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The Effect of Er: YAG Laser Assisted Endodontic Irrigation Using Endo Tip on the Pushout Bond Strength of Fiber Posts to the Root Dentine: An In- Vitro Study

Abhishek M[1], Kiran Kumar N[2], Savitha B Naik[3], Swetha Geervani V[4], M Manimozhi[5]

[1,2,3,4,5] Government Dental College and Research Institute, Bangalore, Karnataka, India

1. Corresponding Author: Dr Abhishek M, Department of Conservative Dentistry & Endodontics, Government Dental College and Research Institute, Bangalore, Karnataka, India – 560002.

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ABSTRACT:
Background: Effective smear layer removal is critical for improving the adhesive strength of fiber posts in endodontically treated teeth. Laser-assisted irrigation, particularly using the Er:YAG laser with specialized endo tips, has shown promise in enhancing root canal cleanliness, thereby potentially increasing post retention.Aim and objective: To compare and evaluate the pushout bond strength of fiber posts to root dentine following endodontic irrigation using different irrigants, with and without Er:YAG laser activation using endo tips.Materials and methods: Sixty-five extracted single-rooted teeth were selected and decoronated to obtain standardized root lengths. Root canal preparation was carried out using the crown-down technique, followed by lateral condensation obturation. Post space was prepared, and specimens were categorized into five groups (n = 13) based on irrigation protocol: Group 1 – 0.5% saline (control); Group 2 – 5.25% NaOCl + EDTA + Er:YAG laser with sapphire tip; Group 3 – 2% CHX + EDTA + Er:YAG laser with sapphire tip; Group 4 – 5.25% NaOCl + EDTA + Er:YAG laser with side-firing endo tip; Group 5 – 2% CHX + EDTA + Er:YAG laser with side-firing endo tip. Glass fiber posts were luted into the post space, and the roots were sectioned into coronal, middle, and apical thirds. Pushout bond strength was measured using a universal testing machine. Results: Among the tested groups, Group 4 demonstrated the highest mean pushout bond strength, followed by Groups 5, 2, 3, and 1, respectively. Statistical evaluation revealed significant intergroup differences ($p < 0.05$), indicating that Er:YAG laser activation using a side-firing tip substantially improved bonding efficacy.Conclusion:Er:YAG laser-assisted irrigation, particularly when paired with a side-firing endodontic tip in conjunction with NaOCl and EDTA, substantially improves the pushout bond strength of fiber posts to root dentine. This technique holds promise for enhancing the durability of post-endodontic restorations.

KEYWORDS: Er:YAG laser, Sodium hypochlorite, Chlorhexidine, Laser assisted irrigation, Pushout bond strength, Fiber post, smear layer removal.

I. INTRODUCTION

Root canal treatment (RCT) is a core procedure in dentistry, intended to preserve teeth compromised by pulpal or periapical conditions. Its success depends on meticulous shaping,cleaning, disinfection, and obturation to prevent microbial reinfection[1].Although advancements in endodontic technology have improved procedural outcomes, long-term treatment success remains a challenge. A crucial phase of RCT is post-endodontic restoration, which often involves the use of fiber posts to reinforce the structural integrity of treated teeth. The longevity of such restorations is highly dependent on the bond strength between root dentine and the fiber post, which in turn is affected by factors such as smear layer presence, irrigant choice, and bonding protocols [2].

The primary goal of RCT is to alleviate symptoms and maintain natural teeth by eliminating bacteria from the root canal system. Effective cleaning and shaping are critical for removing microbial biofilms, necrotic tissue, and debris. However, due to the intricate root canal anatomy, complete debridement is often difficult. Residual pathogens and debris frequently persist in uninstrumented areas, making effective irrigation essential for improving disinfection [3]. Failures in endodontic therapy are commonly associated with incomplete bacterial removal and insufficient sealing. Although methods such as rotary instrumentation and ultrasonic activation have enhanced cleaning efficacy, total bacterial eradication remains elusive, particularly in curved or accessory canals[4].

One significant by-product of mechanical instrumentation is the formation of a smear layer—a combination of organic and inorganic debris, including necrotic tissue and microorganisms. This layer adheres tightly to canal walls and interferes with the success of root canal treatment [5]. It obstructs irrigants and sealers from penetrating dentinal tubules, compromising the bonding between fiber posts and root dentine. Despite its thin profile (typically 1–2 µm), smear plugs can penetrate deep into dentinal tubules, further hampering adhesion [6].

Beyond impeding bonding, the smear layer can harbor microorganisms, acting as a source for reinfection. Studies indicate that bacteria can survive within this layer, contributing to endodontic failure [7]. Consequently, both conventional and advanced strategies have been developed for smear layer removal, including laser-assisted techniques [8].

Effective smear layer removal is vital for successful bonding in post-endodontic restorations. Traditional chemical agents like sodium hypochlorite (NaOCl) and ethylene diamine tetra acetic acid (EDTA) are commonly used. NaOCl provides strong antimicrobial action and dissolves organic matter, while EDTA targets inorganic components. However, these irrigants are often unable to eliminate the smear layer uniformly throughout the root canal system [9].

The penetration depth of NaOCl is influenced by its concentration, exposure duration, and temperature. Studies show that 6% NaOCl can reach up to 300 µm after 20 minutes at 45°C, whereas 1% NaOCl at room temperature reaches just 77 µm. This indicates that higher concentrations and longer exposure times improve efficacy [10].

Chlorhexidine (CHX), another widely used irrigant, has a different penetration pattern. At 2% concentration, CHX reaches 138 µm in the coronal third, 80 µm in the middle third, and 44 µm in the apical third. This reduced apical penetration is attributed to lower tubule density and more peritubular dentin. CHX is appreciated for its substantivity, remaining adsorbed on dentin surfaces for prolonged antimicrobial action [11].

To address limitations of conventional irrigation, alternative approaches such as laser-assisted irrigation have been introduced [12]. Recent technological advances have enabled the use of Er:YAG lasers for endodontic irrigation. Operating at 2940 nm, this laser induces a photoacoustic effect, effectively disrupting smear layer and biofilm without harming dentinal structures [13]. Research indicates that Er:YAG laser irrigation outperforms traditional methods, particularly in hard-to-reach apical regions [14].

Innovations like photon-induced photoacoustic streaming (PIPS) and shock wave-enhanced emission photoacoustic streaming (SWEEPS) have been developed to further improve irrigation outcomes by achieving cleaner dentinal surfaces, which are essential for robust adhesive bonding [15].

Resin-based adhesives are integral to the durability of fiber post restorations. Bond strength depends on adhesive type, dentin condition, and smear layer presence. A hybrid layer, formed by resin infiltration into demineralized dentin, is key to secure bonding [16]. However, achieving uniform adhesion is complicated by limited canal access, tubule orientation, and varying dentin density. Post surface treatments like silanization or sandblasting, along with the use of dual-cure and self-adhesive cements, have been shown to improve bonding performance [17].

Smear layer removal enhances adhesive penetration and improves bond strength. Evidence supports that eliminating the smear layer promotes resin infiltration, resulting in more reliable adhesion [18]. Despite this, traditional irrigants often fail to fully clean the apical third, which is where laser-assisted irrigation shows promise [19].

Although laser-assisted irrigation appears advantageous, further studies are needed to standardize protocols and confirm its clinical efficacy. Current findings suggest that Er:YAG lasers may enhance bond strength in difficult-to-reach regions, but comparative research with conventional methods remains necessary [20].

This study aims to evaluate the impact of various irrigating solutions on the pushout bond strength of fiber posts to root dentine. It also seeks to assess the effectiveness of Er:YAG laser-activated irrigation using an endo tip. By addressing these goals, the study aims to refine endodontic irrigation protocols and improve outcomes in post-endodontic restoration [21].

II. MATERIALS AND METHODS

Sixty-five single-rooted human teeth were selected for the study. Cracked teeth, eroded teeth, hypocalcified teeth, tooth with root caries, tooth with vertical root fracture were excluded. To ensure proper disinfection, all teeth were stored in a 0.5% thymol solution for one month. Remaining periodontal tissues and surface debris were carefully removed using a periodontal scaler. Only teeth with a root length of approximately 14 mm were included, and the crowns were removed at the cementoenamel junction using a low-speed handpiece under water cooling.

To establish the working length, a size 10 K-file was inserted into each canal until it was just visible at the apical foramen, then withdrawn by 1 mm. Root canal preparation was carried out using the crown-down technique with ProTaper nickel–titanium rotary instruments. The coronal and middle thirds were shaped using SX and S1 files, while the S2 file was used to extend shaping to the full working length. Canal finishing was completed with sequential use of F1, F2, and F3 files.

During instrumentation, canals were continuously irrigated with 2 ml of 2.5% sodium hypochlorite between each file to aid in debridement and disinfection. After instrumentation, the canals were dried with paper points and obturated using gutta-percha cones and AH Plus sealer through the lateral condensation technique. All specimens were then stored in an incubator at 37°C with 100% humidity for seven days to allow the sealer to set completely.

For mounting, each tooth was vertically embedded in self-curing acrylic resin using polyvinyl pipes with an internal diameter of 6 mm. Post spaces were prepared using Peeso reamers. Finally, the samples were randomly divided into five groups, with each group containing 13 specimens (n = 13).

Group 1-Irrigation with 0.5% saline (control)

Group 2: Irrigation with 5.25% Sodium hypochlorite +17% EDTA + Er: YAG laser with sapphire tip

Group 3: Irrigation with 2% Chlorhexidine +17% EDTA + Er: YAG laser with sapphire tip

Group 4: Irrigation with 5.25 % Sodium hypochlorite +17% EDTA +Er: YAG laser with side firing endo tip

Group 5: Irrigation with 2% chlorhexidine +17% EDTA + Er: YAG laser with side firing endo tip

Laser parameters

An Er:YAG laser system (Light Instruments, Israel) was employed for this study, equipped with a specialized Endo tip. This tip features a side-firing spiral design with a hollow, flexible, and conical structure, incorporating a circumferential spiral slit that allows for 360° lateral emission.

Laser irradiation was conducted using the following parameters: 1.5 W power output, 150 mJ energy, and a pulse frequency of 10 Hz, applied for 60 seconds per canal. Following laser activation and irrigation procedures, all root canals were thoroughly rinsed with distilled water and dried with paper points.

Glass fiber posts were cleaned using 70% ethanol and gently air-dried before placement. These posts were then cemented into the prepared post spaces using a self-etch dual-cure resin cement. After cementation, all specimens were stored in an environment with 100% humidity at 37°C for 48 hours to ensure complete setting of the cement.

For bond strength evaluation, the roots with cemented posts were transversely sectioned into slices representing coronal, middle, and apical thirds. Each slice was approximately 1.0 to 0.5 mm thick and was prepared using a low-speed diamond saw under continuous water irrigation to prevent heat generation.

Each slice was mounted in a custom-made metal jig and subjected to a push-out test using a universal testing machine. The load was applied in the apico-coronal direction at the center of the post using a cylindrical plunger at a crosshead speed of 1 mm/min until bond failure occurred.

In total, 195 slices were evaluated for push-out bond strength, comprising approximately 39 slices per experimental group. The bond strength was calculated in megapascals (MPa) using the formula:

Debond Stress (MPa) = N / A

Where: N = load at debonding (in Newtons), A = bonded surface area of the post, calculated as $2\pi rh$, $\pi = 3.14$, r = radius of the post, h = thickness of the slice

Statistical analysis

Data was analyzed using the statistical package SPSS 26.0 (SPSS Inc., Chicago, IL) and level of significance was set at $P<0.05$. Descriptive statistics was performed to assess the mean and standard deviation of the respective groups. Inferential statistics to find out the difference between the group was done by One way Anova test.

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III. RESULTS

Table 1: One way Anova Comparison of Push out bond strength - Coronal Third

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
Group 1	13	21.3269	1.63740	.45413	20.3375	22.3164	18.50	24.00
Group 2	13	100.192	4.62010	1.28139	97.4004	102.9842	95.00	108.25
Group 3	13	97.5577	3.44322	.95498	95.4770	99.6384	91.25	102.50
Group 4	13	141.500	2.90115	.80463	139.7469	143.2531	136.25	146.75
Group 5	13	130.942	5.96706	1.65496	127.3365	134.5482	120.25	141.25
F Value				1801.97				
P Value				0.0001*				

Considering Coronal third, the results demonstrate significant variations in push-out loads among the different treatments, with Group 4 showing the highest mean push-out load, followed closely by Group 5. In contrast, Group 1 (the control) exhibited a much lower mean load. The significant p-value indicates that the treatments have a substantial effect on the push-out load.

Table 2: One way Anova Comparison of Push out bond strength - Middle Third

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
Group 1	13	11.3846	.95533	.26496	10.8073	11.9619	10.00	13.00
Group 2	13	59.3654	3.18953	.88462	57.4380	61.2928	55.25	65.00
Group 3	13	58.1346	3.27015	.90698	56.1585	60.1107	53.25	63.50
Group 4	13	79.3269	4.24679	1.17785	76.7606	81.8932	72.25	85.50
Group 5	13	69.6538	2.93247	.81332	67.8818	71.4259	65.50	74.50
F Value				918.35				
P Value				0.0001*				

In the middle third of the root sections, one-way ANOVA revealed a statistically significant difference in push-out bond strength among the various treatment groups ($F = 918.35$, $p < 0.0001$). Group 4 (sodium hypochlorite + EDTA with side firing tip) had the highest mean load (79.33), while Group 1 (saline control) had the lowest (11.38), indicating the effectiveness of the treatments.

Table 3: One way Anova Comparison of Push out bond strength - Apical Third

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
Group 1	13	7.9423	1.15539	.32045	7.2441	8.6405	6.00	9.50
Group 2	13	45.8269	3.12147	.86574	43.9406	47.7132	41.25	52.25
Group 3	13	40.2692	3.21530	.89176	38.3262	42.2122	36.25	47.00
Group 4	13	54.7885	2.60578	.72271	53.2138	56.3631	51.25	59.75
Group 5	13	44.0192	2.50720	.69537	42.5041	45.5343	40.00	48.50
F Value				606.01				
P Value				0.0001*				

In the apical third of the root specimens, one-way ANOVA demonstrated statistically significant differences in push-out bond strength across the treatment groups ($F = 606.01$, $p < 0.0001$). Group 4 (sodium hypochlorite + EDTA with side firing tip) had the highest mean load (54.79), while Group 1 (saline control) had the lowest (7.94), indicating the treatments' effectiveness.

Table 4: Within group comparison of Push out bond strength

		N	Mean	SD	95% Confidence Interval for Mean		Minimum	Maximum	P Value
					Lower Bound	Upper Bound			
Group 1	CORONAL	13	31.35	2.995	29.5437	33.1640	25.00	36.20	.0001*
	MIDDLE	13	17.10	1.452	16.2222	17.9778	15.00	19.60	
	APICAL	13	11.93	1.740	10.8867	12.9902	9.00	14.30	
Group 2	CORONAL	13	151.1	6.963	146.9076	155.3232	143.30	163.30	.0001*
	MIDDLE	13	89.53	4.810	86.6277	92.4415	83.30	98.00	
	APICAL	13	69.10	4.706	66.2562	71.9438	62.20	78.80	
Group 3	CORONAL	13	147.1	5.203	144.0170	150.3060	137.60	154.60	.0001*
	MIDDLE	13	87.66	4.934	84.6871	90.6514	80.30	95.80	
	APICAL	13	60.72	4.84	57.7935	63.6526	54.70	70.90	
Group 4	CORONAL	13	213.4	4.368	210.8295	216.1090	205.60	221.40	.0001*
	MIDDLE	13	119.6	6.412	115.7868	123.5363	109.00	129.00	
	APICAL	13	82.63	3.920	80.2637	85.0025	77.33	90.10	
Group 5	CORONAL	13	197.2	9.016	192.0976	202.9947	181.40	213.10	.0001*
	MIDDLE	13	105.0	4.437	102.3875	107.7510	98.80	112.40	
	APICAL	13	66.36	3.776	64.0868	68.6516	60.30	73.10	

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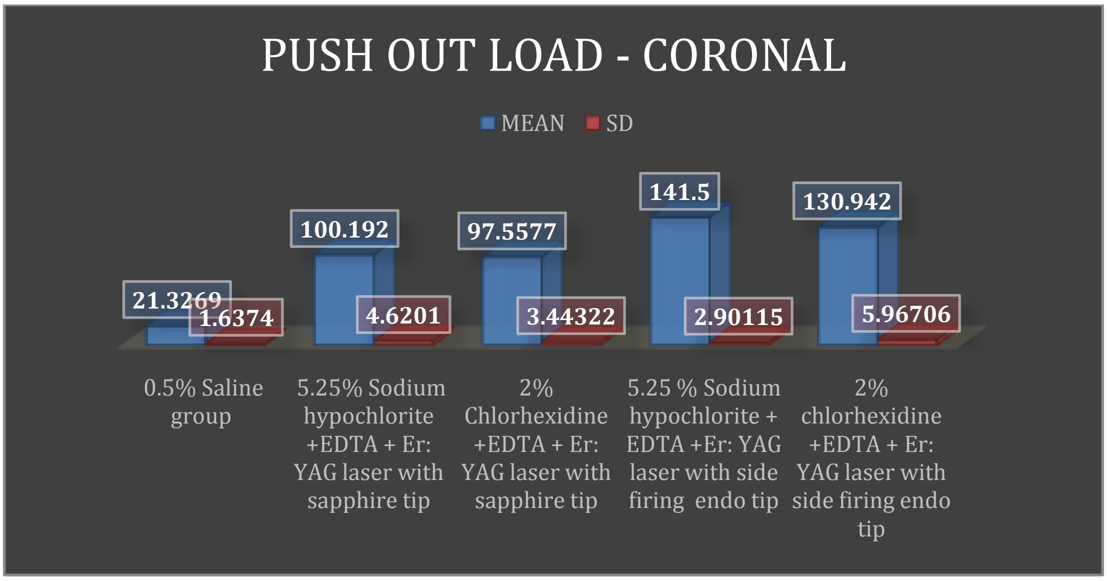
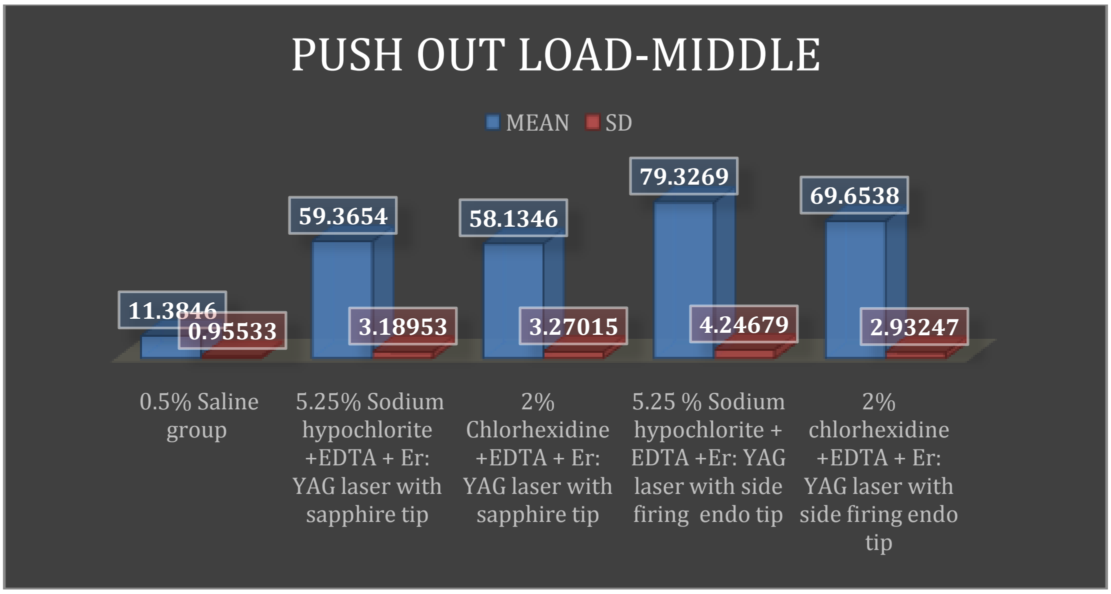
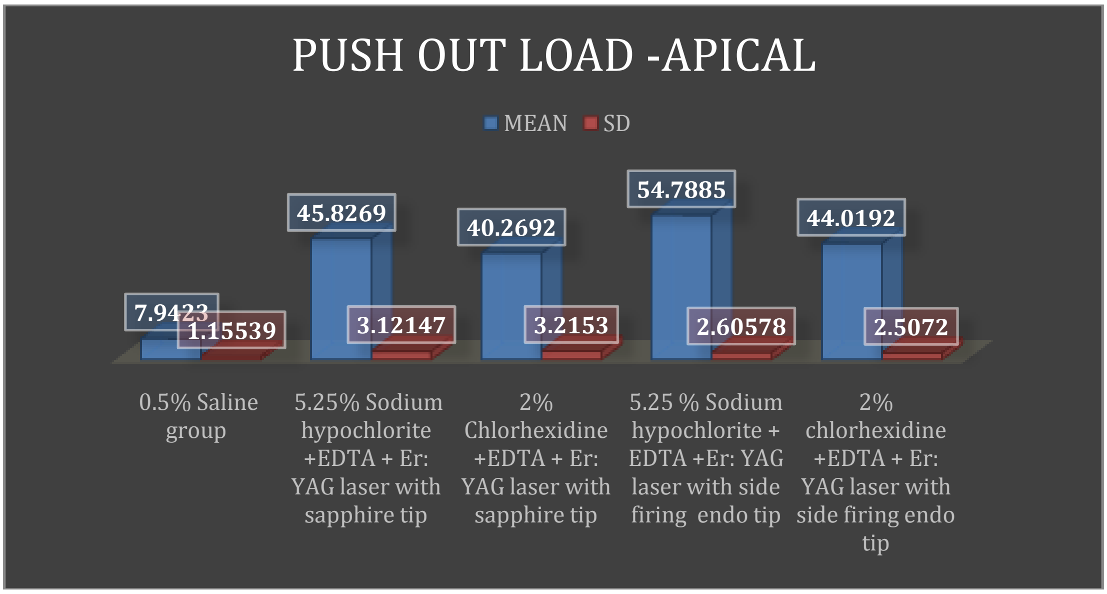
Table 4 presents within-group comparisons of pushout bond strength, showing significant differences across coronal, middle, and apical sections ($p < 0.0001$). Group 4 exhibited the highest mean bond strength in all sections, while Group 1 had the lowest values. Coronal measurements consistently outperformed middle and apical values across all groups, indicating a clear trend of decreasing bond strength from coronal to apical regions.



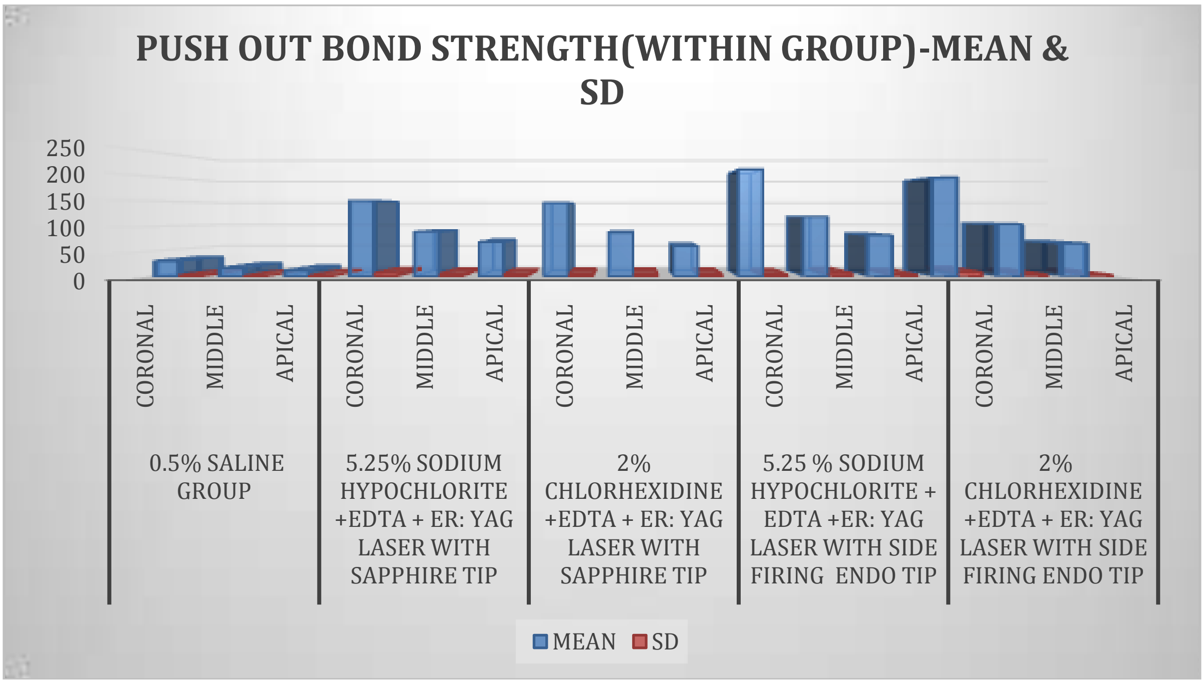
Graph 1: Comparison of Push out bond strength - Coronal Third



Graph 2: Comparison of Push out bond strength - Middle Third



Graph 3: Comparison of Push out bond strength - Apical Third



Graph 4: Within group comparison of Push outbond strength

IV. DISCUSSION

This in-vitro study was conducted to assess the influence of different irrigating protocols, including Er:YAG laser-assisted irrigation with an endo tip, on the push-out bond strength of fiber posts to root dentine. The findings shed light on how variations in irrigation strategies can significantly impact the adhesion between fiber posts and root dentinal walls, an essential factor in ensuring the long-term success of post-endodontic restorations. Since effective adhesion is paramount in restorative dentistry, especially in cases involving weakened tooth structure, optimizing irrigation protocols could greatly enhance clinical outcomes and the durability of fiber post-retained restorations [1].

The results clearly demonstrated that the choice of irrigation protocol had a notable effect on push-out bond strength. Specimens treated with a combination of sodium hypochlorite (NaOCl) and ethylenediaminetetraacetic acid (EDTA) as final irrigants exhibited superior bond strength values. These findings are consistent with previous research that emphasized the importance of complete smear layer removal for achieving optimal adhesive performance [1]. The improvement in bonding could be attributed to better exposure of dentinal tubules and increased surface energy, which facilitate deeper resin penetration [2].

Conversely, samples irrigated with chlorhexidine (CHX) showed comparatively reduced bond strength. This may be explained by the tendency of CHX to form a precipitate or residual film on the dentinal surface, which may interfere with the penetration and polymerization of resin-based cements. Previous studies corroborate this finding, emphasizing the adverse effect of CHX on resin-dentin adhesion [7,10]. The residual film of CHX is believed to interfere with the polymerization of adhesive resins, reducing the micromechanical interlocking necessary for durable bonding [3].

The interaction between the chemical composition of irrigants and dentin structure is a crucial aspect that dictates bonding efficacy. Dentin permeability and surface energy play a role in how irrigants affect adhesion, with NaOCl and EDTA demonstrating superior capabilities in modifying dentinal substrates to enhance bonding performance. Comparative research suggests that alternative irrigants such as peracetic acid may offer similar benefits by effectively removing the smear layer while preserving collagen integrity [4].

Furthermore, studies conducted previously have demonstrated that different irrigation activation techniques influence the bond strength outcomes [8]. While ultrasonic and conventional needle irrigation methods show moderate improvements, laser-assisted irrigation has been consistently associated with better smear layer removal and enhanced adhesion properties. The enhanced performance observed with Er:YAG laser activation can be largely attributed to its capacity to improve fluid movement within the root canal system. This dynamic activation facilitates the disruption and removal of smear plugs while simultaneously opening dentinal tubules, thereby creating a more receptive surface for adhesive bonding [5].

Irrigation protocols that incorporated Er:YAG laser activation, particularly in combination with sodium hypochlorite and EDTA, demonstrated the highest push-out bond strength values. This effect was most prominent when using the side-firing endo tip, which allows for circumferential energy distribution and more effective interaction with canal walls. These findings align with previous reports[11,13] that have emphasized the superior cleaning ability and enhanced adhesion achieved through laser-assisted irrigation techniques [6].

One of the key advantages of the Er:YAG laser is its ability to induce photoacoustic streaming. This phenomenon significantly improves the penetration and distribution of irrigating solutions within the intricate anatomy of the root canal system, including dentinal tubules, thereby promoting better smear layer removal and resin infiltration at the bonding interface. Studies carried out previously suggest that the use of laser-assisted irrigation not only improves cleanliness but also contributes to better long-term adhesion by reducing microleakage [6,15]. This reduction in microleakage has clinical implications in preventing bacterial reinfection and improving the longevity of bonded restorations [7].

Extending from bond strength improvements, research has also shown that laser-activated irrigation can improve the overall mechanical stability of the adhesive interface. The degree of monomer conversion and polymerization efficiency in resin cement is directly influenced by dentinal surface characteristics, which are significantly modified by laser activation [8].

While laser activation improves bond strength, excessive laser energy could potentially alter the dentinal surface. However, in this study, optimal laser parameters were employed to avoid adverse thermal effects, supporting the notion that controlled laser settings contribute positively to adhesion. The findings align with previous research, which emphasized that appropriate energy levels in Er:YAG laser activation prevent dentinal damage while maximizing cleaning efficiency [11].

The findings underscore the clinical importance of selecting appropriate irrigation protocols for fiber post cementation. The combination of EDTA, NaOCl, and Er:YAG laser activation demonstrated the highest bond strength, suggesting its potential as an effective protocol in clinical practice. However, caution is warranted when using CHX, given its observed interference with resin bonding [12].

Beyond bond strength, the choice of irrigants also plays a role in the prevention of bacterial colonization, which is crucial for long-term clinical success. The antimicrobial efficacy of laser-activated irrigation has been demonstrated against resistant endodontic pathogens such as Enterococcus faecalis, making it a viable option for complex endodontic cases [13].

Despite its promising findings, this study has some limitations. The in-vitro nature of the study does not fully replicate intraoral conditions, such as temperature fluctuations, occlusal loading, and long-term degradation of adhesive interfaces. Future research should explore in-vivo assessments and investigate the longevity of fiber post retention under functional conditions [14].

Another limitation is the exclusive focus on a single type of fiber post and adhesive system. Since different post materials and luting agents exhibit varying adhesive properties, further studies should compare various combinations of fiber posts and cementing agents under different irrigation protocols [15].

Push-out bond strength plays a vital role in the long-term success of fiber post restorations, as it directly reflects the quality of adhesion between the fiber post, the resin cement, and the surrounding root dentine. Various factors influence bond strength, including the choice of irrigants, irrigation activation methods, post-surface treatments, and the anatomical region of the root. Studies indicate that effective smear layer removal enhances the adhesive interface, thereby improving bond strength [8].

The results indicate that irrigation protocols significantly influence the pushout bond strength of fiber posts. Groups that received effective smear layer removal exhibited higher bond strength, aligning with studies emphasizing the importance of dentin surface preparation for improved adhesive bonding. Similar findings were reported in the previous study, which demonstrated that photodynamic activation of irrigation enhanced the pushout bond strength of fiber posts. These results suggest that optimal irrigants play a critical role in eliminating debris and enhancing the adhesive interface [1].

Different irrigation activation techniques also affect bond strength outcomes. While passive ultrasonic irrigation (PUI) and needle irrigation show moderate improvements, laser-activated irrigation (LAI) has been shown to yield the best results in terms of smear layer removal and adhesion enhancement [11]. Previous studies have shown that activation of irrigants using the Er:YAG laser significantly enhances bond strength when compared to conventional irrigation methods [13].

The bond strength of fiber posts is also influenced by the anatomical region of the root. Studies consistently show that the coronal third of the root canal exhibits the highest bond strength, followed by the middle third, with the lowest values observed in the apical third. This trend is attributed to variations in dentinal tubule density, adhesive penetration, and accessibility for irrigants and bonding agents in different root regions [21].

The adhesion of fiber posts to root dentin can also be influenced by surface treatment of the post itself. A range of mechanical and chemical modification techniques such as sandblasting, silanization, and laser application have been investigated to enhance bonding performance. Notably, studies indicate that Er,Cr:YSGG laser irradiation can significantly improve the post resin interface by altering the surface morphology of fiber posts, thereby promoting better interaction with the resin cement [19]. Similarly, studies have reported that hydrofluoric acid etching and airborne-particle abrasion enhance the micromechanical retention of posts, contributing to superior bond strength [23].

Additionally, further studies could evaluate the effect of different adhesive systems and post materials to determine their interaction with various irrigation protocols. Optimizing laser parameters and assessing their impact on long-term bonding performance could also refine clinical recommendations. Future research should also aim to standardize laser parameters, including wavelength, pulse duration, and energy settings, to ensure reproducibility and consistency across different studies [16].

The impact of laser-assisted irrigation on bacterial reduction and overall endodontic disinfection remains an area for further exploration. While this study primarily focused on bond strength, additional research could investigate the antimicrobial efficacy of laser-assisted irrigation protocols [17].

Future investigations should also consider the effects of different curing strategies and bonding agents in conjunction with laser-assisted irrigation to determine optimal adhesive outcomes. Studies evaluating the influence of various energy settings and irradiation times on dentinal microstructure could contribute to more precise guidelines for clinical application [18]

V. CONCLUSION

This study highlights the significant role of irrigation protocols in influencing the pushout bond strength between fiber posts and root dentine. The combination of Er:YAG laser-assisted irrigation using a side firing endo tip, along with NaOCl and EDTA, demonstrated superior bonding performance, suggesting its effectiveness in post-endodontic restorations.

The findings support the clinical application of laser-activated irrigation as an adjunct to conventional irrigation methods. By improving smear layer removal, enhancing adhesive penetration, and optimizing bond strength, Er:YAG laser activation can contribute to the long-term success of fiber post restorations.

Future studies should focus on validating these findings in clinical settings and optimizing laser parameters for enhanced adhesion while preserving dentinal integrity. Additionally, further research should explore the long-term performance of fiber posts in vivo to determine the true clinical impact of various irrigation techniques. By expanding the scope of investigation, the integration of advanced laser technology in endodontics can be further refined to enhance patient outcomes and treatment success rates.

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