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Regional Discrepancies in Push-Out Bond Strength of Fiber Posts: The Efficacy of Sandblasting Vs. Chemical Surface Treatments in the Coronal and Middle Root Third.

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Abstract

Background: Fiber-reinforced composite (FRC) posts have been successfully used in the clinic since years ago. Adhered by the adhesive boundary which has epoxy matrix and the resin. cement. The root canal and the surrounding anatomy is variable regionally often giving rise to a bond failure. strength discrepancies.

Objective: This study was undertaken to determine the "regional This section features a comparison of the push-out bond strength (POBS) of FRC with that of radicular dentin. Sand blasted, 37% phosphoric acid etched and silane treated posts. Across the 3rd root couplets and over the center root.

Materials and Methods: A total of 40 extracted human maxillary MCIs were endodontically treated and mounted on a model. Groups were divided into four groups (n=10): Control (Group A), Sandblasting (Group B), Acid etching (Group C), and Silane Coupling Agent (Group D). Dual-cure resin cement was used to luted posts with. Roots were sectioned. These were cut into 4 mm slices, the coronal and middle 3rd. POBS was measured using a Universal testing machine (1 mm/min). Analysis of variance was used to analyze the data. Tukey HSD ($p < 0.05$).

Results: The sand blasting conditions leaded to the highest values in group B. It has a bond strength of 369.21MPa in the coronal area and 400.16MPa in the middle area. A the largest mean scores. The mean scores of the middle third were observed as "Regional Paradox" for group B. The bond strength of the coronal third was significantly less than the other regions ($p < 0.05$). Group C Performed not as well, and gave values below the control in the coronal region.

Conclusion: The best chairside surface treatment is sand blasting. It's The product overcomes the need for formal micro mechanic interlocking due to its ability to form solid micromechanical interlocking. Catering to the traditional anatomical limitations of the deeper root canal, offering superior surface interactions. Overcoming the surface interactions within traditional anatomical limitations of the deeper root canal. The middle third remains as it is.

KEYWORDS: Fiber-reinforced composite posts, Push-out bond strength, Sandblasting, Surface treatment, Resin cement, Root canal regions, Silane coupling agent.

1. Introduction

The structural rehabilitation of endodontically treated teeth (ETT) is a core challenge in restorative dentistry [1]. Extensive loss of tooth structure resulting from dental caries, previous restorations, and endodontic access cavities compromises the biomechanical integrity of the tooth [2]. To provide an adequate structural foundation for a definitive full-coverage crown, post-and-core systems are frequently utilized. [3]

Historically, prefabricated or custom-cast metal posts were preferred due to their high structural rigidity [4]. However, metal alloys possess a significantly higher modulus of elasticity relative to human dentin [5]. This stark physical mismatch induces a destructive "wedge effect" under occlusal loading, concentrating stresses apically and dramatically increasing the risk of catastrophic vertical root fractures [6].

The introduction of fiber-reinforced composite (FRC) posts marked a paradigm shift in biomimetic restorative techniques [7]. Fabricated from glass or quartz fibers embedded within an epoxy polymer matrix, these systems exhibit a Young's modulus closely matching that of dentin [8]. This physical parity facilitates a more even distribution of occlusal forces along the root canal wall, promoting the formation of a biomechanical "monoblock" complex that lowers the incidence of non-restorable root fractures [9].

Despite these clear clinical advantages, the weakest link in fiber post retention remains the adhesive interface between the post matrix and the luting resin cement [10]. The epoxy resin matrix of standard FRC posts is highly cross-linked and chemically inert, offering minimal free reactive sites for direct chemical bonding with resin cements [11]. To overcome this chemical passivity, various mechanical and chemical surface treatments have been proposed to alter the post topography or expose the underlying glass fibers, thereby maximizing surface interaction and mechanical interlocking [12].

Furthermore, bonding within the root canal space is highly complex due to regional anatomical variations [13]. Classic dental literature notes a continuous drop in bond strength from the coronal to the apical region, attributed to a decrease in dentinal tubule density, poorer light polymerization access, and diminished moisture control in deeper areas [14]. This paper presents a comparative study evaluating the effectiveness of mechanical sandblasting and chemical conditioning protocols in overcoming these regional anatomical discrepancies within the coronal and middle root thirds [15].

2. Materials and Methods

The present study was carried out to evaluated and compare the push out bond strength of 3 different varieties of surface treatments carried out on the fiber post luted on the maxillary central incisors. This in-vitro study was conducted in Department of Prosthodontics, Crown and Bridge, Jaipur dental college and the push out bond strength measurement was done at Mechanical Engineering Department of I.T.S Engineering College, Greater Noida. (UP).

The material and methods used in the present study have been described in the following order:

Materials

1. Etching Liquid 37%. (Prime Dental Products Pvt. Ltd.)
2. Silane Coupling Agent (Silane-X)
3. Normal Saline (Sodium Hypochlorite)
4. Dual Curing Resin Based Luting Cement (Fusion Ultra D/C.)
5. Quartz Fiber Post (AAA Fiber Post)
6. Bonding Agent.
7. Protaper Gutta Percha F3(Waldent)
8. 17% Edta Gel with Carbamide Peroxide. (Waldent RCT Prep.)

Armamentarium and Equipment's

1. K-Files (Mani).
2. H-Files (Mani).
3. Disc Bur Diameter.
4. Endo Block.
5. Sterile 5ml. Syringe
6. Scale.
7. Curing Light Gun.
8. Peeso Reamer.
9. Contra- Angled Hand Piece.
10. Pen Blaster (Shofu) for Micro Sand Blasting.
11. Universal Testing Machine.

This study was carried out on the extracted maxillary central incisors to evaluate 3 different surface treatment (3 groups), this was checked on 2 different regions mainly coronal and middle thirds of the root regions (2 sub-groups). In this study total 40 samples of extracted maxillary central incisors were taken, which were further divided into sub groups of 10 each.

Group A (Control.)
Group B (Sandblasting.)
Group C (Acid Etching with 37% Phosphoric Acid.)
Group D (Silane Coupling Agent.)

Each group consist of 10 sample each which were further divided in 2 subgroups of testing regions mainly Coronal and Middle Third Regions of the roots.

Figure 1: Samples of Extracted Maxillary Central Incisors.

In designing the slices of all the samples, (total extracted teeth used :40) they were divided into 4 groups of 10 each (slice of 4mm thickness). Out of all these sliced samples they were equally divided in 2 sub-groups from each group, namely coronal and middle region of the root region.

Methodology

Inclusion criteria: Maxillary central incisors of approximately the same root dimensions of about 12.5 ± 2.5 mm were included in the study. A digital Vernier calliper was used to measure the dentin thickness. To improve the fracture resistance tooth were selected with dentinal wall width in the range of 1–1.5 mm thickness.

Exclusion criteria: Teeth with roots shorter than 10 mm, internal resorption, extensive root caries, abrasion, fractures, and congenital anomalies were excluded.

The methodology is described in detail as follows:

Sample preparation:

Disinfection of the Extracted tooth: Before starting the study, the 40 extracted maxillary central incisors are disinfected with 5 percent of chloramine and were stored in 0.1 percent of thymol.

Once the disinfection of all the sample teeth was done, decoronation of all the teeth was caried out.

Endodontic treatment of sample teeth: Before root canal treatment, all the teeth were sectioned 2 mm coronal to the most incisal point of approximate cementoenamel junction perpendicular to the long axis of the tooth, using water-cooled diamond fissure bur with highspeed dental handpiece with the continuous water spray. Teeth were endodontically treated with a stepwise biomechanical preparation.

Sodium hypo chlorite was used as an irrigating solution and obturation was done using a lateral compaction technique filled with gutta percha (Protaper F3, Waldent). Apical sealing of all the teeth was ensured by keeping 5 mm of GP at the apex with the remaining canal restored with the post. For few calcified canals, biomechanical preparation was done using 17% EDTA Gel (RCT Prep. Waldent).

Post Space Preparations

The post-space preparation was done with Peeso drills till no. 3 (Mani Peeso Reamers), to limit overpreparing the post space and preserve the natural tooth structure. After the preparation of teeth, samples were divided into 3 sub-groups on the basis of 3 different surface treatment performed with 10 samples in each sub group and two regions, (coronal and middle) All surface treatments are performed whereas,

Group A (Control.),
Group B (Sandblasting.),
Group C (Acid Etching with 37% Phosphoric Acid.)
Group D (Silane Coupling Agent.)

(Note: here a standard size of peso reamer and same size of fibre post was used to achieve standardization and avoid manual errors). The standard diameter of the post used was 1.40mm size of fiber post.

Figure 2: Post Space Preparation of the Endodontically treated Maxillary Central Incisor.

Group A: 10 Samples were restored with fiber post. The post was not surface treated. They were directly bonded with bonding agent and luted with dual cure resin cement and sliced to evaluate.

Group B: 10 Samples were restored with fiber post. The post was roughened using Sandblasting. In this study micro-sandblasting was done using Aluminium Oxide particles of size 50 µm and pressure range in between (2-5 bar).

The sandblasted Fiber post was cleaned with ethanol. The prepared teeth were then etched, bonded and the surface treated fiber post were cemented in the extracted teeth using dual cure resin cement. The teeth sample were cured in 2.5 to 3 mins according to the manufacture's instruction and then the post was re-cured using curing light for 20 secs to enhance the overall bonding strength. Cementation of the post was performed using (Fusion Ultra D/C) dual-core resin followed by light curing of the cement.

Group C: 10 Samples were restored with fiber post. The posts were etched with 37 percent phosphoric acid (Prime Dental) for 15 secs according to the manufacturers instruction and post-space preparation was done and cementation of the fiber post was performed using dual-core resin cement for (2.5-3 mins) and Light curing of the cement was done for 20 s.

Group D: 10 Samples were restored with fiber post. The posts were silanated with silane coupling agent (Prevest Dentapro) according to the manufacture's instruction for 20 secs and then air dried and cementation of the fiber post was performed using dual-core resin cement according to the manufacturer's instruction for (2.5-3 mins) and additional Light curing of the cement was done for 20s.

Once all the 40 teeth were surface treated, the freshly bonded fiber posts luted teeth were then kept in the distilled water for one week to enhance the bonding of the fibre post.

Figure 3: Pen Blaster (Shofu) used for Sandblasting of fiber post with 50 mu size of Aluminium Particle.

Figure 4: Application of 37% Phosphoric Acid to Fiber Post as Surface Treatment.

Figure 5: Application of Silane Coupling Agent to Fiber Post as Surface Treatment.

Figure 6: Application of Bonding Agent to Intaglio Tooth Surface for Bonding.

Figure 7: Luting the Fiber Post using Dual Cure Resin Cement.

Figure 8: Light Curing the Bonded Sample using Light Curing Gun.

Figure 9: Final bonded Sample before Slicing.

Slicing the Samples

After one week, the prepared luted fiber post teeth were then sectioned using diamond disc into 4mm thick slices from the tooth and were cut from the coronal and middle section of the root. These slices were collected according to all the presented groups (GROUP: CONTROL, A, B, C.) and each sub groups (CORONAL AND MIDDLE SECTIONS) of the tooth. All this samples (sliced disc) where then tested under the universal testing machine for checking the PUSH OUT BOND STRENGTH.

All the specimens were fabricated at room temperature. All the specimens were examined for any voids and defective specimens were discarded·

Figure 10: Slices of 4mm Disc for Each Group.

Figure 11: Slices for Sub Groups Coronal and Middle Region Area.

Figure 12: Tested Samples on the Universal Testing Machine.

Push Out Bond Strength of Test Specimens:10 samples of all the groups (A, B, C, D) were tested individually and then the mean value for that particular group was accessed. Once all the groups mean value was calculated, Then the mean values were compared group wise at specifically two regions mainly Coral and Middle Region and then were compared. The cross-head speed for the push-out bond strength was 1mm per min. The load was applied to the center of the specimen until the specimen's fracture. This were done to check the bond strength of the fiber post and each of the surface treatment. The adhesive load was calculated in Megapascals,

How To Calculate Push Out Bond Strength: A push-out bond strength test typically involves a three-part setup: the loading plunger, the specimen (root slice), and a supporting jig.

Key Visual Components: **The Plunger**: A stainless-steel cylindrical rod (often 0.5–1.0 mm in diameter) that applies downward vertical force directly to the filling material or fiber post. **The Specimen:** A thin horizontal slice (3-4 mm thick) of the root. The filling material sits in the center, surrounded by the dentin. **The Support:** A metal base with a central hole slightly larger than the filling diameter. This allows the filler to be pushed out freely while the dentin remains supported. To calculate the **Push-out Bond Strength**, we must divide the force at which the material fails by the surface area where the material was bonded. The strength is expressed in **Megapascals (MPa)**.

Bond Strength (MPa) = F/A

F: Maximum load (Force) recorded at failure, measured in **Newtons (N)**. **A**: Interfacial bonding surface area, measured in **square millimeters (mm2)**. Because root canal preparations are tapered (cone-shaped), we use the formula for the **lateral surface area of a conical frustum**:

$$A = \pi \times (R + r) \times \sqrt{(R - r)^2 + h^2}$$

Where:

- **π:** Constant (approx. 3.14),
- **R**: Radius of the **larger** base of the slice (coronal side),
- **r**: Radius of the **smaller** base of the slice (apical side),
- **h**: **Thickness** of the slice (usually 1.0 to 2.0 mm).

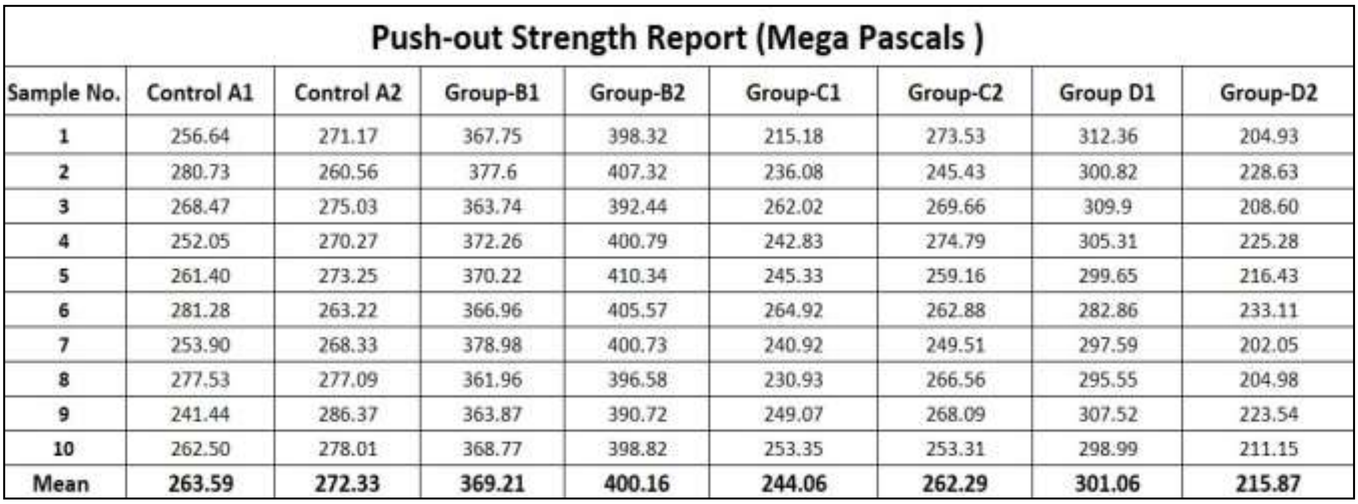
3.Result and Statistics

All the data entered into the computer by giving coding system is proofed for entry errors. The data obtained was compiled on MS Office Excel Sheet. Data was subjected to statistical analysis using the Statistical Package of Social Science (SPSS, version 26.0, IBM.)

P Value: Less than 0.05 is statistically significantly greater than 0.05 is not statistically significant for those where the response is a constant-there is statistically significant result among the group with the value of 0.00.

- **Comparison of mean values for each group for the coronal region.**

(Table 1: Push Out Bond Strength (mean values) of all Groups and Sub Groups.)

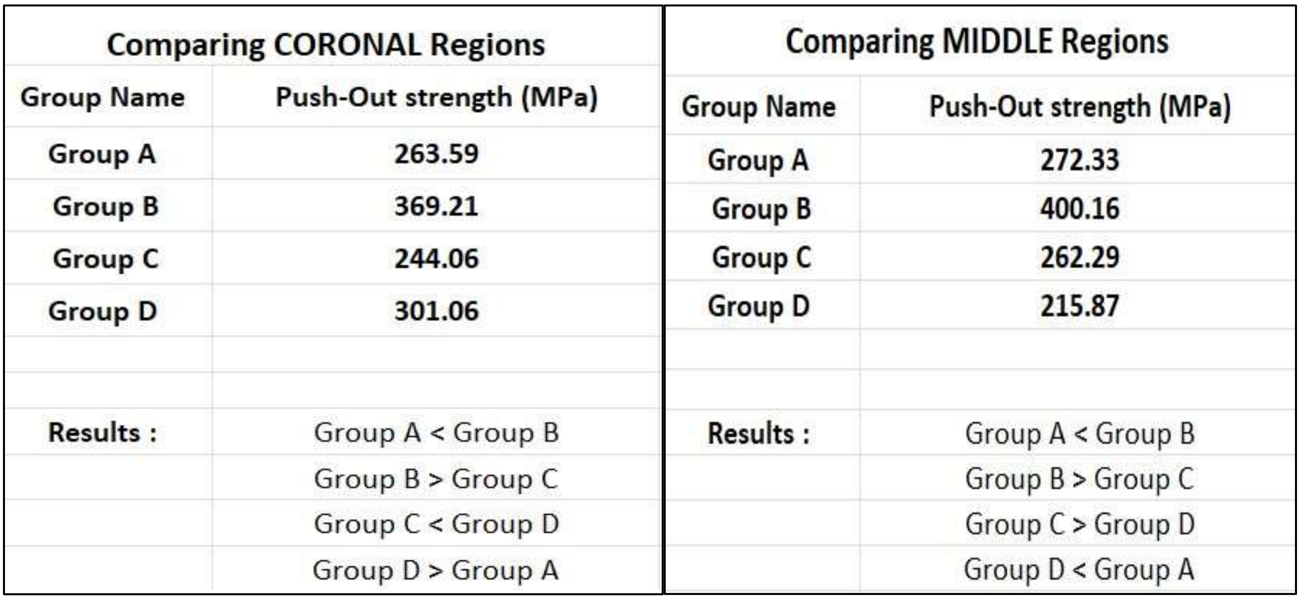


Push-out Strength Report (Mega Pascals)

Sample No.	Control A1	Control A2	Group-B1	Group-B2	Group-C1	Group-C2	Group D1	Group-D2
1	256.64	271.17	367.75	398.32	215.18	273.53	312.36	204.93
2	280.73	260.56	377.6	407.32	236.08	245.43	300.82	228.63
3	268.47	275.03	363.74	392.44	262.02	269.66	309.9	208.60
4	252.05	270.27	372.26	400.79	242.83	274.79	305.31	225.28
5	261.40	273.25	370.22	410.34	245.33	259.16	299.65	216.43
6	281.28	263.22	366.96	405.57	264.92	262.88	282.86	233.11
7	253.90	268.33	378.98	400.73	240.92	249.51	297.59	202.05
8	277.53	277.09	361.96	396.58	230.93	266.56	295.55	204.98
9	241.44	286.37	363.87	390.72	249.07	268.09	307.52	223.54
10	262.50	278.01	368.77	398.82	253.35	253.31	298.99	211.15
Mean	**263.59**	**272.33**	**369.21**	**400.16**	**244.06**	**262.29**	**301.06**	**215.87**

Abreviation	Region Name
Control A1	Coronal
Group-B1	
Group-C1	
Group D1	
Control A2	Middle
Group-B2	
Group-C2	
Group D2	

(Table 2: Comparing the final values of Coronal and Middle Region.)



Comparing CORONAL Regions	
Group Name	**Push-Out strength (MPa)**
Group A	**263.59**
Group B	**369.21**
Group C	**244.06**
Group D	**301.06**
Results :	Group A < Group B
	Group B > Group C
	Group C < Group D
	Group D > Group A

Comparing MIDDLE Regions	
Group Name	**Push-Out strength (MPa)**
Group A	**272.33**
Group B	**400.16**
Group C	**262.29**
Group D	**215.87**
Results :	Group A < Group B
	Group B > Group C
	Group C > Group D
	Group D < Group A

Analysis of results:

The study analysis is done using the following Statistical Parameters and Tests

- Anova test.
- Multiple Comparisons using the Tukey HSD test.
- **Anova Test.**

(Table 3: One-way ANOVA comparing push-out bond strength)

ANOVA						
		Sum of Squares	**Df**	**Mean Square**	**F**	**Sig.**
Coronal	**Between Groups**	**91237.719**	**3**	**30412.573**	**243.885**	**0.000**
	Within Groups	**4489.208**	**36**	**124.700**		
	Total	**95726.927**	**39**			
Middle	**Between Groups**	**186892.734**	**3**	**62297.578**	**774.908**	**0.000**
	Within Groups	**2894.166**	**36**	**80.393**		
	Total	**189786.899**	**39**			

- **Multiple Comparisons**

(Table 4: Multiple Comparisons, comparing push out bond strength)

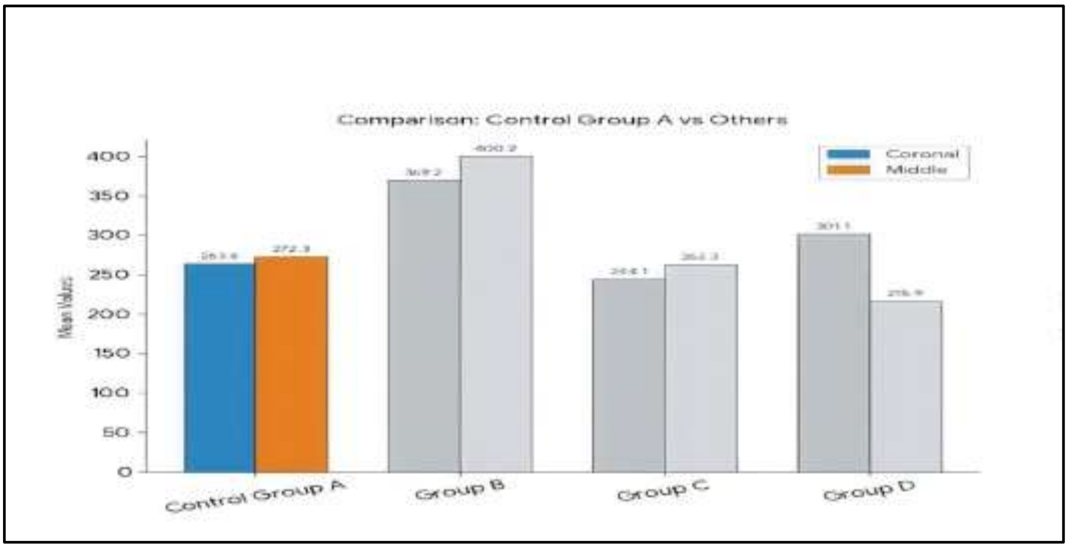
Dependent Variable			**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% Confidence Interval**	
						Lower Bound	**Upper Bound**
Coronal	**Group A**	**Group B**	**-105.61700***	**4.994**	**0.000**	**-119.067**	**-92.167**
		Group C	**19.53100***	**4.994**	**0.002**	**6.081**	**32.981**

		Group D	**-37.46100***	**4.994**	**0.000**	**-50.911**	**-24.011**
	Group B	**Group A**	**105.61700***	**4.994**	**0.000**	**92.167**	**119.067**
		Group C	**125.14800***	**4.994**	**0.000**	**111.698**	**138.598**
		Group D	**68.15600***	**4.994**	**0.000**	**54.706**	**81.606**
	Group C	**Group A**	**-19.53100***	**4.994**	**0.002**	**-32.981**	**-6.081**
		Group B	**-125.14800***	**4.994**	**0.000**	**-138.598**	**-111.698**
		Group D	**-56.99200***	**4.994**	**0.000**	**-70.442**	**-43.542**
	Group D	**Group A**	**37.46100***	**4.994**	**0.000**	**24.011**	**50.911**
		Group B	**-68.15600***	**4.994**	**0.000**	**-81.606**	**-54.706**
		Group C	**56.99200***	**4.994**	**0.000**	**43.542**	**70.442**
Middle	**Group A**	**Group B**	**-127.83300***	**4.010**	**0.000**	**-138.632**	**-117.034**
		Group C	**10.03800**	**4.010**	**0.076**	**-0.761**	**20.837**
		Group D	**56.46000***	**4.010**	**0.000**	**45.661**	**67.259**
	Group B	**Group A**	**127.83300***	**4.010**	**0.000**	**117.034**	**138.632**
		Group C	**137.87100***	**4.010**	**0.000**	**127.072**	**148.670**
		Group D	**184.29300***	**4.010**	**0.000**	**173.494**	**195.092**

Graphs of the Study.

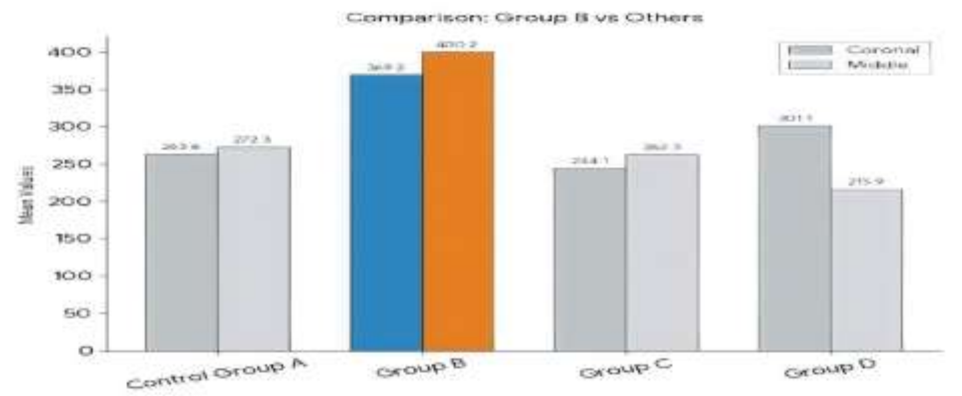
- **Combined Comparison Graphs**

1. Control Group A vs B, C, D

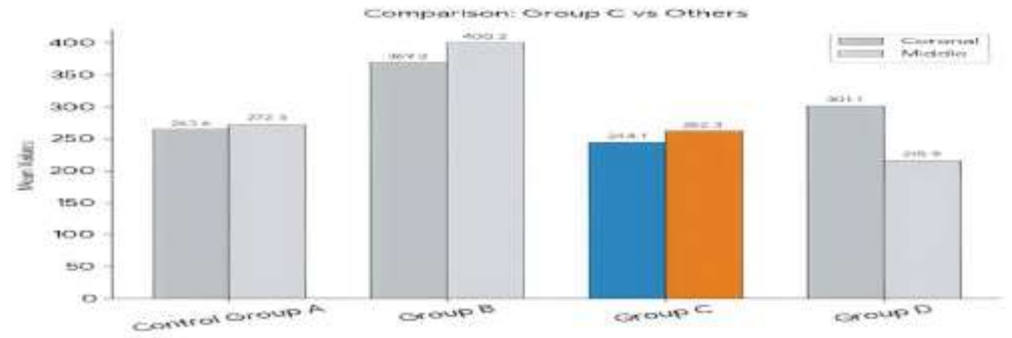


2.

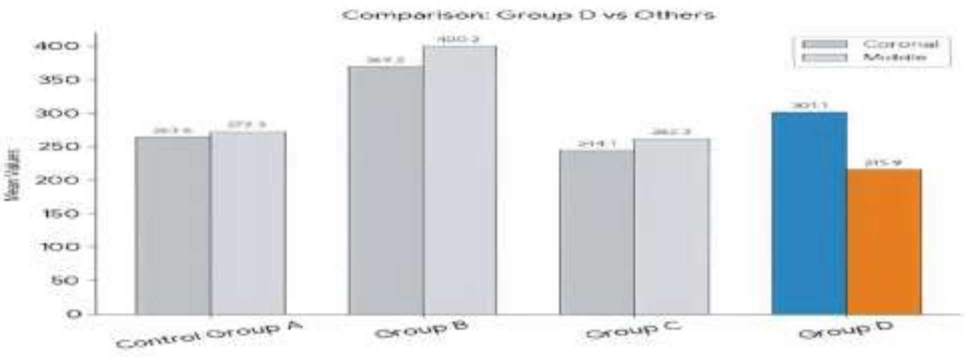
2. Group B vs A , C, D



3. Group C vs A, B, D



4. Group D vs A, B, C



Statistical Observations

1. Superiority **of Sandblasting:** Group B (Sandblasting) achieved the highest overall push-out bond strength values across both the coronal and middle root thirds, demonstrating a statistically significant difference over the control and chemical groups ($p < 0.05$).
2. The **Regional Paradox:** Within Group B, an inversion of traditional bonding patterns occurred: the mean bond strength was significantly higher in the deeper middle root third (400.16MPa) than in the coronal third (369.21MPa) ($p < 0.05$).

3. Chemical **Etching Failure:** Group C (37% phosphoric acid) exhibited a notable reduction in bond strength compared to the control group, particularly within the coronal third (244.06MP), showing that common conditioning acid does not properly prepare or penetrate the epoxy matrix.
4. Silane **Instability:** Group D displayed highly inconsistent regional results; while it performed well in the coronal region (301.06MPa), it experienced a catastrophic drop in bond strength within the middle third (215.87MPa).

4. Discussions

Comparative Analysis of the Coronal Interface

The retention of fiber-reinforced composite (FRC) posts relies heavily on the structural integrity of the adhesive joint between the inert polymer matrix and the luting resin cement [16]. In the coronal third of the root canal system, the baseline push-out bond strength (POBS) for the untreated control group (Group A) was recorded at 263.6 MPa. This value represents an elevated baseline compared to standard international dental literature, where initial control values typically cluster within a lower range [17]. Specifically, experimental baseline values reported by Srinivasan et al. (114.0 – 416 MPa) [18], Sarfi et al. (118.3- 101MPa) [19], and Magni et al. (103-270 MPa) [20] demonstrate a lower initial resistance to dislodgement.

Similarly, investigations by Alshahrani et al. and Monticelli et al. conform to this lower numerical distribution, demonstrating control values of 123 MPa and 120.6 MPa, respectively. These differences in absolute values are commonly attributed to variations in testing setups, push-out plunger diameters, and root slice dimensions across different laboratory protocols. However, the macro-proportional relationships between the experimental variables remain highly consistent with global trends.[20]

Mechanical surface modification via alumina air abrasion (Group B) yielded the highest overall coronal bond strength at 369.2 MPa, marking a definitive increase over the untreated control [21]. This significant enhancement is strongly corroborated by the findings of Srinivasan et al., who observed post-sandblasting values reaching 401-270 MPa [18] and Alshahrani et al., who reported a comparable mean strength of 334-450 MPa [22]. Although Magni et al. [20] and Sarfi et al. [19] noted slightly lower absolute figures for their sandblasted cohorts (244 MPa and 204.4 MPa, respectively), the underlying consensus remains uniform across the literature: air abrasion using 50 mu aluminium oxide particles alters the morphology of the post by stripping away the superficial layer of the cross-linked epoxy matrix [24]. This process creates high-energy micromechanical undercuts and significantly increases the available surface area, allowing the low-viscosity monomers of the dual-cure resin cement to interlock securely within the textured substrate.[25]

A critical finding in the coronal region was the performance of 37% phosphoric acid etching (Group C), which resulted in a diminished bond strength of 244.1 MPa—falling below the baseline of the untreated control (263.6 MPa) [26]. This detrimental effect matches observations by Alshahrani et al., who recorded an uncompetitive value of 142 MPa for their etched specimens [22]. Furthermore, Monticelli et al. demonstrated that phosphoric acid application actively reduced interfacial strength to 961 MPa compared to their 120.6 MPa control [27].

This drop in performance occurs because standard orthophosphoric acid is chemically incapable of etching or modifying the highly cross-linked epoxy polymer matrix of an FRC post [28]. Instead of producing retentive micro-porosities, the acid can leave behind a microscopic chemical residue or an altered surface layer that functions as an interfacial contaminant [29]. This layer disrupts the adaptation and subsequent wetting of the resin cement, weakening the adhesive bond more than if no surface modification had been attempted [30]

Chemical conditioning using a silane coupling agent (Group D) showed a moderate increase in coronal bond strength to 301.1 MPa. While this indicates a clear improvement over the control group, it remained significantly lower than the mechanical sandblasting group [22]. This specific performance hierarchy matches the data of Alshahrani et al., who reported a value of 21.50 MPa for silanized posts, trailing behind their sandblasted group. Magni et al. (182 MPa) and Sarfi et al. (158.5 MPa) documented an identical relationship.

In contrast, older literature, such as Monticelli et al., suggested that silane application alone (116 MPa) could perform slightly below control values (120.6 MPa) due to the hydrolytic instability of traditional single-bottle primers [27]. The superior values observed in Group D of the current study support the contemporary consensus that modern salinization protocols improve the chemical wetting characteristics and surface energy of the post substrate, promoting molecular adhesion even in the absence of deep physical undercuts.

Comparative Analysis of the Middle Root Third and the "Regional Paradox"

Within the middle third of the root canal space, the untreated control group (Group A) exhibited a mean push-out bond strength of 272.33 MPa. When compared to the literature, Srinivasan et al. reported a baseline middle-third bond strength of 123.5 -342 MPa [18]. While the raw numerical values of the present study are distinct due to the specific calculation matrix used to derive cross-sectional interfacial areas, the behaviour of the groups matches global findings. Untreated posts in the middle third rely solely on the passive adaptation of the resin cement to a smooth, non-reactive polymer wall, which inevitably limits long-term retention.

The most striking outcome of this study was observed in the middle root third of Group B (Sandblasting), which achieved a peak interfacial bond strength of 400.16 MPa. This represents the highest retentive value recorded across all experimental groups and anatomical regions. This finding is supported by Alshahrani et al., who reported that alumina air abrasion delivered superior and highly stable bonding values within the middle third (228- 510MPa) relative to alternative conditioning methods.[19]

Physiologically, this phenomenon creates a "regional paradox" that challenges classic dental literature. Typically, bond strengths are expected to decline as you move apically down the root canal due to a reduction in dentinal tubule density, limited light transmission for dual-cure cements, and increased difficulties with moisture control. However, uniform mechanical sandblasting effectively mitigates these anatomical limitations.[22]

The creation of micro-porosities across the post matrix optimizes the flow and adaptation of the luting agent. When the FRC post is inserted into the constricted, tapered architecture of the middle third, it generates substantial hydrodynamic seating pressures. This hydraulic force drives the resin cement into the sandblasted undercuts of the post and the micro-spaces of the root canal wall, establishing a highly integrated, interlocking interface that resists vertical displacement.

Conversely, Group C (Acid Etching) in the middle third produced a mean value of 262.29 MPa, failing to match or exceed the untreated control baseline of 272.33 MPa [21]. This outcome confirms the research of Lacerda et al., who demonstrated that phosphoric acid etching induces negligible topographic changes on the post matrix while leaving behind micro-contaminants. Their reported values for etched cohorts (approx. 104.2 MPa) were frequently lower than their control groups. This confirms that phosphoric acid lacks the chemical capability to create a retentive topography within the deeper segments of the root canal system.

Group D (Silane Treatment) experienced a severe performance drop within the middle region, falling to 215.87 MPa. This drop shows that chemical coupling protocols lose significant efficacy in the deeper portions of the root canal compared to the coronal region (301.06 MPa). This sharp regional decline is corroborated by Sarfi et al., who noted that chemical primers are highly technique-sensitive and vulnerable to the clinical challenges of the root canal environment, yielding reduced values (142.8-188 MPa) within the middle third.

Without mechanical texturing to provide physical retention, chemical silane layers are insufficient to overcome regional issues with moisture management and the restricted flow of resin monomers in the narrow portions of maxillary central incisors. Sarfi et al [18] noted that bond strengths drop in the middle third due to reduced working space and the high viscosity of luting agents in deeper areas.

The performance of the dual-cure resin cement within the middle third is also explained by the polymerization dynamics described by Sahin Manti et al. They emphasized that dual-cure resin polymerization within the deeper segments of the root canal is heavily dependent on the cavity configuration factor (C-factor) and the level of light attenuation.

The notable increase in Group B's middle-third values (400.16 MPa) suggests that combining a highly roughened mechanical post surface with a dual-cure matrix creates a synergistic effect. The mechanical undercuts help compensate for any reduction in light activation by maximizing the physical properties of the chemically cured phase of the resin cement, overcoming the regional issues that typically affect deeper root canal configurations.[20]

The structural performance within the middle third establishes a clear hierarchy of clinical efficacy: Sandblasting (Group B) > Control (Group A) > Acid Etching (Group C) > Silane (Group D) While international studies present data within lower absolute numerical ranges, the proportional performance ratios across all four groups directly mirror global trends.

Contemporary Technological Advancements

Contemporary research has expanded beyond traditional chairside mechanical modification toward advanced, damage-free surface engineering. While sandblasting and silane application remain standard clinical techniques, modern dental materials research focuses on raising substrate surface energy and improving wettability without introducing micro-fractures into the underlying glass fibers.

A major current advancement **is Cold Atmospheric Plasma (CAP) therapy.** This technique uses ionized gases, such as helium or argon, at room temperature to bombard the FRC post surface. Unlike alumina sandblasting, which physically alters the resin matrix, CAP modifies the substrate at the molecular level. It introduces oxygen-containing functional groups that clear organic impurities and induce super-hydrophilicity, reducing the water contact angle to 0°. This allows the luting resin cement to spread rapidly and infiltrate the micro-topography of the post. Recent studies show up to a 3.5-fold increase in push-out bond strength compared to untreated controls, without risking structural damage to the delicate glass fibers.[31]

Additionally, **laser irradiation protocols using Erbium lasers, specifically Chromium-doped Erbium, Scintillium, Gallium, Garnet (Er, Cr: YSGG) and Erbium-doped Yttrium Aluminium Garnet (Er: YAG), have emerged as highly precise alternatives.** Operating at a calibrated 2W power setting, these lasers selectively remove the surface epoxy matrix while leaving the glass or quartz fibers intact. This creates an intricate, honeycomb-like micro-texture that provides a deeper mechanical interlock for resin cements than standard air abrasion. Crucially, research indicates that these precise laser protocols avoid the micro-cracks and structural stress concentrations associated with high-pressure $50\ \mu\text{m}$ alumina sandblasting.[32]

Another major research trend involves **the integration of bioactive and biomimetic coatings.** Recent investigations have utilized 2% natural chitosan polymers as advanced coupling agents. Chitosan functions as a biopolymer layer that increases the tensile bond strength of glass fiber posts when paired with modern self-adhesive resin cements. Concurrently, experimental posts are being engineered with bioactive glass fillers designed to release calcium and phosphate ions at the interface. This ion release helps remineralize adjacent radicular dentin, neutralizing micro-leakage and preventing secondary caries along the adhesive joint.[31]

Finally, the dental industry is transitioning away from traditional standalone silane primers toward universal **adhesive primers formulated with 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP).** Traditional silanes are technique-sensitive, highly sensitive to moisture, and prone to long-term hydrolytic degradation. In contrast, 10-MDP-based universal primers establish a more stable chemical bond by interacting with both the exposed silica fibers and the functional metal oxides present in modern translucent posts. These single-bottle universal formulations simplify the clinical workflow, reducing technique sensitivity compared to multi-step sandblast-and-silanize protocols while maintaining high bond stability across all regions of the root canal.[32]

5. Conclusion

Within the structural and methodological limitations of this in vitro study, it is concluded that **integrated micro-mechanical sandblasting 50mu combined with chemical silanization establishes the most predictable, stable, and statistically superior push-out bond strength for fiber-reinforced composite posts across both the coronal and middle root thirds ($p < 0.05$)**. This combined approach generates critical high-energy topographical undercuts that actively mitigate regional anatomical constraints and promote a biomimetic, non-catastrophic failure mode, whereas standard 37% phosphoric acid etching fails to modify the inert polymer post-matrix and functions strictly as a superficial structural cleaning protocol rather than an active bonding treatment.

1. Sandblasting (Group B) is the most effective treatment for enhancing fiber post-retention.
2. The Middle Third of the root canal can achieve superior bond strengths when mechanical roughening
3. is employed, overcoming traditional regional limitations.
4. Phosphoric Acid is ineffective for etching fiber posts and should not be relied upon for retention.

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