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The effect of different materials and lengths of custom made post and core on the fracture resistance of endodontically treated teeth

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Aim: To investigate the fracture resistance and the mode of failure of custom-made post and cores fabricated with different materials and two post space lengths.
Materials and methods: forty-two extracted maxillary central incisors were chosen, and split into 3 groups randomly (n = 14) according to each material: group1: Hybrid ceramic (Vita Enamic), group 2: Fiber reinforced composite (Trilor) and group3: polyetheretherketone (Pekton). All groups were subdivided into two subgroups based on post length (6 mm and 9 mm). All teeth were endodontically treated and the post spaces had been scanned by primescan intraoral scanner. The post-and-cores were designed, manufactured using CAD/CAM and cemented using a self-adhesive resin cement (G-CEM). The fracture resistance was tested in a universal testing machine under controlled load at a crosshead speed of 1mm per minute. The failure mode was tested using optical microscope at a x40 magnification. Statistical analysis was performed using two way ANOVA to detect significance between groups.
Results: Two-Way ANOVA showed that both post material and length had a significant effect on fracture resistance ($p<0.001$). Post material and post lengths interactions had no significant impact on the fracture resistance ($p=0.160$).
Conclusion: Trilor custom-made posts had the highest fracture resistance, with the most unfavorable fracture. Nine mm post length had higher fracture resistance than six mm.

Keywords: Custom-made post, Endodontically treated teeth, Polyetheretherketon, Glass fiber reinforced composite, fracture resistance.

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Introduction

Endodontically treated teeth (ETT) has a great attention regarding its restoration in dentistry. They exhibit a high biomechanical failure risk due to losing of significant tooth structure from preceding caries, old restorations, and/or endodontic procedure, which decrease the bulk of the tooth and healthy dentin thickness, leading to increasing the likelihood of fracture liability and increased cuspal deflection.[1]

Restorative approaches involving cuspal coverage are recommended in order to lowering the risk of fracture.[2] However, when there is a significant tooth structure loss, durabilty of the coronal restoration is decreased; therefore, the post and cores is required to enhance the coronal restoration stability. [3] For the inserted post to serve its purpose, many factors need to be considered, including post length, diameter, geometric design, and material. [4]

The correlation between the post's length and the endodontically treated teeth fracture resitance were frequently reported to be interlinked. [5] If the post is either too lengthy or too short, the root may be at risk of breaking. The retention of the post, core, and crown is improved with increasing apical length of the post inside the root canal.[6] Conversely, decreasing the post's length was argued that it could help preserve tooth structure due to advancements in the adhesive systems used to bind posts inside root canals.[7]

Prefabricated fiber reinforced composite posts are known for their remarkable aesthetic characteristics and modulus of elasticity, which is equivalent to that of dentin (25–27 GPa), that allow for fewer unfavorable root fractures. [8] However, posts' retention decrease in canals with no circularity or over tapering due to the circular cross-section of the prefabricated post, which causes increasing the cement layer thickness and debonding being the most frequent failure type. [9]

Custom-made post serve as better substitute in such situations, allowing ideal adjustment to the root canal morphology, lowering the risk of debonding, and even stress distribution.[10] Computer-Aided Design and Computer-Aided Manufacturing (CAD-CAM) technology has become a successful technique for construction of post and core restorations with remarkable precision and simplify the utilization of different materials, like zirconia, glass ceramic. Recently, Glass fiber reinforced composite, PEEK and polymer-infiltrated ceramic-network have developed as a willing substitute for these conventional materials as their elastic modulus is comparable to that of dentin, this enables them to act as efficient stress breaker, lowering the stresses transmitted to the tooth underneath and enhance the resistance of the ETT to fracture. [11]

The aim of our research was to investigate the impact of three different post and core materials (hybrid ceramic, PEEK and glass fiber reinforced composite) and two different post lengths (6 mm and 9 mm) on endodontically treated teeth fracture resistance. The null hypothesis was that there would be no difference in the fracture resistance of the teeth restored with either different post materials or lengths.

Material and Methods

The materials used in this study is shown in (table 1).

Sample size calculation

By adopting alpha (α) and beta (β) levels of (0.05) (i.e., power = 95%) and an effect size (f) of (1.39) calculated based on the results of a previous study [12]; the total estimated sample size (n) was (18) samples. The sample size was increased to 42 samples to account for possible variability. The sample size was calculated using R statistical analysis software version 4.4.1 for Windows.[13]

Table 1: Materials, manufacturer, composition and lot number.

Materials	Manufacturer	Composition	Lot number
Vita Enamic	Vita Zahnfabric, Germany	86 % inorganic (58–63 % SiO_2, 20–23 % Al_2O_3, 9–11 % Na_2O, 4–6 % K_2O, 0.1 % ZrO_2) 14 %	**88820**
PEEK	Pekkton Ivory, Cendres + Métaux, Biel/Bienne, Switzerland	Polyetherketoneketone, titanium dioxide pigments	**20685**
Trilor	Bioloren, Saronno, Italy	Epoxy resin matrix (25 % vol), multi directional glass fiber reinforcement (75 % vol)	**1928**

Samples Grouping

The roots were assigned into 3 groups randomly (n = 14) according to the used material (Table 1); group 1: Hybrid ceramic (Vita Enamic), group 2: polyetheretherketone (PEEK) and group 3 : Fiber-reinforced composite (Trilor). Then, All groups was subdivided into 2 sub-groups (n = 7) according to post length: subgroup (S): 6 mm, subgroup (T): 9 mm. This study was approved by Ain shams research ethics committee (approval no. FDASU-RecEM022131).

Samples Preparation

Forty-two newly extracted upper central incisors with almost un-curved roots and with similar dimensions and, free from caries, fracture and cervical abrasion with an average length of the root 15 +/- 1 mm were chosen, cleaned from calculus and kept in water. The crown of all samples were removed 1 mm above proximal CEJ using an IsoMet saw (IsoMet 1000, Buhler, USA). The root of each tooth was dipped into melted pink modelling wax (CAVEX; CAVEX Dental, Haarlem, Netherlands). Each tooth was individually mounted in auto-cured acrylic resin using a paralleling device surveyor to ensure the centralization and parallel alignment of the specimens in the mould. The tooth was removed from the mould, and the wax was washed away using heated water bath. A light body silicon impression material (Speedex; Colten Whaledent, Altstätten, Switzrland) was injected into the socket of the mould, and the tooth was subsequently placed back into the socket using a paralleling device, creating a thin layer that resemble the periodontal ligament and retain the tooth into the acrylic socket undercuts. [14]

Root Canal Treatment

Endodontic therapy was performed using the crown-down technique utilizing rotary M-Pro nickel-titanium instruments (IMD Company; Shanghai, China) connected to an endodontic micromotor (Wismy; Changzhou, China) up to #40 taper 6. Each canal was irrigated with 2 ml of 5.25% Naocl. Finally, obturation was done using the lateral condensation technique with gutta-percha (Dia-Pro T; Dia Dent,*TianJin, China)* and root canal sealer (Adseal; MetaBiomed resin sealer, Cheongju-si,South Korea). Then the access cavity was sealed with provisional restoration (Orafil-G, Prevest, DENPRO LTD).

Post-space preparation

Gates Glidden drills (Dentsply Sirona) size 2 were used initially to remove the gutta percha to the following pre-determined lengths for each group (6mm and 9mm). Using the same sizes and shapes of post drill provided by the manufacturer (Ena, MICERIUM S.p.A., Italy) for all tooth samples, post spaces were prepared with size 1, followed by size 2 post drills with 2% taper. Each prepared post space flushed with saline and dried completely using a paper points.

Scanning, designing and milling

All prepared post spaces were digitally scanned using an intraoral scanner

(Primescan; Dentsply Sirona, Germany).[15] post and core were designed using 3D software (CEREC 3D, versin 5.0; Dentsply Sirona, Germany). Then, the STL file was exported to a milling machine (CEREC in lab MCX5, Dentsply Sirona, Germany) for milling the custom-made posts and cores (Figure 1).

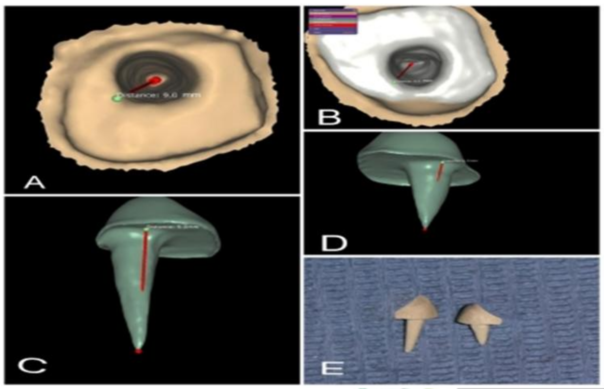

Figure 1: A and B showing scanning of post space, C and D showing custom made post and core designing, E showing the milled posts with different lenghts; 6 and 9 mm

Post cementation

For post cementation, post space was irrigated with 1 ml of 3% NaOCl, followed by 1 ml of saline, and finally dried with paper points. Regarding the tested posts, sandblasting with Al_2O_3. (50 µm; 4 bar) for 14 Sec. All posts were cemented with dual cured self-adhesive resin cement (G-CEM, USA), and retained under light finger pressure for 15 Sec. After the excess cement was completely removed, light curing was done for 40 s using (Elipar™, 3MESPE, USA).

Fracture resistance

The fracture resistance test was done using a universal testing machine (Model 3345; Instron Industrial Products, USA). All specimen with the acrylic resin block was fixed at a 45-degree angle to its long axis. Then, each sample was exposed to a controlled loading force at a cross-head speed of 1 mm per minute to the core using 1 mm stainless-steel rod, until failure by audible crack or fracture occurred.

Mode of failure

After the fracture resistance testing, specimens, fragments and failure patterns were examined under a digital microscope (Nikon SMZ745T Stereo microscope; Nikon Japan) at 40X magnification. The mode of failure was classified as favourable or non-favourable depending on the restorability of the tooth; failure was regarded as a favourable failure that could be repaired in instances where the fracture in the post, core, or tooth above the cement-enamel junction or debonding of the post. On the other hand, the unfavorable failure exhibited as vertical, horizontal, or oblique fracture in root that occurred underneath the cement-enamel junction. [16]

Statistical analysis

Data were normally distributed with homogenous variances and were analyzed using two-way ANOVA followed by Tukey's post hoc test. Simple effects comparisons were made using the ANOVA error term with p-values adjustment using the False Discovery Rate (FDR) method. The significance level was set at $p<0.05$. Statistical analysis was performed with R statistical analysis software version 4.4.1 for Windows. [17]

Results

Two-way ANOVA showed that both post material and length had a significant effect on fracture resistance ($p<0.001$). However, the effect of their interaction was not statistically significant ($p=0.160$) (Table 2).

Regarding the post materials, there difference between different materials was significant ($p<0.001$). The highest strength was in Trilor posts (655.33±22.35) (N), followed by PEEK posts (489.98±25.28) (N), while the lowest strength was found in Vita Enamic posts (391.24±14.12) (N). All post hoc pairwise comparisons were statistically significant (p<0.001). Regarding the post lengths, 9 mm long posts (527.97±116.90) (N) had a significantly higher strength than 6 mm posts (496.39±109.98) (N) (p<0.001) (Figure 2).

Table 2: Intergroup comparisons, mean and standard deviation values of fracture resistance (N) for different post materials and lengths.

Material / Length	Fracture resistance (N) (Mean±SD) PEEK	Trilor	Vita Enamic	p-value
6 mm	470.21±12.83^{B}	637.02±11.01^{A}	381.96±10.18^{C}	<0.001*
9 mm	509.76±17.19^{B}	673.63±12.85^{A}	400.52±11.38^{C}	<0.001*
p-value	<0.001*	<0.001*	0.031*	

Values with different superscripts within the same horizontal row are significantly different, * significant (p<0.05).

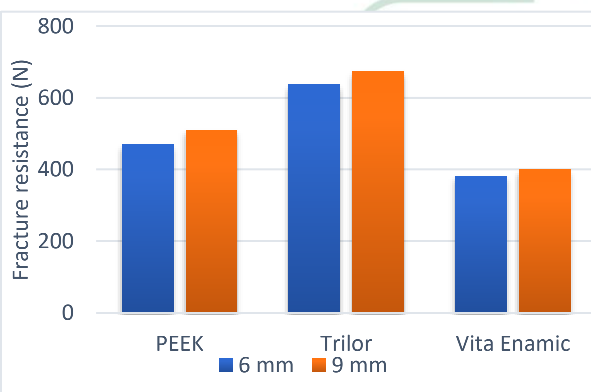

Figure 2: Bar chart showing average fracture resistance (N) for different post materials and lengths (B)

Ragrading the mode of failure, Of the 42 specimens, 9 displayed unfavorable fracture patterns. The unfavorable fracture were 4, 3, and 2 samples for Trilor, PEEK, and Vita Enamic respectively. Additionally, 5 and 4 samples showed unfavorable fracture for lengths of 9 and 6 mm respectively. (Table 3)

Table 3: Number of samples showed mode of failure

Material / Length	Mode of failure: Trilor (N=14)		PEEK (N=14)		Vita Enamic (N=14)	
Type of fracture	Favoravble Fracture	Unfavorable fracture	Favoravble fracture	Unfavorable fracture	Favoravble fracture	Unfavorable fracture
6 mm	71.42%	28.5%	85.71%	14.2%	85.71%	14.2%
9 mm	71.42%	28.5%	71.42%	28.5%	85.71%	14.2%

In Vita Enamic samples, the favorable failure mode displayed as tooth fractures above the cement-enamel junction (CEJ) and fractures within the core segments, as opposed to the unfavourable failure exhibited by a vertical root fracture (VRF) underneath the cement-enamel junction. PEEK samples that displayed favorable failure were dislodged without resulting in component fractures. However, VRF below the cement-enamel junction without post or core fractures were indicative of the unfavorable failures. In Trilor samples, Observations revealed favorable failure characterized by core separation or tooth fractures above CEJ. On the other hand, the unfavorable failure exhibited as post damage and VRF beneath the CEJ (Figure 3).

Discussion

The custom made post and core system is considered as the preferred restoration for ETT in case of significant tooth structure loss and in flared, elliptical or non-circular canals [16]. The challenge of large cement spaces of the prefabricated post is resolved by the ideal adjustment of custom-made posts and cores to the canal space, which offer better retention and internal fit. It also lessens the chance of core separation [18]. However, it is declared that the custom-made posts negatively impact the root's ability to withstand fracture and exhibiting noticeably high internal stresses and fracture, especially during the placement of the post due to the stress intensity that occurred at the root, which lead to root fractures. [19]

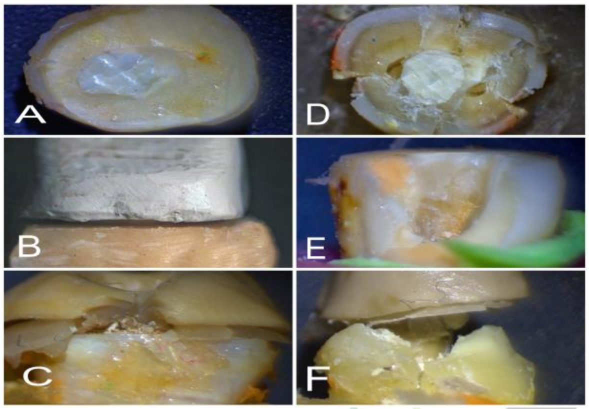

Figure 3: Stereomicroscope images with 4 X magnification. A, B and C showing favorable fracture patterns for Trilor, PEEK and Vita Enamic, respectively. D, E and F showing nonfavorable fracture patterns for Trilor, PEEK and Vita Enamic, respectively.

The objective of this research was to investigate the impact of 3 different CAD/CAM post and core materials (hybrid ceramic, PEEK and glass fiber reinforced composite) and 2 different post lengths (6 mm and 9 mm) on the fracture resistance of ETT. According to the results of this study, the null hypothesis was rejected as there was a significant difference between the three different tested materials and the two tested post lengths in terms of fracture resistance mean values.

In this study, there was a significant difference between different materials ($p<0.001$). The Trilor samples recorded the highest fracture resistance (655.33±22.35) (N); this can be attributed to Trilor composition. Trilor has an elastic modulus of 26 GPa and is formed of a 25% vol epoxy resin matrix and 75% vol multi-directional glass fiber.[20] It is known that the bond between the matrix and the fibers, allowing the transmission of load from the matrix to the supporting fibres, which improve the mechanical properties and the resistance to fracture.[21] This result was aligned with studies by Buthaina et al., who compared the fracture resistance between Trilor, Vita Enamic and PEEK and reported that the Trilor group recorded higher fracture resistance.[12] Eid et al. reported a variation in Trilor's resistance to fracture; these difference can be due to variances in crown coverage and thermal aging. [22]

Nevertheless, the Trilor samples showed the highest unfavorable fracture pattern, which can be detected by VRF beneath the CEJ. The failure of the Trilor material resulting from tearing of its fibers. The failure occurs when a crack begins in the matrix and spreads to the interface, inclosing scattered fibers, inducing the tearing of the fibers. This failure mode is frequently referred to as 'brush-like cracking. [23]

The PEKK group, have a mean fracture load of (489.98±25.28) (N). PEEK has low EM (3 − 4 MPa) that exhibits a remarkable stress release, reducing the danger of fracture [24]. These findings were aligned with the observations of Fathey et al., who evaluated the fracture resistance of Peek and fiber reinforced composite and reported that Peek displayed lower fracture resistance than FRC.[25] Nevertheless, Abdelmohsen et al., that reported that custom made PEEK post and core have a mean fracture resistance values of 1055.25 ± 119.32 N. [26] The cause of this difference may be due to the use of the premolars and the different applied force angulations.

Regarding the mode of failure, most of the PEEK samples showed favorable fracture and underwent dislodgement without fracturing any components. The stiff molecular chain structure of PEEK, gives it exceptional ductility and permits considerable deformation under unilateral pressure during compression. [27] The material experiences elastic deformation when load is applied within its yield limit. Nevertheless, PEEK experience a permanent deformation without breaking when these forces exceed the yield limit.[28] Load is transferred to cement causing debonding without fracture. On the other hand, a vertical root fracture may result from this stress concentration on the root. According to the research reported by Özarslan et al., who discover that 40% of the PEEK samples experienced debonding without fracture. [29] However, none of the specimens showed debonding, according to Pourkhalili et al.'s investigation on the fracture resistance of Peek post and core [30]. This discrepancy in the outcomes may be attributed to that they applied force in a different angulations throughout their investigation and used premolars rather than anterior teeth. Furthermore, Kasem et al. reported that custom made PEEK post and core have experienced a successful follow up for five-years. [31]

The lowest fracture resistance was found in the Vita Enamic group (391.24±14.12) (N). This can be due to its chemical composition which is made of feldspar ceramic network (75% vol.), which is supported by a polymer network (25% vol.). The increased amount of the glass form debilitate the matrix and decrease the crack propagation resistance. [32] This conclusion was aligned with research by Buthaina et al., who found that, in comparison to PEEk and Vita Enamic, the Vita Enamic group had the lowest fracture resistance [12]. Elmaghraby et al. similarly found consistency in their study, observing mean fracture resistance for Vita Enamic custom made post and core was 386.6 ±25.77 N. [33]

Vita Enamic samples exhibited the most favorable failure mode, which marked by a crack or fracture within the core segments. This is explained by decreased resistance in the polymer matrix of hybrid ceramics, causing the development of a linear cracking and increase crack propagation. [34]

In this study, Vita Enamic, PEEK and Trilor groups, there were significant differences detected between the two post lengths. 9 mm long posts (527.97±116.90) (N) had a significantly higher strength than 6 mm posts (496.39±109.98) (N) ($p<0.001$). This can be attributed to that increasing the length of the post, increases the retention of the post, which lead to a more homogenous stress distribution in the canal and enhance the fracture resistance of the ETT. These findings were consistent with those of Standlee JP et al. and lin et al., who discovered that increasing the post length will increase the fracture resistance.[35-36] Nevertheless, this result contrasted with those of Nissan J et al., who observed that even with a shorter post length, the adhesive resin cement increased post retention and optimized fracture mode. [37]

Regarding the mode of failure, the difference between 6 mm and 9 mm post lengths was insignificant. These findings were agreeing with those from Özarslan M et al., who discovered no discernible variation in failure pattern between the short and long posts in. [29]

Despite the differences noted, the averages of each group's maximal fracture resistance still exceeded the maximum force values recorded during normal adult occlusal function, that reaches 180–280 N for anterior teeth and 210–350 N for posterior teeth. [38] According to these averages, all post-and-core materials have a very good behavior.

However, this study try to simulate the natural clinical situation as closely as possible. This study had some limitations that could have an adverse impact on the findings. This in vitro test does not represent the actual clinical situations. The samples were not exposed to thermal cycling. Furthermore, no artificial crown was used to restore any of the teeth. These elements could have an impact on the findings' external validity and generalizability. This limitations should be considered and further researches should be conducted to take into account variables such as artificial crowns, the thermocycling, and dynamic loading.

Conclusion

1. Trilor posts have the highest fracture resistance with the most unfavorable failure mode.
2. Vita Enamic have the lowest fracture resistance with the most favorable fracture pattern.
3. Nine mm post length provided higher fracture resistance than six mm post length.

Funding

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Data availability

Data is available if needed.

Competing interest

No competing interests.

Ethics approval

This study was approved by the Research Ethics Committee, Faculty of Dentistry, Ain Shams university, anad approval number, FDASU-RecEM022131

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