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Original Article

Shear Bond Strength of Metal Orthodontic Brackets on CAD/CAM Provisional Crowns: Role of Surface Treatments

Mohammed Sayed Mohammed Ali[1], Esam Safa Fahmy Elbeshehy[2]*

[1]Dental Biomaterials Department, Faculty of Dentistry, Mansoura University, Mansoura, Egypt.
[2]Department of Restorative Dental Sciences, College of Dentistry, Taibah University, Madinah 41477, Saudi Arabia.

***E-mail** ✉ esafafelbeshehy@yahoo.com

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ABSTRACT

Achieving reliable bracket adhesion to CAD/CAM provisional crowns is clinically challenging. This study evaluated various surface treatments to determine which method provides the strongest bond strength for metal orthodontic brackets. A total of 30 lower bicuspids and 180 provisional crowns were included and randomly assigned to six groups according to surface preparation: Group 1 (no treatment), Group 2 (diamond bur), Group 3 (sandblasting), Group 4 (Plastic Conditioner), Group 5 (diamond bur + Plastic Conditioner), and Group 6 (sandblasting + Plastic Conditioner). Natural teeth were etched with 37% orthophosphoric acid. Brackets were bonded using Transbond XT® Primer and Transbond XT® Paste. Samples underwent artificial aging before measuring shear bond strength. The adhesive remnants on crown surfaces were analyzed after bracket removal. The strongest bond strength was recorded for natural teeth, followed closely by Groups 5 and 6. Group 1 had the weakest bonding values. Similar performance was observed between Groups 2 and 4, as well as between Groups 5 and 6. Statistical analysis indicated significant differences among most groups ($p < 0.001$), except between Groups 2 and 4 ($p = 0.965$) and Groups 5 and 6 ($p = 0.941$). Bracket adhesion to provisional crowns is less predictable than to natural teeth, as conventional phosphoric acid etching has minimal effect on provisional materials. Surface preparation combining either a diamond bur or sandblasting with Plastic Conditioner effectively enhances bond strength, achieving levels comparable to those on natural teeth.

Keywords: CAD/CAM provisional crowns, Surface modification, Orthodontic bracket bonding, Shear bond strength

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Introduction

Orthodontic treatment continues to attract both adolescents and adults seeking an improved smile [1-3]. In certain clinical situations, provisional crowns are necessary to preserve the esthetic, functional, and therapeutic integrity of the dental arch [4-6]. During orthodontic therapy, it may be required to bond brackets directly onto these provisional restorations. Like natural teeth, provisional crowns must provide adequate bond strength to withstand both orthodontic and masticatory forces.

Provisional crowns vary widely in composition and properties [5-8]. Although no material meets all ideal criteria, laboratory-fabricated crowns offer several clinical advantages. Modern CAD/CAM technology has emerged as a leading approach for producing high-quality provisional crowns [9-11]. Despite these advances, achieving reliable bracket adhesion remains challenging, making the choice of surface treatment critical [12].

This study tests the null hypothesis that applying a plastic conditioner, an adhesion-enhancing agent, improves the shear bond strength of brackets on CAD/CAM provisional crowns. Identifying the optimal surface treatment may reduce bracket failures and shorten overall orthodontic treatment time.

Materials and Methods

Sample preparation

A total of 30 freshly extracted lower bicuspids, all with intact buccal surfaces, were collected for the study due to periodontal or orthodontic indications. One tooth from the sample was scanned using the Ceramill Map 400, and 180 provisional crowns were fabricated with a milling machine (Ceramill Motion 2) operated via the CAD/CAM system **(Figure 1)**.

Figure 1. The Ceramill Motion 2 machine and one of the provisional teeth.

All teeth were embedded in acrylic blocks that were cooled in a custom mold. A surveyor device ensured that the long axis of each tooth was aligned consistently across the entire sample. Lower bicuspid metal brackets (Mini Twin, Ormco Corporation, Brea, CA, USA) were used [13], and all sample preparation was performed by a single operator to maintain consistency.

Bonding and measurement procedures

Natural teeth (NT)

The buccal surfaces of the natural teeth were etched with 37% orthophosphoric acid (Biodinamica R. Ronat Valter Sodré, Ibiporã, Brazil) for 15 seconds, then thoroughly rinsed with water and air-dried. A thin layer of Transbond XT® Primer (3M Unitek, Irwindale, CA, USA) was applied. Brackets were positioned along the tooth axis at 4 mm from the incisal edge, using Transbond XT® Paste (3M Unitek) and a standardized gauge. A force of 5 N was applied for 5 seconds using a tensiometer (Bongshin, Osan, Korea, Model BS-201 Series) to ensure uniform adhesive thickness. Excess adhesive was removed, and the bracket was light-cured for 10 seconds on both the mesial and distal sides [14, 15].

Provisional teeth

The 180 CAD/CAM-fabricated provisional crowns were randomly allocated into six groups (n = 30) according to surface treatment protocol:

- **Group 1 (Control):** No surface treatment applied.
- **Group 2 (Diamond bur):** The buccal surface was abraded with a cylindrical diamond bur (PacDent, Brea, CA, USA) at 2000 rpm. The bur was kept parallel to the surface, moving in a brushing motion for 10 seconds. A tensiometer monitored the force, ensuring it did not exceed 1 N.
- **Group 3 (Sandblasting):** Surfaces were treated with 50 μm aluminum oxide particles using a sandblaster to create micro-roughness. The nozzle was held perpendicular at 1 cm for at least 5 seconds until a uniform texture was achieved. Residual particles were removed with an air jet [16, 17].
- **Group 4 (Plastic Conditioner):** A thin, even layer of Plastic Conditioner (Reliance Orthodontic Products, Itasca, IL, USA) was applied to the buccal surface. Bracket bonding commenced after 60 seconds [18, 19].
- **Group 5 (Diamond bur + Plastic Conditioner):** Surfaces were first abraded with a diamond bur (as in Group 2) and then treated with Plastic Conditioner (as in Group 4).
- **Group 6 (Sandblaster + Plastic Conditioner):** Surfaces were sandblasted (as in Group 3) and subsequently treated with Plastic Conditioner (as in Group 4).

Brackets were bonded in all groups following the same protocol used for natural teeth, with Transbond XT® Primer and Transbond XT® Paste. To standardize bracket placement, a transparent thermoplastic guide, modeled on the natural tooth used for provisional crown fabrication, was employed **(Figure 2)**.

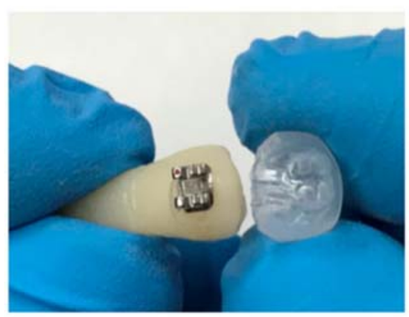

Figure 2. Transparent thermoplastic mould specially designed to standardize the placement and bonding of brackets.

The entire sample was subjected to artificial aging using the SD Mechatronik THERMOCYCLER. The aging protocol involved 2200 thermal cycles, simulating the typical duration of an orthodontic treatment (approximately 18–20 months) [20-22]. Each cycle consisted of immersing the samples in cold water at 5 °C for 30 seconds, followed by immersion in hot water at 55 °C for 30 seconds, with a 10-second interval in ambient air between immersions.

Shear bond strength testing was performed on all specimens using a Universal Testing Machine (YLE GmbH, Waldstrasse 1, D-64732 Bad Koenig, Germany) connected to a computer for data acquisition **(Figure 3)**.

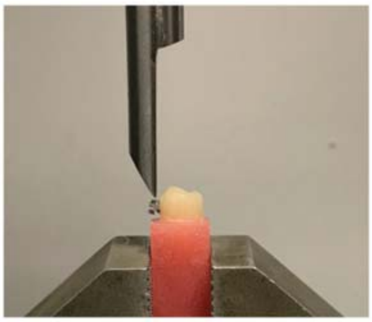

Figure 3. Universal Testing Machine YLE (YLE GmbH, Waldstraße 1/1a, D-64732 Bad Koenig, Germany).

Shear bond strength (SBS) was calculated in megapascals (MPa) by dividing the recorded fracture load (in Newtons) by the bracket base area, which measured 8 mm².

After debonding, the tooth surfaces were independently evaluated by two observers under an optical microscope (Karl Kaps Optik-Feinmechanik-Gerätebau GmbH & Co. KG, Europastraße, 35614 Aßlar, Germany) at various magnifications. The amount of adhesive remaining was scored according to the Artun and Bergland index (1984) [23, 24]:

- Score 0: No adhesive remaining on the tooth **(Figure 4)**.
- Score 1: Less than 50% of the adhesive remaining **(Figure 5)**.
- Score 2: More than 50% of the adhesive remaining **(Figure 6)**.
- Score 3: All adhesive retained on the tooth with a clear impression of the bracket mesh **(Figure 7)**.

Scores 0 and 1 indicate adhesive failure at the tooth–adhesive interface, whereas scores 2 and 3 indicate cohesive failure within the adhesive or at the adhesive–bracket interface.

a) b) c)

Figure 4. Score 0. a) Magnification: 10 × 1; b) Magnification: 10 × 1.6; c) Magnification: 10 × 2.5.

a) b) c)

Figure 5. Score 1. a) Magnification: 10 × 1; b) Magnification: 10 × 1.6; c) Magnification: 10 × 2.5.

a) b) c)

Figure 6. Score 2. a) Magnification: 10 × 1; b) Magnification: 10 × 1.6; c) Magnification: 10 × 2.5.

a) b) c)

Figure 7. Score 3. a) Magnification: 10 × 1; b) Magnification: 10 × 1.6; c) Magnification: 10 × 2.5.

All specimens were prepared under uniform conditions, ensuring consistent bracket type, adhesive quantity, and debonding technique.

Statistical analysis

Statistical evaluations were conducted using SPSS version 23.0 (IBM Corp., Armonk, NY, USA), with significance defined at $p \leq 0.05$. The Shapiro–Wilk test assessed the normality of bond strength distributions, and Levene's test checked variance homogeneity.

To compare bond strength across the seven experimental groups, a one-way ANOVA adjusted with Welch's correction was applied. Post hoc pairwise comparisons were performed using Tukey's test to identify which group differences were statistically significant.

Adhesive Remnant Index (ARI) scores were independently examined by two observers. Differences in ARI distributions were evaluated using the Chi-square test, supplemented by Cramer's V for association strength. Additionally, Pearson correlation coefficients were computed to assess the relationship between bond strength and ARI values within each group.

Results and Discussion

Shear bond strength varied considerably among groups. Natural teeth achieved the highest mean bond strength (6.58 ± 1.09 MPa). Among provisional crown groups, the combination treatments—diamond bur + Plastic Conditioner (group 5) and sandblasting + Plastic Conditioner (group 6)—showed the strongest adhesion (5.15 ± 0.68 MPa and 5.35 ± 0.66 MPa, respectively). The untreated control group exhibited the lowest mean value (0.48 ± 0.73 MPa). Intermediate values were observed for single-treatment groups: diamond bur (group 2) averaged 2.89 ± 0.56 MPa, and Plastic Conditioner alone (group 4) averaged 2.71 ± 0.44 MPa. Groups 5 and 6 displayed closely matching outcomes, reflecting the effectiveness of combining surface roughening with adhesive promotion **(Table 1)**.

Table 1. Means of bond strength for the different groups.

Group	N	Average (in MPa)	Standard Deviation	Confidence Interval at 95%
NT	30	6.58	1.09	6.98–6.17
1	30	0.48	0.73	0.75–0.21
2	30	2.89	0.56	3.10–2.68
3	30	4.21	0.82	4.52–3.70
4	30	2.71	0.44	2.88–2.55

5	30	5.15	0.68	5.40–4.89
6	30	5.35	0.66	5.59–5.10

Normality testing indicated that bond strength values were not distributed uniformly (p < 0.001), supporting the use of parametric analyses. Variance analysis revealed significant heterogeneity among groups (p < 0.001).

Analysis of variance demonstrated a statistically significant difference in mean bond strength across the groups (p < 0.001). Pairwise comparisons showed that all groups differed significantly from each other except for groups 2 and 4 (p = 0.965) and groups 5 and 6 (p = 0.941), which did not differ significantly.

Evaluation of the Adhesive Remnant Index (ARI) indicated that natural teeth, group 3 (sandblasting), and the combination treatment groups (5 and 6) had higher ARI scores compared with groups 1, 2, and 4. The control group (group 1) predominantly exhibited an ARI score of 0, while groups 2 and 4 were mostly scored as 1. In contrast, groups with higher bond strength (natural teeth, 3, 5, and 6) were dominated by ARI score 2, indicating cohesive failure at the adhesive–bracket interface. Statistical analysis confirmed significant differences in ARI distribution among the groups (p < 0.001).

Table 2. Scores of the quantity of residual adhesive (ARI) for each group.

Group	N	Scores of the Quantity of Residual Adhesive (ARI), %			
		0	1	2	3
NT	30			70	30
1	30	90	10		
2	30	10	70	20	
3	30		36.7	60	3.3
4	30	23.3	56.7	20	
5	30		30	63.3	6.7
6	30		20	56.7	23.3

Residual adhesive quantity (ARI)

Table 2 indicates that natural teeth, group 3, and the combination treatment groups (5 and 6) displayed similar ARI scores, whereas groups 1, 2, and 4 formed another comparable set. Nevertheless, the difference in ARI scores between these two sets of groups was statistically significant.

Correlation between bond strength and ARI

A positive correlation was observed between mean bond strength and ARI scores. Group 1 showed a moderate correlation (r = 0.689), while all other groups—including natural teeth, 2, 3, 4, 5, and 6—demonstrated a very strong positive correlation (r = 0.840), indicating a consistent relationship between adhesive retention and shear bond strength.

The adoption of CAD/CAM technology in dentistry is expected to increase as clinicians become more familiar with its advantages [25]. This system enables the fabrication of crowns from polymethyl methacrylate (PMMA) blocks, providing improved mechanical and esthetic properties compared with direct provisional crowns. Despite its growing use, studies investigating the bonding of orthodontic brackets to CAD/CAM provisional crowns remain limited, with most research focusing on light-cured resins [26, 27], acrylic resins [14, 28], and prefabricated resin crowns [29, 30].

Lower bicuspids were chosen for this study due to their higher incidence of bracket fracture in the mandibular lateral regions [31-33]. Bond strength during orthodontic treatment is influenced by multiple factors, including the substrate material and the surface preparation. Brackets can be bonded to natural enamel or dentin, restorative composites, or provisional crowns, each requiring specific bonding protocols. Laboratory-fabricated provisional crowns undergo intense polymerization and heat treatment, which enhances mechanical properties but reduces surface reactivity and bonding potential. Consequently, surface modification is essential to improve adhesive retention. Orthophosphoric acid, commonly used for enamel etching, does not significantly affect provisional crown surfaces but can remove debris following sandblasting [28, 34]. Various surface treatment techniques, such as milling and sandblasting, have been shown to increase bracket bond strength by creating micro-roughness on the crown surface [28, 35-37]. Comparisons of these methods indicate that sandblasting generally produces a rougher surface and slightly better bond strength, although still below the optimal values observed on natural teeth [35]. These findings align with our results.

To further enhance adhesion, the application of a plastic conditioner—comprising methyl methacrylate and isobutyl methacrylate—has been proposed. This agent acts as a chemical intermediary, promoting bonding between the provisional crown surface and the adhesive. Studies have reported mixed results: Egan *et al*. observed no improvement on natural teeth [38], while Masioli *et al*. found that the product alone could hinder bracket adhesion on provisional crowns [28]. Tse (2012) reported similar findings for restorative composites [18]. In our study, the combination of plastic conditioner with either milling or sandblasting improved bond strength, approaching the values seen on natural teeth. This likely occurs because the conditioner penetrates the micro-roughened surface created by mechanical preparation.

Alternative treatments, such as the application of 9.6% hydrofluoric acid, have been shown to be ineffective on provisional crowns [20]. Regarding adhesive selection, light-cured adhesives such as Transbond XT® are widely used, although chemical polymerized acrylic resins often demonstrate superior bonding to acrylic surfaces [14, 37, 39]. Despite theoretical advantages, acrylic resins present practical limitations, including handling complexity and extended working time, which justify the choice of Transbond XT® in this study.

The present work therefore aimed to identify the optimal surface treatment for CAD/CAM provisional crowns to maximize bracket bond strength while using a clinically practical adhesive system.

During orthodontic treatment, which typically spans 18–24 months, the bond strength of brackets gradually declines over time [40]. Therefore, simulating this aging process in vitro using thermocycling is of clinical interest. According to the International Organization for Standardization (ISO 11405), 500 cycles between 5 °C and 55 °C, with a 5-second interval in air, are recommended to mimic aging [41]. However, this number may not accurately reflect the actual duration of clinical treatment [42]. Recent orthodontic research has increased thermocycling to 1,500 cycles between 10 °C and 50 °C [43] and even up to 6,000 cycles between 5 °C and 55 °C [44].

Reicheneder *et al*. (2007) simulated a 9–10 month period over three days by exposing brackets to 1,100 alternating hot (55 °C) and cold (5 °C) water cycles [20]. To replicate an 18–20 month treatment, the same methodology can be extended to 2,200 cycles over six days. In our study, we adopted 2,200 cycles to approximate the average orthodontic treatment duration. Each cycle followed the ISO 11405 guidelines: 30 seconds in 5 °C and 55 °C baths, separated by a 10-second interval in air.

Assessment of residual adhesive after debonding is essential for evaluating the performance of orthodontic adhesives and was performed using the ARI scoring system [45]. To ensure comparability with prior studies [14, 35, 37, 40], the original Artun and Bergland (1984) method was employed, rather than the modified version by Bishara and Trulove (1990), since the scoring scales differ [46].

In our study, ARI scores of 1 predominated in groups 2, 3, and 4, whereas groups 5 and 6 mostly scored 2. This pattern can be attributed to the Plastic Conditioner penetrating the microporosities generated by diamond bur or sandblasting, resulting in improved chemical bonding and higher bond strength [28]. A drawback of this enhanced adhesion is the additional time required to remove all residual adhesive [45].

Study limitations include the subjective visual assessment of ARI under an optical microscope (KAPS, Germany) at various magnifications, which may affect measurement reliability. Additionally, oral environmental factors can influence bracket bond strength; in vivo values have been reported to be approximately 40% lower than those obtained in vitro [47, 48]. Further research is needed to evaluate how different surface treatments perform under clinical conditions.

Conclusion

Provisional crowns treated with either diamond bur plus Plastic Conditioner or sandblasting plus Plastic Conditioner demonstrated bond strengths comparable to natural teeth. Given that no statistically significant difference was observed between these two methods, sandblasting may be preferred due to its greater simplicity and ease of application.

Overall, these findings provide orthodontists with evidence-based guidance on selecting the most effective surface treatment for CAD/CAM provisional crowns, thereby reducing bracket debonding and potentially shortening the overall treatment duration.

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