Available online at www.giornaleitalianoendodonzia.it

ORIGINAL ARTICLE

Influence of the direct composite restauration on the fracture strength and failure modes of endodontically treated premolars restored with posts

ABSTRACT

Aim: *The long-term success of endodontically treated teeth requires maintaining structural integrity, functionality, and aesthetics. The combined use of endodontic fiber posts with resin-based micro- and nano-composites seems to be an intriguing solution for the reinforcement of the damaged tooth structures. This in vitro study aimed to evaluate the mechanical behavior and fracture patterns of premolars restored with different combinations of endodontic fiber posts and composite resins, subjected to thermomechanical aging and masticatory force simulation.*
Methods: *Fifty extracted maxillary premolars were divided into five groups, including a control group of healthy teeth and four experimental groups with two types of fiber posts (hollow and compact) and two composite resins with different elasticity (traditional and bulk-fill). After cyclic fatigue testing, fracture strength and failure modes were analyzed using statistical methods.*
Results: *The control group exhibited significantly higher fracture resistance (1909±177) than the experimental groups, with no significant differences among experimental groups (p. value >0.05). However, teeth restored with bulk-fill composites demonstrated slightly higher fracture resistance and a higher percentage of favorable fractures than other samples. The combination of bulk-fill composite and hollow fiber posts was associated with more favorable fracture outcomes (n=8 favorable fractures).*
Conclusion: *These findings suggest that bulk-fill composites, due to ease of use and favorable fracture behavior, may be a viable restorative option. Further studies with larger sample sizes are needed to confirm these results.*

Vincenzo Spinelli[1]
Vito Gallicchio[1]
Francesco Traino[1]
Ciro Marino[1]
Roberto De Santis[2]
Sandro Rengo[1]
Niccolò Giuseppe Armogida[1*]

[1]Department of Neurosciences, Reproductive and Odontostomatological Sciences, University Federico II of Naples, Naples, Italy
[2]Institute of Polymers, Composites and Biomaterials-National Research Council of Italy, Naples, Italy

Received 2024, August 19
Accepted 2024, September 26

KEYWORDS *fiber post, endodontic treatment, cyclic fatigue, dental restoration failure*

Corresponding Author*
Niccolò G. Armogida | Department of Neurosciences, Reproductive and Odontostomatological Sciences, University Federico II of Naples, Naples | Italy
Tel +39 3932438489 Email: ng.armogida@gmail.com

Peer review under responsibility of Società Italiana di Endodonzia
10.32067/GIE.2024.38.01.18

Introduction

Ensuring long-term structural integrity while preserving functionality and aesthetics of endodontically treated teeth is one of the main goals of modern dentistry (1-3). Although many restorative techniques have been studied and developed, the combined use of endodontic fiber posts with micro- and nano-resin-based composites seems to be a good solution to reinforce damaged tooth structures (4-7). Fiber posts provide support to the remaining tooth structure and at the same time facilitate the occlusal forces distribution, ensuring the longevity of the restoration by reducing the risk of root fracture (8). The strength and rigidity of fiber posts are crucial to achieve a homogenous restorative system and to balance stress distribution between the restoration and the surrounding tissues, thus preventing root fractures (9, 10). In recent years, hollow fiber-reinforced posts have been developed as alternatives to compact ones. These endodontic posts take advantage of the reverse extrusion of luting cement from the apex to the crown, ensuring a homogeneous distribution within the root cavity and minimizing air bubble formation. Due to their reduced stiffness, hollow fiber posts should prevent catastrophic root fractures (11-13).
Failure modes and fracture patterns are essential to understand and predict the mechanical and structural behavior of restorative systems involving endodontic fiber posts. Fracture types are strictly linked to the axial stiffness of posts. High axial stiffness promotes fractures below the cement-enamel junction (CEJ), which are considered unfavorable as they hinder tooth restoration. On the other hand, lower axial stiffness promotes favorable fractures above the CEJ, allowing for tooth restoration in the event of failure (14).
The selection of appropriate materials and techniques is critical for successful restorations, although the use of composite materials with endodontic fiber posts are well-established in restorative dentistry. Composite resins are a common choice for the direct restoration of endodontically treated teeth: they are aesthetic and versatile materials capable of offering excellent mechanical (15) and adhesive (16) properties.
Controlled aging and fracture tests are valuable methods for studying and defining the retention and strength of tooth restoration systems, since they are subjected to various functional forces during mastication (5).
But, to the best of authors' knowledge, there is a lack of evidence regarding the evaluation of the role of the direct composite restoration on the mechanical resistance and on the fracture patterns.
Therefore, the aim of this study was to define the mechanical behavior and fracture types of premolars restored with different combinations of endodontic fiber posts and composite resins subjected to thermomechanical aging and simulation of masticatory forces. By delineating the performance of restorative systems, clinicians can better comprehend clinical outcomes and accordingly select optimal materials and techniques for long-term success.

Materials and Methods

In this in-vitro study, 50 dental elements extracted for orthodontic reasons were selected. Subsequently, root canal treatment was performed, including cleaning, disinfection, shaping, and obturation. The dowel space was prepared, the post was cemented, and finally the dental reconstruction was carried out using a direct technique.
The dental elements were randomly divided into five groups: one control group consisting of healthy teeth, and four experimental groups created by combining two types of posts and two types of composites.
Following reconstruction, the teeth underwent cyclic fatigue testing, and their fracture resistance was evaluated. The data were then statistically analyzed using analysis of variance.

Endodontic Posts and Materials Selection
Two types of endodontic posts with identical composition but different characteristics were used: a hollow glass fiber post (HGP) and a compact glass fiber post (GP).

Table 1

Composition and geometrical details of endodontic fiber posts

Materials	Manufacturer	Code	Composition	D [mm]	d [mm]	E [GPa]	Axial Stiffness [kN]	Bendin Stiffness [kN·mm²]
Hollow Glass Fiber Post – Tech21	Isasan (Italy)	HGP	- Silica fibers 55% - Diphenylpropane + methyloxirane 45%	1.2	0.5	38.80 (0.98)	36.47 (0.92)	3.83 (0.10)
Glass Fiber Post – Techole	Isasan (Italy)	GP	- Silica fibers 55% - Diphenylpropane + methyloxirane 45%	1.2		40.22 (0.95)	45.44 (1.07)	4.10 (0.10)

D and d represent the external and internal radius of hollow posts, respectively.
Numbers in brackets represent the standard deviation.

Table 2

Properties of composite materials according to manufacturer's data

Materials	Manufacturer	Code	Bending Stiffness [kN·mm²]	E [GPa]	Polymerization depth [mm]	Shrinkage [%-vol]
Venus® Pearl ONE	Kulzer	K	145	10.7	2.4	1.9
Venus® Bulk Flow ONE	Kulzer	KB	120	120	6.2	1.59

Besides, the self-etching and self-adhesive dual cement G-CEM ONE™ (GC Dental, Tokyo, Japan) was employed to lute the posts inside the dowel space. Details of the selected posts are reported in Table 1. The mechanical properties (Young's Modulus, Axial Stiffness and Bending Stiffness) of the fiber posts were previously defined through a three-point bending test by analyzing the load-displacement curves (14).
For the direct restorations, two different resin-based composite materials were utilized: Venus Pearl ONE (Kulzer, Hanau, Germany) (K) and Venus Bulk Flow ONE (Kulzer, Hanau, Germany) (KB). Details of the selected materials are reported in Table 2.

Maxillary first premolar selection
Fifty maxillary first premolars were chosen for this study. The teeth were extracted for orthodontic reasons. The study was approved by the Ethics Committee of the University of Naples Federico II (protocol number 137/2017) and conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from all patients.
Inclusion criteria comprised the absence of carious lesions, comparable crown and root dimensions, presence of two root canals, absence of abfractions, cracks, or erosions. Subsequently, the teeth were immersed in a 5% NaOCl solution for 5 minutes and then stored in a physiological solution at room temperature to avoid dehydration.

Root canal treatment and obturation
The dental specimens underwent root canal treatment, excluding the control

group (healthy teeth). The access cavity was created using a pear-shaped diamond bur with a 1.6 mm diameter mounted on the high-speed handpiece Fona8080 (Fonadental, Assago, Italy). Canal scouting to the working length was performed using size 10 K-files (Kerr Corporation, CA, USA). The glide path was established using a PathFile P2 (Maillefer, Ballaigues, Switzerland). The canals were instrumented to working length using the crown-down technique with ProTaper•Next X1-X2-X3 rotary files (Maillefer). Following each file change, the canals were irrigated with a 5.25% NaOCl solution. The canals were dried with ProTaper•Next X3 paper points (Maillefer) and obturated with ProTaper•Next X3 gutta-percha cones (Maillefer) employing a single-cone technique. The specimens were stored at 37 °C and 100% humidity. Every tooth was consistently prepared by the same operator. Samples were randomly divided into five groups (n=10) as shown below and different fiber posts were employed for the restoration.

MOD cavity preparation, post cementation and restoration

Group 1 (Healthy Teeth): teeth in this group served as the control group (n=10) and underwent no procedures.

Group 2 (K-GP). A 1.4 mm diameter cylindrical diamond bur mounted on a high-speed handpiece was used to prepare MOD cavities with predetermined dimensions measured with a digital caliper: buccal-palatal width was set at 3 mm, while in the coronal-apical direction preparations extended to the CEJ. The post space was prepared in the palatal root using a Gates Glidden bur No. 4. For post cementation, the self-adhesive resin cement G-CEM ONE (GC Dental) was utilized following the manufacturer's instructions. For compact posts (Tech21, Isasan, Como, Italy), cement was initially placed inside the post space using a Lentulo spiral (Dentsply Sirona, North Carolina, USA), followed by the post itself. After a 3-minute self-polymerization phase, cement was light-polymerized using the Bluephase PowerCure lamp (Ivoclar, Schaan, Liechtenstein) at 1200 mW/cm2 for 40 seconds. The post was reduced in the coronal-apical direction using a 1.4 mm diameter cylindrical diamond bur mounted on a high-speed handpiece to ensure it was 2 mm apical to the occlusal table. After post cementation, teeth underwent adhesive procedures: etching with 37% orthophosphoric acid on both enamel and dentin for 15 seconds, followed by rinsing for 60 seconds, thorough drying of dental tissues, application of the one-bottle universal adhesive G-Premio BOND (GC Dental), and light-polymerization using the Bluephase PowerCure lamp (Ivoclar) at 1200 mW/cm2 for 20 seconds. Subsequently, reconstruction was performed by incrementally applying Venus Pearl ONE (Kulzer) to restore dental anatomy. Each composite increment presented a thickness lower or equal to 2 mm and was light-polymerized using the Bluephase PowerCure lamp (Ivoclar) at 1200 mW/cm^2 for 20 seconds.

Group 3 (K-HGP): the procedures for this group mirrored those of group 2 in terms of post housing and restoration. The only distinction lies in the use of a hollow post (Techole, Isasan, Como, Italy) and its cementation. After inserting Techole into the post-space, cement was applied through the central hole in a single step via a reverse extrusion mechanism. Following post cementation, Venus Pearl ONE (Kulzer, Hanau, Germany) was employed for the direct restoration of teeth, as in group 2.

Group 4 (KB-GP): in this group, identical procedures to those in group 2 were applied, except for using Venus Bulk Flow ONE (Kulzer, Hanau, Germany) for restoration. For group 4 and 5, each increment of composite presented a thickness of about 4 mm in order to assess the mechanical properties of this type of composite following the advertised features.

Group 5 (KB-HGP): identical procedures to those in group 3 were followed, except for the use of Venus Bulk Flow ONE (Kulzer, Hanau, Germany) for restoration.

Cyclic Fatigue and Fracture Testing

A low-temperature self-polymerizing

Figure 1
Compression test set-up.

acrylic resin was used to fix the premolars into 16 mm diameter aluminum cylinders. Teeth were cemented 2 mm below the CEJ to simulate alveolar bone. Specimens were then subjected to an aging protocol: cyclic fatigue testing was conducted in a controlled environment (H_2O at 37 °C) for one million cycles by simulating masticatory loads via a sinewave ranging from 10 to 100 N at 2 Hz frequency. The cyclic fatigue load was applied between the two cusps of each premolar through a horizontal stainless cylinder (D=6 mm). As in real conditions, the dynamically vertical load is combined of a vertical compound (compression) and a horizontal compound (bending). This means that a complex fatigue stress cyclic loading is applied to specimens, consisting of compressive and bending loads. After controlled aging, specimens underwent static mechanical testing utilizing the Instron 5566 dynamometer (Instron Ltd., High Wycombe, UK) at a speed of 1 mm/min (Figure 1). The compliance of the dynamometer was initially determined experimentally by assessing its compression stiffness based on the stress–strain curve steepness in the elastic region.

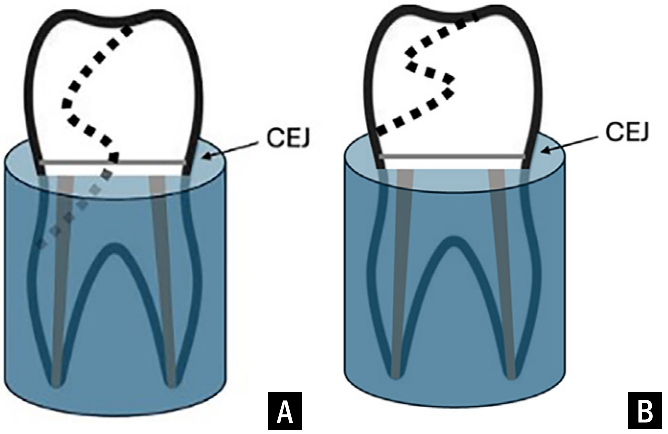

Figure 2
Comparison between an unfavorable fracture **(A)** and a favorable fracture **(B).**

Statistical Data Analysis
The data underwent statistical analysis employing two-way ANOVA, followed by Tukey's test at a critical value of 0.05; mean values and standard deviations (SD) of fracture resistance were calculated for each group. For the fracture patterns statistical significance, a Chi-squared test and a Fisher's Exact test for larger tables were employed.

Optical Microscopy and Fracture Pattern Analysis
In order to define and classify fracture types, the optical microscope Motic AE21 (Motic Ltd., Kowloon, Hong Kong) equipped with a Nikon D3200 camera was employed. Fractures were categorized as either favorable or unfavorable based on the position of the lower edge of the fracture surface relative to the cement-enamel junction (CEJ) (Fig. 2). Specifically, fractures with the edge positioned above the CEJ were deemed favorable, as they are more likely to be easily restorable. Conversely, fractures with the edge positioned below the CEJ were classified as unfavorable, as restoration of the premolar would require a more complex and multidisciplinary approach, or not be feasible at all (9, 17, 18).

Results

Figure 3 illustrates the mechanical behavior after aging of both healthy teeth (Group 1) and premolars restored using the investigated endodontic posts and composite materials (Groups 2 to 5), while Table 3 reports the values of mechanical strength for all groups recorded after fatigue. After the cyclic fatigue protocol, fracture strength was assessed by analyzing the maximum load achieved by the specimens. The control group (Group 1)

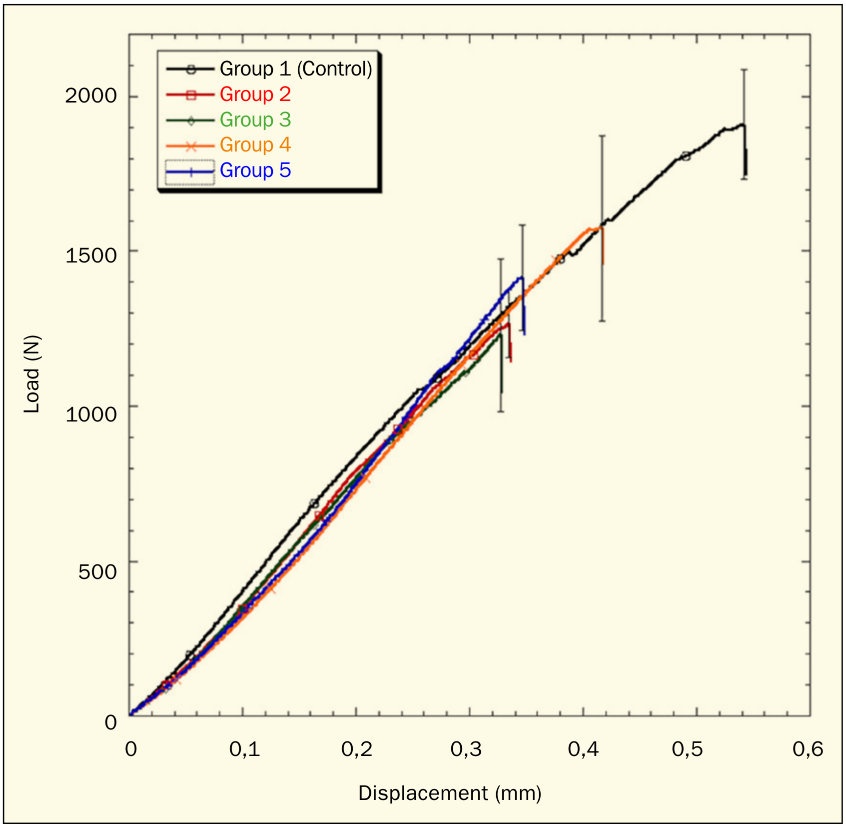

Figure 3
Mechanical behavior after fatigue of control group (Group 1), K-GP group (G2), K-HGP group (G3), KB-GP group (G4) and KB-HGP group (G5).

exhibited significantly higher strength compared to all other groups ($p<0.05$). No statistically significant difference in strength was observed among premolars restored with different endodontic posts and composite materials (Groups 2 to 5).

Table 4 displays the fracture pattern results of the investigated groups after compression testing. All groups exhibited a majority of favorable fractures. A Chi-squared test was performed to investigate potential differences between the groups; the computed chi-squared statistic was 1.287 with a p-value of 0.864, indicating no statistically significant difference among the groups. For completeness, a generalized Fisher's Exact test was employed, yielding a p-value of 0.956, consistent with the chi-squared test results.
Figure 4 shows the images of the favorable and unfavorable fractures of the evaluated five groups taken with the digital microscopy.

Discussion

The fracture resistance of the dental elements selected in this in vitro study was evaluated by analyzing the maximum load-at-break values obtained using a specialized testing machine.
The control group exhibited significantly higher fracture resistance compared to the other groups. It must be considered that the endodontically treated tooth undergo significant biological changes, such as a decrease in water content (19, 20), and the loss of cross-links between collagen fibers (20). However, some studies suggested that these factors do not specifically cause al-

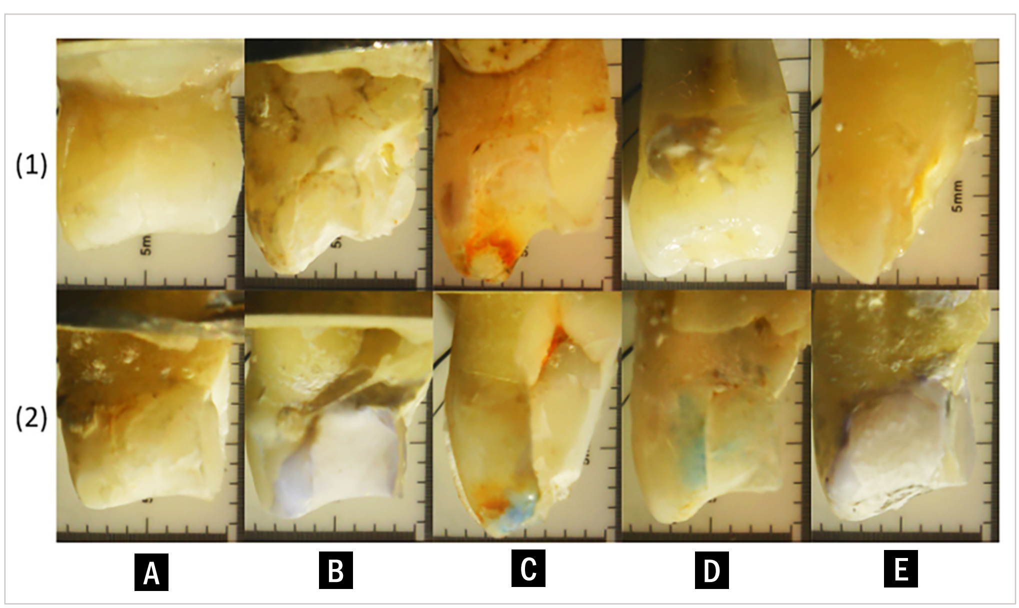

Figure 4
Digital microscopy to define 1) favoable and 2) unfavorable fractures of **A)** control group, **B)** K-GP group, **C)** K-HGP group, **D)** KB-GP group and **E)** KB-HGP group.

Table 3
Fracture strength of investigated teeth after fatigue

	Group 1 (Control)	Group 2 (K-GP)	Group 3 (K-HGP)	Group 4 (KB-GP)	Group 5 (KB-HGP)
Load [N]	1909 (177)[b]	1252.89 (110.40)[a]	1219.53 (247.78)[a]	1575.03 (300.12)[a]	1411.09 (169.66)[a]

Numbers into brackets denote the standard deviation.

Table 4
Failure mode observed frequencies for each group

Group	Favorable		Unfavorable		*p*-Value
	n	%	n	%	
Control	7	70.00	3	30.00	
K-GP	6	60.00	4	40.00	p>0.05[1]
K-HGP	7	70.00	3	30.00	p>0.05[2]
KB-GP	6	60.00	4	40.00	
KB-HGP	8	80.00	2	20.00	

[1]A chi-squared test was used to determine whether there was a statistically significant difference between the groups in terms of observed frequencies.
[2]For completeness, a generalized Fisher's Exact test for larger tables was also employed.

terations in the mechanical and physical properties of dentin (21); as a matter of fact, the endodontically treated tooth is likely to undergo other changes that compromise its behavior, such as carious lesions, fractures, and access cavities, which proportionally reduce its biomechanical resistance based on the amount of tissue removed (22). In particular, the factor that most significantly affects the structural weakening of the tooth is the loss of marginal ridge integrity, which can lead to a stiffness reduction of up to 63% for a mesio-occluso-distal cavity (22). According to previous studies (23-28), the fracture strength of healthy premolars consistently surpassed that of endodontically treated teeth, irrespective of the restoration strategy employed. On the other hand, it was found out that endodontically treated teeth restored with composite resins showed fracture resistance values statistically similar to those of healthy teeth (29-31).

The mechanical performance and the relevance of the materials employed can be evaluated by comparing the results observed in groups where teeth were restored with the same composite resin but different posts, and in groups where teeth were restored with the same post but different composite resins.

Composite resin is typically applied using an incremental technique, involving the placement of composite layers no thicker than 2 mm: layers thicker than 2 mm do not allow UV light to penetrate deeply enough to initiate and complete the polymerization of the deepest portion of the composite (32). Additionally, smaller amounts of composite resin experience less shrinkage, thus resulting in lower contraction stress. However, layering in increments of up to 2 mm is time-consuming and technique-sensitive (33). That's why bulk-fill resin composites have been introduced to the market, as they are designed to allow layering in increments of 4-5 mm (34-37). The manufacturers of these composites claim that they offer greater depth of cure and reduced polymerization stress compared to traditional composites (38, 39). No statistically significant difference was found between groups restored with the traditional composite and groups restored with the bulk-fill one, in accordance with other studies (26, 40-45). Although not statistically significant, the groups in which specimens were restored with VenusÒ Bulk Flow ONE exhibit, on average, higher fracture resistance (1575.03 N and 1411.09 N) compared to those restored with VenusÒ Pearl ONE (1252.89 N and 1219.53 N). These results reflect the properties of bulk-fill composites and holds significant clinical value as it reassures the operator about the possibility of using bulk composites, with all their associated advantages in terms of ease of use, without sacrificing the physical properties of the restoration (33, 36, 37, 39, 46-48) and, there-

fore, the medium- to long-term success.
With regards to the role of the fiber post in the fracture resistance of the endodontically treated teeth, it's quite intriguing to observe how, even though posts with different characteristics are employed, results in terms of fracture resistance overlap. Likely, this can be attributed to the lower probability of air bubbles formation, but mainly to the cementation mechanism of the hollow post: the cement occupies the hollow post central portion and prevents phenomena of ovalization and bending that occur when a circular tube is subjected to flexural stresses, allowing it to exhibit mechanical behavior and fracture resistance values comparable to those of the compact post (14).
Regarding the fracture modes showed by the investigated groups, the statistical analysis carried on using a chi-squared test didn't show any statistically significant difference among the groups ($p>0.05$). In order to provide a thorough assessment of the data, considering the small sample size, a generalized Fisher's Exact test for larger contingency tables was employed. The results confirmed that there were no significant differences between the groups. Despite the results of the statistical analysis, a trend towards a higher number of favorable fractures can be observed among all the groups, with the KB-HGP group scoring the higher percentage of favorable fractures (80%).
Posts, and in particular their axial stiffness, play a critical role in determining the failure mode and the fracture type of premolars. Unfavorable fractures beneath the cement-enamel junction result from posts with high axial stiffness, which transfer higher stress to the root canal walls; repair and reconstruction of the tooth are not possible in case of unfavorable fractures. Compact glass fiber posts present higher axial stiffness compared to hollow fiber posts, thus exhibiting a higher percentage of unfavorable fractures (40% of specimens). Conversely, lower stress concentration at the root canal walls is obtained with endodontic posts featuring a lower axial stiffness as hollow fiber posts, leading to a more uniform and less destructive stress distribution to the coronal dentin. The stress conditions induced by these posts determine a lower percentage of unfavorable fractures (25% of specimens), allowing for more favorable outcomes in terms of tooth integrity and potential for subsequent repair.
The role of the composite regarding fracture mode should also be taken in consideration. The groups restored with the conventional composite showed a 65% of favorable fractures, while those restored with the bulk-fill one had a slightly higher percentage (75%) of favorable fractures. These results were in common with those observed in two studies (31, 40), while other two studies (43, 45) found no differences in fracture patterns between teeth restored with conventional and bulk-fill composites.
The results emerged from the analysis suggest that the use of the investigated materials, especially the combination of bulk-fill composite and hollow fiber post, may be associated with a more favorable fracture outcome.
Larger studies are needed to investigate in depth the most effective direct restorative approach in terms of materials employed to improve medium- to long-term success, since the sample size of this in-vitro study may not have been sufficient to identify meaningful differences or outcomes.

Conclusions

The following conclusions may be drawn, considering the limitations of the present investigation.
The fracture strength of healthy teeth is significantly greater than that of teeth restored using endodontic posts. This suggests that, regardless of the direct restoration strategy employed for damaged teeth, their strength will always be lower than that of healthy teeth.
There is no statistically significant difference in fracture resistance among the four treated groups; however, the use of a bulk-fill composite as restoration material determines an average higher fracture strength, making it a viable, or even the preferred option for tooth restoration due to its superior ease of use.

The use of a hollow post together with a bulk-fill composite may increase the likelihood of a favorable fracture, allowing a further tooth re-treatment.

Clinical Relevance

The use of bulk-fill composites and hollow fiber posts may improve the fracture resistance and failure mode outcomes of endodontically treated premolars. These materials provide an easier and more efficient restoration process while maintaining favorable biomechanical properties. Clinicians can consider this approach for better long-term success in direct composite restorations.

Conflict of Interest

None.

Acknowledgements

None.

References

1 *De Santis R, Lodato V, Gallicchio V, Prisco D, Ricciello F, Rengo S, et al. Cuspal Deflection and Temperature Rise of MOD Cavities Restored through the Bulk-Fill and Incremental Layering Techniques Using Flowable and Packable Bulk-Fill Composites. Materials (Basel). 2020;13(24).*
2 *Bainy PT, Melara R, Lhb J, de Melo TAF. Effect of glass fiber on the restorative procedure in relation to fracture strength of endodontically treated molars Giornale italiano di endodonzia. Milão. Vol. 35, no. 1 pp. 178–186, 2021*
3 *Qing H, Zhu Z, Chao Y, Zhang W. In vitro evaluation of the fracture resistance of anterior endodontically treated teeth restored with glass fiber and zircon posts. J Prosthet Dent. 2007;97(2):93-8.*
4 *De Santis R, Prisco D, Apicella A, Ambrosio L, Rengo S, Nicolais L. Carbon fiber post adhesion to resin luting cement in the restoration of endodontically treated teeth. J Mater Sci Mater Med. 2000;11(4):201-6.*
5 *Sasaki K, Yamamoto T, Ikawa T, Shigeta Y, Shigemoto S, Ando E, et al. Pre-endodontic Post and Core Technique for Endodontic and Prosthodontic Treatment. J Contemp Dent Pract. 2018;19(1):117-22.*
6 *Zotti F, Ferrari F, Paganelli C, Pilati F, Lanzaretti G, Arlacchi D, Zerman N. Increasing the fracture strength of MOD restorations with Ribbond fibers. J Clin Exp Dent. 2024 Jun 1;16(6):e707-e713. doi: 10.4317/jced.61608. PMID: 39130368; PMCID: PMC11310981.*
7 *Tsintsadze N, Garcia M, Grandini S, Goracci C, Ferrari M. Effect of Reciproc endodontic treatment with three different post space preparation instruments on fiber post retention. Am J Dent. 2015;28(5):251-4.*
8 *Prisco D, De Santis R, Mollica F, Ambrosio L, Rengo S, Nicolais L. Fiber post adhesion to resin luting cements in the restoration of endodontically-treated teeth. Oper Dent. 2003;28(5):515-21.*
9 *Alkhatri R, Saleh ARM, Kheder W. Impact of post and core materials on the apical extension of root fracture in root canal treated teeth. Journal of Materials Research and Technology. 2021;10:730-7.*
10 *Gbadebo OS, Ajayi DM, Oyekunle OO, Shaba PO. Randomized clinical study comparing metallic and glass fiber post in restoration of endodontically treated teeth. Indian J Dent Res. 2014;25(1):58-63.*
11 *Doshi P, Kanaparthy A, Kanaparthy R, Parikh DS. A Comparative Analysis of Fracture Resistance and Mode of Failure of Endodontically Treated Teeth Restored Using Different Fiber Posts: An In Vitro Study. J Contemp Dent Pract. 2019;20(10):1195-9.*
12 *Lo Giudice G, Ferrari Cagidiaco E, Lo Giudice R, Puleio F, Nicita F, Calapaj M. Evaluation of Mechanical Properties of a Hollow Endodontic Post by Three Point Test and SEM Analysis: A Pilot Study. Materials (Basel). 2019;12(12).*
13 *Iaculli F, Rengo C, Lodato V, Patini R, Spagnuolo G, Rengo S. Fracture resistance of endodontically-treated maxillary premolars restored with different type of posts and direct composite reconstructions: A systematic review and meta-analysis of in vitro studies. Dent Mater. 2021 Sep;37(9):e455-e484. doi: 10.1016/j.dental.2021.06.007. Epub 2021 Jun 18. PMID: 34148785.*
14 *Gallicchio V, Lodato V, De Santis R, Rengo S. Fracture Strength and Failure Modes of Endodontically Treated Premolars Restored with Compact and Hollow Composite Posts Subjected to Cyclic Fatigue. Materials (Basel). 2022;15(3).*
15 *Hickel R, Manhart J, García-Godoy F. Clinical results and new developments of direct posterior restorations. Am J Dent. 2000;13(Spec No):41d-54d.*
16 *De Munck J, Van Landuyt K, Peumans M, Poitevin A, Lambrechts P, Braem M, et al. A critical review of the durability of adhesion to tooth tissue: methods and results. J Dent Res. 2005;84(2):118-32.*
17 *Scotti N, Coero Borga FA, Alovisi M, Rota R, Pasqualini D, Berutti E. Is fracture resistance of endodontically treated mandibular molars restored with indirect onlay composite restorations influenced by fibre post insertion? J Dent. 2012;40(10):814-20.*
18 *Fujihara K, Teo K, Gopal R, Loh PL, Ganesh VK, Ramakrishna S, et al. Fibrous composite materials in dentistry and orthopaedics: review and applications. Composites Science and Technology. 2004;64(6):775-88.*
19 *Helfer AR, Melnick S, Schilder H. Determination of the moisture content of vital and pulpless teeth. Oral Surg Oral Med Oral Pathol. 1972;34(4):661-70.*
20 *Rivera EM, Yamauchi M. Site comparisons of dentine collagen cross-links from extracted human teeth. Arch Oral Biol. 1993;38(7):541-6.*
21 *Huang TJ, Schilder H, Nathanson D. Effects of moisture content and endodontic treatment on some mechanical properties of human dentin. J Endod. 1992;18(5):209-15.*
22 *Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and re-*

storative procedures. J Endod. 1989;15(11):512-6.
23 Bianchi ESAA, Ghiggi PC, Mota EG, Borges GA, Burnett LH, Jr., Spohr AM. Influence of restorative techniques on fracture load of endodontically treated premolars. Stomatologija. 2013;15(4):123-8.
24 de VHL, Camacho GB, Azevedo EC, Demarco FF. Fracture resistance of thermal cycled and endodontically treated premolars with adhesive restorations. J Prosthet Dent. 2007;98(3):186-92.
25 Karzoun W, Abdulkarim A, Samran A, Kern M. Fracture strength of endodontically treated maxillary premolars supported by a horizontal glass fiber post: an in vitro study. J Endod. 2015;41(6):907-12.
26 Mincik J, Urban D, Timkova S, Urban R. Fracture Resistance of Endodontically Treated Maxillary Premolars Restored by Various Direct Filling Materials: An In Vitro Study. Int J Biomater. 2016;2016:9138945.
27 Santos MJ, Bezerra RB. Fracture resistance of maxillary premolars restored with direct and indirect adhesive techniques. J Can Dent Assoc. 2005;71(8):585.
28 Soares PV, Santos-Filho PC, Martins LR, Soares CJ. Influence of restorative technique on the biomechanical behavior of endodontically treated maxillary premolars. Part I: fracture resistance and fracture mode. J Prosthet Dent. 2008;99(1):30-7.
29 Dalpino PH, Francischone CE, Ishikiriama A, Franco EB. Fracture resistance of teeth directly and indirectly restored with composite resin and indirectly restored with ceramic materials. Am J Dent. 2002;15(6):389-94.
30 de Freitas CR, Miranda MI, de Andrade MF, Flores VH, Vaz LG, Guimarães C. Resistance to maxillary premolar fractures after restoration of class II preparations with resin composite or ceromer. Quintessence Int. 2002;33(8):589-94.
31 Mergulhão VA, de Mendonça LS, de Albuquerque MS, Braz R. Fracture Resistance of Endodontically Treated Maxillary Premolars Restored With Different Methods. Oper Dent. 2019;44(1):E1-e11.
32 Sakaguchi RL, Douglas WH, Peters MC. Curing light performance and polymerization of composite restorative materials. J Dent. 1992;20(3):183-8.
33 Hamlin NJ, Bailey C, Motyka NC, Vandewalle KS. Effect of Tooth-structure Thickness on Light Attenuation and Depth of Cure. Oper Dent. 2016;41(2):200-7.
34 Czasch P, Ilie N. In vitro comparison of mechanical properties and degree of cure of bulk fill composites. Clin Oral Investig. 2013;17(1):227-35.
35 Ludovichetti, F.S.; Lucchi, P.; Zambon, G.; Pezzato, L.; Bertolini, R.; Zerman, N.; Stellini, E.; Mazzoleni, S. Depth of Cure, Hardness, Roughness and Filler Dimension of Bulk-Fill Flowable, Conventional Flowable and High-Strength Universal Injectable Composites: An In Vitro Study. Nanomaterials 2022, 12, 1951. https://doi.org/10.3390/nano12121951
36 Ilie N, Bucuta S, Draenert M. Bulk-fill resin-based composites: an in vitro assessment of their mechanical performance. Oper Dent. 2013;38(6):618-25.
37 Tiba A, Zeller GG, Estrich CG, Hong A. A laboratory evaluation of bulk-fill versus traditional multi-increment-fill resin-based composites. J Am Dent Assoc. 2013;144(10):1182-3.
38 Leprince JG, Palin WM, Vanacker J, Sabbagh J, Devaux J, Leloup G. Physico-mechanical characteristics of commercially available bulk-fill composites. J Dent. 2014;42(8):993-1000.
39 Rosatto CM, Bicalho AA, Veríssimo C, Bragança GF, Rodrigues MP, Tantbirojn D, et al. Mechanical properties, shrinkage stress, cuspal strain and fracture resistance of molars restored with bulk-fill composites and incremental filling technique. J Dent. 2015;43(12):1519-28.
40 Atalay C, Yazici AR, Horuztepe A, Nagas E, Ertan A, Ozgunaltay G. Fracture Resistance of Endodontically Treated Teeth Restored With Bulk Fill, Bulk Fill Flowable, Fiber-reinforced, and Conventional Resin Composite. Oper Dent. 2016;41(5):E131-e40.
41 de Assis FS, Lima SN, Tonetto MR, Bhandi SH, Pinto SC, Malaquias P, et al. Evaluation of Bond Strength, Marginal Integrity, and Fracture Strength of Bulk- vs Incrementally-filled Restorations. J Adhes Dent. 2016;18(4):317-23.
42 Isufi A, Plotino G, Grande NM, Ioppolo P, Testarelli L, Bedini R, et al. Fracture resistance of endodontically treated teeth restored with a bulkfill flowable material and a resin composite. Ann Stomatol (Roma). 2016;7(1-2):4-10.
43 Kemaloglu H, Emin Kaval M, Turkun M, Micoogullari Kurt S. Effect of novel restoration techniques on the fracture resistance of teeth treated endodontically: An in vitro study. Dent Mater J. 2015;34(5):618-22.
44 Toz t, Tuncer S, Öztürk Bozkurt F, Kara A, Gozukara Bag H. The effect of bulk-fill flowable composites on the fracture resistance and cuspal deflection of endodontically treated premolars. Journal of Adhesion Science and Technology. 2015;29.
45 Yasa B, Arslan H, Yasa E, Akcay M, Hatirli H. Effect of novel restorative materials and retention slots on fracture resistance of endodontically-treated teeth. Acta Odontol Scand. 2016;74(2):96-102.
46 Iandolo, A.; Simeone, M.; Riccitiello, F. The preparation of coronal isthmus is a fundamental step for long term success. G. Ital. Di Endod. 2012, 26, 150–154.
47 Moorthy A, Hogg CH, Dowling AH, Grufferty BF, Benetti AR, Fleming GJ. Cuspal deflection and microleakage in premolar teeth restored with bulk-fill flowable resin-based composite base materials. J Dent. 2012;40(6):500-5.
48 Parra Gatica E, Duran Ojeda G, Wendler M. Contemporary flowable bulk-fill resin-based composites: a systematic review. Biomater Investig Dent. 2023;10(1):8-19.