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Compressive strength of endodontically treated mandibular premolars rehabilitated with three techniques: core buildup material, intraradicular fiber posts and polyethylene fibers

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ABSTRACT

The biomechanical rehabilitation of endodontically treated premolars with extensive mesio-occluso-distal (MOD) cavities is a clinical challenge due to their increased susceptibility to fracture. The aim of this in vitro study was to compare the compressive strength of endodontically treated mandibular premolars restored using different post-endodontic reconstruction protocols, using intact teeth as a reference for maximum mechanical performance. ***Materials and Method:*** *Forty single-rooted premolars were distributed into four groups: one control group with no interventions, and three experimental groups with standardized mesio-occluso-distal (MOD) preparations. Experimental groups were restored respectively with core buildup, glass fiber posts, and polyethylene fiber reinforcement. After final composite resin restoration, specimens were tested for compressive strength using an INSTRON 1011 universal testing machine. Data were analyzed using the Kruskal–Wallis test ($p<0.05$).* ***Results:*** *When examining median (95%CI) compressive strength in Newtons (N), the highest value was found in the control group with 557.4 N (100.8-574.8), followed by the polyethylene fiber group with 471.4 N (194.2 to 565.5), the glass fiber posts group with 427.5 N (146.3 to 495.4) and the core buildup group with 345.1 N (216.8 to 574.9), ($p = 0.84$).* ***Conclusion:*** *Under the experimental conditions of the present study, the compressive strength of endodontically treated mandibular premolars did not differ significantly among the evaluated reconstruction protocols. Although polyethylene fiber reinforcement showed a tendency toward higher resistance values, the results do not enable the establishment of conclusive mechanical advantages among the restorative systems assessed.*

Keywords: *bicuspid - root canal therapy - compressive strength - composite resins*

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Resistencia a la compresión de premolares endodónticamente tratados y rehabilitados con tres tipos de técnicas: sustituto dentinario, anclaje intrarradicular y refuerzo con fibras

RESUMEN

La rehabilitación biomecánica de premolares tratados endodónticamente con cavidades mesio ocluso distales (MOD) extensas continúa siendo un desafío clínico debido a su mayor susceptibilidad a la fractura. El objetivo de este estudio in vitro fue comparar la resistencia a la compresión de premolares mandibulares tratados endodónticamente y restaurados mediante diferentes protocolos de reconstrucción postendodóntica, utilizando dientes íntegros como referencia de máximo desempeño mecánico. ***Materiales y Método:*** *Se utilizaron 40 premolares unirradiculares divididos en cuatro grupos: un grupo control sin intervenciones y tres grupos experimentales con preparaciones estandarizadas de cavidades mesio ocluso distales (MOD). Los grupos experimentales incluyeron restauraciones con sustituto dentinario, postes de fibra de vidrio y refuerzo con fibras de polietileno. Tras la reconstrucción final con resina compuesta, las muestras se sometieron a pruebas de resistencia a la compresión en una máquina de ensayo universal INSTRON modelo 1011. Los datos se analizaron mediante la prueba de Kruskal-Wallis ($p<0,05$, significativo).* ***Resultados:*** *Al analizar la mediana (IC95%) de la resistencia a la compresión en Newtons (N), el valor más alto se observó en el grupo control 557,4 N (100,8-574,8), seguido del grupo de fibras de refuerzo 471,4 N (194,2 a 565,5), postes de fibra de vidrio 427,5 N (146,3 a 495,4) y grupo con sustituto dentinario 345,1 N (216,8 a 574,9), respectivamente ($p = 0,84$).* ***Conclusión:*** *Bajo las condiciones experimentales del presente estudio, la resistencia a la compresión de premolares inferiores tratados endodónticamente no difirió significativamente entre los distintos protocolos de reconstrucción evaluados. Aunque el refuerzo con fibras de polietileno mostró una tendencia a mayores valores de resistencia, los resultados no permiten establecer ventajas mecánicas concluyentes entre los sistemas restauradores analizados.*

Palabras clave: *bicúspide - tratamiento de conducto radicular - resistencia a la compresión - resinas compuestas*

INTRODUCTION

The choice of the ideal restoration for endodontically treated teeth (ETT) has been widely discussed in the dental literature[1]. The outcome of root canal treatment is known to be positively correlated with the technical quality of the root filling, while high failure rates are mainly associated with a lack of adequate coronal sealing. Post-endodontic restoration therefore plays a key role. Not only should it provide function, aesthetics and marginal sealing, but it must also protect the remaining tooth structure[2,3].

One of the issues for ETT is the significant loss of tooth structure due to carious/non-carious lesions, previous restorations or fractures, and access cavities performed during the endodontic procedure[4]. Thus, endodontically treated teeth have a higher risk of biomechanical failure than do vital teeth[5].

The endodontic and restorative procedure outcome on the stiffness of teeth under occlusal stresses has been widely discussed. It has been shown that endodontic access reduced stiffness by about 5%, while proximal-occlusal cavity or the MOD preparations reduced resistance by 46% and 63%, respectively. The removal of one or both proximal marginal ridges is the major factor contributing to tooth strength loss[6].

This reduced structural strength is relevant in premolars, since, unlike the molars, they are more frequently exposed to destructive lateral forces, making them more prone to cuspal fractures[7]. Likewise, when cervical dentin is lost due to endodontic access or cavity preparation, the placement of a fiber post may be indicated. This may help to compensate for the remaining structure loss by avoiding stress concentration and enabling better distribution of stress to other areas of the tooth[8]. These posts are made of a resin matrix with reinforcing glass, carbon or quartz fiber[9], and because their elastic modulus is similar to that of dentin, they are fatigue-resistant and have tensile strength.

Another option for restoring ETT is the use of high molecular-weight polyethylene fibers. Ribbond fibers (Ribbond Inc., Seattle, WA, USA) are among the most commonly used. Their surface is plasma-treated to improve wettability and enhance adhesion to resin-based restorative materials. In addition, they exhibit an elastic modulus of 117 GPa and a tensile strength of 3 GPa. These mechanical properties, together with their flexibility, facilitate adaptation to the dental cavity[10].

Composite resins show good compressive strength but are weak against tensile forces; therefore, fiber reinforcement is proposed. It has been demonstrated that Ribbond fibers can increase the flexural strength and fracture toughness of composite resin restorations. The fiber design can increase the flexural strength through its pattern based on a dense network of locked nodal intersections, which are able to act as a crack stopping mechanism by changing direction that ultimately dissipates the strain. Furthermore, incorporating Ribbond fibers into composite resin restorations may reduce marginal microleakage in high C-factor cavities by decreasing the amount of resin matrix required for the final restoration[11].

In the area of coronal reconstruction, another widely used material is dual-curing resin, which behaves as a dentinal substitute in extensive cavities, and enables both direct and indirect teeth restorations[12]. This material is also recommended for intracanal cementation of fiber posts and core build-up due to its good mechanical properties and curing ability in areas where the light wave does not achieve adequate polymerization[13]. Its bonding protocols are specific, according to the manufacturer's instructions, as is the case of the ParaCore system (Coltene/Whaledent AG, Altstätten, Switzerland).

The aim of this *in vitro* study was to compare the compressive strength of endodontically treated mandibular premolars with MOD preparations restored using different post-endodontic reconstruction protocols (fiber posts, polyethylene fibers, and core buildup material), using intact teeth as a reference for maximum mechanical performance. The null hypothesis was that no significant differences in compressive strength would be observed among the evaluated groups.

MATERIALS AND METHOD

Sample selection

We used 40 single-rooted mandibular premolars which had been extracted for orthodontic reasons. Organic debris and periodontal tissue were removed with a G1 scaler tip (Woodpecker Medical Instrument Co., LTD, Guilin, China). The teeth were decontaminated in 2.5% sodium hypochlorite solution and stored in a solution of equal parts of alcohol and glycerin at room temperature for two weeks. Teeth with open apices, carious or non-carious lesions, preexistent restorations, root resorption, fractures, excessively wide root canals, or severely calcified canals were excluded. The sample dimensions of the coronal region were taken into account as selection criteria: mesiodistal (MD) 6 mm +/- 0.5 mm and buccolingual (BL) 7.5 mm +/- 0.7 mm. Digital preoperative radiographs were taken in MD and BL direction with radio-visiograph (RVG) Carestream 5200 (Carestream Dental LLC, Atlanta, GA, USA) to confirm the presence of a single root canal (type I) according to Vertucci et al. classification[14].

Endodontic procedure

Endodontic access was performed with a diamond round bur, round tungsten carbide bur #06 (Microdont, São Paulo, SP, Brazil) followed by Endo-Z bur (Coltene/Whaledent AG, Altstätten, Switzerland) to finish and refine the access cavity. The first exploration was done with a #10 25 mm K-file (MicroMega SA, Besançon, France) to ensure the patency of the teeth, and the cervical and middle thirds of the root canal were prepared with One Flare File N25 9% L17 (MicroMega SA, Besançon, France). The working length was established by inserting a size #15 25 mm K-file (MicroMega SA, Besançon, France) into the canal until it was visible at the apical foramen, then subtracting 1 mm.

Endodontic treatments were performed by the same operator through the crown-apical technique using the MicroMega One RECI #25.04 reciprocating single-file system (MicroMega SA, Besançon, France) and X-Smart Plus motor (Dentsply Maillefer, Ballaigues, Switzerland), according to the manufacturer's instructions.

The canals were irrigated with 2.5% sodium hypochlorite throughout the preparation process using a 10-mL Luer syringe and a 25-gauge needle. The irrigant was activated with the EndoActivator system (Dentsply, Tulsa, OK, USA). The penultimate irrigation was done with 17% EDTA (Farmadental, Ultra D SRL, CABA, Argentina), followed by a final irrigation with 2.5% sodium hypochlorite.

Once the chemical-mechanical preparation had been completed, the coronal area was dried with cotton pellets, and the root canal with paper points (Meta Biomed Co. LTD., Chungcheongbuk-do, Korea). The gutta-percha point selected as the master point was #20.04 (Meta Biomed Co. LTD., Chungcheongbuk-do, Korea), accurately gauged with the endodontic gauge (Maillefer, Dentsply Sirona, Switzerland) consistently with the preset working length, and the obturation was performed according to the hybrid Tagger technique using accessory gutta-percha points (Meta Biomed Co. LTD., Chungcheongbuk-do, Korea) and AH26 sealer (Dentsply De Trey GmbH, Konstanz, Germany). A radiograph of each tooth was made to evaluate the quality of the endodontic treatment. Finally, the samples were stored at 37 °C and 100% humidity for one week.

In all the teeth except those of the control group, 6 mm deep standardized MOD cavities were prepared with the diamond instrument FG 846 KRF-018 (JOTA AG, Rüthi, Switzerland), which was changed after every six uses to ensure its grinding power (Fig. 1). The widths of the lingual and buccal walls were standardized at 2.5 +/- 0.3 mm with an approximate angulation of 6° given by the same instrument, and all the angles were rounded. All the preparations were performed by one operator.

The teeth were divided into 4 groups:

1. Control GROUP (n= 10): Intact teeth, with neither endodontic treatment nor restoration, included as a reference group to represent the maximum compressive resistance of sound dental structure.

2. Core buildup material GROUP (n= 10): Endodontically treated teeth (ETT), MOD preparation, ParaCore buildup (Coltene/Whaledent AG, Altstätten, Switzerland) and direct final restoration with microhybrid composite Brilliant Everglow Body 4g shade A2/B2 (Coltene/Whaledent AG, Altstätten, Switzerland).

3. Intraradicular fiber post GROUP (n= 10): ETT, MOD preparation, placement of glass fiber posts #1 ParaPost Taper Lux (Coltene/Whaledent AG, Altstätten, Switzerland) and direct final restoration with microhybrid composite Brilliant Everglow Body 4g shade A2/B2 (Coltene/Whaledent AG, Altstätten, Switzerland).

4. Polyethylene fibers GROUP (n= 10): ETT, MOD preparation, placement of fiber continuous strip (Ribbond Inc., Seattle, USA) and direct final restoration with microhybrid composite Brilliant Everglow Body 4g color A2/B2 (Coltene/Whaledent AG, Altstätten, Switzerland).

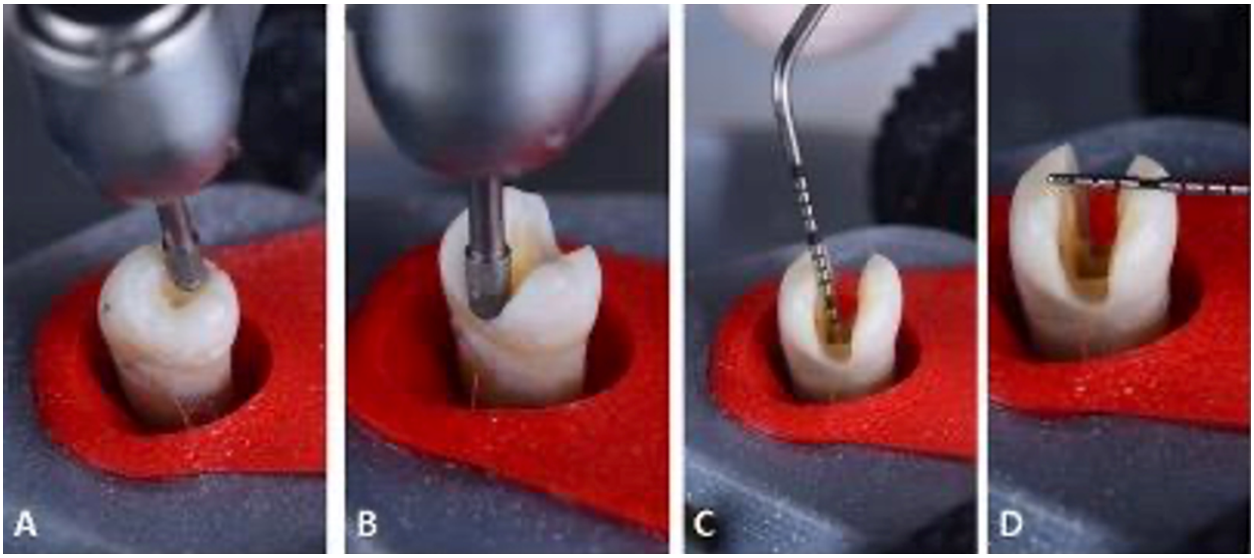

Fig. 1: MOD cavity preparation. **A:** *Extension of the cavity to the distal ridge.* **B:** *Extension to the mesial ridge* **C:** *Checking the axial wall depth* **D:** *Checking the isthmus width.*

Restoration procedure

Core buildup material GROUP: a 1-2 mm desobturation was performed on the teeth with Gates-Glidden burs (Dentsply, Sirona, Switzerland). Teeth were selectively etched with 35% phosphoric acid (Etchant Gel S, Coltene/Whaledent AG, Altstätten, Switzerland) on the dental enamel for 15 seconds, and rinsed for 30 seconds with water followed by water spray. Each specimen was air dried and the root canal entrance sealed with composite Brilliant Flow (Coltene/Whaledent AG, Altstätten, Switzerland). Dentinal substrate was prepared according to the manufacturer's instructions. The dual-cured composite resin system ParaCore (Coltene/Whaledent AG, Altstätten, Switzerland) was dispensed up to the dentinoenamel junction (DEJ) through the automix tip of the kit. After the initial setting time, polymerization was performed on each tooth surface for 20 seconds, until the curing process was completed (Fig. 2).

Intraradicular fiber post GROUP: Desobturation was performed with a Peeso drill #1 (Deltajet, Guangdong, China) 9 mm apically from the cementoenamel junction (CEJ). A #1 ParaPost drill

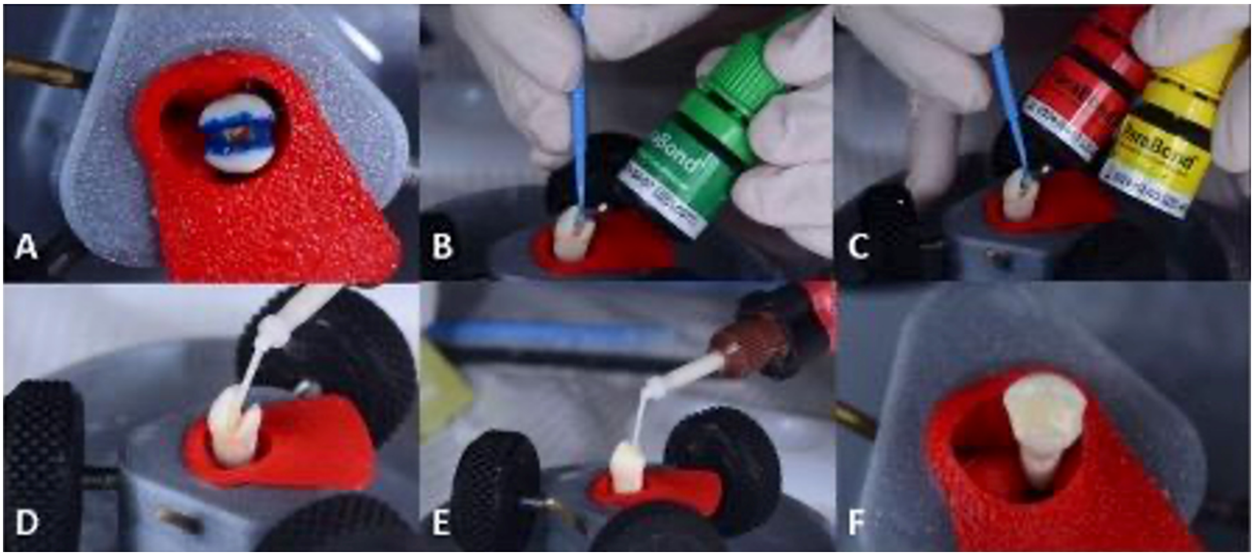

Fig. 2: Restoration protocol with core build-up material. **A:** *Selective etch of the enamel* **B:** *Primer application.* **C:** *Applying the adhesive.* **D** *and* **E:** *Applying ParaCore automix syringe tip* **F:** *After polymerization.*

(Coltene/Whaledent AG, Altstätten, Switzerland) was used to shape the root space, and control radiographs were taken. Each tooth was etched selectively with 35% phosphoric acid (Etchant Gel S, Coltene/Whaledent AG, Altstätten, Switzerland), following the same protocol as described above. Post cementation and core reconstruction were done with the resin system ParaCore (Coltene/Whaledent AG, Altstätten, Switzerland), according to the manufacturer's instructions (Fig. 3).

Polyethylene fibers GROUP: 1-2 mm root canal filling was removed from the entrance of the canal with Gates-Glidden burs (Dentsply, Sirona, Switzerland). Enamel was etched selectively with 35% phosphoric acid (Etchant Gel S, Coltene/Whaledent AG, Altstätten, Switzerland), as in the other two groups. Then, the adhesive system ONE COAT 7 Universal (Coltene/Whaledent GmbH Co., Langenau, Germany) was applied for 20 seconds over the whole preparation. The adhesive solvent was evaporated with air, and polymerization was conducted for 20 seconds with a Led D curing light lamp (Woodpecker Medical Instrument Co., LTD, Guilin, China). The root canal entrance was sealed with composite Brilliant Flow (Coltene/Whaledent AG, Altstätten, Switzerland). A 2-mm-wide polyethylene fiber strip (Ribbond Inc., Seattle, WA, USA) was cut to a length sufficient to span the MOD preparation in a buccolingual direction, using the scissors provided in the kit. The fibers were coated in the pure waterproof adhesive ClearFil SE Bond (Kuraray Medical Inc., Okayama, Japan) to enhance their handling and adaptation. Once inside the cavity, they were fixed with composite Brilliant Flow (Coltene/Whaledent AG, Altstätten, Switzerland) and light cured (Fig. 4).

The final restoration was done with microhybrid composite Brilliant Everglow A2/B2 (Coltene/Whaledent AG, Altstätten, Switzerland) in the core buildup material, intraradicular fiber post and polyethylene fiber groups, with the aim of performing the anatomic restoration. To hold the restorative material inside the proximal aspects of the tooth, a metal matrix assembled in a Tofflemire matrix retainer was used.

Roots were coated with light-body silicone (President Coltene/Whaledent AG, Altstätten, Switzerland) 1 mm below the CEJ to simulate the 0.3 mm periodontal membrane space, and inserted into a block of transparent self-curing acrylic resin (Subiton, Laboratorio SL, Prov. de Bs. As., Argentina). When specimen preparation was complete, they were stored at 100% humidity and at 37 °C for 15 days.

Specimens were tested for compressive strength in a universal INSTRON type testing machine, model 1011 (Instron Mechanical Testing Systems, Norwood, MA, USA). A round metallic tip 5 mm in diameter was placed parallel to the long axis of the tooth against the occlusal surface restoration, connecting the buccal and lingual cusps simultaneously. Each tooth was submitted

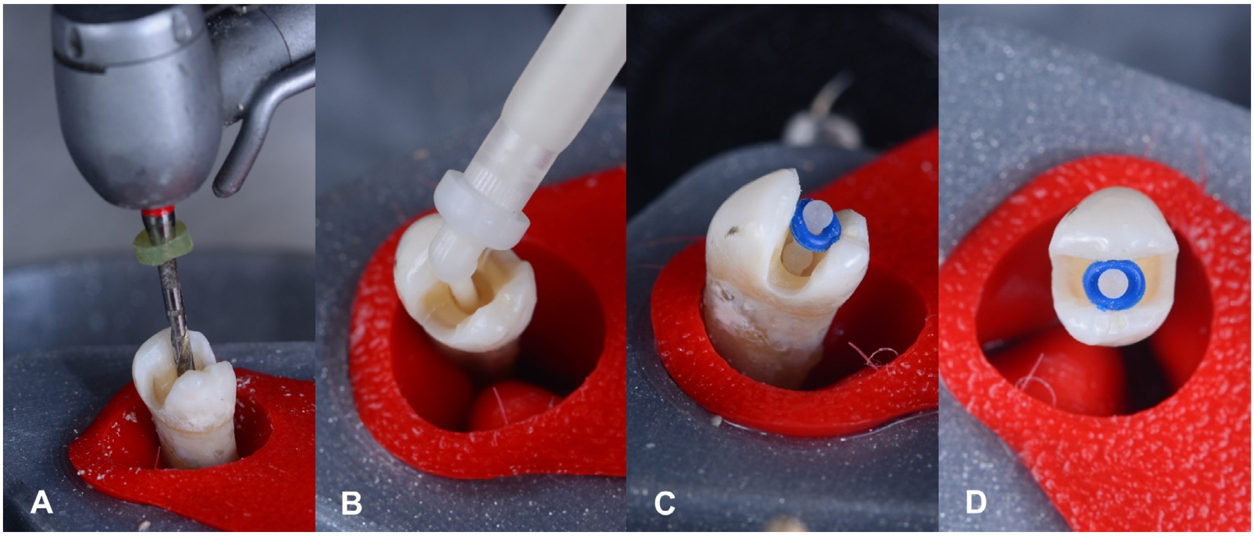

Fig. 3: Intraradicular fiber post cementation protocol: **A:** *Preparation of the post cavity.* **B:** *Cementation with ParaCore.* **C:** *Insertion of the post, lateral view.* **D:** *Insertion of the post, occlusal view.*

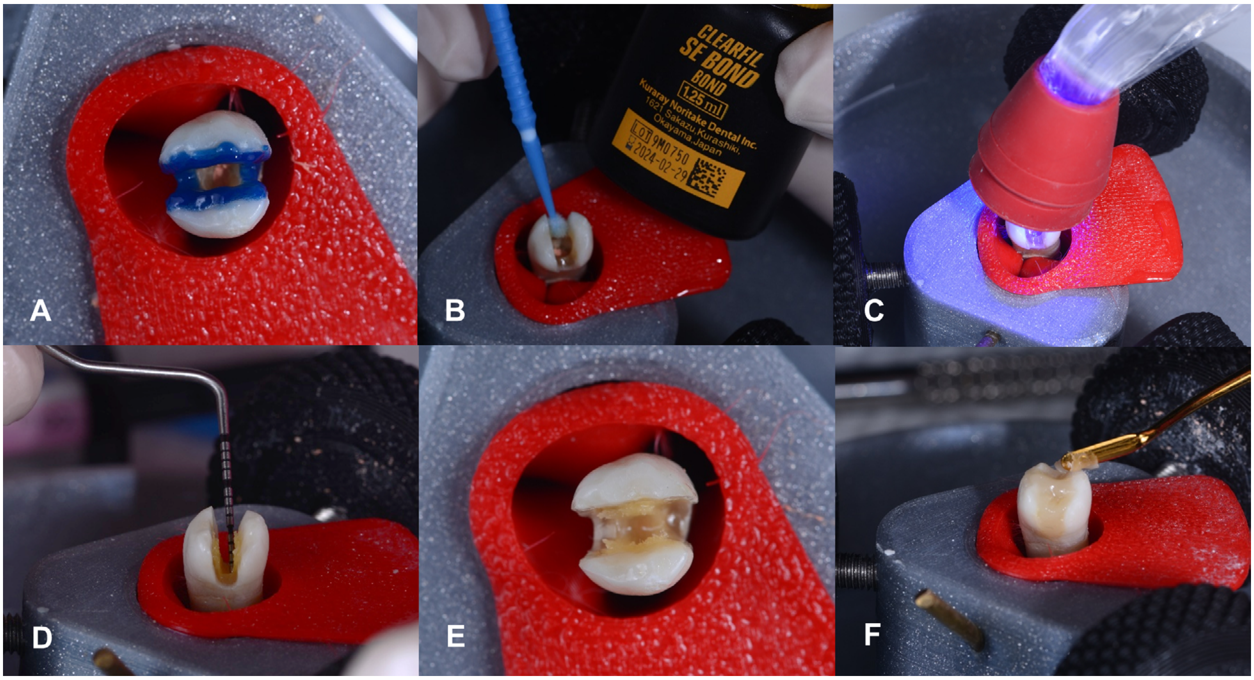

Fig. 4: Polyethylene fibers protocol. **A:** *Selective etch of the enamel.* **B:** *Application of the adhesive system.* **C:** *Light activation.* **D:** *Depth control with periodontal probe.* **E**: *Following the fiber polymerization inside the cavity.* **F:** *Insertion of direct composite resin.*

to axial compressive stresses at 1 mm/min and the maximal load reached at the fracture was recorded in Newtons, as suggested by different authors[15,16].

Data were distributed normally, and analysis of variance (ANOVA) was applied in statistical software. Compressive strength (N) was described by the following measurements: median with 95% confidence interval (CI95) estimated by exact method, mean standard deviation (SD), first quartile (Q_1), third quartile (Q_3), minimum (Min) and maximum (Max). Resistance was compared among the four protocols using non-parametric Kruskal-Wallis test. One-way parametric ANOVA test was not used because it does not meet the assumptions of normality, although it does meet the homoscedasticity. The assumptions of normality and homoscedasticity were assessed by the Shapiro Wilk test with approximations of Royston and Levene, respectively. A p-value lower than 0.05 was considered significant. The program R v. 4.3.1 (R Core Team, 2023)[17] was used: database package, *DescTools*[18], *ggplot2*[19] and *lawstat*[20].

RESULTS

The compressive strength values (N) showed numerical differences among the evaluated groups; however, no statistically significant difference was observed (Kruskal–Wallis: $H = 0.85$; $df = 3$; $p = 0.84$). The median (95% CI) compressive strength values were 557.4 N (100.8–574.8) for the control group, 345.1 N (216.8–574.9) for the core buildup material group, 427.5 N (146.3–495.4) for the intraradicular fiber post group, and 471.4 N (194.2–565.5) for the polyethylene fiber group (Fig. 5, Table 1).

DISCUSSION

This *in vitro* study investigated the compressive strength of endodontically treated premolars with MOD cavities restored with three different restorative protocols. No significant difference was found among the 4 groups (p=0.84).

Intact teeth were included as a control group to provide a reference value for the maximum compressive resistance of non-restored dental structures. Although the primary aim of the study was to compare different post-endodontic reconstruction protocols, the inclusion of intact teeth enabled biomechanical comparison with the original condition of the dental substrate, and facilitated interpretation of the restorative behavior relative to intact teeth.

Premolars are more prone than molars to being submitted to lateral forces during mastication. The remaining dental structure and the functional

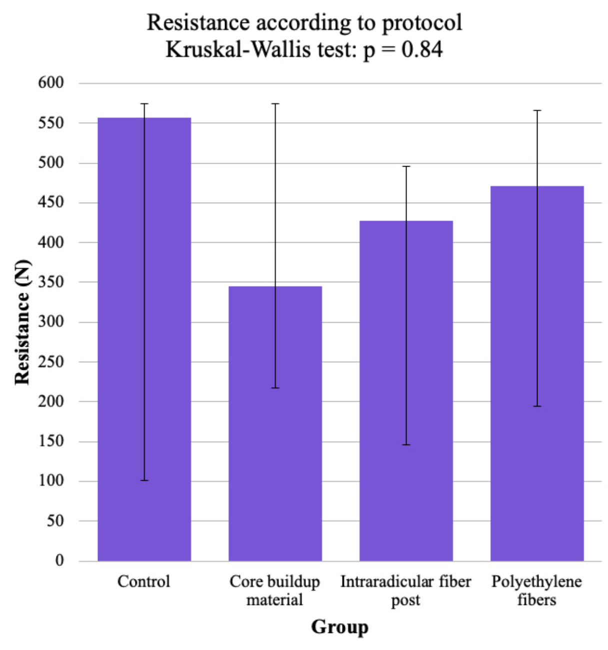

Fig. 5: Compressive strength compared in the four protocols (Median, CI95).

demands are decisive factors, as they must ensure compressive strength and long-term clinical performance. Premolars were used in the current study because they exhibit characteristics that make them more prone to being subjected to those stresses[21].

Although fiber posts are generally recommended in teeth with extensive loss of coronal structure, they were included in the present study to evaluate their reinforcing effect under standardized experimental conditions and compare their mechanical behavior with alternative restorative strategies. The use of fiber posts in ETT has been associated with improved stress distribution because their elastic modulus is similar to that of dentin. However, their use should be considered carefully, according to the amount of remaining dental structure[8,9,21].

Cavity preparations which cause a tooth further weakening due to their depth or extension must be restored by means of adhesive restorations with cuspal coverage[22]. This approach contributes to preventing cuspal flexion and reduces marginal leakage, which are crucial to ensure long-term durability of the restoration[23].

This study compared the axial stress loads of the restorative materials in anatomical restorations of endodontically treated teeth. Currently, restorative dentistry is based on biomimetic adhesive techniques, and consists of preserving the greatest possible amount of dental tissue. The restoration type (direct vs. indirect, and composite vs. ceramics) should be selected according to the extent of the cavity[24]. The restorative procedure and the filling material must provide sufficient mechanical resistance to a tooth with an MOD cavity[25]. In teeth with missing walls and high C factor cavities, the restorative technique is the key to achieving the adhesion of restorative materials[26].

It should also be considered that direct composite restorations in premolars with MOD cavities may present a greater risk of structural failure under functional loading due to the loss of both marginal ridges. This structural compromise may negatively affect the distribution of occlusal forces and increase susceptibility to cuspal or radicular fractures[22,26]. Therefore, in clinical situations with extensive loss of tooth structure, indirect restorations with cuspal coverage could provide a more predictable long-term restorative alternative[22,24].

Daher et al.[27] evaluated the fracture resistance and failure mode of non-invasively reinforced endodontically treated mandibular molars, and reported no significant difference in fracture resistance among the evaluated restorative approaches. However, the use of glass fiber reinforcement was associated with a more favorable failure pattern, suggesting a potential biomechanical benefit despite the absence of differences in maximum fracture resistance values.

Table 1. Comparison of the compressive strength in the four protocols

Group	Resistance (N)				
	Median (CI95)	Mean (SD)	Q_1 / Q_3	Min/Max	N
Control	557.4 (100.8 to 574.8)	419.5 (207.4)	293.5 / 572.1	63.6 / 575.5	10
Core buildup material	345.1 (216.8 to 574.9)	361.2 (158.8)	233.6 / 501.4	132.3 / 576.4	10
Intraradicular fiber post	427.5 (146.3 to 495.4)	386.6 (152.6)	389.2 / 457.3	86.4 / 576.1	10
Polyethylene fibers	471.4 (194.2 to 565.5)	408.4 (171.8)	243.3 / 560.7	153.0 / 574.5	10

Kruskal-Wallis test: H = 0.85; DF = 3; p = 0.84

Another study assessed the fiber positioning and the orientation of fracture resistance in mandibular premolars with MOD cavities. The results showed that horizontally positioned fibers, oriented in a buccolingual direction, increased fracture resistance[15]. This orientation was also used in the present study. Previous investigations showed that the reinforcement with fibers, regardless of position or orientation, resulted in an increase in resistance to fracture of teeth[28-32]. These results are consistent with the findings of the present work.

Different studies have reported that fiber placement is an effective, practical treatment option to reinforce the material in endodontically treated teeth, with no posts that distribute the stresses along the interface tooth-restoration. The restoration transfers the matrix stresses to the fibers, preventing cracks from spreading through the filling materials[8,9]. The present study supports the research of Soto-Cadena et al.[7] on the reinforcement of endodontically treated MOD cavities with Ribbond fibers and a resin subsequently used as build-up material increased the resistance to fracture, suggesting that it may be adequate for the direct coronal restoration of large posterior cavities in stress-bearing areas.

Göktürk et al.[16] investigated fracture resistance in endodontically treated maxillary premolars, with Class II cavities with different types of restorations. They analyzed the following groups: intact teeth; unrestored endodontically treated teeth; direct resins; direct resin buccolingually reinforced with glass fiber, and inlay ceramic restorations. All restorative techniques increased fracture resistance compared with the unrestored group; however, the values remained lower than those of intact teeth. No significant differences were observed among the restored groups, which is consistent with the findings of the present study.

According to Sengun et al.[33], fiber-reinforced composite restoration seemed to be a more reliable restorative technique than traditional composite restorations for endodontically treated teeth with MOD cavities, since was associated with a more favorable failure pattern under occlusal loading.

The present study has limitations inherent to *in vitro* investigations. The compressive load was applied under static axial conditions, which do not completely reproduce the multidirectional and cyclic forces present in the oral environment. In addition, thermal cycling, fatigue loading, aging of restorative materials, and indirect restorations with cuspal coverage were not evaluated. Another limitation is that fracture mode was not analyzed. Future studies should include these variables to better simulate clinical conditions and assess the long-term biomechanical behavior of restored endodontically treated teeth.

CONCLUSION

Under the experimental conditions of the present study, the evaluated post-endodontic reconstruction protocols showed similar mechanical behavior regarding compressive strength in endodontically treated mandibular premolars. Although polyethylene fiber reinforcement demonstrated a tendency toward higher resistance values, the results do not enable the establishment of any conclusive mechanical advantages of the restorative systems assessed.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interests.

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