic treatment. Therefore, caution is advised in using these brackets.

The visual observations and the SBS findings agreed with each other when it came to ARI score evaluation. Lower adhesive retention on the bracket base was correlated with, predictably, lower adhesive strengths. We observed that SBS of Bionic® and Radiance™ brackets remained moderate after 5000 thermocycles, however, an increased "Index 1" among Discreet™, Symetri™, and Translux® brackets was observed. Following 10,000 thermocycles, all groups showed a tendency toward more cohesive failures (score 2), with the Bionic® and Radiance™ brackets exhibiting greater rates of ARI score 2. This suggests that extended thermocycling weakens the adhesive connection and increases the likelihood of cohesive breakdowns in all bracket types.

In vitro, studies with inherent limitations might not accurately replicate the complex oral environment. Variations in the points of shear force application can influence results by introducing different stress distributions on the bracket base. Changing the location of force application might lead to variations in SBS values and failure modes, affecting the overall study outcomes. In this study, debonding force was applied at the bracket ligature groove. In the future, different force application points would be interesting to gauge. Also, only one type of adhesive might limit understanding of how different adhesives interact with various bracket base designs. Therefore, in future work, different adhesives would be interesting to evaluate.

CONCLUSION

The study concluded that SBS is significantly influenced by bracket base design and water ageing. Radiance™ exhibited significantly higher SBS compared to other brackets tested. This superior performance is attributed to the bracket's increased surface area and roughness, which enhance mechanical interlocking with PMMA-based materials. While other brackets like Bionic®, Discreet™, Symetri™, and Translux® showed significant SBS reductions over time, Radiance™ maintained superior performance. However, caution is advised when using the Radiance bracket on PMMA crowns, as its SBS exceeds the clinically acceptable range.

Conflicts of interest

There are no conflicts of interest.

Data Availability Statements

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Figure legends

Fig. 1: Chisel positioned against the adhesive interface of orthodontic bracket bonded with PMMA provisional crown: (A) Bionic® bracket and (B) Radiance™ bracket.

Fig. 2: Representative images of provisional PMMA crown after debonding of orthodontic brackets under varying conditions: From A-E, debonding of Bionic®, Discreet™, Radiance™, Symetri™, and Translux®, respectively at baseline evaluation; from F-J, debonding of Bionic®, Discreet™, Radiance™, Symetri™, and Translux®, respectively at 5000 thermocycles evaluation; and from K-O, debonding of Bionic®, Discreet™, Radiance™, Symetri™, and Translux®, respectively at 10000 thermocycles evaluation.