



BASIC RESEARCH:

Impact of Endodontic Obturation Technique on the Adhesive Interface Between Fiber Post Cementation System Using Universal Adhesive and Radicular Dentin

Impacto de la técnica de obturación endodóntica en la interfaz adhesiva entre el sistema de cementación de poste de fibra utilizando un adhesivo universal y la dentina radicular

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Received: 30-III-2026

Accepted: 3-VI-2026

ABSTRACT: This study evaluated the incidence of residues on dentin after endodontic obturation using warm vertical condensation (WC), cold single cone (SC), and lateral condensation (LC) techniques, as well as their effect on push-out bond strength and adhesive failure mode of a fiber post cementation system using a universal adhesive (Ambar Universal Plus APS). Sixty roots underwent chemo-mechanical preparation and were distributed into three groups (n=20) according to the obturation technique. Post space preparation was performed after 7 days. Thirty roots (n=10 per group) were subjected to scanning electron microscopy analysis to assess the incidence of residues on dentin. In the remaining thirty roots, fiber posts were cemented using the universal adhesive with a conventional resin cement and subsequently subjected to the push-out test. All analyses were conducted at the cervical, middle, and apical thirds of the post space. Data were analyzed considering the factors "obturation technique" and "root canal third," with a significance level set at 5%. The WC technique showed the lowest incidence of residues on dentin and the highest push-out bond strength values, regardless of the root canal third evaluated ($P<0.05$), whereas SC and LC demonstrated similar results for both analyses ($P>0.05$). The warm vertical condensation technique improved the adhesive performance of fiber post cementation using a universal adhesive, likely due to reduced residual obturation materials on radicular dentin,

independent of the root canal third, while cold single cone and lateral condensation techniques exhibited comparable behavior.

KEYWORDS: Adhesion; Endodontics; Root Canal; Fiber Post.

RESUMEN: Este estudio evaluó la incidencia de residuos en la dentina tras la obturación endodóntica mediante las técnicas de condensación vertical caliente (WC), cono único en frío (SC) y condensación lateral (LC), así como su efecto sobre la resistencia de unión por push-out de un sistema de cementación de postes de fibra utilizando un adhesivo universal (Ambar Universal Plus APS). Sesenta raíces fueron sometidas a preparación químico-mecánica y distribuidas en tres grupos (n=20) según la técnica de obturación. La preparación del espacio para el poste se realizó después de 7 días. Treinta raíces (n=10 por grupo) fueron analizadas mediante microscopía electrónica de barrido para evaluar la presencia de residuos en la dentina. En las treinta restantes, se cementaron postes de fibra con adhesivo universal y cemento resinoso convencional, y posteriormente se realizó el ensayo de push-out. Los análisis se efectuaron en los tercios cervical, medio y apical del conducto. Los datos se analizaron considerando los factores técnica de obturación y tercio radicular ($\alpha=0.05$). La técnica WC mostró la menor incidencia de residuos y los mayores valores de resistencia de unión, independientemente del tercio evaluado ($P<0.05$), mientras que SC y LC presentaron resultados similares ($P>0.05$). La condensación vertical caliente mejoró el desempeño adhesivo, probablemente por la menor cantidad de residuos en la dentina radicular, independientemente del tercio del conducto, mientras que SC y LC mostraron comportamiento comparable.

PALABRAS CLAVE: Adhesión; Endodoncia; Conducto radicular; Poste de fibra.

INTRODUCTION

The rehabilitation of endodontically treated teeth represents a clinical challenge, especially in cases of extensive structural loss (1). Fiber glass posts are still widely indicated in these situations (2); however, they require a reliable adhesive interface between the cementation system and the dentin to ensure long-term treatment success (3). Several factors may interfere with the integrity of this interface, including the presence of endodontic sealer residues on the post space dentin surface (4). These remnants can act as a physical barrier, hindering adhesive system infiltration and proper micromechanical interaction with root dentin (5-7).

Endodontic obturation techniques, such as warm vertical condensation (WC), cold single cone (SC), and lateral condensation (LC), are commonly used in endodontics (8). These protocols differ in

the amount and distribution of endodontic sealer along the root canal, the adaptation of gutta-percha to canal walls, and the potential for residue formation after post space preparation (9-11). Lateral condensation and single-cone techniques promote filling of the entire canal with gutta-percha and endodontic sealer, which are subsequently removed mechanically during post space preparation (12). In contrast, WC concentrates the plasticization and compaction of gutta-percha mainly in the apical portion of the root canal, which may result in less contact of filling materials with the cervical and middle thirds, critical regions for intraradicular post adhesion (13).

Thus, considering the scarcity of studies on the influence of obturation techniques on the adhesive interface of fiber post cementation systems, the present investigation aimed to evaluate the incidence of residues on root dentin

after endodontic obturation using WC, SC, or LC, as well as their effect on push-out bond strength and adhesive failure mode of a fiber post cementation system using a universal adhesive in the cervical, middle, and apical thirds of the post space after six months of storage. The null hypothesis tested was that there would be no differences among obturation techniques or post space thirds in the incidence of dentin residues, push-out bond strength, or adhesive failure mode of the fiber post cementation system.

MATERIALS AND METHODS

Sixty extracted bovine conoids incisors were stored in a 0.1% thymol solution at 4°C until the moment of use. The use of bovine teeth in this in vitro study did not require approval by an Ethics Committee, according to the regulations of the Ethics Committee of the School of Dentistry of Araraquara, São Paulo State University (UNESP), since the specimens were obtained from animals slaughtered for commercial purposes. After washing under running water, the teeth were sectioned transversely along the long axis of the root using a diamond disc (Isomet 2000; Buehler Ltd., Lake Bluff, IL, USA) under refrigeration, and the roots were standardized to a length of 17 mm.

The root canals were instrumented to a working length of 16 mm from the root apex using the F5 instrument (ProTaper; Dentsply Maillefer, Ballaigues, Switzerland), following the manufacturer's recommendations. At each instrument change, irrigation was performed with 5 mL of 2.5% sodium hypochlorite solution (Asfer, São Caetano do Sul, SP, Brazil). The apical foramina were sealed with composite resin to prevent irrigation solution apical extrusion.

Following completion of the chemical-mechanical preparation, the root canals were irrigated with 5 mL of 17% EDTA solution (Biodynamics, Ibioporã, PR, Brazil), which was maintained for 1

minute, followed by a final irrigation with 5 mL of 2.5% sodium hypochlorite solution. All root canals were then dried using absorbent paper points.

ENDODONTIC OBTURATION PROTOCOL

The 60 teeth were randomly divided into three groups (n=20). Each specimen was endodontically obturated using an epoxy resin-based sealer (Sealer Plus; MKLife, RS, Brazil) and one of the following filling techniques: WC, SC, or LC. All endodontic procedures were performed by the same experienced operator as follows:

- WC protocol: a F5 gutta-percha cone (Dentsply Sirona, Pirassununga, SP, Brazil) was used. The gutta-percha cone, coated with endodontic sealer (Sealer Plus; MKLife, Porto Alegre, RS, Brazil), was placed into the root canal. A thermoplastic plugger (Fast Pack; MKLife, Porto Alegre, RS, Brazil), set at 200°C, was then used for plasticization, sectioning, and vertical compaction of the gutta-percha within the apical portion of the root canal, with a fine plugger positioned at 3.5 mm from the working length, filling up to 5 mm of the working length (14).
- SC protocol: F5 gutta-percha cone (Dentsply Sirona, Pirassununga, SP, Brazil), previously fitted to the full working length, was coated with endodontic sealer (Sealer Plus; MKLife, Porto Alegre, RS, Brazil) and inserted into the root canal. Subsequently, a heated instrument was used to cut the gutta-percha cone, at the cervical level (12).
- LC protocol: F5 gutta-percha cones, size 35, 0.02 taper (Dentsply Sirona, Pirassununga, SP, Brazil), coated with the endodontic sealer (Sealer Plus; MKLife, Porto Alegre, RS, Brazil), were placed in the root canal. A #B finger spreader (Dentsply Sirona, Pirassununga, Brazil) was used for inserting the XF cones (Dentsply Sirona, Pirassununga, SP, Brazil) into the apical third. Afterwards, a #C finger spreader (Dentsply Sirona, Pirassununga, SP, Brazil) was used

for inserting the auxiliary FF gutta-percha cones (VDW GmbH, Munich, Germany) into the middle and coronal thirds (12).

The roots were sealed with temporary restorative material (Coltosol; Coltene, Rio de Janeiro, RJ, Brazil) and immediately immersed in distilled water for 7 days at 37°C. After this period, the post space was prepared using rotary #1 and #2 Largo instruments (MKLife, Porto Alegre, RS, Brazil) at low rotation (8,000 rpm) and finished using a #2 rotary instrument (White Post DC; FGM, Joinville, SC, Brazil) to a depth of 11 mm from the cervical root face, without refrigeration. Therefore, the cervical, middle, and apical thirds evaluated in this study refer specifically to the prepared post space and not to the entire root canal length or to the remaining apical obturation segment. Figure 1 is a schematic representation of the study design.

INCIDENCE OF RESIDUES

Thirty specimens were selected, 10 from each protocol, for dentin post space incidence of residues analysis. The specimens were cleaved longitudinally in the buccolingual direction using a chisel. The post space was divided into thirds by means of a demarcation performed on the vestibular face of each distal hemi-section of the root. The specimens were then stored in an oven at 37°C for 24 hours.

The specimens were mounted on metallic stubs, subjected to gold sputter-coating (single cycle of 120 s) under vacuum in a specific chamber (MED 010; Balzers Union, Balzers, Liechtenstein), and analyzed by scanning electron microscopy (JSM 6060; Jeol Co., Tokyo, Japan) operating at 20 kV. Four different fields on the dentin surface were evaluated in each third of the post space, and the most representative image was obtained at 500× magnification, as described by Escalante-Otárola *et al.* (15) All images were captured by the same operator.

Two independent and properly calibrated examiners ($k=0.82$) assigned scores according to the persistence of residues on the dentin surface according to the modified parameters, previously described by Kuga *et al.* (16) modified parameters: Score 1- absence or slight incidence of smear layer and most open dentinal tubules; Score 2- minimum smear layer incidence and > 50% of the dentin surface without residues; Score 3- moderate incidence of smear layer and <50% of the dentin surface without residues and Score 4- intense incidence of smear layer and obstructed dentinal tubule openings.

BOND STRENGTH

Thirty specimens were selected and randomly distributed into three experimental groups ($n=10$), according to the endodontic obturation protocol employed. Push-out bond strength was evaluated after a storage period of six months.

PREPARATION OF SPECIMENS

Fiber posts #2 (White Post DC; FGM, Joinville, SC, Brazil) were cleaned with 70% ethyl alcohol. Two layers of universal adhesive (Ambar Universal Plus APS; FGM, Joinville, SC, Brazil) were actively applied to the post surface and photoactivated for 10 seconds across the entire extension using a light-emitting diode (LED) curing unit (Quazar, 1,200 mW/cm²; South Jordan, UT, USA) for 20 seconds.

Prior to fiber post cementation, the post space dentin was subjected to a mechanical cleaning protocol using a rotary brush (MKLife, Porto Alegre, RS, Brazil) adapted to an electric motor (XSmart Plus; Dentsply Sirona, Pirassununga, SP, Brazil), operating at 350 rpm and 1 N·cm, in association with 2.5% sodium hypochlorite solution. Subsequently, the post space was irrigated with 10 mL of distilled water and dried with absorbent paper points (17).

Then, a universal adhesive (Ambar Universal Plus APS; FGM, Joinville, SC, Brazil) was actively applied to the post space dentin for 20 seconds using a microapplicator (Cavibrush; FGM, Joinville, SC, Brazil). The dual-cure resin cement (AllCem Core; FGM, Joinville, SC, Brazil) was manipulated according to the manufacturer's instructions and introduced into the root canal using a Centrix syringe (Nova DFL; Rio de Janeiro, RJ, Brazil). The cement was also applied to the post surface prior to its insertion into the root canal.

Fiber post insertion was standardized using a parallelometer (Bio-Art Equipamentos Odontológicos Ltda., São Carlos, SP, Brazil) to ensure centralized positioning parallel to the long axis of the root. Light activation was performed for 40 seconds on each face using a LED curing unit (Quazar, 1,000 mW/cm²; FGM, Joinville, SC, Brazil). Following cementation, all specimens were stored in distilled water at 37°C for a period of 6 months.

The specimens were embedded in plastic matrices with vinyl resin (Maxi Rubber, São Paulo, SP, Brazil). After 24 hours, the specimens were sectioned transversely to the long axis using a double-faced diamond disk (Buehler Ltd., Lake Bluff, IL, USA) adapted to a hard tissue cutting machine (Isomet; Buehler Ltd., Lake Bluff, IL, USA), under constant water cooling.

Three slices of 2.0±0.1 mm thickness were obtained from the cervical, middle, and apical thirds of the prepared post space, at distances of 1.0 mm, 5.0 mm, and 9.0 mm from the cervical face of the root, respectively. Surface irregularities were removed with #1200 silicon carbide abrasive paper (Norton, São Paulo, SP, Brazil).

PUSH-OUT TEST

The push-out bond strength test was performed on each section using a universal testing

machine (OM150; Odeme, Luzerna, SC, Brazil) equipped with a 1 kN load cell, operating at a crosshead speed of 0.5 mm/min and bond strength values were calculated and expressed in megapascals (MPa), as described by Magro *et al.* (18).

ADHESIVE FAILURE MODE

The failure mode of each slice was evaluated under a stereomicroscope, at 20x magnification, to determine the percentage of each type of failure mode, as described by Ramos *et al.* (19) namely type 1 (adhesive 1), occurs in interface between fiber post and resin cement; type 2 (adhesive 2), occurs at the interface between cementation system and dentin; type 3 (cohesive), in the cementation system; type 4 (mixed), combination of 2 or more types of adhesive failures.

STATISTICAL ANALYSIS

Data for incidence of residues and push out bond strength were analyzed using the Statistical Package for the Social Sciences (SPSS v25.0; IBM Corp., Armonk, NY, USA). Normality was assessed using the Shapiro–Wilk test. Data on incidence of residues were analyzed using the Kruskal–Wallis test followed by Dunn's post hoc test. Push out bond strength was analyzed using one-way ANOVA followed by Tukey's post hoc test ($P=0.05$).

RESULTS

INCIDENCE OF RESIDUES

Regardless of the post space third, the WC protocol showed the lowest incidence of residues on radicular dentin ($P<0.05$), with no significant difference observed between the SC and LC protocols ($P>0.05$).

Table 1 shows the median, minimum–maximum range, first quartile (Q1), and third quartile (Q3) values of the scores attributed to the incidence

of residues on dentin, according to the endodontic obturation protocol and post space thirds.

Figure 2 shows representative images of the incidence of residues on post space dentin, according to the endodontic obturation protocols and post space thirds.

BOND STRENGTH

BETWEEN EXPERIMENTAL PROTOCOLS

In all post space thirds, the WC protocol provided the highest push-out bond strength values ($P < 0.05$), whereas the SC and LC protocols showed similar push-out bond strength values to each other ($P > 0.05$).

BETWEEN POST SPACE THIRDS

Independently of the endodontic obturation protocol, the apical third of the post space exhibi-

ted the lowest push-out bond strength values ($P < 0.05$), whereas no significant differences were observed between the cervical and middle thirds ($P > 0.05$).

Table 2 shows the arithmetic mean, standard deviation, and confidence intervals (MPa) of the push-out bond strength values of the fiber post cementation system, according to the endodontic obturation protocols and post space thirds.

ADHESIVE FAILURE MODE

Independently of the post space third, the WC protocol showed a higher incidence of cohesive failure mode, whereas the SC and LC protocols exhibited a higher incidence of adhesive type 2 failure mode.

Figure 3 illustrates the incidence of adhesive failure mode (in %), according to the endodontic obturation protocol and post space thirds.

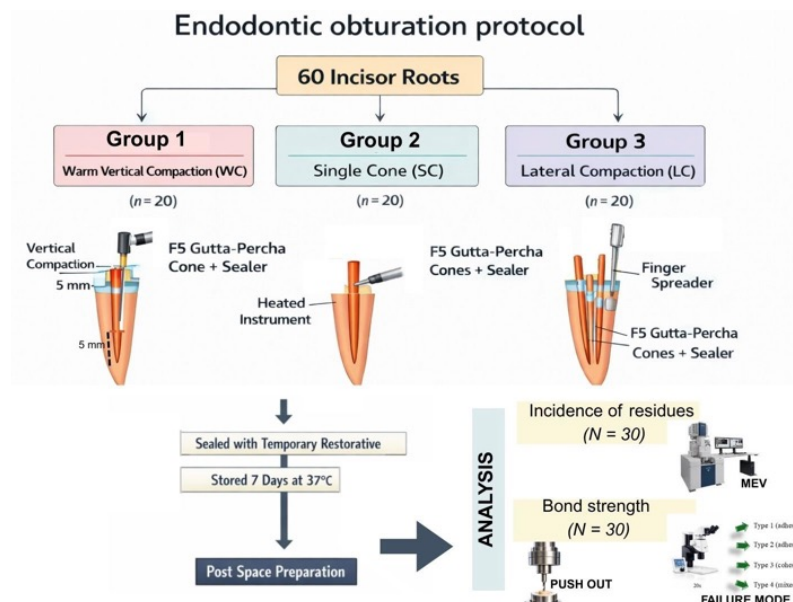


Figure 1. Schematic representation of the methodology used in the study.

Table 1. Median, minimum, maximum, first quartile (Q1), and third quartile (Q3) values of the scores attributed to the incidence of residues on dentin, according to the endodontic obturation protocol and post space third.

Post space third	Descriptive measure	WC	SC	LC
Cervical third	Median	1 ^a	4 ^b	4 ^b
	Vmin-Vmax	1-1	3-4	3-4
	1Q-3Q	1-1	3-4	3-4
Middle third	Median	1 ^a	4 ^b	4 ^b
	Vmin-Vmax	1-1	3-4	3-4
	1Q-3Q	1-1	4-4	4-4
Apical third	Median	1 ^a	4 ^b	4 ^b
	Vmin-Vmax	1-1	4-3	4-3
	1Q-3Q	1-1	4-4	4-4

^{a,b} Different lowercase letters in the same row indicate significant differences among obturation protocols ($P < 0.05$). Vmin, minimum value; Vmax, maximum value; 1Q, first quartile; 3Q, third quartile; WC, warm vertical condensation technique; SC, single cone technique; LC, Lateral condensation.

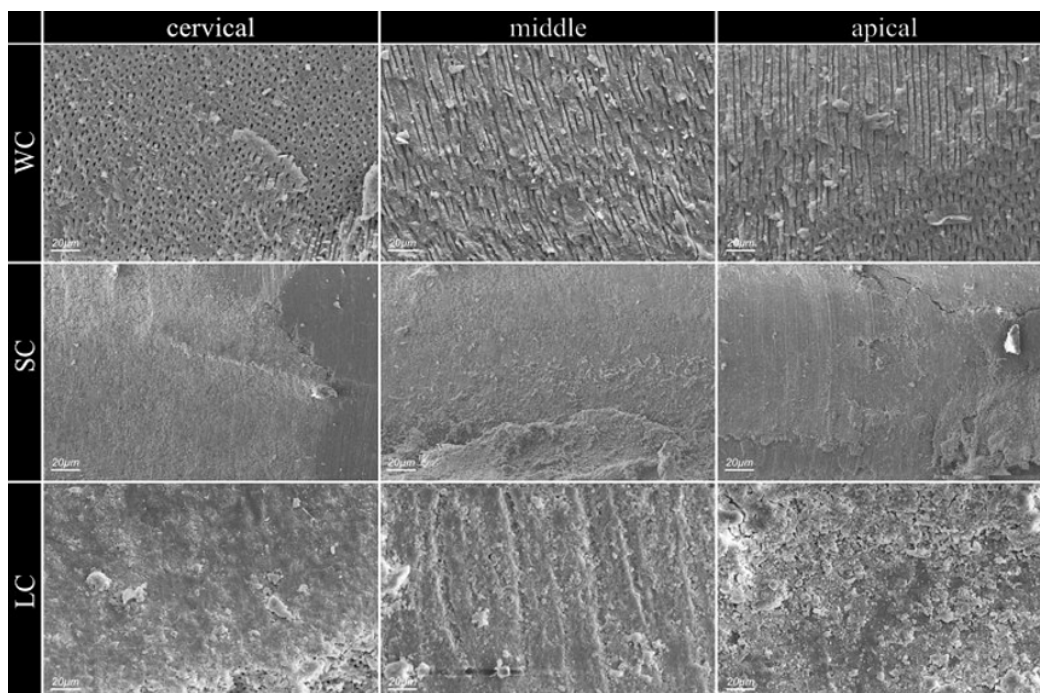


Figure 2. Images of the incidence of residues on post space dentin, according to the endodontic obturation protocols and post space thirds. WC, warm vertical condensation technique; SC, single cone technique; LC, Lateral condensation. Magnification: 500x. Scale: 20µm.

Table 2. Arithmetic means, standard deviation, and confidence intervals (MPa) of the push-out bond strength values of the fiber post cementation system, according to the endodontic obturation protocols and post space thirds.

		WC	SC	LC
C	m (sd)	23.08 (1.69) ^{aA}	14.03 (0.93) ^{bA}	13.85 (0.98) ^{bA}
	ci	22.03 < μ < 24.13	13.45 < μ < 14.61	13.24 < μ < 14.46
M	m (sd)	22.73 (0.82) ^{aA}	13.83 (0.85) ^{bA}	13.98 (0.49) ^{bA}
	ci	22.22 < μ < 23.24	13.31 < μ < 14.35	13.67 < μ < 14.29
A	m (sd)	21.35 (0.79) ^{aB}	12.12 (0.76) ^{bB}	12.36 (0.86) ^{bB}
	ci	20.86 < μ < 21.83	11.65 < μ < 12.60	11.83 < μ < 12.89

^{a,b} Different lowercase letters in the same row indicate significant difference ($P < 0.05$). A,B Different uppercase letters in the same column indicate significant difference ($P < 0.05$). C, cervical third; M, middle third; A, apical third; m, arithmetic mean; sd, standard deviation; ci, confidence interval. WC, warm vertical condensation technique; SC, single cone technique; LC, Lateral condensation.

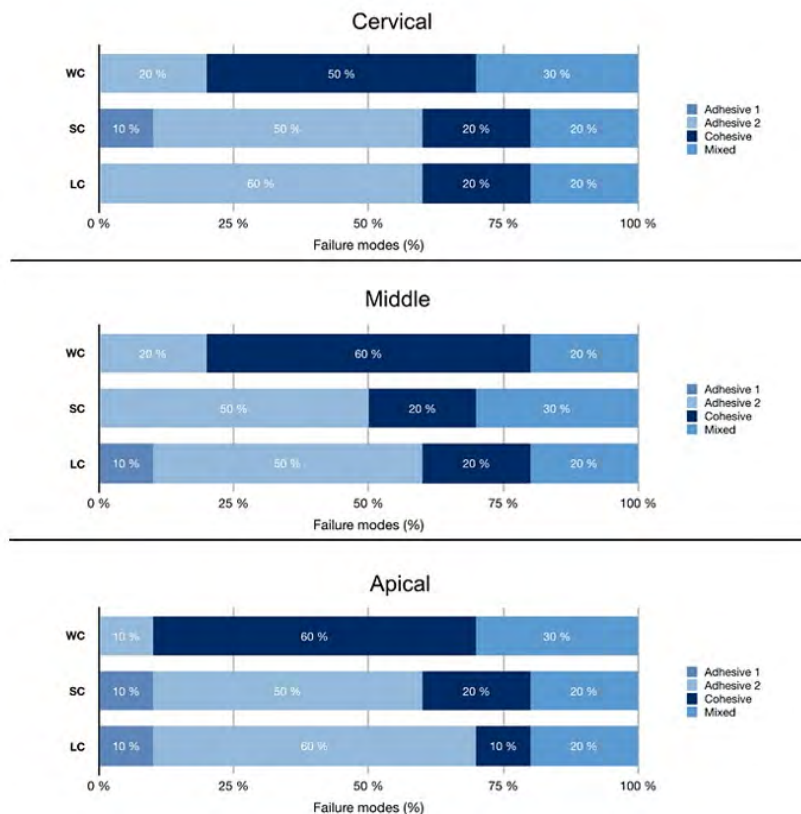


Figure 3. Incidence of adhesive failure mode (in %), according to the endodontic obturation protocol and post space thirds.

DISCUSSION

This study evaluated the incidence of residues on root dentin after endodontic obturation using WC, SC, and LC, as well as their impact on the bond strength and adhesive failure mode of the fiber post cementation system. The results demonstrated that WC showed a lower incidence of residues and higher bond strength values compared with the other techniques, leading to rejection of the null hypothesis.

It is known that the presence of residues in the post space can directly interfere with the performance of the adhesive system (4). These remnants reduce the surface energy of dentin, hinder adequate adhesive infiltration into dentinal tubules, and compromise the formation of a uniform and stable hybrid layer (5). As a consequence, adhesive failures occur more frequently and the bond strength values of the fiber post are reduced (7).

In this study, the lowest incidence of endodontic cement residues was observed with WC. This technique promoted condensation mainly in the apical portion of the root canal, so that the cervical and middle thirds of the post space showed minimal presence of remaining filling material. It should be clarified that the term “apical third” used for residue and bond strength analyses refers to the apical third of the prepared post space, not to the remaining apical obturation segment. Additionally, it is likely that the post space cleaning method using a rotary brush further enhanced the removal of residues from the cervical and middle thirds, resulting in higher bond strength values (20).

It is known that the mechanical action of nylon bristles in direct contact with the dentinal walls promotes the disruption and removal of residual endodontic cement that may persist after post space preparation (17,20). Previous evidence

indicates that mechanical cleaning protocols using rotary brushes significantly improve the quality of the adhesive interface by promoting cleaner surfaces in the cervical and middle thirds of the post space (7), which is particularly relevant in the WC group, where these regions already tend to present a lower volume of remaining filling material.

On the other hand, the absence of differences in residue incidence between the SC and LC techniques may be explained by the fact that, in both groups, the entire canal space was initially filled and subsequently re-prepared after 7 days using a drill for post space preparation. This standardized procedure tends to produce a similar removal pattern, as the mechanical action of the drill predominantly affects the de-obturation of the cervical and middle thirds, regardless of the obturation technique previously employed.

Additionally, since both SC and LC resulted in complete canal filling prior to delayed post space preparation, the amount of residual material became more dependent on the post space preparation method than on the obturation technique itself. In such cases, complementary post space cleaning methods or the activation of chemical agents through mechanical means, as performed in a previous study (4,21,22), may be required. This may explain the absence of differences observed between the groups and, consequently, the similar bond strength values.

This study also demonstrated that, regardless of the post space third, WC showed the highest incidence of cohesive failure. Since WC concentrates the filling mass mainly in the apical portion of the root canal and tends to leave the cervical and middle thirds of the post space cleaner after post space preparation, it is possible that the adhesive interface formed during post cementation became more intact and resistant, favoring the occurrence of cohesive failures.

In contrast, the SC and LC techniques showed a higher incidence of type 2 adhesive failure, possibly due to the presence of endodontic cement residues along the walls of the post space after de-obturation. Because in these protocols the entire canal is initially filled and subsequently re-prepared with a drill, it is more likely that remnants remain and interfere with adhesive infiltration and proper hybrid layer formation. This condition compromises the quality of the bond between the resin cement and dentin, making the adhesive interface the weakest link in the assembly (5).

Among the limitations of this study, the absence of material penetrability assessment should be highlighted, as such analysis could provide additional information regarding the quality of resin cement infiltration into root dentin. Moreover, only a single observation period (6 months) was adopted, which restricts the understanding of the long-term adhesive behavior, especially in light of possible interfacial degradation processes.

Another limiting factor is the use of only one type of endodontic sealer during obturation, which prevents extrapolation of the results to other materials with different compositions and physicochemical properties. Therefore, future studies are recommended to evaluate multiple aging periods, as well as to compare different cementation systems and endodontic materials in order to broaden the robustness and clinical applicability of the findings.

CONCLUSION

Within the limitations of this study, the endodontic obturation technique influenced the incidence of residues on radicular dentin and the adhesive performance of the fiber post cementation system. The warm vertical condensation

protocol resulted in lower residue incidence and higher push-out bond strength values, regardless of the post space third evaluated, whereas cold single cone and lateral condensation techniques showed similar behavior.

From a mechanistic perspective, reduced contamination of radicular dentin by obturation materials may favor a more stable adhesive interface; however, further studies are required to better understand the relationship between residue persistence and long-term bond durability.

From a clinical perspective, obturation techniques associated with lower residue incidence may contribute to improved adhesion of fiber posts and potentially enhance the longevity of restorations, although clinical studies are necessary to confirm these findings.

CONFLICT OF INTEREST: No conflict of interest.

FUNDING: This study was supported by CAPES (Coordination for the Improvement of Higher Education Personnel), grant number 88887.949460/2024-00.

AUTHOR CONTRIBUTION STATEMENT: Conceptualization and design: A.P.O.B. and M.C.K.; Literature review: A.P.O.B., J.L.S.G.C., G.M.C.N. and W.G.E.O.; Methodology and validation: A.P.O.B. and M.C.K.; Formal analysis: J.A.R.L. and M.C.K.; Investigation and data collection: J.L.S.G.C., G.M.C.N. and W.G.E.O.; Resources: M.C.K.; Data analysis and interpretation: J.A.R.L. and M.C.K.; Writing-review and editing: A.P.O.B., J.L.S.G.C., G.M.C.N. and W.G.E.O.; Supervision: M.C.K.; Project administration: J.A.R.L.

ACKNOWLEDGMENTS: The authors would like to thank CAPES (Coordination for the Improvement of Higher Education Personnel, Finance Code 001).

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