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Fracture resistance of CAD/CAM tooth-colored versus cast metal post-and-core restorations in root filled teeth: An in vitro study

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ABSTRACT

Purpose: This study investigated the fracture resistance and failure modes of custom-fabricated post- and core dental restorations using various CAD/CAM materials.
Materials and Methods: Seventy-five mandibular second premolars were allocated to five groups ($n = 15$) and prepared for standardized post and core restorations. The groups included a control group comprising cast metal and four CAD/CAM materials: Vita Enamic, Shofu HC, Trilor, and PEKK. Fracture resistance was assessed using a compressive force at a crosshead speed of 1 mm/min until failure occurred. Data were analyzed using one-way analysis of variance (ANOVA) and chi-square tests.
Results: The metal group had the highest fracture resistance (244.41 ± 75.20 N), with a significant variance compared to that in the CAD/CAM groups ($p < 0.001$). No significant differences were observed among the non-metallic groups.
Conclusions: While several CAD/CAM materials displayed satisfactory flexural properties, cast metal posts showed superior fracture resistance in endodontically treated teeth but were mostly associated with catastrophic failure. The clinical application of CAD/CAM materials for post-core restorations presents a viable alternative to traditional metal posts, potentially reducing the risk of unfavorable fractures.

1. Introduction

The rehabilitation of endodontically treated teeth (ETT) presents a challenge that has long been debated among dental professionals (Baba et al., 2009; Afrashtehfar & Tamimi, 2017). Prefabricated fiber posts have been extensively used in restorative treatments for ETT because of their favorable modulus of elasticity akin to dentin (25–27 GPa) (Figueiredo et al., 2015), which confers biocompatibility. Their ability to flex under masticatory forces and dissipate occlusal stress (Stricker and Göhring, 2006; Bru et al., 2013) minimizes the likelihood of structural failure (Martínez-Insua et al., 1998). Nonetheless, the retention integrity of prefabricated posts may be compromised in canals with significant tapering or noncircularity (King et al., 2003; Awad and Marghalani, 2007; Anchieta et al., 2012). Custom-made posts serve as superior alternatives in such scenarios, permitting optimal adaptation to the root canal morphology and reducing debonding risks (Rasimick et al., 2010), in addition to a more homogeneous stress distribution concentrated apically (Huang et al., 2024). Traditional materials for these posts include metals and, subsequently, zirconia (Bergman et al., 1989; Creugers et al., 1993), which, despite their high fracture resistance, pose concerns owing to their high modulus of elasticity that can overstress radicular dentin and induce catastrophic failures (Fernandes and Dessai,

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2001).

The popularity of CAD/CAM technology has shifted the focus toward producing customized restorative materials with a lower modulus of elasticity (Abuhammoud et al., 2024). This approach, involving milling (subtractive technology) of a monolithic post-core unit, enhances retention and adaptation to root canal walls, eliminating the need for altering root canal geometry and potentially weakening tooth structure (Rexhepi et al., 2023). CAD/CAM hybrid materials, harmonizing a modulus of elasticity similar to that of dentin with the resilience of their resin component and mechanical strength of their ceramic counterparts, show promise (Awada and Nathanson, 2015). In this study, the fracture resistance and failure modes of custom-made post and core restorations fabricated from various CAD/CAM materials, including Vita Enamic, Shofu HC, Trilor, and polyetherketoneketone (PEKK), were compared with those of traditional cast metal posts. This research tests the hypothesis that there is no significant difference in fracture resistance and failure mode among the diverse post and core materials and no disparity compared with their metallic counterparts.

2. Materials and methods

Seventy-five human mandibular premolars with straight canals extracted for orthodontic reasons were selected for this investigation. A consent form was obtained from all patients. This study was approved by the local research ethics committee of Ajman University (D-H-S-MARCH-23). These teeth were stored in saline at 100 % humidity and 37 °C after cleaning of external debris. Microscopic inspection (Leica EZ4, Wetzlar, Germany) confirmed the absence of caries, defects, cracks, and previous restorations, with radiographs showing single canals and orifices. Teeth with orifice diameters larger than 1.7 mm at the cementoenamel junction (CEJ) were excluded. Additionally, teeth with roots shorter than 14 mm or mesiodistal dimensions less than 2.4 mm (5 mm from the apex) were excluded. The selected teeth were then sectioned to 14 mm using an IsoMet Saw (IsoMet 1000, Buehler, USA) at 325 rpm, endodontically treated, and finalized with a WaveOne Gold Large file (Dentsply Sirona, Maillefer, Switzerland). Post-treatment, the canals were irrigated and sealed with AH+ (Dentsply Sirona, Maillefer, Switzerland) and vertically condensed gutta-percha to form a 4–4.5 mm apical plug. The orifice and apex were sealed with Cavit (3 M ESPE, USA), and the teeth were stored in saline for 72 h before testing.

Group allocation of the roots was based on cervical area measurements and confirmed using ANOVA to ensure homogeneity. The groups were assigned as follows: Group 1 utilized a custom CAD/CAM metal post-core, and Groups 2–5 used Vita Enamic, Shofu HC, Trilor, and PEKK, respectively (Table 1). The biological width and periodontal ligament (PDL) were simulated by dipping the roots in molten wax (Renfert, Germany) to create a thin coating, followed by setting them in acrylic blocks (GC Unifast Trade, Aich, Japan). The PDL simulation space created by wax removal was filled with Impregum (3 M, USA) (Santana et al., 2011).

Post space preparation was standardized using a milling machine (Amann Girrbach, Austria), with post spaces created to a depth of 9 mm using a color-coded unimetric post drill (0.8 kit-color yellow, Dentsply Maillefer, Ballaigues, Switzerland). The post and core were then fabricated using a polymerizing acrylic resin-lined prefabricated post (Pi-ku-plast HP 36, XPdent, Florida, USA), scanned with a 3D scanner (Ceramill map300, Amann Girrbach GMBH, Pforzheim, Germany), and processed using CAD/CAM software (Fig. 1 and Fig. 2).

The post fit was verified before cleaning post spaces with 3 % NaOCl 1 ml, saline 1 ml, and EDTA 17 % 1 ml irrigation for 1 min each, flushed with saline 1 ml, and dry with paper points. Sandblasting with aluminum oxide particles for 20 s, ultrasonic cleaning, and cementation with Relyx self-adhesive resin cement (3 M, ESPE, USA) were performed according to a standardized protocol. Post-cementation, a uniform metal crown was designed using CAD/CAM for all the samples, with minor adjustments to fit the individual samples. Thermal cycling simulated oral cavity temperature changes across five thousand cycles between 5℃ and 55℃.

Table 1
The blocks tested in the study.

Material	Manufacture	Composition
Vita Enamic	Vita Zahnfabric, Germany	86 % inorganic (58–63 % SiO2, 20–23 % Al2O3, 9–11 % Na2O, 4–6 % K2O, 0.1 % ZrO2) 14 %
Shofu block HC	Shofu inc., Kyoto, Japan	UDMA, TEGMA, 61 wt% silica powder, micro fumed silica, zirconium silicate
Trilor	Bioloren, Saronno, Italy	Epoxy resin matrix (25 % vol), multi directional glass fiber reinforcement (75 % vol)
PEKK	Pekkton Ivory, Cendres + Métaux, Biel/Bienne, Switzerland	Polyetherketoneketone, titanium dioxide pigments

2.1. Statistical analysis

Fracture resistance testing was performed by applying a compressive force with a universal testing machine (M350-5CT, Testometric, UK) until failure, with the load recorded in Newtons. Failures were categorized as repairable or catastrophic based on whether they occurred above or below the acrylic level. Fracture data were analyzed using analysis of variance (ANOVA), while failure modes were assessed with chi-square tests using SPSS (IBM SPSS Statistics version 22, Chicago, IL, USA).

3. Results

The analysis of the fracture load indicated that the metal group required the highest force to fracture, averaging 244.41 ± 75.2 N. In contrast, the Vita Enamic group exhibited the lowest fracture resistance, with an average force of 89.67 ± 24.08 N needed to induce fracture (Table 2). ANOVA revealed significant differences across groups ($p < 0.001$). Subsequent Tukey's HSD post hoc analysis indicated no significant differences in fracture load among the Vita Enamic, Shofu HC, Trilor, and PEKK groups (Table 2). However, this test highlighted a statistically significant difference when comparing the fracture load of the cast metal group with that of the other groups ($p < 0.001$).

Of the 75 samples, 21 displayed unfavorable fracture patterns (Figs. 3 and 4). This subset comprised 15 individuals from the metal group, two from the Shofu HC and PEKK groups, and one from the Trilor

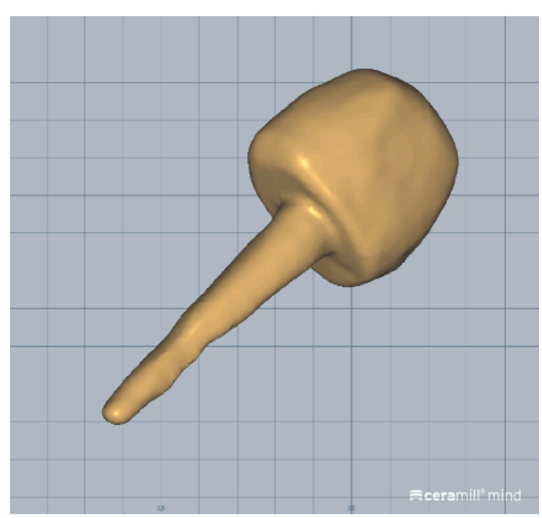

Fig. 1. The picture shows the CAD/CAM scan of the post using CAD/CAM Ceramill Mind software.

Fig. 2. CAD/CAM fabricated posts utilized in this study. From left to right Cast Metal post-core, Vita Enamic post-core, PEKK post-core, Trilor post-core, Shofu HC post-core.

Table 2
Fracture load mean values for each post-core group.

Groups	Mean ± SD, Newtons	Highest and lowest values registered, Newtons
Metal	244.41 ± 75.2[a]	391.75, 152.09
Vita Enamic	89.67 ± 24.08[b]	161.86, 53.55
Shofu HC	97.06 ± 28.11[b]	158.78, 65.76
Trilor	109.2 ± 33.06[b]	192.17, 63.24
PEKK	102.56 ± 25.2[b]	147.44, 52.66

Abbreviations: SD, standard deviation; PEKK, Polyetherketoneketone.
In the 'Mean ± SD' column, values sharing a superscript letter were not significantly different ($p \geq 0.05$).

and Vita Enamic groups. Chi-square analysis confirmed significant disparities across the groups in terms of favorable versus unfavorable fractures ($p < 0.001$). Pairwise comparisons identified a significant difference between the metal control group and CAD/CAM experimental groups ($p < 0.001$); no significant differences were found within the CAD/CAM groups.

4. Discussion

The coronal restoration quality of ETT is a significant determinant of endodontic treatment success and durability (Afrashtehfar et al., 2017). For extensively damaged teeth, post placement is recommended to improve the retention of the core and coronal restorations and their long-term survival (Salvi et al., 2007). Traditional metal posts, often linked to catastrophic failures (Özkurt et al., 2010), are being re-evaluated because of innovations in materials with elastic moduli close to that of dentin (10–30 GPa) (Plotino et al., 2007), aiming to better distribute masticatory loads (Stricker et al., 2006; Bru et al., 2013). This study explored major tooth loss repair in the lower second premolars using five different CAD/CAM materials, one metal, and four tooth-colored materials with low elastic moduli.

Mandibular premolars are frequently chosen for post- and core fracture strength testing (Forberger and Göhring, 2008; Mangold and Kern, 2011; Falcão et al., 2017; Eid et al., 2019; Samran et al., 2020), with a standardized 14-mm root length as used in previous investigations (Teixeira et al., 2020; Sherfudhin et al., 2011; Castro et al., 2012). The impact of PDL simulation on fracture loads remains debated (Soares et al., 2005; Marchionatti et al., 2014); however, the present study used elastomeric PDL simulation to mimic clinical conditions, consistent with methodologies in the literature (Forberger and Göhring, 2008; Falcão et al., 2017; Teixeira et al., 2020; Sherfudhin et al., 2011; Barcellos et al., 2013; Alkhatri et al., 2019). Adhesive resin cement, capable of bonding to both the tooth structure and posts (Kainose et al., 2015), was used, recognizing that bond integrity at the cervical region is crucial for the survival of restored teeth (Kainose et al., 2015). The resin-cement bonding agent acts as part of the post-core-crown system, efficiently dispersing loads to the tooth support structures and improving post-to-root canal wall adaptability (Weiser and Behr, 2015; He et al., 2021).

In replicating clinical settings, single-unit full-coverage restorations were placed over post-core units and subjected to thermal cycling to simulatee six months of oral cavity temperature fluctuations (Gale and Darvell, 1999). The metal group exhibited the highest fracture resistance mean (244.41 ± 75.2 N), likely due to its superior mechanical properties and high modulus of elasticity (200 GPa). These findings are consistent with those of Tan et al. (2005) and Palepwad and Kulkarni (2020), who reported comparable mean fracture resistance values for metal posts. Iemsaengchairat et al. (2022) reported that thin-walled endodontically treated mandibular premolars without ferrules showed the highest fracture resistance when metal-cast posts and cores were used. Teixeira et al. reported higher resistance values, potentially attributed to differences in alloy composition and the absence of thermal cycling (Teixeira et al., 2020), which have been linked to dentin-restoration bond deterioration. Alkhatri et al. also found greater fracture resistance for metal than for CAD/CAM Vita Enamic, possibly due to variations in thermal cycling and tooth type (Alkhatri et al., 2019).

Among the non-metal groups, the performance was relatively more consistent with favorable failure modes, but all were significantly weaker than the metal group. The lowest fracture resistance was in the Vita Enamic group (89.67 ± 24.08 N), diverging from Alkhatri et al., potentially due to differences in thermal cycling or tooth selection (Alkhatri et al., 2019). Falcao et al. reported higher fracture resistance without crown coverage or thermal cycling using teeth with larger canal diameters (Falcão et al., 2017), suggesting that canal diameter may influence fracture resistance. The Trilor group recorded the highest non-metal fracture resistance (109.2 ± 33.06 N), consistent with studies by Eid et al. that reported variability in Trilor's fracture resistance (Eid et al., 2021). These variations can be attributed to differences in thermal cycling and crown coverage. The PEKK group, which had not been previously studied as a post-core material, demonstrated a mean fracture load of (102.56 ± 25.2 N). Although direct comparisons with PEEK studies are not strictly appropriate, similarities in the polyaryletherketone (PAEK) family invite comparisons because of literature scarcity (Teixeira et al., 2020). Fathey et al. (2024) reported fracture load values of 286.16 ± 67.09 N for central incisors restored with custom PEEK posts and cores. The Shofu HC group presented a mean fracture resistance of 97.06 ± 28.11 N. Caution is advised when interpreting these results as no direct comparisons exist in the literature, and

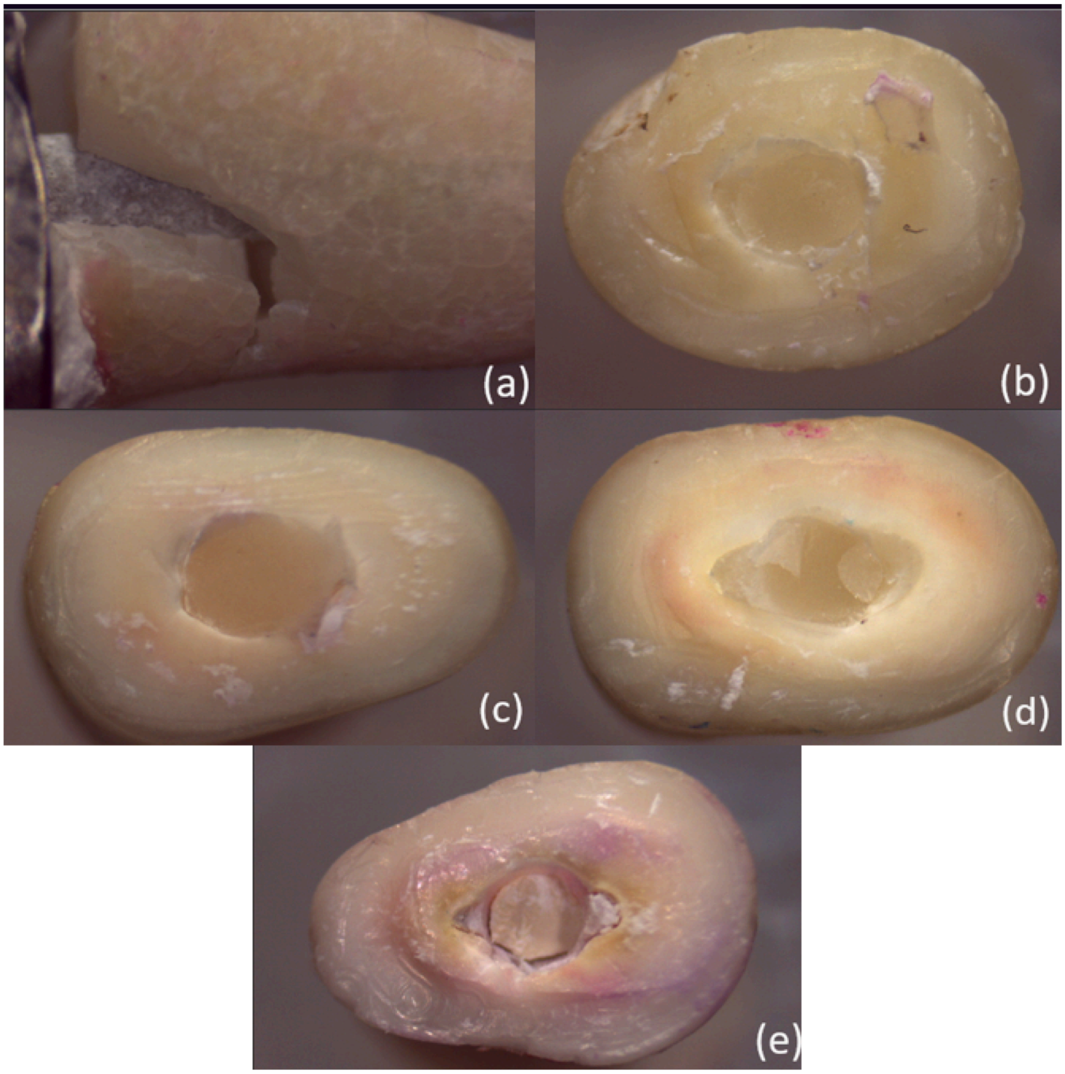

Fig. 3. Figures (a-e) showcase the unfavorable fracture of ETT treated with (a) metal post- core sample and favorable fracture with different post-core systems, (b) Vita Enamic post-core sample (c) Shofu HC sample (d) Trilor post-core sample (e) PEKK post-core sample.

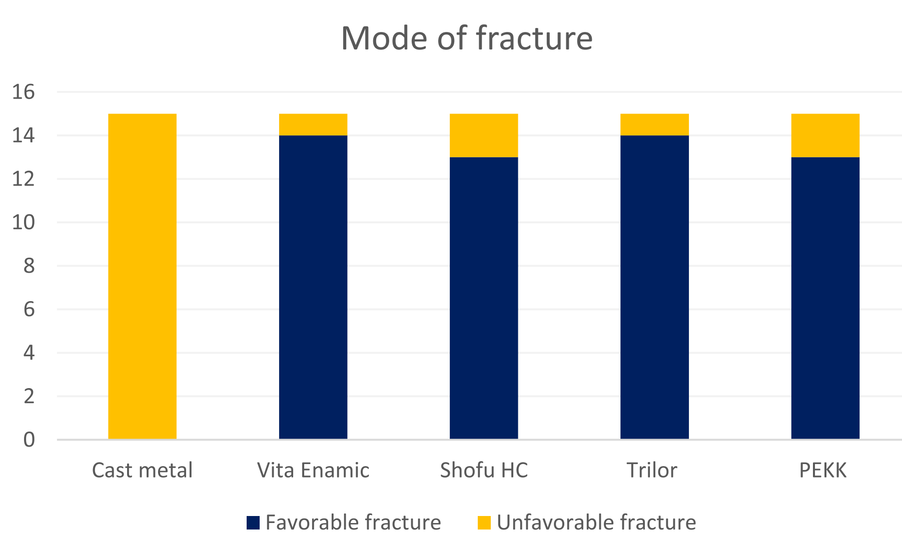

Fig. 4. The bar graph demonstrates the number of the samples and mode of failure of each experimental group.

it is distinct from the TRINIA Shofu material (Suzaki et al., 2021; Altitinchi et al., 2022).

Owing to their low fracture resistance values, non-metal CAD/CAM materials are not recommended for posterior ETT restorations without a ferrule. However, this conclusion is conditional on factors such as the presence of ferrules, tooth type, and canal morphology, warranting further investigation (Falcão et al., 2017; Eid et al., 2019; Teixeira et al., 2020; Suzaki et al., 2021).

Despite their higher fracture resistance, all metal samples fail catastrophically owing to their high modulus of elasticity, in contrast to dentin, which leads to stress concentration in the less rigid material, causing fracture (Salameh et al., 2008; Lassila et al., 2004). This suggests the need for post materials that match dentin rigidity to distribute stress uniformly (Pontius et al., 2002). Consistent with the literature, most metal-restored teeth experienced beyond-repair fractures (Teixeira et al., 2020; Alkhatri et al., 2019; Bilgin et al., 2016; Pang et al., 2019), contrasting with Eid et al.'s favorable fracture patterns in the presence of a ferrule (Eid et al., 2021). Non-metal samples mostly exhibit favorable fracture patterns owing to their modulus of elasticity being closer to dentin, fracturing at the post-core interface without significant group differences (Falcão et al., 2017; Eid et al., 2019; Teixeira et al., 2020; Suzaki et al., 2021).

This study had some limitations that may have influenced the results. The specimens were not subjected to masticatory simulation to evaluate their long-term durability in various oral environments, and in vitro, testing does not fully represent real-life clinical scenarios, which may affect the generalizability and external validation of the findings. Additionally, the findings were specific to mandibular second premolars, and only one loading point and angle were examined. This should be considered in future studies on this topic.

5. Conclusion

Within the limitations of the study, the following conclusions were identified:

- Metal posts had the highest fracture resistance in endodontically treated teeth but led to catastrophic failure.
- No significant differences were observed in the fracture force or mode among the non-metal CAD/CAM options.
- Additional research on CAD/CAM fabricated posts is required for effective clinical use.
- Author Statement

Authors disclose the use of AI and AI-assisted technologies in the writing process of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sdentj.2024.07.002.

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