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Fracture Mode Analysis and Assessment of Fiber-Post Insertion On Fracture Resistance of Endodontically Treated Anterior Maxillary Teeth

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ABSTRACT

Background: The present study aimed to assess the resistance to fracture and analyze the failure mode of root canal treated anterior teeth with and without application of fiber post. Materials and methods: forty-five sound upper central incisor teeth were collected, then allocated into three main groups, (n=15/each), regarding post application (Group 'A': sound teeth, Group 'B': root canal treated teeth, Group 'C': root canal treated teeth with post insertion). Root canal treatment was performed, and the prepared canals were obturated using gutta-percha. The tested fiber-posts were inserted, and then adhesively cemented inside the prepared root canals of the assigned specimens and the access cavities were restored with resin composite restorations. Fracture resistance test was conducted, and fracture mode was performed. One-way ANOVA used for fracture load data. Tukey's post-hoc statistical test was performed for pair-wise comparison. Results: significantly highest fracture strength was recorded for Group A. Insignificantly fracture strength was found between Group B and C. Conclusions: fracture resistance of root canal treated teeth is adversely affected by fiber posts insertion. The conservation of the remaining sound tooth structure in root canal treated teeth present the ultimate goal to maintain their physical and mechanical properties

Keywords: Fiber post, fracture mode, root canal treated teeth, fracture resistance, maxillary anterior.

1. Introduction

It is evident that endodontically treated teeth (ETT) become weak and highly prone to fracture, which will lead to a significant reduction in their resistance and fracture toughness. This could be owed to an alternation of some physical features, including loss of the tooth structure, the arching roof of the pulp, ridges, and cusps (Selvaraj *et al.,* 2023). A successfully restored root canal-treated tooth relies upon proper root canal treatment (RCT) and the consequent restoration. Restoration of an endodontically treated tooth comprises direct resin composite materials, inlays, onlays, posts, endo-crowns, and crowns. Therefore, the proper restoration selection of a root canal-treated tooth is dictated by multiple factors that involve complete deliberations of function, esthetics, and the remaining amount of tooth structure following RCT (Dong *et al.,* 2024). A considerable amount of the remaining hard structure of ETT may only necessitate the application of a minimally invasive using a direct resin composite restoration. However, an ETT with substantial tooth structure loss may entail further inclusive restorative interventions, including post- and core placement, to guarantee adequate support for the finally applied restoration (Dong *et al.,* 2024). Several factors might result in loss of the structure of the endodontically treated tooth, such as access cavity preparation, coronal caries and its extension, radicular preparation, and trauma. Moreover, endodontic irrigants and intracanal medicaments can also affect the fracture resistance of endodontically treated teeth significantly. The

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preparation of the access cavity can intensify the cuspal deflection, increasing the hazard of cuspal breakage during tooth function (Bhuva *et al.,* 2021). The prognosis of an endodontically treated tooth can be directly related to remaining dentin thickness, RCT effectiveness, and postoperative healing capacity. Furthermore, the quality of the final coronal restoration is critical in clinical practice as it decreases the microleakage (Bhuva *et al.,* 2021). Coupling the recent concept of conservative endodontic treatment and restorative strategies with the hasty advances in novel adhesives and ceramics, as well as digital technology (Alves de Carvalho *et al.,* 2018), has immensely amplified the available possibilities for restoration. Furthermore, the emergent research of micro-tissue engineering to improve the biomechanical features of dentin (Li *et al.,* 2020) through collagen cross-linking improvement as well as the use of nanoparticle technology for dentin matrix stabilization (Bhuva *et al.,* 2021; Kishen *et al.,* 2016). Not only are resin composite materials the most commonly used direct restorations of anterior and posterior ETT, but they have also been used as luting cement for posts and core materials. Thus, conservation of the tooth structure and enhanced bonding to radicular and root dentin is significantly improved (Jurema *et al.,* 2022). The application of the intra-radicular posts that are cemented adhesively within the ETT is advocated whenever the remaining hard structure of the tooth is not enough for proper retention for forthcoming prosthetic final restorations. Intra-radicular post-insertion allows uniform masticatory force distribution lengthwise the root, and accordingly it can prevent tooth fracture. However, gross weakening of the tooth structure and loss of dentin may occur due to stress concentration cervically (Jurema *et al.,* 2022). The merits of using intra-radicular posts constructed from diverse fiber types, such as carbon, quartz, and glass, may include aesthetics, elasticity, and biocompatibility. Such merits might have caused their prevalent application in a grand manner in the field of restorative dentistry (Marinescu *et al.,* 2023). Furthermore, augmenting mechanical and esthetic features of fiber-based devices helped in developing conservative dentistry. Sound dentin should be conserved at the prosthetic restoration margins to enhance the retention and strength of ETT (Naumann *et al.,* 2018).

Post-insertion relies principally on the tooth and final restoration type, as well as the remaining coronal hard tissue. Maxillary anterior teeth are subjected to high shear forces, increasing the risk for failures (Schmitter *et al.,* 2011). Thus, it is assumed that post insertion is more commonly required in such areas, though this assumption necessitates additional appraisal (Bhuva *et al.,* 2021). Hence, the objective of the in vitro current study was to assess the impact of fiber post-insertion on resistance to fracture and fracture mode for endodontically treated upper anterior teeth.

2. Materials and method

A total of forty-five upper central incisor teeth were collected. The selected teeth were assigned to three main groups (n = 15), regarding fiber post-insertion into:
Group A: the control group; sound maxillary anterior teeth.
Group B: root canal-treated maxillary anterior teeth without insertion of fiber post.
Group C: root canal-treated maxillary anterior teeth with insertion of fiber post.

2.1. Selected Materials

One root canal sealer, 'AH' Plus (Dentsply DeTrey GmbH, Germany), one Glass ionomer resin modified RelyX Unicem 2 Automix Cement (3M ESPE Inc., GmbH, Deutschland), one universal adhesive, All Bond Universal (BISCO, Schaumburg, IL, USA), and one nanohybrid resin composite restorative material, Z350 XT (Filtek™, 3M Oral Care, MN, USA), were utilized in the present study. Table 1 describes the tested materials brand name, chemical composition, and manufacturers.

2.2. Teeth selection

A total number of 45 extracted human permanent maxillary central incisors were collected for research purpose from the outpatient clinic of National Research Centre, Giza, Egypt.

The teeth were inspected using 25x magnification with stereomicroscope (Olympus® BX 60, Olympus Optical Co., Tokyo, Japan) to eliminate any teeth with caries, cracks and root resorption. Then the teeth were rinsed thoroughly under tab water then ultrasonically scaled to eliminate calculus deposits. The teeth were stored for in 5.25% NaOCl 10 min to eliminate any remaining soft tissues on the root surface and finally kept in distilled water up until the time of use.

Table 1: The tested materials of the present study.

Material	Description	Composition	Manufacturer
AH Plus	Root canal sealer	≥ 2.5 – < 10 wt% oligomeric reaction products with 1-chloro-2,3- Epoxypropane, formaldehyde, phenol. 25-50 wt% 1-chloro2,3-epoxypropane, oligomeric reaction products, 4, 4'-Isopropylidenediphenol.	Dentsply DeTrey GmbH, Germany.
RelyX Unicem 2 Automix Cement	Self-adhesive glass ionomer resin modified cement	20-30 wt%, 2-methyl-, 1,1'- (1-(hydroxymethyl)-1,2-ethanediyl) ester,2-propenoic acid, reaction products, 2-hydroxy-1,3-Propanediyl dimethacrylate, phosphorus oxide, 45-55 wt% Glass powder, 2-propenoic acid, 2-methyl-3-(trimethoxysilyl) propyl ester, 2-propenoic acid, phenyltrimethoxy silane.	3M ESPE Inc., GmbH, Deutschland.
All-Bond Universal	Universal adhesive	Bis-GMA, HEMA, ethanol, 10-MDP.	BISCO Inc., Schaumburg, IL, USA
Filtek™ Z350 XT Universal	Nanohybrid resin composite	TEGDMA, UDMA, Bis-GMA, Bis-EMA, 20nm nonagglomerated-aggregated Silica clusters, 4-11nm nonagglomerated - aggregated and agglomerated Zirconia particles, 20nm silica particles and 4-11nm zirconia particles	3M Oral Care, St. Paul, MN, USA

Bis-GMA; Bisphenol A diglycidyl methacrylate. UDMA; Urethane dimethacrylate. HEMA; Hydroxyethyl methacrylate. TEGDMA; Triethylene glycol dimethacrylate. Bis-EMA; Bisphenol A ethoxylate dimethacrylates. MDP; Methacryloyloxydecyl dihydrogen phosphate.

2.3. Root canal treatment steps

To determine the working length, a 10 K-file (Mani Inc., Tochigi-Ken, Japan) was into each root canal till it was detected at the point of the apical foramen, then 1mm was subtracted from the apical foramen. Using step-back technique and K-files, enlargement of all canals was done to size 45. Irrigation of the canals was carried out using 5 mL of 2.5% NaOCl alternating with 17% EDTA (Ethylene-diamine-tetra-acetic acid). Following one minute of final irrigation with five milliliters of distilled water, points made of paper were used to dry out the canals. The prepared canals were obturated using the lateral compaction technique. A 45 ISO standard master cone gutta-percha was checked for working length, retention, and proper seating, then a sealer (AH Plus-Dentsply, De-Trey Konstanz, Germany) was applied at the gutta-percha cone tip before insertion it inside the canal. The accessory gutta-percha cones (25 ISO standardized gutta-percha cones) were laterally compacted using a 30/02 finger spreader until the canals were filled. Excess gutta-percha was trimmed using a hot instrument below the orifice level by 1 mm. Sterilized cotton pellets were used for the elimination of excess gutta-percha and sealer from all prepared access cavities.

2.4. Post-preparation and cementation

A 10 mm post-length space was drilled using the yellow rely X drill. The yellow RelyX™ Fiber Post (the diameter of the apical post end is 0.70 mm (3M ESPE, Deutschland GmbH) was tested in each corresponding post space to confirm its internal adaptation, followed by the injection RelyX Unicem 2 Automix Cement (3M ESPE, Deutschland GmbH). The fiber post was placed into the root canal and held with a light finger pressure for 10-15s to ensure proper seating and displacement of the excess cement. Excess cement was entirely removed, and light curing was done for 40s with a 600 mW/cm_2 LED light curing unit (Elipar™, 3MESPE, USA). The coronal portion of the post was trimmed.

2.5. Adhesive system and resin composite restoration application

All Bond Universal Adhesive was applied to the prepared access cavities in two coats with active motion using disposable micro brushes for 10-15s for each coat. Then light-curing was done for 10s using an LED light-curing unit. 3M Filtek Z350 XT Universal Restorative material (3-M Oral-Care, St. Paul-MN-USA) was used to fill the prepared access cavities in all specimens. The resin composite restorations were applied into the cavities in 2 mm increments, and light curing was done for each increment for 20s following the supplier's instructions using the light curing LED device.

2.6. Fracture resistance testing

A universal testing apparatus was used to measure failure loads during a static loading test. A conventional model with a tooth tilt of 45 degrees (facio-lingual) was selected and attached to the bottom fixed compartment of the testing apparatus (Instron-Industrial-Products-Model:3345; Norwood, USA). The testing parameters were 5 kN for loadcell and 1 mm/min for crosshead speed with angle 135° to the tooth axis.

2.7. Failure mode analysis

Failure modes were observed and recorded. Evaluations were based on the four categories of A to D as listed in Table 2 (Soares *et al.,* 2005).

Table 2: Classification of failure modes.

A	If the fracture line's lowest point is positioned above the cervical line
B	If the fracture line's lowest point is situated between the tooth-root placed within the die and cervical line
C	If the fracture line's lowest point is situated inside a tooth-root placed within the die
D	Numerous fracture lines extend in both horizontal and vertical directions.

2.8. Statistical analysis

The Kolmogorov-Smirnov test was used to investigate the normalization of the results. One-way ANOVA was utilized for fracturing load results. Tukey's post-hoc analysis is employed in pairwise comparisons. A significance threshold of $\alpha = 0.05$ was established.

3. Results

Group A displayed the greatest significant fracture strength in contrast to all other groups. Insignificant fracture strength was found between B and C at $p = 0.612$, as presented in Table 3 and Figure 1. Failure mode as presented in Figure 2 revealed that Group A showed a 20% adhesive failure, 60% cohesive/dentin, and 20% cohesive/resin. For group B, all specimens showed cohesive failure in dentin. While for group C, 100% of the specimen showed a cohesive failure in resin.

Table 3: Fracture resistance of different tested groups.

	Maximum Load (N)		**Rank**	**p-value**
	Mean	**SD**		
A	397.1	160.2	a	0.0003
B	115.5	47.9	b	
C	56.5	12.2	b	

Different superscript letters are statistically significant differences.

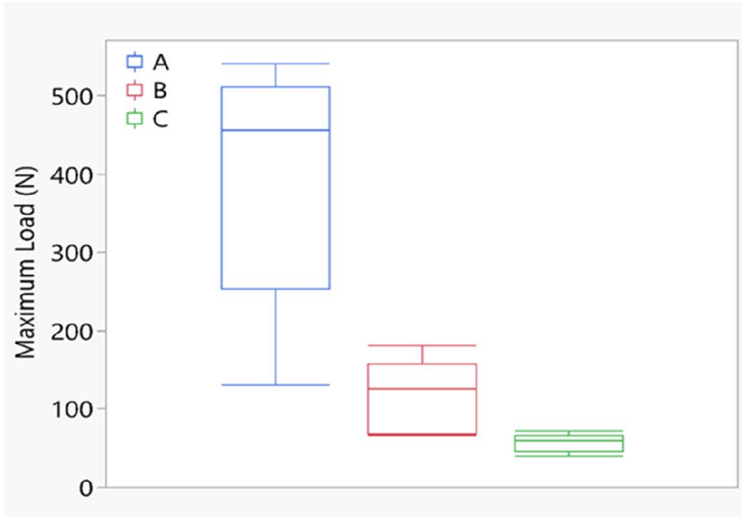

Fig. 1: Fracture resistance of different tested groups.

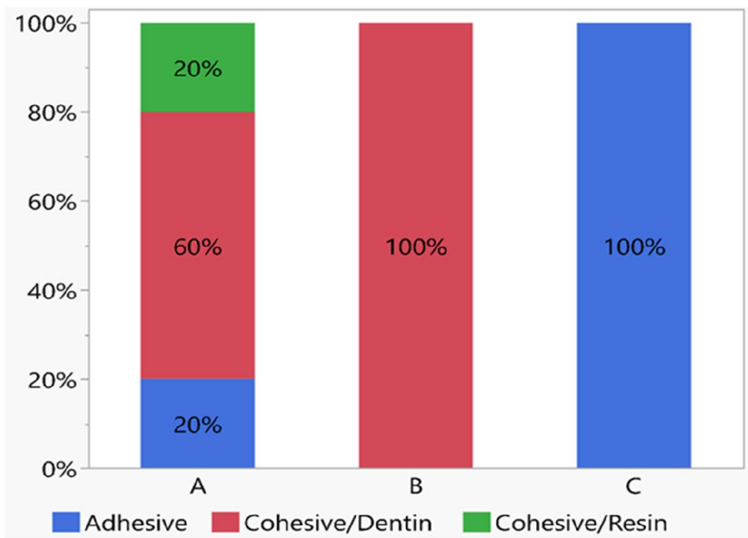

Fig. 2: Failure mode for all tested groups.

4. Discussion

Effective repair of teeth using root canal therapy, utilizing optimum materials with acceptable fracture resistance, is a crucial feature during post-endodontic teeth rehabilitation. Newer restorative systems can support the weak teeth both chemically and structurally (Selvaraj *et al.,* 2023). Hence, the novel initiative for further conservative access, cavity preparation, and RCT is to reserve the remaining tooth structure (Plotino *et al.,* 2017). Irreparable fracture of an ETT is mainly credited to the variance in stiffness between the intra-radicular posts and the radicular dentin, resulting in the development of stress concentration areas (Nahar *et al.,* 2020).

The primary objective of this investigation was to examine whether the insertion of fiber posts affected the ETT's fracture resistance and mechanism of failure. Based on the current outcomes, there was a difference of statistical significance between the control group that included sound teeth and the other two test groups (ETT with and without post-insertion, respectively). Therefore, it could be stated that intra-radicular posts have been advocated for the final coronal restoration and core build-up anchorage despite showing controversial outcomes. In agreement with the findings of the present study, it was reported that luted posts do not strengthen the residual tooth structure (Zicari *et al.,* 2012). Nevertheless, a conceivable strengthening of anterior teeth with trauma and wide root canals was proposed by luted fiber post insertion (Ree *et al.,* 2017). Kawasaki *et al.* (2022) stated that the more coronal tooth structure that is still present, the better stability between the tooth and the post.

However, it is yet controversial whether post-application can impact the fracture mode and fracture resistance. Thus, post-insertion was found to be redundant when two or three walls exist. Furthermore, there was no discernible difference between teeth that had undergone root canal therapy and those that were repaired without fiber posts (Dong *et al.,* 2024). The outcomes of the current study were further supported by failure mode findings that showed a predominance of cohesive failure in dentin for group B. While group C showed a predominant cohesive failure in resin, illustrating how RCT, both with and without fiber post-insertion, appears to have a negative impact on the ETT's ability to withstand fracture when compared to normal teeth without RCT. On the other hand, the outcomes of our study were contradicted by Samran *et al.* (2015), who came to the conclusion that teeth restored with fiber posts after root canal intervention exhibited better fracture mode in contrast to teeth with no posts. Additionally, Marinescu *et al*. (2023) highlighted that the luted post length greatly influences the maxillary ETT's ability to withstand fracture. They showed that when having an ETT repaired with a glass fiber post, the longer the post length inside the root canal, the better the fracture resistance. In this context, Berman *et al.*(2021) concluded that prepared post-space should be preserved in the same proportions as the residual radicular substance to lessen the probability of a root fracture at higher degrees. They demonstrated that the cemented radicular posts play biological and mechanical roles in defending the apical seal of the root from microorganisms' infiltration as a consequence of leakage of coronal restoration, such roles that should not jeopardize the tooth's integrity and maintain its function and strength (Berman *et al.,* 2021). Kawasaki *et al.* (2022) stated that the degree of attachment between the tooth and the post enhances as the amount of coronal tooth structure remains intact.

The present in vitro study has some limitations that should be highlighted, as in vitro studies partly mirror the clinical conditions. In the present investigation, the oral environment challenges, such as the chemical and temperature fluctuations and the repetitive nature of the masticatory forces, cannot be properly imitated (Marinescu AG *et al.,* 2023). As a wide range of variables is involved in this study, such as the restricted investigated tooth number as well as the alterations in the dentin physical characteristics, evaluating fracture resistance clinically is challenging, with the current research. One can admit that the utmost erratic aspect is the tooth condition, which relies upon the quantity and quality of the remaining dentin.

5. Conclusions

In accordance with the current study's outcomes, it can be concluded that the fracture resistance of the ETT is adversely affected by the insertion of fiber posts. The primary target with ETT is to protect any remaining intact tooth structure in order to maintain the physical and mechanical properties of such teeth to be able to resist tooth fracture.

Abbreviations

RCT; root canal treatment, ETT; endodontically treated teeth, NaoCl; sodium hypochlorite, NiTi; Nickel Titanium, EDTA; Ethylene-diamine-tetra-acetic acid, LED: light emitting diode, ANOVA: Analysis of Variance.

Ethics approval and consent to participate
Not applicable

Consent for publication
Not applicable

Availability of data and materials
Available upon request

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The authors declare no competing interests

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Author contributions
LMM, AA, and HNS collected the data. NO, LMM and HNS conducted the methodology. LMM wrote the original manuscript. LMM and AA modified the manuscript, wrote, and revised the final manuscript. AA conducted the statistical analysis for the results. All authors have read and approved the final manuscript.

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