A COMPARATIVE STUDY TO EVALUATE THE SHEAR BOND STRENGTH OF DIFFERENT BRACKET BASE DESIGN ON PRECONDITIONED ENAMEL SURFACE BONDED WITH LIGHT CURE BONDING MATERIAL. AN IN-VITRO STUDY

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ABSTRACT
Aim and Objectives: To evaluate and compare the shear bond strength (SBS) of stainless-steel foil mesh, sandblasted foil mesh, and laser-structured orthodontic bracket base designs bonded with a light-cure adhesive on normal and sandblasted enamel surfaces, and to assess enamel surface changes after debonding using scanning electron microscopy (SEM).

Materials and Methods: A total of 120 freshly extracted premolars with intact enamel surfaces were used. The samples were divided into two groups: normal enamel (Group A) and sandblasted enamel (Group B), with 60 teeth in each group. Each group was further subdivided into three subgroups (n=20): foil mesh brackets (A1/B1), sandblasted foil mesh brackets (A2/B2), and laser-structured brackets (A3/B3). Brackets were bonded using a light-cure adhesive. SBS was measured using a universal testing machine, and enamel surface morphology after debonding was evaluated using SEM. Statistical analysis was performed using one-way ANOVA.

Results: All groups demonstrated clinically acceptable SBS values (>8 MPa). The highest SBS was observed in laser-structured brackets bonded to sandblasted enamel (11.9 MPa), followed by sandblasted foil mesh brackets on sandblasted enamel (11.26 MPa). Sandblasting of enamel significantly increased SBS in all bracket types. SEM evaluation revealed minimal enamel surface alterations in foil mesh bracket groups, whereas laser-structured and sandblasted bracket groups showed greater enamel surface changes. Occasional enamel cracks were observed in the sandblasted foil mesh bracket group bonded to sandblasted enamel.

Conclusion: Sandblasting of enamel enhances shear bond strength irrespective of bracket design. Laser-structured brackets provide the highest bond strength but may result in greater enamel surface alterations. Sandblasted bracket bases offer improved bond strength with comparatively less enamel damage and may serve as a clinically favorable alternative for orthodontic bonding.

Keywords: Orthodontic brackets, Shear bond strength, Bracket base design, Sandblasting, Laser-structured brackets, Enamel surface, Scanning electron microscopy, Orthodontic bonding

How to cite this article: Chouksey G, Mishra A, Maheshwari R, Singh S, Kaushik S, Mary J. A Comparative Study to Evaluate the Shear Bond Strength of Different Bracket Base Design on Preconditioned Enamel Surface Bonded with Light Cure Bonding Material. An In-Vitro Study. Int J Drug Deliv Technol. 2026;16(61s):1596-1608. DOI: 10.25258/ijddt.16.61s.181

Source of support: Nil.

Conflict of interest: None

INTRODUCTION

Direct bonding of orthodontic brackets is an essential component of modern fixed appliance therapy and has significantly improved the efficiency and esthetics of orthodontic treatment1. Buonocore[2], regarded as the pioneer of adhesive dentistry, introduced the acid-etch technique in 1955, demonstrating that phosphoric acid treatment enhances the adhesion of resin materials to enamel. This breakthrough laid the foundation for

contemporary orthodontic bonding procedures. Subsequently, Newman[3] applied adhesive bonding techniques to orthodontics

and highlighted the potential of direct bracket bonding as an alternative to banding. Since then, continuous improvements in bonding materials and bracket base designs have enhanced clinical performance and reduced bond failures.

An ideal orthodontic bonding system should provide sufficient bond strength to withstand orthodontic and masticatory forces while allowing safe bracket removal without damaging the enamel surface. Reynolds reported that a bond strength of approximately 6–8 MPa is clinically adequate for successful orthodontic treatment. This concept remains a benchmark for evaluating orthodontic adhesives and bracket systems. Conventional phosphoric acid etching creates microporosities within enamel, facilitating micromechanical retention of resin adhesives. Although this method has proven highly successful, concerns regarding enamel demineralization, surface loss, and technique sensitivity have encouraged researchers to explore alternative surface-conditioning methods. Carstensen[9] demonstrated that variations in acid concentration can influence bonding outcomes, while Ogaard and Fjeld[47] emphasized the importance of preserving enamel integrity during orthodontic bonding procedures.

Among the alternative conditioning techniques, sandblasting has attracted considerable interest. Chung et al.[19] reported that sandblasting increases surface roughness and may enhance bracket retention. Similarly, Castro et al.[54] found that enamel sandblasting before etching can improve shear bond strength. However, concerns remain regarding the potential for enamel surface damage associated with this procedure. In addition to enamel preparation, bracket base design is a critical determinant of bond strength. Conventional foil-mesh brackets rely on mechanical interlocking between the adhesive and mesh structure. Faltermeier et al.[39] demonstrated that modifications in bracket base conditioning can significantly influence bond performance. More recently, laser-structured bracket bases have been introduced to create precisely engineered micro-retentive surfaces, potentially providing superior bond strength and reducing the incidence of bracket failure. While maximizing bond strength is desirable, preservation of enamel remains equally important. Ogaard and Fjeld[47] emphasized that excessive bond strength may increase the risk of enamel damage during debonding. Therefore, evaluation of enamel surface changes following bracket removal is essential. Scanning Electron Microscopy (SEM) enables detailed assessment of enamel topography and provides valuable information regarding the effects of different bonding protocols on enamel integrity.

In view of the continued search for an optimal balance between bond strength and enamel preservation, the present study was undertaken to evaluate and compare the shear bond strength of stainless-steel foil mesh, sandblasted foil mesh, and laser-structured bracket base designs bonded with a light-cure adhesive on normal and sandblasted enamel surfaces. Additionally, enamel surface changes following debonding were assessed using Scanning Electron Microscopy.

AIM & OBJECTIVES

To evaluate and compare the shear bond strength of different bracket base designs bonded with light cure bonding material on normal enamel surface and sandblasted enamel surface.

To evaluate and compare the shear bond strength of stainless-steel brackets with foil-mesh bracket base designs bonded with light cure bonding material on normal enamel surface and sandblasted enamel surface.

To evaluate and compare the shear bond strength of stainless-steel brackets with sandblasted foil mesh bracket base design bonded with light cure bonding material on normal enamel surface and sandblasted enamel surface.

To evaluate and compare the shear bond strength of stainless-steel brackets with laser structured bracket base design bonded with light cure bonding material on normal enamel surface and sandblasted enamel surface.

To evaluate and compare the surface topography of these de-bonded enamel surfaces using Scanning Electron Microscope.

MATERIALS AND METHODS

This in vitro study was conducted on 120 freshly extracted human premolar teeth with intact enamel surfaces. Teeth exhibiting caries, restorations, cracks, hypoplastic defects, or any surface irregularities were excluded. The extracted teeth were cleaned of debris and soft tissue remnants and stored in 0.1% thymol solution until use.

The samples were randomly divided into two main groups of 60 teeth each. Group A consisted of teeth with normal enamel surfaces, whereas Group B consisted of teeth whose enamel surfaces were subjected to sandblasting using aluminum oxide particles before bonding. Each main group was further subdivided into three subgroups of 20 teeth each according to the bracket base design used: stainless-steel foil mesh brackets (A1/B1), sandblasted foil mesh brackets (A2/B2), and laser-structured brackets (A3/B3). All brackets were bonded using a light-cure orthodontic adhesive following the manufacturer's instructions. After bonding, the specimens were mounted in acrylic blocks and subjected to shear bond strength testing using a universal testing machine. The force required for bracket debonding was recorded, and shear bond strength values were calculated in megapascals (MPa). Following debonding, selected enamel surfaces were examined under Scanning Electron Microscopy (SEM) to assess surface topography, enamel damage, and the effects of different bracket base designs and enamel conditioning procedures. The obtained data were statistically analyzed using descriptive statistics and one-way Analysis of Variance (ANOVA), with the level of significance set at $p < 0.05$

Group A1

Group A2

Group A3

Group B1

Group B2

Group B3

STATISTICAL ANALYSES

- Descriptive studies including Mean and Standard Deviation were computed for the entire group. The study had two main groups with three subgroups each.
- A general linear Analysis of variance (ANOVA) was performed to test the difference between groups – A1, A2, A3, B1, B2, B3.

RESULTS AND OBSERVATION FOR SEM STUDY

1. The SEM study of the brackets of group A has revealed that the subgroup A1 which has a mean SBS of 9.09MPa and subgroup A2 which has a mean SBS of 9.84MPa minimal enamel surface effects after debonding.
2. Whereas laser structured brackets of subgroup A3 had considerable surface effects on the debonded enamel surface.
3. The SEM study of the brackets of group B has revealed that the subgroup B1 which has a mean SBS of 9.80MPa has revealed minimal enamel surface defects after debonding of brackets. Whereas the SEM of subgroup B2 and B3 had,

considerable surface effect on the enamel surface after debonding. The sample of subgroup B2 also revealed cracks on the enamel surface after debonding.

4. It has been observed in this study that bonding with laser structured bracket base design and sandblasted stainless steel foil mesh bracket base design on normal enamel surface has revealed clinically acceptable SBS with minimal surface topographical effects under SEM

OBSERVATIONS

The results obtained in this study for shear bond strength of different groups and subgroups have revealed higher SBS of sandblasted of tooth surface in group B than that of group A which is indicative of the fact that the sandblasting of the tooth surface resulted in better shear bond strength than that of the normal enamel surface.

Observation for Group A (Table 1, Bar Diagram for Comparison of Group A, and Comparison of Mean SBS of Group A)

Observation for Group A (Table 1, Bar Diagram for Comparison of Group A, and Comparison of Mean SBS of Group A)

The comparative evaluation of the mean shear bond strength (SBS) of various bracket base designs bonded to normal enamel surfaces revealed that subgroup A1 (stainless steel foil mesh bracket base) showed the lowest mean SBS (9.09 ± 1.21 MPa), followed by subgroup A2 (sandblasted stainless steel bracket base) with a mean SBS of 9.85 ± 1.37 MPa. The highest mean SBS was observed in subgroup A3 (laser-structured bracket base) with a value of 10.91 ± 0.48 MPa. Although A1 exhibited the lowest bond strength, it was still above the clinically acceptable bond strength of 8 MPa.

Observation for Group B (Table 1, Bar Diagram for Comparison of Group B, and Mean SBS of Group B)

The comparison of the mean SBS of various bracket base designs bonded to sandblasted enamel surfaces demonstrated that subgroup B1 (stainless steel foil mesh bracket base) had the lowest mean SBS (9.80 ± 0.54 MPa). Subgroup B2 (sandblasted stainless steel bracket base) showed a higher mean SBS of 11.27 ± 1.04 MPa, while subgroup B3 (laser-structured bracket base) exhibited the highest mean SBS (11.98 ± 1.13 MPa). These findings indicate that laser-structured bracket bases provide superior bond strength on sandblasted enamel surfaces.

Observation for Subgroups A1 and B1 (Bar Diagram for Comparison of Normal and Sandblasted Enamel – Group A1/B1)

The comparison between subgroup A1 and subgroup B1 showed that the mean SBS of B1 (9.80 ± 0.54 MPa) was higher than that of A1 (9.09 ± 1.21 MPa). This suggests that sandblasting of the enamel surface increased the bond strength of conventional stainless steel foil mesh brackets.

Observation for Subgroups A2 and B2 (Table 4 and Bar Diagram for Comparison of Group A2/B2)

Subgroup B2 demonstrated a significantly higher mean SBS (11.27 ± 1.04 MPa) than subgroup A2 (9.85 ± 1.37 MPa). The difference was found to be statistically highly significant ($p < 0.0001$), indicating that enamel sandblasting significantly enhanced the bond strength of sandblasted stainless steel bracket bases.

Observation for Subgroups A3 and B3 (Table 5 and Bar Diagram for Comparison of Group A3/B3)

The comparison between laser-structured brackets bonded to normal enamel (A3) and sandblasted enamel (B3) revealed that subgroup B3 (11.98 ± 1.13 MPa) exhibited significantly higher mean SBS than subgroup A3 (10.91 ± 0.48 MPa). The difference was statistically highly significant ($p < 0.0001$), suggesting that sandblasting of the enamel surface further improved the bond strength of laser-structured bracket bases.

Observation from Table 2 (Table 2: Mean Bond Force in Newtons of Various Subgroups)

The highest mean bond force was recorded in subgroup B3 (151.73 ± 14.30 N), followed by B2 (142.61 ± 13.16 N) and A3 (138.12 ± 6.13 N). The lowest mean bond force was observed in subgroup A1 (115.08 ± 15.33 N). These findings correspond closely with the SBS values and indicate superior retention of laser-structured bracket bases.

Observation from Table 3 (Table 3: Comparative Evaluation of Mean Bond Strength of Group A and Group B)

The overall mean SBS of Group B (10.97 MPa) was higher than that of Group A (9.95 MPa), indicating that sandblasting of the enamel surface enhanced bond strength irrespective of the bracket base design used

The bond strength of the laser structured bracket (A3 and B3) was found to be significantly higher than all other bracket base in both the groups. It

was revealed that the bond strength of the laser structured brackets used on the normal enamel surface i.e. subgroup A3 was comparable to the bond strength of the sandblasted brackets used on the sandblasted enamel surface subgroup B2.

There was no significant variation seen in the mean SBS of foil mesh brackets bonded on the normal enamel surface and the sandblasted surface and that of the sandblasted brackets bonded on the normal enamel surface.

Table 1. Table-1: Showing the mean value of the shear bond strength of various bracket base designs

Subgroup	Type of sample	Sample size	Mean SBS	Std dev
A1	SBS OF STAINLESS STEEL FOIL MESH BRACKET BASE DESIGN ON NORMAL ENAMEL SURFACE	20	9.0900	1.21087
A2	SBS OF SANDBLASTED STAINLESS STEEL BRACKET BASE DESIGN ON NORMAL ENAMEL SURFACE	20	9.8450	1.36785
A3	SBS OF LASER STRUCTURED BRACKET BASE DESIGN ON NORMAL ENAMEL SURFACE	20	10.9100	.48439
B1	SBS OF STAINLESS STEEL FOIL MESH BRACKET BASE ON SANDBLASTED ENAMEL SURFACE	20	9.8000	.53803
B2	SBS OF SANDBLASTED STAINLESS STEEL FOIL MESH BRACKET BASE ON SANDBLASTED ENAMEL SURFACE	20	11.2650	1.03988
B3	SBS OF LASER STRUCTURED MESH BRACKET BASE ON SANDBLASTED TOOTH SURFACE	20	11.9850	1.12964

TABLE 2: SHOWING THE MEAN VALUE OF BOND FORCE IN NEWTON OF VARIOUS SUBGROUPS

SUBGROUPS	N	Mean	Std. Deviation
A1	20	115.0794	15.32964
A2	20	124.6377	17.31704
A3	20	138.1206	6.13235
B1	20	124.0680	6.81143
B2	20	142.6149	13.16483
B3	20	151.7301	14.30120

Table 3: Comparative evaluation of mean bond strength of group A and B

Group	N	Mean	Stand dev
A	60	9.948	1
B	60	10.966	1

TABLE 4: COMPARISON OF MEAN SHEAR BOND STRENGTH BETWEEN SUBGROUP A2 AND B2

SUBGROUP	N	MEAN	STD DEV	LEVEL OF SIGNIFICANCE
A2	20	9.8450	1.36785	SIGNIFICANT VARIATION
B2	20	11.2650	1.03988	<0.0001

TABLE 5: COMPARISON OF SHEAR BOND STRENGTH BETWEEN SUBGROUP A3 AND B3

SUBGROUP	N	MEAN	STD DEV	LEVEL OF SIGNIFICANCE
A3	20	10.9100	.48439	SIGNIFICANT VARIATION
B3	20	11.9850	1.12964	<0.0001

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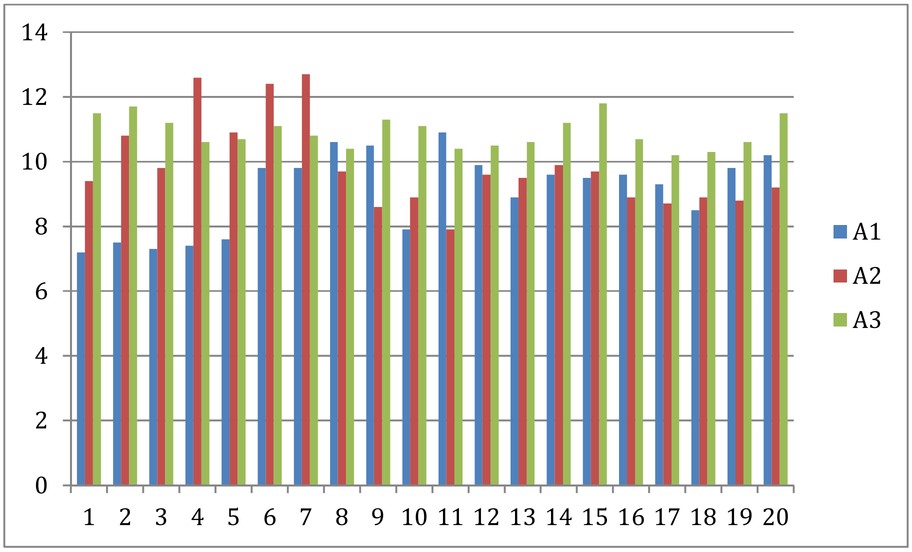
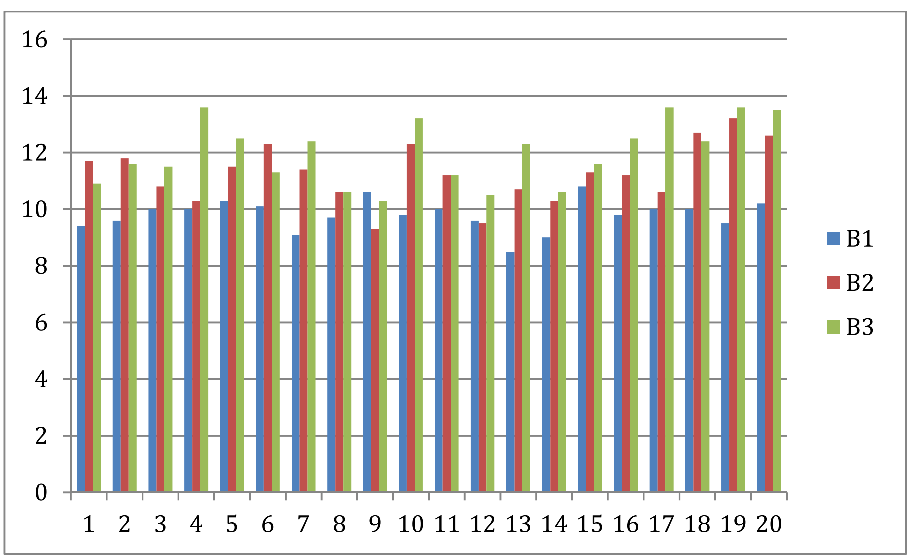
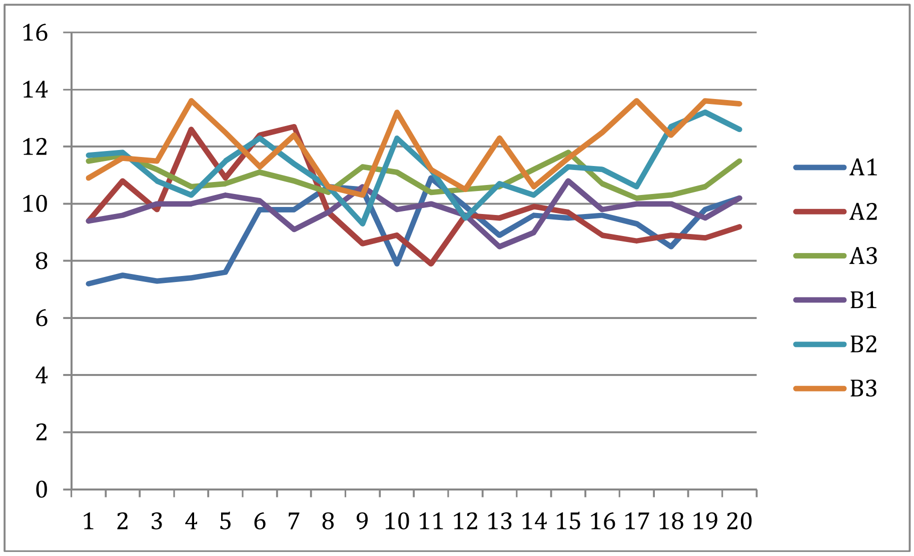


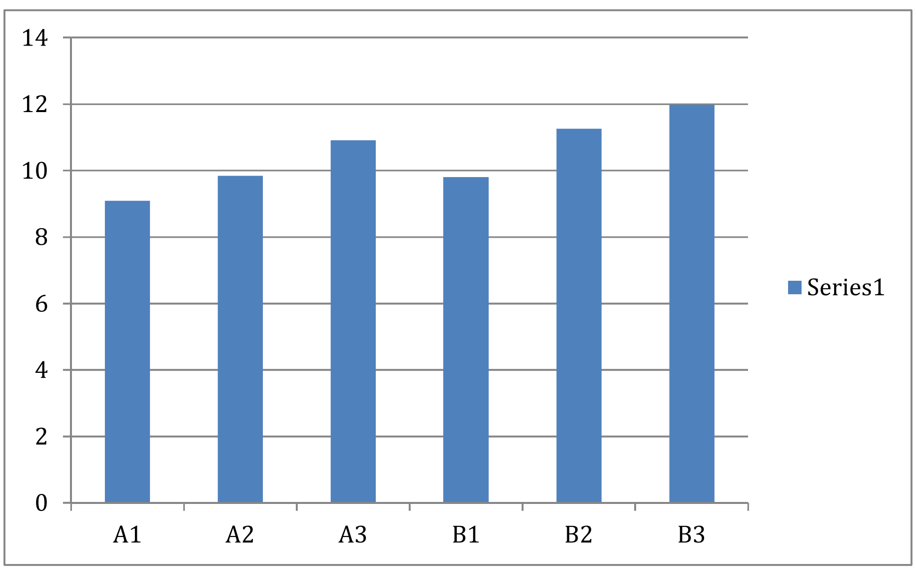
GRAPHS: BAR DIAGRAM FOR COMPARISON OF GROUP A



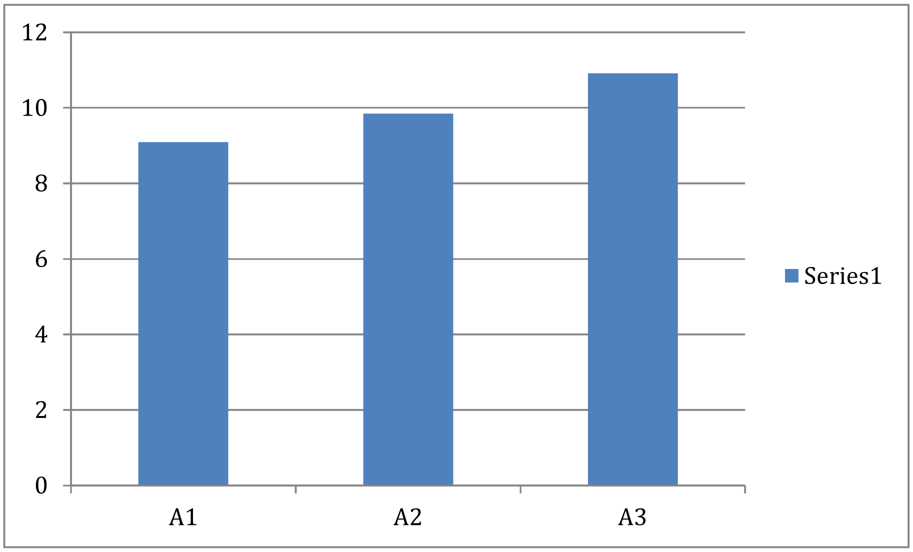
BAR DIAGRAM FOR COMPARISON OF GROUP B



LINE DIAGRAM FOR COMPARISON OF ALL THE GROUPS



COMPARISON OF MEAN SBS



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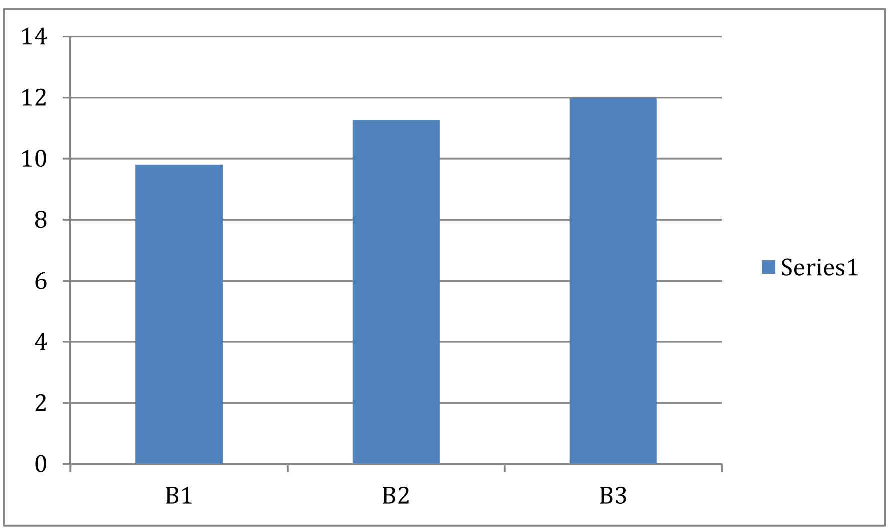
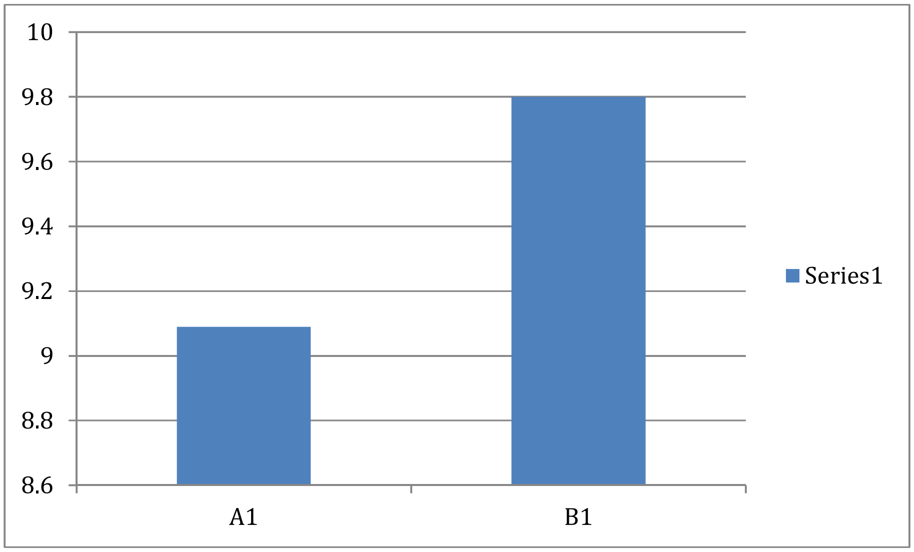
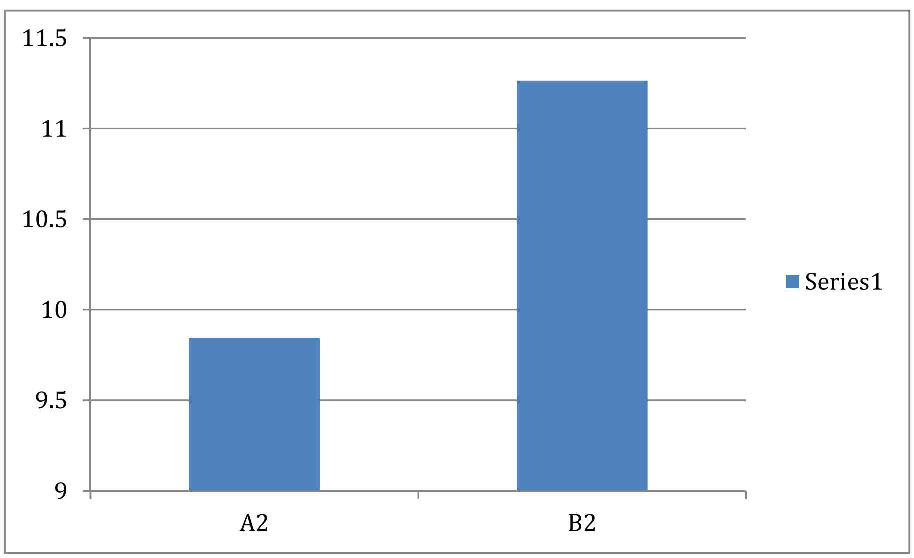


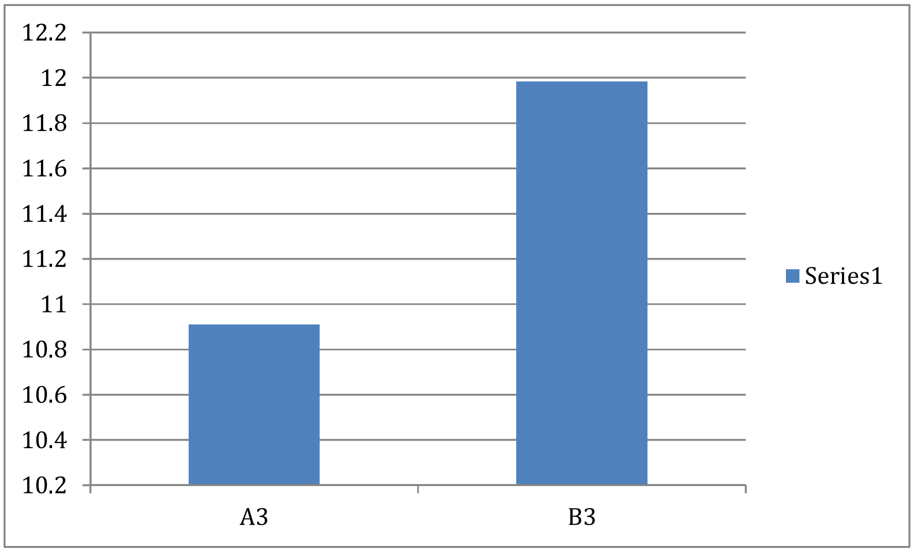
MEAN SBS OF GROUP B



BAR DIAGRAM FOR COMPARISON OF NORMAL AND SA NDBLASTED ENAMEL (GROUP A1/B1)



GROUP A2/B2



GROUP A3/B3

DISCUSSION

The success of orthodontic treatment largely depends on adequate bracket retention throughout treatment. Shear bond strength (SBS) remains the most widely accepted parameter for evaluating the clinical performance of orthodontic bonding systems. Oesterle and Shellhart demonstrated that aging procedures significantly influence SBS values, emphasizing the importance of long-term bond stability rather than immediate bond strength alone.[30, 35] Similarly, Pakshir et al. and Shooter et al. reported that testing variables such as crosshead speed can affect measured SBS values, highlighting the need for standardized testing protocols.[31, 57]

Surface conditioning of enamel plays a crucial role in bond effectiveness. Ozer, Basaran and Berk showed that laser etching can produce clinically acceptable bond strengths by creating micro-retentive enamel patterns.[32] Furthermore, Ozturk et al. and Endo et al. reported that enamel characteristics vary among different tooth types and dentitions, which may influence bonding performance.[33, 34]

The present study demonstrated that sandblasting of enamel increased SBS compared with conventional etching alone. Similar findings were reported by Castro et al., who observed enhanced bond strength when enamel sandblasting preceded acid etching during indirect bonding procedures.[54] However, despite the increase in SBS, SEM evaluation revealed greater enamel surface alterations, suggesting that routine enamel sandblasting may not always be justified because of the risk of iatrogenic damage.

Evaluation of bond failure patterns is equally important. Montasser and Drummond emphasized the reliability of the Adhesive Remnant Index (ARI) for assessing the site of bond failure and the amount of residual adhesive following debonding.[38] In the present investigation, ARI findings indicated that sandblasted and laser-structured bracket bases tended to retain more adhesive at the bracket–adhesive interface, thereby reducing enamel damage during debonding.

Bracket-base design has a substantial influence on bond strength. Faltermeier and Behr demonstrated that bracket-base conditioning significantly improves adhesive retention by increasing surface roughness and mechanical interlocking.[39] Similarly, Talpur et al. reported that bracket base dimensions and design directly affect bond strength and resistance to debonding.[58] In the current study, sandblasted bracket bases produced significantly higher SBS than conventional foil-mesh brackets, supporting the concept that increased micro-retention enhances adhesive performance.

Laser-structured brackets exhibited the highest SBS values among all tested groups. The superior performance may be attributed to the precisely engineered retentive architecture produced during manufacturing. However, ARI analysis suggested a greater tendency for adhesive retention on the bracket base, which may increase stresses transferred to enamel during debonding. These findings are consistent with observations by Zanarini et al., who reported that bracket-base characteristics strongly influence adhesive remnants and debonding patterns.[62]

Several studies have examined factors influencing the mechanical properties of enamel surrounding bonded brackets. Iijima et al. and Kohda et al. reported that bonding materials can alter enamel mechanical behavior adjacent to orthodontic brackets.[43, 60] Likewise, Tostes et al. demonstrated that laser irradiation can modify enamel microhardness around orthodontic attachments.[64] These findings suggest that both bonding procedures and surface treatments can affect enamel integrity and should be considered when selecting a bonding protocol.

Recent investigations have focused on improving adhesive performance through material modification. Naidu et al. demonstrated that caries infiltrant pretreatment can influence SBS values, while Poosti et al. reported enhanced antibacterial activity with TiO_2 nanoparticle-containing orthodontic composites without compromising bond strength.[61, 63] Additionally, Sfondrini et al. found that bracket reconditioning procedures can maintain acceptable SBS values, supporting the clinical feasibility of bracket recycling.[59]

The present findings indicate that both sandblasted and laser-structured bracket bases provide superior bond strength compared with conventional brackets. While enamel sandblasting improved SBS, the associated enamel surface loss remains a significant drawback. In contrast, bracket-base sandblasting increased bond strength with minimal risk to enamel integrity. Therefore, modification of the bracket base appears to be a more conservative and clinically acceptable method for improving orthodontic bond performance. Although laser-structured brackets demonstrated the highest SBS values, their increased cost and potential for greater enamel stress during debonding should be considered when selecting bracket systems for routine clinical use.

CONCLUSIONS

Within the limitations of this in vitro study, bracket base design significantly affected shear bond strength. Laser-structured brackets showed the highest bond strength, followed by sandblasted bracket bases, while conventional foil-mesh brackets exhibited the lowest values. Although sandblasting of enamel increased bond strength, it also caused greater enamel surface alterations. Sandblasting of the bracket base improved bond strength without significant enamel damage and appears to be a more conservative and clinically acceptable method for enhancing bracket retention.

LIMITATIONS

As an in vitro study, the oral environment could not be fully simulated. Factors such as saliva, temperature changes, masticatory forces, and long-term aging were not evaluated. In addition, only premolar teeth and a single bonding system were tested, which may limit the direct clinical applicability of the results.

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