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**Original Research Article**

# Comparison of Shear Bond Strength in Orthodontic Bracket Bonding to Porcelain Tooth Surface with Different Surface Preparation Methods

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**Abstract**

**Background:** With the increasing number of adult orthodontic patients, bonding orthodontic brackets to porcelain restorations has become a common clinical challenge. Achieving adequate bond strength without damaging the porcelain surface is critical for successful orthodontic treatment.

**Aim:** To compare the shear bond strength (SBS) of orthodontic brackets bonded to porcelain surfaces using different surface preparation methods.

**Materials and Methods:** A total of 60 glazed porcelain specimens were randomly divided into four groups ($n = 15$) based on surface preparation techniques: Group I – no surface treatment (control), Group II – hydrofluoric acid etching, Group III – sandblasting with aluminum oxide, and Group IV – sandblasting followed by silane application. Standard metal orthodontic brackets were bonded using light-cured composite resin. SBS was tested using a universal testing machine. Failure modes were assessed using the Adhesive Remnant Index (ARI). Statistical analysis was performed using one-way ANOVA and post-hoc Tukey tests.

**Results:** Group IV showed the highest mean SBS, followed by Group II and Group III, while Group I demonstrated the lowest bond strength. Statistically significant differences were observed among the groups ($p < 0.05$). ARI scores indicated predominantly adhesive failures in the control group and mixed failures in surface-treated groups.

**Conclusion:** Surface preparation significantly influences the shear bond strength of orthodontic brackets bonded to porcelain. Sandblasting followed by silane application provides optimal bond strength while minimizing porcelain damage.

**Keywords:** Porcelain surface, Orthodontic brackets, Shear bond strength, Surface preparation, Silane.



## Introduction

The paradigm shift in orthodontic practice over recent decades has resulted in a substantial increase in adult patients seeking orthodontic treatment. Unlike adolescent patients, adults frequently present with existing fixed prosthodontic restorations such as porcelain-fused-to-metal crowns, all-ceramic crowns, veneers, and inlays. This has introduced new clinical challenges, particularly in achieving reliable bonding of orthodontic brackets to non-enamel surfaces such as porcelain.[1,2]

Bonding orthodontic brackets to porcelain surfaces is fundamentally different from bonding to natural enamel. Enamel bonding relies on predictable micromechanical retention created by phosphoric acid etching, whereas porcelain is a chemically inert, highly glazed material with low surface energy, making adhesion difficult without surface modification.[3] Inadequate bond strength can lead to frequent bracket failures, prolonged treatment duration, increased chairside time, and patient dissatisfaction. Conversely, excessively high bond strength may result in irreversible porcelain damage during debonding, which is clinically unacceptable.[4]

An optimal bonding protocol to porcelain should therefore provide sufficient shear bond strength (SBS) to withstand orthodontic forces while ensuring safe debonding without surface fracture. Reynolds proposed that an SBS of 6–8 MPa is clinically adequate for orthodontic brackets; however, untreated porcelain surfaces often fail to meet this threshold.[5] Several surface preparation methods have been advocated to improve bonding to porcelain. These include mechanical roughening with diamond burs, airborne-particle abrasion (sandblasting), chemical etching with hydrofluoric (HF) acid, laser surface treatment, and the application of silane coupling agents.[6-8] HF acid etching selectively dissolves the glassy phase of porcelain, producing microporosities that enhance micromechanical retention, but its clinical use is limited due to its corrosive nature and risk of soft tissue injury.[9]

Sandblasting with aluminum oxide particles provides a safer mechanical alternative by increasing surface roughness and surface area available for bonding. However, mechanical roughening alone may not provide adequate chemical adhesion.[10] Silane coupling agents have therefore been introduced to promote chemical bonding between the silica content of porcelain and the organic matrix of resin adhesives, resulting in improved bond strength.[11]

Despite extensive research, there remains no universal consensus regarding the most effective and clinically safe surface preparation method for orthodontic bonding to porcelain. Variations in porcelain type, surface treatment protocols, adhesive systems, and testing methods contribute to inconsistent findings across studies.[12,13] Hence, this study was undertaken to compare the shear bond strength of orthodontic brackets bonded to porcelain surfaces using different surface preparation techniques and to evaluate their failure patterns.

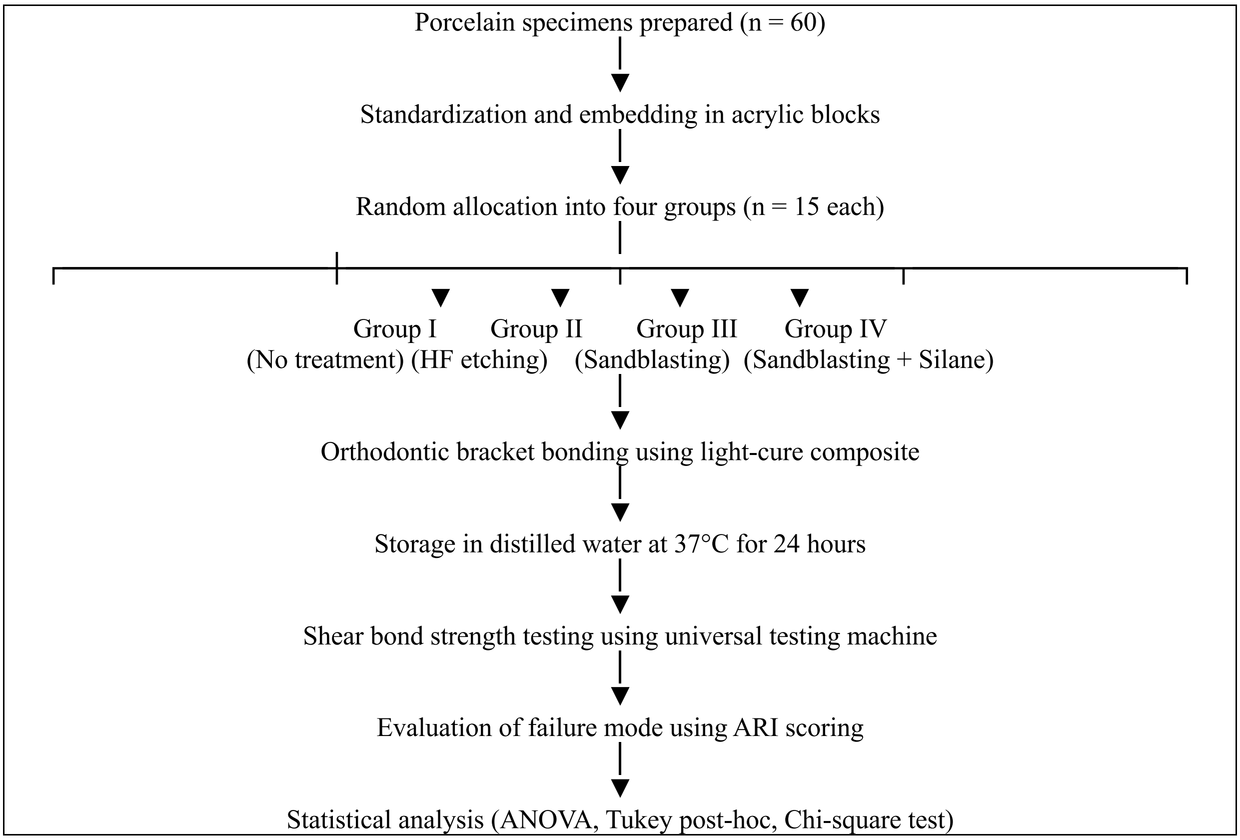
## Materials and Methods

**Study Design and Setting:** This in vitro experimental study was conducted in the Department of Orthodontics in collaboration with the Department of Dental Materials Science. The study was designed to evaluate and compare the shear bond strength (SBS) of orthodontic brackets bonded to porcelain surfaces subjected to different surface preparation protocols.

**Ethical Considerations:** Although the study was conducted in vitro, institutional ethical clearance was obtained prior to commencement. All procedures were performed following standard laboratory safety and research guidelines.

**Sample Size Determination:** Sample size was calculated based on previously published shear bond strength studies, assuming a power of 80% and a confidence level of 95%. A minimum of 15 samples per group was considered adequate to detect statistically significant differences among groups. A total of 60 porcelain specimens were included in the study.

**Flow Chart of Study Methodology (CONSORT-Style)**



**Porcelain Specimen Preparation:** Sixty standardized glazed feldspathic porcelain discs were fabricated using a silicone mold. Each specimen measured 10 mm in diameter and 2 mm in thickness. The porcelain discs were fired according to the manufacturer's instructions and finished with a uniform glazed surface to simulate clinically relevant porcelain restorations. Each specimen was embedded in self-cure acrylic resin blocks using cylindrical molds, leaving the glazed porcelain surface exposed for bonding. The exposed surface was cleaned with pumice slurry, rinsed with distilled water, and air-dried prior to surface treatment.

**Grouping of Samples:** The specimens were randomly allocated into four groups (n = 15) based on the surface preparation technique used:

- **Group I (Control):** No surface treatment
- **Group II:** Hydrofluoric acid etching
- **Group III:** Sandblasting with aluminum oxide
- **Group IV:** Sandblasting followed by silane application

**Surface Preparation Protocols**

**Group I – Control:** No surface treatment was performed. The glazed porcelain surface was used directly for bracket bonding.

**Group II – Hydrofluoric Acid Etching:** Porcelain surfaces were etched with 9.6% hydrofluoric acid gel for 60 seconds. The etched surfaces were thoroughly rinsed with water for 30 seconds and air-dried. Proper laboratory precautions were followed during acid handling.

**Group III – Sandblasting:** Porcelain surfaces were sandblasted using 50 µm aluminum oxide particles for 10 seconds at a pressure of 2.5 bar, maintaining a nozzle distance of approximately 10 mm. The surfaces were then rinsed and air-dried.

**Group IV – Sandblasting Followed by Silane Application:** Sandblasting was performed as described for Group III. After drying, a silane coupling agent was applied using a microbrush and allowed to react for 60 seconds, followed by gentle air drying.

**Bracket Bonding Procedure:** Standard stainless steel maxillary premolar orthodontic brackets with a mesh base were used for all specimens to ensure uniformity. A light-cured orthodontic composite resin adhesive was applied to the bracket base, and the bracket was positioned at the center of the porcelain surface under firm pressure.

Excess adhesive was removed using a dental explorer. Polymerization was performed using an LED curing light for 20 seconds (10 seconds from the mesial side and 10 seconds from the distal side), maintaining a constant light intensity.

**Storage Conditions:** After bonding, all specimens were stored in distilled water at 37°C for 24 hours to simulate intraoral conditions prior to mechanical testing.

**Shear Bond Strength Testing:** Each specimen was mounted in a universal testing machine. A chisel-shaped blade was positioned parallel to the porcelain surface at the bracket–adhesive interface.

Shear force was applied at a crosshead speed of 1 mm/min until bracket debonding occurred. The maximum force required to debond the bracket was recorded in Newtons (N) and converted into megapascals (MPa) using the formula:

SBS (MPa)=Force (N)/ Bracket base area (mm2)

**Failure Mode Analysis:** After debonding, porcelain surfaces were examined under a stereomicroscope at 10× magnification. The amount of residual adhesive on the porcelain surface was assessed using the Adhesive Remnant Index (ARI):

- **Score 0:** No adhesive remaining on porcelain
- **Score 1:** Less than 50% adhesive remaining
- **Score 2:** More than 50% adhesive remaining
- **Score 3:** All adhesive remaining on porcelain

**Statistical Analysis:** Statistical analysis was performed using SPSS software(Version 26.0). Mean and standard deviation values were calculated for SBS. Intergroup comparison was carried out using one-way ANOVA, followed by Tukey's post-hoc test. ARI scores were analyzed using the Chi-square test. A p value of $< 0.05$ was considered statistically significant.

**Results**

A total of 60 porcelain specimens were evaluated for shear bond strength (SBS) and mode of bond failure after orthodontic bracket debonding. All specimens were tested successfully without porcelain fracture.

The results clearly indicate that surface preparation plays a critical role in improving the shear bond strength of orthodontic brackets bonded to porcelain surfaces. Among the evaluated methods, sandblasting followed by silane application produced the highest bond strength and favorable failure patterns, suggesting its suitability for clinical application.

The mean shear bond strength values for the four study groups are summarized in Table 1. This demonstrates a progressive increase in SBS with the use of surface preparation techniques. The control group showed the lowest mean SBS, which was well below the clinically acceptable threshold. HF acid etching and sandblasting produced significantly higher bond strengths; however, the highest SBS was achieved when sandblasting was combined with silane application. This indicates that combined mechanical and chemical surface treatment provides superior adhesion compared to individual methods.One-way ANOVA revealed a statistically significant difference in SBS among the groups ($p < 0.001$).(Table1)

Post-hoc Tukey analysis revealed statistically significant differences between most pairwise group comparisons. Table 2 demonstrates that all surface-treated groups showed statistically significant improvement in SBS compared to the control group.

The sandblasting plus silane group exhibited significantly higher bond strength than both HF etching and sandblasting alone ($p < 0.001$), indicating the superiority of combined mechanical and chemical surface treatment. The difference between HF etching and sandblasting alone was also statistically significant ($p = 0.041$), suggesting that HF etching provides better bonding than mechanical roughening alone. (Table 2)

The distribution of Adhesive Remnant Index (ARI) scores among the groups is presented in Table 3.The control group predominantly showed ARI score 0, indicating adhesive failure at the porcelain–resin interface. In contrast, surface-treated groups, especially Group IV, demonstrated higher ARI scores (2 and 3), reflecting stronger adhesion and mixed failure patterns. Mixed failures are considered clinically favorable as they reduce the risk of porcelain damage during debonding.(Table3)

**Table 1: Mean Shear Bond Strength of Orthodontic Brackets Bonded to Porcelain Surfaces**

| Group | Surface Preparation Method | Mean SBS (MPa) | SD | Minimum | Maximum |
|---|---|---|---|---|---|
| I | No surface treatment (Control) | 3.2 | 0.8 | 2.1 | 4.6 |
| II | Hydrofluoric acid etching | 9.1 | 1.2 | 7.2 | 11.3 |
| III | Sandblasting | 7.4 | 1.0 | 5.8 | 9.2 |
| IV | Sandblasting + Silane | 12.3 | 1.5 | 9.8 | 14.6 |
| ANOVA ‘F’ Value | | 86.42 | | | |
| Significance ‘ P’ Value | | < 0.001 (Highly significant) | | | |

**Table 2: Intergroup Comparison of Shear Bond Strength (Tukey Post-Hoc Test)**

| Group Comparison | Mean Difference (MPa) | p-value | Significance |
|---|---|---|---|
| Group I vs Group II | 5.9 | <0.001 | Significant |
| Group I vs Group III | 4.2 | <0.001 | Significant |
| Group I vs Group IV | 9.1 | <0.001 | Significant |
| Group II vs Group III | 1.7 | 0.041 | Significant |
| Group II vs Group IV | 3.2 | <0.001 | Significant |
| Group III vs Group IV | 4.9 | <0.001 | Significant |

**Table 3: Distribution of Adhesive Remnant Index (ARI) Scores**

| ARI Score | Description | Group I | Group II | Group III | Group IV |
|---|---|---|---|---|---|
| 0 | No adhesive on porcelain | 10 | 2 | 3 | 1 |
| 1 | <50% adhesive on porcelain | 4 | 4 | 5 | 3 |
| 2 | >50% adhesive on porcelain | 1 | 6 | 5 | 7 |
| 3 | All adhesive on porcelain | 0 | 3 | 2 | 4 |
| Chi-squarevalue: | | 18.67 | | | |
| Significance ‘ P’ Value | | 0.009 (Statistically Significant) | | | |

**Discussion**

The present study evaluated the influence of different surface preparation methods on the shear bond strength of orthodontic brackets bonded to porcelain surfaces. The results demonstrated that surface treatment significantly affects bond strength, with the highest SBS values observed in the sandblasting followed by silane application group.

Untreated porcelain surfaces exhibited the lowest mean SBS, well below the clinically acceptable range suggested by Reynolds.[5] This finding is consistent with previous studies, which have reported poor adhesion to glazed porcelain due to its smooth surface and low surface energy.[14] The predominantly adhesive failures observed in the control group further confirm the inadequacy of bonding without surface modification.

HF acid etching significantly increased SBS compared to the control group. This improvement can be attributed to the creation of microporosities within the porcelain surface, allowing resin infiltration and micromechanical interlocking.[6] Similar findings have been reported by Zachrisson and Buyukyilmaz, who emphasized the effectiveness of HF acid in enhancing porcelain bond strength.[15] However, despite its efficacy, HF acid poses significant clinical risks, including chemical burns and irreversible damage to soft tissues, limiting its routine use in chairside orthodontic practice.[9]

Sandblasting with aluminum oxide particles also produced a significant increase in SBS compared to untreated porcelain. Airborne-particle abrasion increases surface roughness and removes the glazed layer, improving mechanical retention.[10] However, the bond strength achieved through sandblasting alone was lower than that achieved with HF etching and combined treatment, indicating that mechanical retention alone may be insufficient for optimal adhesion. These findings are in agreement with studies by Abu Alhaija et al. and Karan et al., who reported moderate bond strengths with sandblasting alone.[16,17]

The highest SBS values were observed in the group where sandblasting was followed by silane application. The superior performance of this method can be explained by the synergistic effect of mechanical roughening and chemical bonding. Sandblasting creates a roughened surface, while silane coupling agents form siloxane bonds with the silica phase of porcelain and copolymerize with the resin matrix, resulting in enhanced adhesion.[11,18] This combination provides both micromechanical and chemical retention, making it one of the most reliable and clinically acceptable techniques. Analysis of the Adhesive Remnant Index (ARI) revealed predominantly adhesive failures in the control group, whereas mixed failures were more common in the surface-treated groups. Mixed failure patterns are generally considered favorable, as they indicate adequate bond strength without excessive stress concentration at the porcelain surface.[19] Importantly, no porcelain fractures were observed in any group, suggesting that the tested surface preparation methods were safe under controlled experimental conditions. The findings of this study corroborate existing literature advocating combined mechanical and chemical surface treatment for bonding orthodontic brackets to porcelain restorations.[17,18] However, this study is limited by its in vitro design, which cannot fully replicate intraoral conditions such as thermal cycling, masticatory forces, and saliva contamination. Future studies incorporating aging protocols and different ceramic systems are recommended to further validate these results.

**Clinical Implications**

- Adult orthodontic patients frequently present with porcelain restorations, making reliable bracket bonding to ceramic surfaces a common clinical challenge.
- Surface preparation is essential for achieving adequate bond strength; bonding orthodontic brackets directly to untreated porcelain is not clinically acceptable due to insufficient adhesion and high failure rates.
- Sandblasting followed by silane application provides optimal shear bond strength while maintaining a favorable debonding pattern, thereby minimizing the risk of porcelain fracture during bracket removal.
- Compared to hydrofluoric acid etching, the sandblasting–silane protocol offers a safer chairside alternative by eliminating the hazards associated with acid handling while still delivering superior bonding performance.
- Adoption of this surface preparation protocol can reduce bracket failure, chairside time, and treatment duration, ultimately improving clinical efficiency and patient satisfaction.

**Conclusion**

Within the limitations of this in vitro study, it can be concluded that the method of surface preparation has a significant influence on the shear bond strength of orthodontic brackets bonded to porcelain surfaces. Untreated porcelain surfaces exhibited inadequate bond strength and unfavourable adhesive failure patterns, emphasizing the necessity of surface modification prior to bracket bonding. Among the evaluated surface preparation techniques, sandblasting followed by silane application produced the highest shear bond strength and demonstrated statistically superior performance compared to hydrofluoric acid etching and sandblasting alone. This combined approach provided both mechanical and chemical adhesion, resulting in clinically acceptable bond strength and favorablede bonding characteristics. Hydrofluoric acid etching and sandblasting individually improved bond strength when compared to untreated porcelain; however, their effectiveness was inferior to the combined treatment protocol. Analysis of the Adhesive Remnant Index revealed predominantly mixed failure patterns in surface-treated groups, suggesting adequate adhesion without increasing the risk of porcelain damage during debonding. Therefore, sandblasting followed by silane application can be recommended as a reliable and clinically safe surface preparation method for bonding orthodontic brackets to porcelain restorations. Future studies incorporating thermal cycling, long-term aging, and different ceramic systems are recommended to further validate these findings under simulated intraoral conditions.

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