ORIGINAL ARTICLE

Fracture Resistance, Failure Mode and Pull-Out Bond Strength of Polymer-Infiltrated Ceramic-Network Post-Core Fabricated using Computer-Aided Design/ Computer-Aided Manufacturing

ZULKEFLE NJ[1,2], AB-GHANI Z[3], ABDUL HAMID NF[4]

[1]*Faculty of Dentistry, Universiti Teknologi MARA, Jalan Hospital 47000 Sungai Buloh, Selangor*

[2]*Dental Restorative Specialist Unit, Kuala Dungun Dental Clinic, Jalan Alur Tembesu, 23000, Dungun Terengganu*

[3]*School of Dental Science, Universiti Sains Malaysia, Kubang Kerian 16150 Kelantan*

[4]*Centre of Restorative Studies, Faculty of Dentistry, Universiti Teknologi MARA, Jalan Hospital 47000 Sungai Buloh, Selangor*

Received: 12 October 2023 / Accepted: 15 November 2023

ABSTRAK

Kajian ini membandingkan rintangan patah (FR), mod kegagalan (FM), dan ketahanan daya tarikan tiang pergigian dalam gigi yang dirawat secara endodontik yang direstorasi dengan rangkaian seramik tersusun polimer (PICN) yang direka bentuk dan dibuat dengan komputer dengan tiang pergigian keluli. Sejumlah 45 batang gigi kacip tengah atas dipilih, diberikan rawatan endodontik dan disediakan untuk menerima restorasi tiang dan teras pergigian. Spesimen dibahagikan secara rawak kepada 5 kumpulan (n = 9); CG: kawalan (tanpa tiang dan teras pergigian); NC1, NC2: tiang dan teras pergigian keluli nikel-kromium (Ni-Cr); dan VE1, VE2: tiang dan teras pergigian PICN. Kumpulan CG, NC1 dan VE1 dikenakan ujian FR, manakala kumpulan NC2 dan VE2 dikenakan ujian ketahanan daya tarikan. FR direkodkan, dan FM diklasifikasikan sebagai menggalakkan atau tidak menggalakkan, manakala tahap pengekalan dalam daya maksimum direkodkan dalam Newton. ANOVA sehala digunakan untuk menilai FR, dan ujian T bebas digunakan untuk pengekalan tiang dan teras. Tiada perbezaan min ketara FR antara kumpulan Ni-Cr berbanding kumpulan PICN (p = 0.261). FM yang tidak menggalakkan telah direkodkan dalam semua sampel dalam kumpulan NC, dengan 88.9% daripada kumpulan VE menunjukkan FM yang menggalakkan. Tiada perbezaan min yang ketara direkodkan dalam pengekalan antara NC2 dan

Address for correspondence and reprint requests: Nor Faharina Abdul Hamid. Centre of Restorative Studies, Faculty of Dentistry, Universiti Teknologi MARA, 47000 Sungai Buloh Campus, Selangor, Malaysia. Tel: +603-6126 6593 Email: faharina@uitm.edu.my

VE2 (p>0.05). Tiang dan teras PICN mempamerkan nilai FR, FM, dan pengekalan yang menggalakkan, sekali gus berpotensi untuk digunakan sebagai tiang dan teras pengganti dalam gigi anterior yang dirawat secara endodontik.

Kata kunci: Pengeluaran bantu komputer; reka bentuk bantu komputer; rintangan patah; tiang dan teras pergigian

ABSTRACT

This study compared fracture resistance (FR), failure mode (FM), and pull-out retention in endodontically-treated teeth restored with computer-aided design-and-manufacturing polymer-infiltrated ceramic networks (PICN) to cast post-core. A total of 45 maxillary central incisors were selected, endodontically treated, and were prepared to receive the post-core restorations. The specimens were randomly divided into five groups (n = 9): CG: control (without post-core); NC1, NC2: cast nickel-chromium (Ni-Cr) post-core; and VE1, VE2: PICN post-core. Groups CG, NC1, and VE1 were subjected to the FR test, while Groups NC2 and VE2 were subjected to the pull-out retention test. FR were recorded, and FM were classified as favourable or non-favourable, while the degree of retention in the maximum force was recorded in Newton. A one-way ANOVA was used to assess the FR, and an independent T-test was used for retention of post-core. No significant mean differences of FR between Ni-Cr versus PICN group (p = 0.261). Non-favourable FM was recorded in all samples in the NC group, with 88.9% of the VE group showed favourable FM. No significant mean differences were recorded in retention between NC2 and VE2 (p>0.05). PICN post-core exhibited favourable FR, FM, and retention values, thus having the potential to be used as a substitute post-core in endodontically-treated anterior teeth.

Keywords: Computer aided design; computer aided manufacturing; fracture resistance, post-core

INTRODUCTION

The restoration of endodontically treated teeth remains a significant challenge for the clinician as the success of the final restoration is subjected to the availability of the remaining tooth structure (Belli et al. 2015; Kimble et al. 2023). Although multiple treatment alternatives are available for the endodontically treated tooth, the clinician is often confused in choosing the most appropriate restorative materials for the final restoration (Mannocci et al. 2021). The use of intraradicular posts in endodontic teeth aims to facilitate the retention of the core. In the case of extensive loss of tooth structure, custom-made cast posts made either from gold, Nickel-chromium (Ni-Cr) or cobalt-chromium (Co-Cr) are more indicated (Hamid & Ahmad 2022). Despite the high success rate and positive long-term prognosis of these materials, the notable difference in modulus of elasticity (MOE) results in non-homogenous stress on the tooth structure, causing catastrophic root fracture as one of the complications (Akkayan & Turgut 2002; Fraga et al. 1998).

The use of dental computer-aided design and computer-aided manufacturing (CAD/CAM) systems in conjunction with tooth-coloured CAD/CAM blocks offer an extensive range of material alternatives, allowing the clinician to select materials with a similar or lower MOE (Eid et al. 2019a; Pang et al. 2019; Suzaki et al. 2021). Polymer-infiltrated ceramic-network (PICN) is a hybrid material composed of ceramic and composite with MOE of 30 GPa which offers optimum performance with stability and elasticity that can optimally absorb occlusal forces (VITA Zahnfabrik 2020). The inclusion of a post with an equivalent MOE helps to prevent stress concentration and better in distributing tension around the tooth which leads to non-catastrophic failure (Alkhatri et al. 2019; Gonzaga & Correr 2017). Additionally, as the hardness of PICN is considerably lower than that of conventional dental ceramics, it allows for a more rapid machining and less wear on CAD/CAM milling burs. Although the material is indicated for extracoronal materials such as inlay, onlay and crown, the remarkable properties of PICN, which encompass superior physical characteristics with lower MOE offer great potential as post and core materials (Spina et al. 2017, VITA Zahnfabrik 2020).

Experimental fracture testing serves as a fundamental tool in ensuring that the post-core restoration meets aesthetic as well as functional requirements. It is conducted by subjecting the restorations to controlled loads and meticulously recording their mechanical behaviour (Belli et al. 2018; Dietschi et al. 2008). Additionally, the testing allows identification of weaknesses in the material composition, design, and/or bonding interface (Dietschi et al. 2008). As failures can be categorised into two main categories: non-catastrophic and catastrophic failures, these distinctions of failure are crucial as they relate to the severity and implications of restorations and patient outcomes (Jurema et al. 2022 ; Alkhatri et al. 2019). While retention testing is conducted to determine the degree to which the post is securely bonded within the tooth structure, contributing to the long-term success and durability of the restoration, the most frequent failure among custom-made posts was due to loss of retention (Marchionatti et al. 2017). Thus, the aim of this study was to compare the fracture resistance (FR) and pull-out retention force between the cast and PICN post and core. If a material with a lower MOE, such as PICN, can yield less non-catastrophic fracture, more endodontic-treated teeth with minimal remaining tooth structure will have a better prognosis, better survival, and higher success rates.

MATERIALS AND METHOD

Experimental Design

Sample size calculation was calculated using power and sample size software (PS) (version 3.1.2) based on comparison between two independent means (Alharbi et al. 2014) (alpha level set at 0.05, 80% power, ratio 1, mean difference of 405.5). With an anticipated of 10% failure rate during the preparation of samples of each group, the final sample size for each group had been decided to be nine. This study obtained ethical approval from the Universiti Teknologi MARA (UiTM) Human Ethics Advisory Committee (Reference: 600-TNCPI (5/1/6). A total of 45 intact maxillary central incisors were extracted from a government dental clinic around Klang Valley. The randomisation method was created using Microsoft Excel by listing numbers from 1 to 45, with each number assigned a random number prior to the specimen's selection to reduce the likelihood of bias and ensure balanced grouping. The teeth were allocated into five groups (n = 9) (Table 1). The specimens were stored in normal saline until the time of the research. All specimens must be free from caries, restorations, or any visible defects following the evaluation under a dental magnifier. A radiographic examination was conducted to verify the presence of a straight, single canal with a completely developed apex, the presence of prior endodontic therapy, or any canal calcifications. Teeth with cracks, defects, flared canals, and internal resorption were excluded from the study. Only roots with almost similar size and shape and comparable in length (mean length ± 2 mm, buccolingual and mesiodistal dimensions mean ± 0.5 mm) were included in the study.

Endodontic Therapy and Post-core Preparation

One operator, a postgraduate prosthodontics student prepared all of the samples. Endodontic therapy

TABLE 1: Distribution of groups according to types of restoration following randomisation

Group	Sample Number	Descriptions	
A (CG)	1, 4, 6, 7, 9, 27, 35, 41, 42	Control group without post and core (n=9)	9 teeth without post, with light cure composite resin as coronal seal and core
B (NC1)	8, 11, 12, 15, 22, 25, 34, 40, 44	Cast post and core (n=9)	9 teeth with Ni-Cr post and core
C (VE1)	14, 21, 24, 28, 32, 36, 38, 43, 45	CAD/CAM post and core (n=9)	9 teeth with PICN post and core
D (NC2)	2, 3, 5, 10, 19, 23, 26, 30, 33	Cast post and core (n=9)	9 teeth with Ni-Cr post and core
E (VE2)	13, 16, 17, 18, 20, 29, 32, 37, 39	CAD/CAM post and core (n=9)	9 teeth with PICN post and core

*Group CG, NC1 and VE21 were subjected to fracture resistance test. Group NC2 and VE2 were subjected to retention test.

was performed using hand K-files (Dentsply, Switzerland) following the stepdown technique. The canals were then dried with paper points, obturated and sealed with gutta-percha points (Dentsply, Switzerland) using lateral compaction with root canal sealer (AH Plus; Dentsply, Germany). The access cavity was restored with light-cured composite resin restorations and kept in a saline solution. The gutta percha was removed using a low-speed Gates-Glidden intrument (Dentsply) (up to size 3) following the endodontic therapy. The post-space preparation was performed using ParaPost® XP™ drills (Coltène Whaledent) following standard sequences, resulting in a 5mm apical seal. The post and core was subsequently built, refined while maintaining the desired 4 mm height (Figure 1). The specimens were divided randomly into five groups accordingly: Groups A, B, and C were allocated for the fracture test, and Groups D and E were allocated for the pull-out tensile

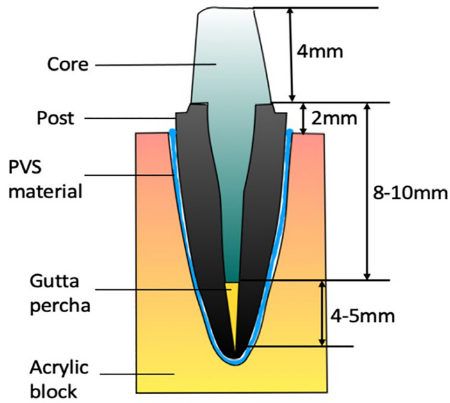

FIGURE 1: Schematic diagram of the specimen's preparation in CG, NC1 and VE1 group. The specimen in NC2 and VE2 groups were mounted in acrylic resin blocks without PVS impression materials

TABLE 2: Composition of cast Nickel-Chromium (Ni-Cr) and Polymer-Infiltrated Ceramic Network (PICN) (Vita Enamic®) materials used in this study

Material	Manufacturer	Characteristics	Composition
4all Nickel-Chromium*	Ivoclar Vivadent, Schaan, Liechtenstein	Metal-ceramic alloy, Type 4 (Cast metal material)	Nickle: 61.4% Chromium: 25.7% Molybdenum: 11.0% Silicon: 1.5 % Manganese: <1.0% Aluminium: <1.0% Carbon: <1.0%
Vita Enamic® Block HT*	VITA Zahnfabrik, Bad Sackingen, Germany	Polymer-infiltrated ceramic-network (PICN) (CAD/CAM fabricated material)	Composition of The Ceramic Network (86.0 wt% / 75.0 vol%): Silicone dioxide: 58.0-63.0% Aluminium oxide: 20.0-23.0% Sodium oxide: 9.0-11.0% Potassium oxide: 4.0-6.0% Boron trioxide: 0.5-2.0% Zirconia: <1.0% Calcium oxide: <1.0% Composition of the polymer network (14.0 wt% / 25.0 vol%): Urethane dimethacrylate (UDMA) and triethylene glycol dimethacrylate (TEGDMA)

*According to composition and characteristic of Ni-Cr and PICN material from the manufacturer strength test. Composition of material used in this study was displayed in Table 2.

Fabrication of Custom-made Cast Post and Core

The post and cores were fabricated using the traditional cast technique following the fabrication of resin pattern in a base metal alloy (Nickel-Chromium, 4all, Ivoclar Vivadent, Liechtenstein). The pressure spots were evaluated and detected with a silicone fitting agent (Fit Checker, GC America) and removed with finishing stone rotary cutting instruments in NP alloy adjustment kit (Shofu Inc., Kyoto, Japan) until a passive fit was achieved prior to cementation. The canals were treated with 37% phosphoric acid (Scotchbond universal etchant 3M™ ESPE, USA) for 15 seconds, rinsed thoroughly with normal saline, and dried with paper points. Following that, Scotchbond universal adhesive (3M™ ESPE,USA) was brushed in the canals and air-dried for 5 seconds. The custom-made posts were sandblasted with 50-µm aluminium oxide particles, silanated, and cemented with self-adhesive dual-cure resin cement (RelyX U200; 3M ESPE,USA) following the manufacturer's instructions. The excess cements were removed with microbrush, and the specimens were lightly polymerised from all directions (labial, palatal, mesial, distal) for 20 seconds per surface. The remaining cements were removed with hand instrument. The specimens were then left undisturbed for 30 minutes to enable complete polymerisation of the resin cements.

Fabrication of CAD/CAM Post and Core

The fabrication of CAD/CAM post and core was conducted using the technique from a previously published technical report (Zulkefle et al. 2022). Indirect digitalisation scanning using a resin pattern was done with an intraoral three-dimensional (3D) scanner (Aoralscan 3, Shining 3D Scanner, China) and processed with design software (Ceramill Match; Amann Girrbach, Austria) to develop a digital 3-dimensional model of the post and core. Then, the post and core milling using Vita Enamic block (VITA Zahnfabrik, Germany) was completed using a 5-axis milling machine (Ceramil Motion 2, Amann Girrbach, Austria) (Figure 2). The PICN posts and cores were cemented with cement (RelyX U200; 3M ESPE,USA) using the same technique as for metal posts and cores according to the manufacturer's

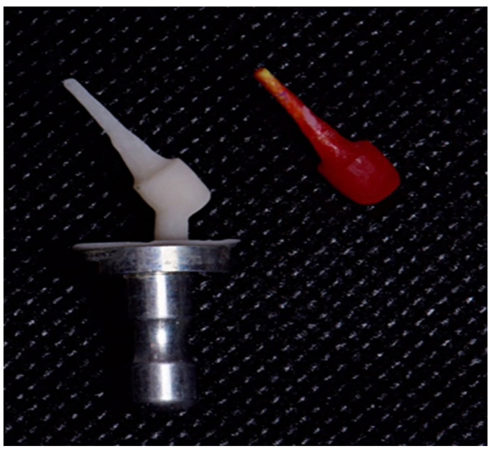

FIGURE 2: Comparison of milled PICN (right) and autopolymerising acrylic resin pattern (left) of post and core

recommendations. All specimen was stored in distilled water at room temperature until the beginning of the experiment and throughout duration of the study.

Thermal Cycling

Thermal cycling was performed to simulate a 6-month period of ageing in vivo. The specimens from were subjected to thermal cycling (5000 cycles) between 5-55˚C with a dwell time of 30 seconds at each temperature.

Fracture Test and Failure Mode

Following fatigue simulation, 27 specimens (n = 27), with nine specimens from group A, B and C group, were subjected to a fracture test. All specimens were tested with a universal testing machine (Shimadzu, Kyoto, Japan) until fracture occurrence (failure load was recorded in Newtons). The constant crosshead speed was 1 mm/min at an angle of 135 and 100 N force was applied to the long axis of the tooth at the centre of palatal fossa. This angle was chosen to simulate the average interincisal angle between maxillary and mandibular incisors in normal class I occlusion and the load intraorally while chewing (Figure 3). The mode of failure was assessed using direct visual and failure patterns were categorised as favourable or non-favourable based on visual inspection (Figures 4).

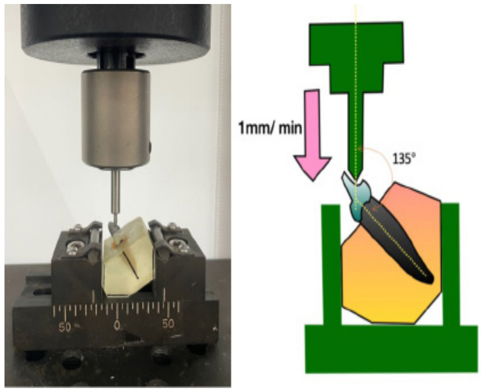

FIGURE 3: Set up of the set-up of the mounted post and core for fracture resistance test in Universal Testing Machine (Shimadzu, Japan) and schematic drawing for fracture resistance test

Pull-out Bond Strength Test

For the pull-out test, 18 specimens were used: Group D (n = 9): custom-

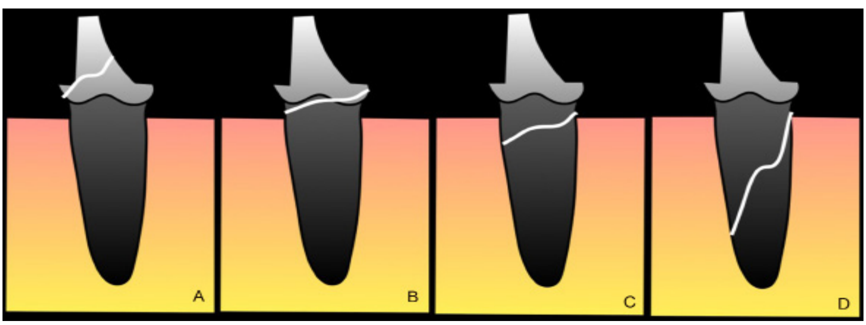

FIGURE 4: Schematic diagram of classification of failure mode. Favourable fracture: A. Core fracture; B. Fracture above the simulated bone level. Unfavourable fracture; C. Fracture below simulated bone level; D. Longitudinal fracture along the root

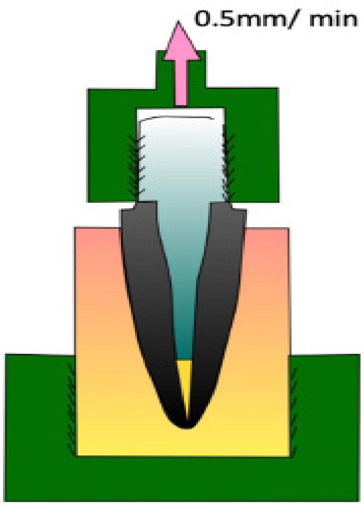

FIGURE 5: Schematic drawing of mounted post and core set-up for retention test

made cast post and core, and Group E (n = 9): CAD/CAM post and core. Tensile force was applied to the post with a crosshead speed of 0.5 mm/min until it dislodged from the canal (Figure 5). The degree of retention was the maximum force recorded that was able to remove the post along its longitudinal axis, and it was recorded in Newton.

Statistical Analysis

Data were analysed using the software Statistical Programme for Social Sciences (IBM SPSS Statistics for Windows, Version 28.0. Armonk, NY: IBM Corp). Prior to data analysis, Shapiro-Wilk tests were used to ensure data conformity to the normal distribution. A One-way ANOVA was used to compare the experimental parameters of the specimens in the control, Ni-Cr and PICN post and core groups with regards to fracture resistance. An independent T-test was used to compare the experimental parameters of the specimens in the Ni-Cr and PICN post and core groups with regards to the retention value. The level of significance, p was set at < 0.05.

RESULTS

Table 3 showed the mean of fracture resistance (N) values for each group; control group without post and core, Ni-Cr post and core and PICN post and core group. There was a significant mean difference of fracture resistance between groups; control group without post and core, Ni-Cr post and core and PICN post and core group [F (2,24) =3.711; $p < 0.05$]. Post Hoc Bonferroni analysis that was conducted and showed there was a significant mean difference of fracture resistance between Ni-Cr post and core group versus control group (p=0.040),

TABLE 3: Comparison of mean fracture resistance (Netwon) between groups

Post and core groups	Mean (SD)	F (df)	p-value
Control	506. 91 (195.71)	3.711 (2, 24)	0.039*
Ni-Cr	741.71 (152.44)		
PICN	585. 07 (206.10)		

One-way ANOVA, significant at p<0.05*
Further Post Hoc Bonferroni test showed significant difference between Ni-Cr and control group with p=0.040.

but there were no significant mean differences of fracture resistance between Ni-Cr post and core group versus PICN post and core group (p=0.261) and control group versus PICN post and core group (p=1.000). In terms of FM, all specimens exhibited favourable FM for all control groups (100%), while all specimens exhibited non-favourable FM for all Ni-Cr groups. 88.9% of specimens from the PICN group show favourable FM (Figure 6). There was no significant mean difference in retention between the Ni-Cr group and the PICN group [t = 0.892; df = 16; p = 0.385.

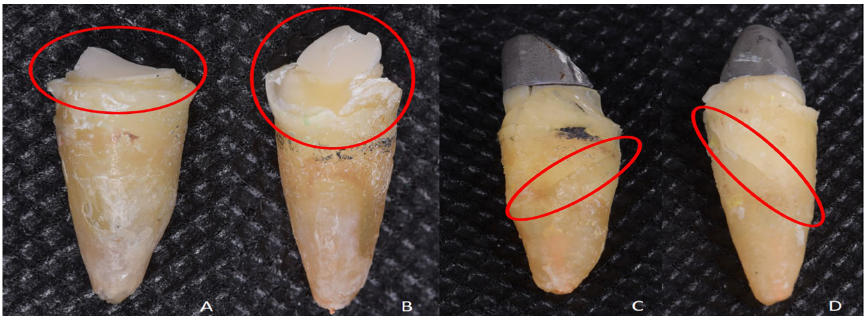

FIGURE 6: Example of favourable (A,B) and non-favourable (C,D) failure modes

DISCUSSION

The biomechanical performance of endodontically treated teeth was influenced by post material. The ideal post and core material should possess comparable physical and mechanical characteristics as dentin (Kimble et al. 2023; Hamid & Ahmad 2022). During occlusion, dentin displays significant plastic deformation that enables resistance from different angles and different degrees of load. Once applied loads exceed the tensile strength or relative limit of dentin, the capability of plastic deformation of dentin decreases, leading to tooth fracture (Kalyoncuoğlu et al. 2015). Thus, it is important that the post can provide crown-core retention without producing detrimental stresses on the residual tooth structure (Machado et al. 2017). Hypothetically, posts with a lower MOE will undergo post-deformation at the luting cement-dentin interface during occlusal function, which can cause non-catastrophic events such as loss of marginal seal, post fracture, and/or loss of retention of posts (Ferrari et al. 2012; Mannocci et al. 2005).

The present study observed that the mean fracture resistance of PICN (585 N) was not significantly different from previously reported values (414 N–664 N) for PICN posts and cores (Hiromi et al. 2023; Spina et al. 2017). In addition, our study found that 8 out of 9 samples in the PICN group underwent favourable failure modes, while unfavourable failure modes or catastrophic failures were found in all specimens from the Ni-Cr group. This was due to the difference in the MOE between the root dentin (10–30 GPa) and the Ni-Cr post material (200 GPa), in which a post with high rigidity can resist forces without deformation while transferring the stress to dentin. This finding was consistent with a previous study that found PICN posts and cores exhibited favourable fractures in comparison to non-favourable fractures in the metal and zirconia posts and cores groups (Alkhatri et al. 2019). Another study also reported that, 90% sample from PICN post and core group exhibited restorable and non-catastrophic failure compare to 60% of sample from resin nano ceramic group; although resin nano ceramic group showed significantly higher fracture resistance (Spina et al. 2017).

Additionally, new experimental fibre-reinforced composite (FRC) CAD/CAM blocks that comprise low MOE material can become alternative materials in CAD/CAM post and core (Gonzaga & Correr 2017; Liu et al. 2010; Pang et al. 2019; Tsintsadze et al. 2018; Tsintsadze et al. 2017). The previous study stated that the composition of FRC which consist of a parallel orientation of fiberglass helps in the absorption of force which can limit the failure involving the root (Gonzaga & Correr 2017). A more recent study on FRC found that a variety of directions of glass fiber in a new type of epoxy matrix glass fiber helps to improve the self-strength of the post-core (Pang et al. 2019). Good interfacial bonding between the silanised fiber and resin matrix also aids in ensuring effective load transfer from the matrix to the reinforcing fibers which enhances the positive mechanical properties of the material, especially in terms of FR (Grandini et al. 2008). In addition, hybrid ceramic is claimed to have MOE less than dentin (10 GPa) causing more favourable failure as it helps to eliminate macro-crack propagation in residual coronal dentin (Eid et al. 2019b). This was supported by a study done by Alkhatri et al. that found few hybrid materials (PICN) exhibited favourable fracture characterised by core fracture only without the involvement of root fracture (Alkhatri et al. 2019; Alkhatri et al. 2021). Interestingly, in contrast to earlier findings, a more recent study indicated that post and core manufactured from materials with MOE similar to or even lower than dentin (polyetheretherketone (4GPa), nanohybrid composite resin (14GPa), and fiber-reinforced epoxy resin (25GPa)) exhibited only non-catastrophic failures, while the PICN post and core (30GPa) group showed catastrophic failures (Hiromi et al. 2023). It is anticipated that variations in composition and modulus of elasticity of the material will impact the failure pattern exhibited by these materials.

In the present study, the mean dislodging force for both groups were between the minimum and maximum values established from previous research, which were roughly between 85N and 342N. However, this result could not be compared with any other study since, to date, no prior research has explored the effect of different post materials on the retention of Ni-Cr and the PICN posts and cores. Nevertheless, one study reported that no significant correlation was noted between pull-out bond strength in four different CAD/CAM materials

(Hiromi et al. 2023). In another study by Jafarian et al. (2020), the retention of Co-Cr posts and cores cemented with glass ionomer luting cement was compared in round- and oval-shaped canals using different fabrication techniques. The study found that the mean retention forces for these Co-Cr posts and cores ranged between 118.84 N and 122.41 N, slightly lower than those of Ni-Cr posts and cores. Furthermore, the authors observed that conventional custom-cast Co-Cr posts and cores exhibited significantly better adaptation than milled materials in both round and oval-shaped canals (Jafarian et al. 2020).

Owing to the in vitro experimental approach, the present study had certain inherent limitations, making it to be impossible to directly compare with clinical situations. Crowns were excluded from this study to prevent external influences on force distribution, reduce the complexity of the result, and focus primarily on radicular occurrences (Ambica et al. 2013; Spina et al. 2017). With the elimination of crown, it is anticipated that the structural integrity and fracture resistance of a post and core foundation could be precisely evaluated (Da Costa et al. 2017). Gonzaga and Correr justifies the nonessential of coronal restoration as the study focus on radicular event where the presence of crown was considered as an external influence over forces distribution (Gonzaga & Correr 2017). A further study conducted by Da Costa et al. (2017) demonstrated that there is no difference in fracture resistance between teeth restored with CAD/CAM post and core, regardless in the presence or absence of a crown. The application of a static load as opposed to a cyclic load does not reflect the intraoral conditions accurately. The forces acting on teeth and restorations in the oral environment include rotating, shearing, and cyclical forces. Thus, when extrapolating the results to clinical situations, caution must be exercised. Nonetheless, the results of this study may be used as a general guide for selecting posts and cores for future research and clinical applications. Self-adhesives and bonded resin cements have various levels of retention; hence, future research should investigate the potential role of different cement types.

CONCLUSION

CAD/CAM material with an almost similar MOE to dentin should be considered as a first option because it has an acceptable FR value and a favourable FM. PICN will be a suitable alternative material for restoring an anterior endodontically treated tooth in areas with high aesthetic requirements. Although the FR of PICN did not differ significantly from Ni-Cr cast posts and cores, unfavourable FM was noted in all specimens in the Ni-Cr groups. No significant difference was noted in retention among the PICN and Ni-Cr groups.

ACKNOWLEDGEMENT

The study was funded by the Ministry of Higher Education through the Fundamental Research Grant Scheme for Research Acculturation of Early Career Researchers (Ref: RACER/1/2019/SKK14/UITM//2) and the Postgraduate Bench Fees Research Grant. The authors would like to thank University Teknologi MARA, 3D Gens Laboratory, and Dr. K Dental Surgery for their technical assistance during the fabrication of the post and core. The authors would also like to thank Mrs. Izyan Hazwani Baharuddin for her assistance with statistical analysis.

REFERENCES

Alharbi, F.A., Dan, N., Steven, M.M., Nadim, Z.B. 2014. Fracture resistance and failure mode of fatigued endodontically treated teeth restored with fiber-reinforced resin posts and metallic posts in vitro. *Dent Traumatol* **30**(4): 317-25.

Akkayan, B., Turgut, G. 2002. Resistance to fracture of endodontically treated teeth restored with different post systems. *J Prosthet Dent* **87**(4): 431-7.

Alkhatri, R., Saleh A.R.M., Kheder, W. 2019. Evaluating fracture resistance and failure modes of root filled teeth restored with CAD/CAM-fabricated post and core. *Clin Cosmet Investig Dent* **11:** 349-55.

Alkhatri, R., Saleh A.R.M., Kheder, W. 2021. Impact of post and core materials on the apical extension of root fracture in root canal treated teeth. *J Mater Res Technol* **10**: 730-7.

Ambica, K., Mahendran, K., Talwar, S., Verma, M., Padmini, G., Periasamy, R. 2013. Comparative evaluation of fracture resistance under static and fatigue loading of endodontically treated teeth restored with carbon fiber posts, glass fiber posts, and an experimental dentin post system: An in vitro study. *J Endod* **39**(1): 96-100.

Belli, R., Wendler, M., José I.Z., Lohbauer, U. 2018. Practical and theoretical considerations on the fracture toughness testing of dental restorative materials. *Dent Mater* **34**(1): 97-119.

Belli, S., Eraslan, O., Eskitascioglu, G. 2015. Direct restoration of endodontically treated teeth: A brief summary of materials and techniques. *Curr Oral Health Rep* **2**: 182-9.

Da Costa, RG, Freire, A., de Morais, E.C.C., de Souza, E.M., Correr, G.M., Rached, R.N. 2017. Effect of CAD/CAM glass fiber post-core on cement micromorphology and fracture resistance of endodontically treated roots. *Am J Dent* **30**(1): 3-8.

Dietschi, D., Duc, O., Krejci,I., Sadan, A. 2008. Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of the literature, Part II (Evaluation of fatigue behavior, interfaces, and in vivo studies). *Quintessence Int* **39**(2): 117-29.

Eid, R.Y., Koken, S., Baba, N.Z., Ounsi, H., Ferrari, M., Salameh, Z. 2019a. Effect of fabrication technique and thermal cycling on the bond strength of CAD/CAM milled custom fit anatomical post and cores: An in vitro study. *J Prosthodont* **28**(8): 898-905.

Eid, R., Juloski, J., Ounsi, H., Silwaidi, M., Ferrari, M., Salameh, Z. 2019b. Fracture resistance and failure pattern of endodontically treated teeth restored with computer-aided design/computer-aided manufacturing post and cores: A pilot study. *J Contemp Dent Pract* **20**(1): 56-63.

Ferrari, M., Vichi, A., Fadda, G.M., Cagidiaco, M.C., Tay, F.R., Breschi, L., Polimeni, A., Goracci, C. 2012. A randomized controlled trial of endodontically treated and restored premolars. *J Dent Res* **91**(7 suppl): 72S-8S.

Fraga, R.C., Chaves B.T, Mello, G.S.B., Siqueira Jr, J.F. 1998. Fracture resistance of endodontically treated roots after restoration. *J Oral Rehabil* **25(11):** 809-13.

Gonzaga C.C., Correr, G.M. 2017. CAD/CAM post-and-core using different esthetic materials: Fracture resistance and bond strengths *Am J Dent* **30**(6): 299-304.

Grandini, S., Chieffi, N., Cagidiaco, M.C., Goracci, C., Ferrari, M. 2008. Fatigue resistance and structural integrity of different types of fiber posts. *Dent Mater J* **27**(5): 687-94.

Hamid, N.F.A., Ahmad, R. 2022. Computer-aided design/computer-aided manufacturing (CAD/CAM) machines with scanning and milling capabilities for fabricating custom posts and cores: A narrative review. *Malaysian J Med Health Sci* **18**(2): 166-72.

Hiromi, S., Gabriela, M., Fabricio, P., Rogério, Goulart.d.C., Evelise, M.d.S., Rodrigo N.R. 2023. Fracture strength, pull-out bond strength, and volume of luting agent of tooth-colored CAD-CAM post-and-cores. *J Prosthet Dent* **129**(4): 599-606

Jafarian, Z., Moharrami, M., Sahebi, M., Alikhasi, M. 2020.Adaptation and retention of conventional and digitally fabricated posts and cores in round and oval-shaped canals. *Int J Prosthodont* **33**(1): 91-8.

Jurema, A.L.B., Filgueiras, A.T., Santos, K.A., Bresciani, E., Caneppele T.M.F. 2022. Effect of intraradicular fiber post on the fracture resistance of endodontically treated and restored anterior teeth: A systematic review and meta-analysis. *J Prosthet Dent* **128(1):** 13-24

Kalyoncuoğlu, E., Ural C., Aydemir, H., Aslan, M.A, Balkaya, V. 2015. Effect of 1-piece post and core fabrication techniques on fracture strength. *J Appl Biomater Funct Mater* **13(3):** e253-8.

Kimble, P., Stuhr, S., McDonald, N., Venugopalan, A., Campos, M.S., Cavalcanti, B. 2023. Decision making in the restoration of endodontically treated teeth: effect of biomimetic dentistry training. *Dent J* **11**(7): 159

Liu, P., Deng, X.L., Wang, X.Z. 2010. Use of a CAD/CAM-fabricated glass fiber post and core to restore fractured anterior teeth: A clinical report. *J Prosthet Dent* **103(6):** 330-3.

Machado J, Almeida, P., Fernandes, S., Marques, A., Vaz, M. 2017. Currently used systems of dental posts for endodontic treatment.*Procedia Struct* **5:** 27-33.

Mannocci, F., Bhuva, B., Roig, M., Zarow, M., Bitter, K. 2021. European Society of Endodontology position statement: The restoration of root filled teeth. *Int Endod J* **54**(11): 1974-81.

Mannocci, F., Qualtrough, A.J., Worthington, H.V., Watson, T.F., Ford, T.R.P. 2005. Randomized clinical comparison of endodontically treated teeth restored with amalgam or with fiber posts and resin composite: Five-year results. *Oper Dent* **30**(1): 9-15.

Marchionatti, A.M.E., Wandscher,V.F., Rippe, M.P., Kaizer, O.B., Valandro, L.F. 2017. Clinical performance and failure modes of pulpless teeth restored with posts: A systematic review. *Braz Oral Res* **31**: e64.

Pang, J.L., Feng, C.F., Zhu, X.R., Liu, B., Deng, T.Z., Gao, Y., Li, Y., Ke, J. 2019. Fracture behaviors of maxillary central incisors with flared root canals restored with CAD/CAM integrated glass fiber post-and-core. *Dent Mater J* **38**(1): 114-9.

Spina, D.R.F., Da Costa, R.G., Farias, I.C., da Cunha, L.G., Ritter, A.V., Gonzaga, C.C., Correr, G.M. 2017. CAD/CAM post-and-core using different esthetic materials: Fracture resistance and bond strengths. *Am J Dent* **30**(6): 299-304.

Suzaki, N., Yamaguchi, S., Nambu, E., Tanaka, R., Imazato, S., Hayashi, M. 2021. Fabricated CAD/CAM post-core using glass fiber-reinforced resin shows innovative potential in restoring pulpless teeth. *Materials* **14**(20): 6199

Tsintsadze, N., Juloski, J., Carrabba, M., Goracci, C., Vichi, A., Grandini, S., Ferrari, M. 2018. Effects of scanning technique on in vitro performance of CAD/CAM-fabricated fiber posts. *J Oral Sci* **60(2):** 262-8.

Tsintsadze, N., Juloski, J., Carrabba, M.,Tricarico, M., Goracci, C., Vichi, A., Ferrari, M., Grandini, S. 2017. Performance of CAD/CAM fabricated fiber posts in oval-shaped root canals: An in vitro study. *Am J Dent* **30**(5): 248-54.

VITA Zahnfabrik H. Rauter GmbH. 2020. VITA ENAMIC® Product information. https://www.vita-zahnfabrik.com/en/CAD/CAM-fabrication/Single-tooth-restoration/VITA-ENAMIC-24970,27568.html [21st July 2023]

Zulkefle, N.J., Hamid, N.F.A., Ariff, T.F.T.M., Ab Ghani, Z. 2022. Fabrication of computer-aided design and computer-aided manufacturing (CAD/CAM) post and core using indirect digitalisation technique. *IIUM J of Orofacial Health Sci* **3**(2): 212-8.