



## Fracture Resistance and Failure Pattern of Endodontically Treated Teeth Restored with Computer-aided Design/Computer-aided Manufacturing Post and Cores: A Pilot Study

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### ABSTRACT

**Aim:** To evaluate the fracture resistance and failure pattern of custom made computer-aided design & computer-aided manufacturing (CAD/CAM) post and cores using a fiber reinforced composite material (FRC) and a high-density-polymer.

**Materials and methods:** Thirty extracted mandibular second premolars were selected, endodontically treated and prepared to receive the posts. The specimens were randomly divided into three groups (n = 10) according to each material: group 1 (RXP) : fiber posts (Rely X, 3M-ESPE) with composite core build-up (Filtek Bulk Fill Posterior, 3M-ESPE) as a control group; group 2 (BLC): one-piece milled post and core from fiber reinforced composite blocks (Trilor, Bioloren); and group 3 (AMC): one-piece milled post and core from hybrid ceramic disks (Ambarino, Creamed). All the posts were cemented using a self-adhesive resin cement (Rely X U200, 3M ESPE). Fracture resistance was tested using a universal testing machine, failure patterns were then observed visually and radiographically then evaluated under SEM. Data was analyzed using One-way analysis of variance (ANOVA) followed by Tamhane post-hoc test in order to determine significant differences among groups ( $\alpha = 0.05$ ).

**Results:** The mean fracture resistance values were:  $426.08 \pm 128.26$  N for group 1 (R X P),  $367.06 \pm 72.34$ N for group 2 (BLC), and  $620.02 \pm 54.29$ N for group 3 (AMC). Statistical analysis revealed that group 3 (AMC) had the highest mean load to fracture in comparison to the other groups ( $p = 0.000$ ). failures were cohesive in group 2 and 3 and mixed in group 1 with no catastrophic failures reported in all groups.

**Conclusion:** All systems evaluated presented sufficient mean load-to-failure values for endodontically treated teeth restorations. CAD/CAM post and cores made from high-density-polymer showed a better performance than prefabricated fiber posts.

**Keywords:** One-piece post and core, Fiber reinforced composite, High-density polymer, Fracture resistance, Laboratory test.

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### INTRODUCTION

Different modalities for restoring endodontically treated teeth (ETT) are guided by strength and esthetics.<sup>1</sup> A post is indicated when the remaining coronal structure of the tooth can no longer provide adequate retention and support for the restoration.<sup>2,3</sup> For decades, cast gold posts and cores have been considered the gold standard thanks to their favorable long-term prognosis;<sup>4,5</sup> however they might compromise the esthetic outcome when used with all-ceramic crowns especially with high-translucency ceramics or when the thickness available is less than 1.5 mm.<sup>6</sup> Moreover, their cost remains relatively high compared to other treatment options. FRC posts are known for their superior esthetic qualities

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and their elastic modulus close to that of dentin<sup>7</sup> and allow for fewer irreparable root fractures and esthetic problems as compared to metallic posts.<sup>8,9</sup> In addition, when compared to ETT with no root canal retention, teeth restored with FRC posts showed better fracture resistance and more favorable failure patterns<sup>10,11</sup> with debonding being the most common failure type.<sup>12-14</sup> Improvements in this field were possible as several trials<sup>15,16</sup> studied the effect of customizing FRC posts and concluded that higher bond strength values were due to the presence of a thin and uniform resin cement layer, and increased retention due to better adaptation to the post space. Furthermore, cohesive failure of the core restoration was also described and was due to the flexure of the post inducing stress on the composite resin core.<sup>17-20</sup> The establishment of reliable bonds at the root, post, and core interfaces are critical for the clinical success of a post retained restoration.<sup>21</sup>

With the introduction of CAD/CAM technology, Bittner et al.<sup>1</sup> described the milling of one-piece zirconia Post and cores and concluded an acceptable load bearing capacity in comparison with gold posts and cores, however the use of zirconia posts has been limited due to their high modulus of elasticity (200 GPa), stiffness, hardness that can result in catastrophic failures,<sup>22</sup> and difficult retrievability.<sup>1</sup> Pressable ceramic posts and cores were also studied<sup>23</sup> and showed acceptable results with 1.7 mm post diameter, while the 1.4 mm diameter did not show satisfactory fracture resistance value. Recently, resin composite and FRC blocks have been introduced for use with CAD/CAM systems as an alternative for machinable ceramics.<sup>24,25</sup> CAD/CAM resin composite restorations have several advantages over their ceramic counter parts: they are milling-damage tolerant, which allows for faster milling and better marginal quality,<sup>26</sup> and no post-milling firing is required. In fact, CAD/CAM composites show an elasticity modulus closer to that of dentin than ceramics, and the property of absorbing masticatory forces.<sup>27</sup> Limited data exist regarding the behavior of these new CAD/CAM materials when used as posts and cores.

The study aims to compare the fracture resistance and failure pattern of teeth restored with CAD/CAM custom posts and cores made from a fiber reinforced composite, and a high-density polymer to teeth restored using prefabricated fiber posts.

The null hypothesis tested was that there are no differences in the fracture strength and failure pattern of teeth restored with milled or prefabricated posts and cores.

## MATERIALS AND METHODS

This study was approved by the ethical committee of the Lebanese University (124/112018). Thirty extracted single-rooted mandibular premolars free of cracks and caries were stored in 0.5% chloramine solution (Chloramine T, Honeywell Riedel de-Haen, Seelze, Germany) for less than 2 months. The root length of each tooth was measured from the cemento-enamel junction (CEJ) to the apex on the buccal side, and the diameter of the teeth was measured buccolingually and mesiodistally at the CEJ using a vernier caliper (Insize Co, Ltd). Lengths between 12 and 14 mm were accepted. Teeth with more than 2 mm variations in terms of mesiodistal and buccolingual diameter were discarded. Teeth were cleaned with an ultrasonic scaler (Mectron S.P.A, Carasco, Italy) and stored in saline solution for no longer than 2 months before testing. Anatomic crowns of the teeth were cut parallel to CEJ at an equal distance of 1.5 mm with a water-cooled low-speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA). Root canals were prepared using ProTaper Next nickel-titanium rotary instruments (Dentsply-Sirona Endodontics, Ballaigues, Switzerland) to X3 (30/.07) at a working length of 0.5 mm from the apex with 5.25% sodium hypochlorite irrigation. Canals were then dried with paper points (DiaDent Group, Burnaby, BC, Canada) and obturated with gutta-percha points (DiaDent) and canal sealer AH Plus (Dentsply-DeTrey, Konstanz, Germany) using warm vertical compaction. Access was sealed with glass ionomer cement (Fuji IILC, GC, Tokyo, Japan) and stored in water for 48 hours to allow for complete setting of the sealer. Each specimen was embedded in an auto-polymerizing acrylic resin (Novacryl, Uredent, Carabobo, Venezuela) 2 mm under the CEJ to simulate bone level and placed perpendicular to the long axis of the root using a dental surveyor. Coronal preparation was standardized with a 1 mm chamfer finish line and a ferrule of 1.5 mm using a dental surveyor, and then the dentinal walls thickness was verified using a digital caliper with 0.01 mm accuracy (Insize Co, Ltd). Samples with less than 1 mm thickness were considered fragile, discarded, and replaced.

Post space was prepared at a constant length of 9 mm from the coronal limit of the preparation for all teeth using Gates-Glidden. Largo drills were then used gradually (size 1 to 3, Dentsply-Sirona Endodontics) to homogenize the shape and remove residual gutta-percha. The specimens were prepared by one operator and randomly divided into 3 groups of 10 teeth each: group 1 (RXP)–prefabricated posts and composite core build-ups used as control group, group 2 (BLC)–custom milled fiber-reinforced posts and cores, group 3 (AMC)–custom milled high-density polymer posts and cores (materials are listed in Table 1).

**Table 1:** Group distribution by material and manufacturer

| Group # | Material             | Manufacturer              | Composition   |
|---------|----------------------|---------------------------|---|
| 1       | Rely X® fiber Post   | 3M-ESPE, St Paul, MN, USA | Epoxy resin matrix:32%<br>Glass fibers:67%,<br>Zirconium and Strontium fillers            |
| 2       | Trilor®              | Bioloren, Saronno, Italy  | Epoxy resin matrix (25% vol), multi directional glass fiber reinforcement (75% vol)       |
| 3       | Ambarino® High Class | Creamed, Marburg, Germany | Highly crosslinked Bis-GMA,<br>UDMA, BODMA matrix<br>70.1wt% inorganic silica nanofillers |

For group 1 (RXP) canal spaces were rinsed with distilled water then dried with paper points (DiaDent Group). The posts were cleaned with alcohol and cemented with self-adhesive resin cement (Rely-X U200 Automix, 3M-ESPE, Seefeld, Germany) as per manufacturer recommendations. Elongation tips were used to place the cement in the canal to avoid air bubbles. Excess cement was removed after light polymerization (Elipar S10 LED curing light, 3M ESPE) for 40 seconds on the tip of the post. The core build-up was prepared using nano-filled composite (FiltekBulk-fill Posterior, 3M-ESPE) 4 mm above the coronal walls with a 30-degree angulation of the buccal cusp slope to the long axis of the tooth verified using a dental surveyor.

For groups 2 (BLC) and 3 (AMC) all prepared canal spaces were lubricated with a minimum die lubricant (Picosep, Renfert, Hilzingen, Germany). Direct resin patterns were fabricated (Pattern Resin, GC America, Alsip IL, USA) maintaining an equal length of 4 mm above the ferrule with a 30-degree angulation of the buccal cusp slope to the long axis of the tooth verified on the dental surveyor. The resin patterns were sprayed with a scan powder (IPS Contrast Spray; Ivoclar Vivadent, Schaan, Liechtenstein) and scanned with a lab scanner (Imetric 1041, Courtenay, Switzerland). After scanning, digitized data collected were transmitted to a special digital software (Exocad dental CAD, Exocad GmbH, Darmstadt, Germany) where a design was conceived for

each post, after what a CAM software (WorkNC Dental, Frankfurt, Germany) was used to develop the milling sequence for each of the materials used. The posts were undersized by 80 microns to compensate for the thickness of the scanning spray and the luting resin cement. The customized posts and cores (groups 2 and 3) were milled using a 5-axes milling machine (Datron D5, Datron AG, Darmstadt, Germany). The machine movement was adjusted by decreasing the Z step and lateral step over speed to reduce lateral bending movement leading to the fracture of the post on its apical end. Burs of 2.5 mm, 1 mm and 0.6 mm were used (Datron AG). In group 2 (BLC), blocks were used since the unidirectional fibers responsible of stress dissipation are concentrated in the long axis of the blocks (Fig. 1A) and posts were silanized (Rely X ceramic primer, 3M ESPE) as per manufacturer recommendations. As for group 3 (AMC) posts were dry milled from disks (Fig. 1B), sand blasted with 50 µ aluminum oxide particles and silanized (Rely X ceramic primer, 3M ESPE) following the manufacturer recommendations. All the post and cores (group 2-RXP and 3-AMC) were cemented in their respective canal spaces previously irrigated with distilled water and dried with paper points using a self-adhesive resin cement (Rely-X U200 Automix, 3M-ESPE, Seefeld, Germany). Elongation tips were used to place the cement in the canal to avoid air bubbles. Excess cement was removed after light polymerization (Elipar S10 LED curing light, 3M ESPE) for 40 seconds on each axial wall of the tooth.

After cementation, the load to fracture test was performed using a universal testing machine with mounting jig (Triax Digital 50, Controls, Milan, Italy). The specimens were loaded on the slope of the buccal cusp 2 mm from the tip of the cusp toward the central fossa with a steel rounded tip of 2.5 mm diameter. The load was applied parallel to the longitudinal axis of the tooth at a crosshead speed of 1 mm/min until failure. The load was measured in Newton (N). The mean failure load for each group was calculated. The mode of failure was determined visually and radiographically, then three random samples of each group were evaluated under scanning electron microscopy (SEM).



**Figs 1A and B :** (A) Representative figure custom milled post and core Trilor; (B) Representative figure custom milled post and core Ambarino

Data were analyzed using statistical analysis software (IBM SPSS Statistics 2015, Ontario, Canada). One-way ANOVA was used followed by Tamhane post-hoc test to determine significant differences among groups. The significance level was set at 0.05.

**RESULTS**

The mean load to fracture was 426.08 N(SD = 128.26) for group 1 (RXP), 367.06N (SD = 72.34) for group 2 (BLC), and 620.02N (SD = 54.29) for group 3 (AMC) (Table 2). Statistical differences were found between groups 1 (RXP), 2 (BLC) and group 3 (AMC) ( $p < 0.001$  and  $p < 0.000$  respectively). No differences were found between group 1 (RXP) and 2 (BLC) ( $p = 0.545$ ). The mode of failure for each

test group is listed in Table 3. Regarding group 1 (RXP) all specimens displayed mixed failure patterns and partial core debonding and core fracture (Figs 2A and B) with no fracture of the tooth, the SEM of the fractured specimens showed a failure at the interface between the post surface and the bonding agent used (Fig. 2C). As for group 2 (BLC) posts and cores, the mode of failure was cohesive within the core: a crack in the coronal part was observed visually and radiographically without any damage to the tooth structure (Figs 3A and B). The SEM revealed rupture of fibers by the failure of the interface between the fiber and the surrounding matrix (Fig. 3C). Group 3

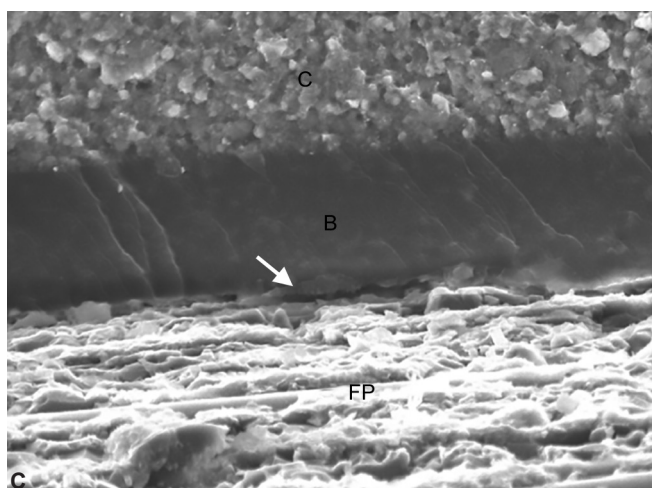
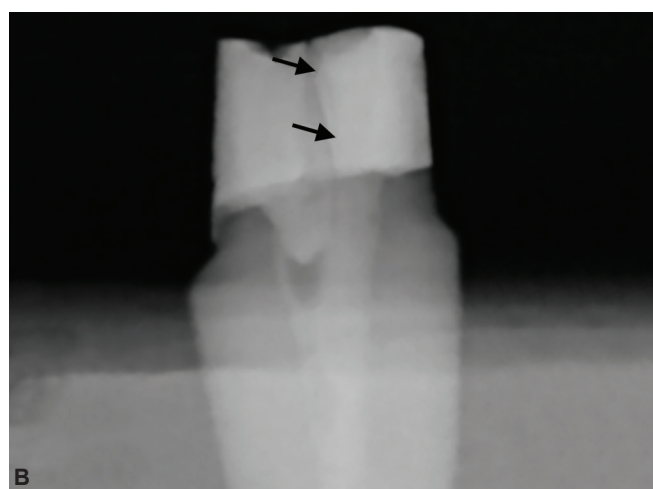
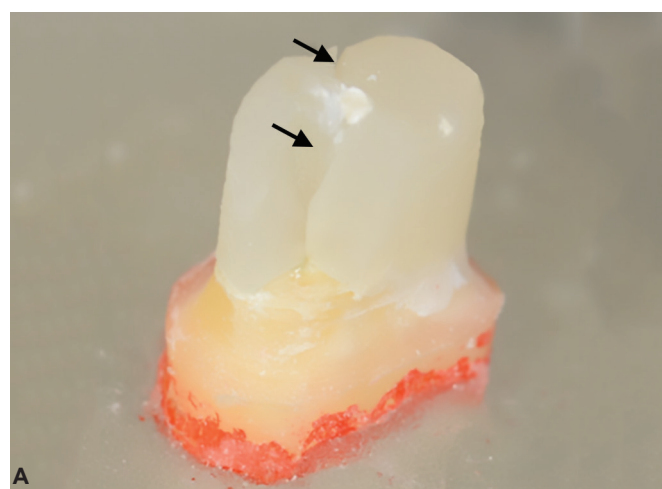
**Table 2:** Mean and standard deviation of the 3 groups

| Group #     | n  | Mean fracture resistance (N) |
|-------------|----|------------------------------|
| 1 (control) | 10 | 426.08 <sup>b</sup>          |
| 2           | 10 | 367.06 <sup>b</sup>          |
| 3           | 10 | 620.02 <sup>a</sup>          |

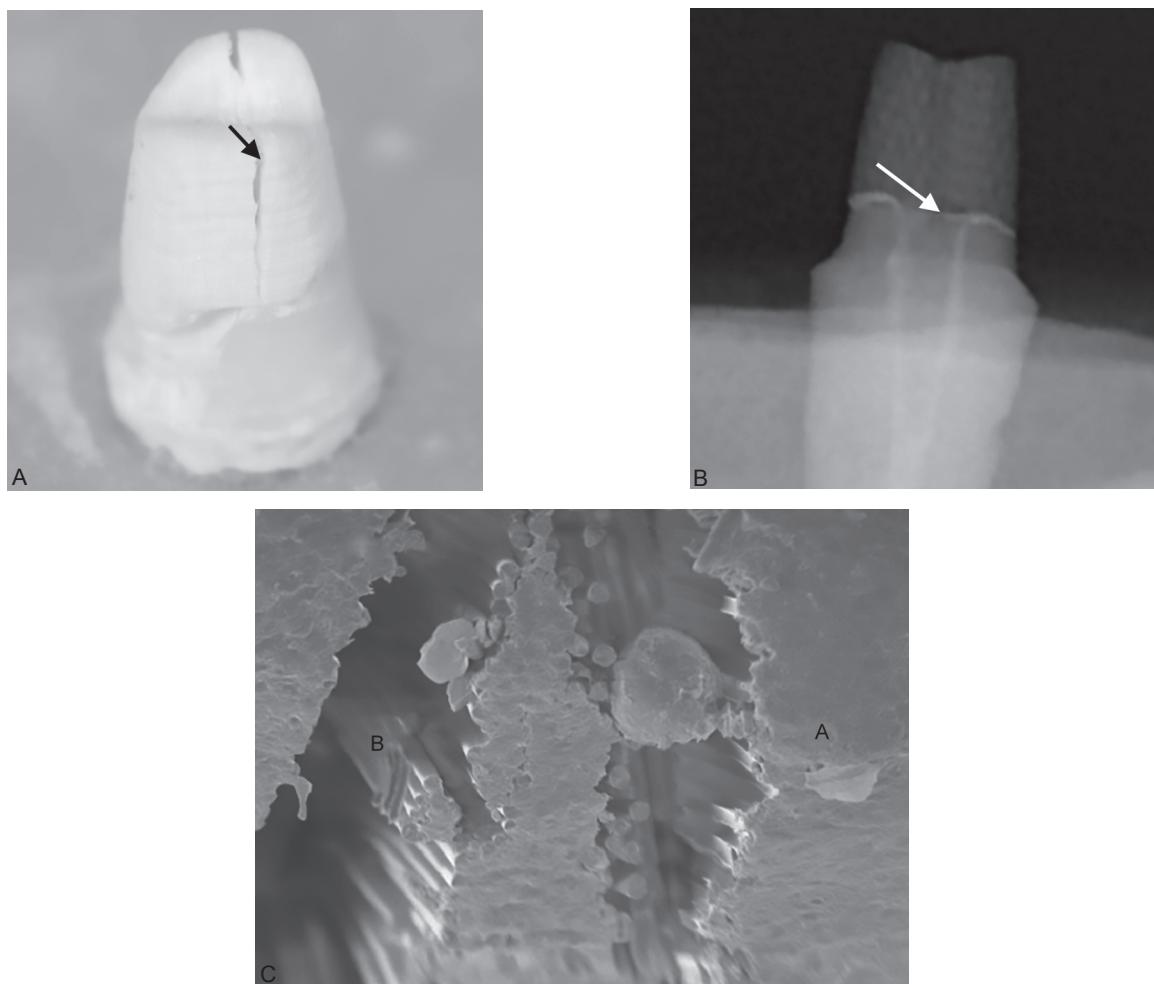
<sup>a,b</sup>One-way ANOVA revealed significant differences ( $p < 0.01$ ) Different letters indicate significant differences

**Table 3:** Failure mode of the different groups

| Group #  | Number of specimens | Mode of failure  |
|----------|---------------------|--|
| 1 (n=10) | 10                  | Partial core debonding and core fracture without tooth involvement |
| 2 (n=10) | 10                  | Crack in the core without tooth involvement                        |
| 3 (n=10) | 8                   | Partial core fracture without tooth involvement                    |
|          | 2                   | Partial core and tooth fracture above the CEJ                      |



**Figs 2A to C:** (A) Representative photograph showing a crack in the core (arrow) and between the post and the core build up (arrow); (B) Radiograph displaying the extent of the crack (arrow); (C): SEM micrograph revealing failure at the interface between the bonding and the fiber post surface (C: Composite; B: Bonding; FP: Fiber post).



**Figs 3A to C:** (A) Representative photograph showing a crack in the core (arrow); (B): Radiograph displaying the extent of the crack (arrow); (C): SEM micrograph revealing a rupture of fibers by failure of the interface between the fiber and the surrounding matrix (A: Occlusal surface; B: Rupture of fibers).

(AMC) showed a cohesive fracture of the core starting from the point of the force application was observed for all samples, minimal fracture of the tooth was observed in two samples above the CEJ (Figs 4A and B). No tooth fracture or post fracture were reported in any of the specimens. SEM revealed a radial crack located below the surface point of load application on the occlusal surface of the post that fanned out as it propagated apically (Fig. 4C).

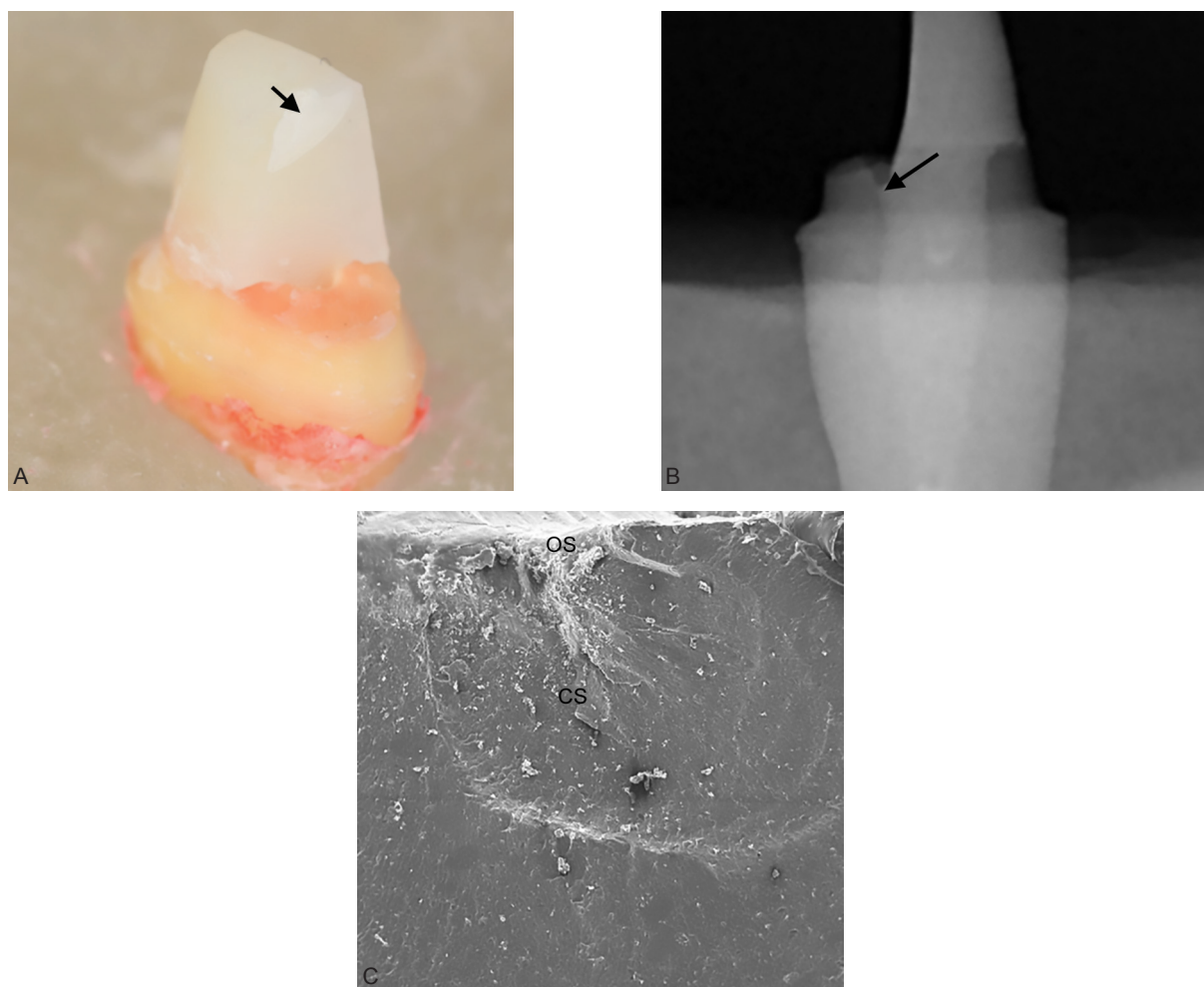
## DISCUSSION

The results of this study led to the rejection of the null hypothesis tested. This study aimed to assess CAD/CAM esthetic materials and milling technique in customized post and core. The two tested materials are not known for the post and core indication. This proof of concept study aimed primarily to test the capability of new materials to withstand masticatory loads and compare their mechanical behavior to that of FRC prefabricated esthetic posts. In fact FRC posts show higher properties in bending and in tensile but their compressive strength is the most affected because the fibers have less side support by the resin and tend to fail at lower applied

loads.<sup>28</sup> A vertical load to fracture seems to test more the cohesive properties of these materials and to distribute the stress more evenly between the dental tissues and the restorative material simulating a physiological occlusion.<sup>2</sup> Consequently, full coverage crowns were eliminated as they are known to increase the fracture resistance of ETT with fiber posts.<sup>20</sup>

This study was performed on extracted mandibular premolars and although the care was taken to ensure comparable dimensions, differences in dimensions might still have affected the maximal load to failure.

For group 1 (RXP), the largest post that reached the working length with mild friction was selected and cut 4 mm coronal to the prepared ferrule with a diamond disk. This technique aimed to conserve the root dentinal substance simulating the clinical situation and to maximize comparability with groups 2 (BLC) and 3 (AMC). Mixed failures were probably due to the dichotomous structure of prefabricated post restorations, the concentrated stress at the interface between post and core can lead to such failures. However, although several papers reported debonding as the main reason for



**Figs 4A to C:** (A) Representative photograph displaying the fracture in the core (arrow); (B) Radiograph displaying the extent of the fracture in the core (arrow); (C) SEM micrograph revealing a radial crack located below the surface point of load application on the occlusal surface of the post that fanned out as it propagated apically (OS: Occlusal surface, CS: Crack surface).

prefabricated post failure,<sup>12,29,30</sup> others reported fracture of the core as mode of failure.<sup>20,31,32</sup> In a randomized clinical trial Ferrari et al.<sup>33</sup> compared prefabricated posts with customized ones in relation to the residual coronal dentin. They concluded that the placement of prefabricated or a customized post contributed to the survival of pulpless teeth with better behavior for the prefabricated group. Most of the failures observed was debonding of the post in the prefabricated group and the post/core fracture in the customized group. Milling a one-piece post and core results in avoiding the interface between the post and the core while ensuring a better adaptation of the radicular part of the post thus creating more favorable conditions for the retention of the post.<sup>34</sup>

Ambarino® high-class is high-density-polymer composed of a radiolucent, ultra-hard composite material using an optimized, highly cross-linked Bis-GMA, UDMA matrix containing 70.1% wt of inorganic silica nanofillers.<sup>35</sup> This composition enhances the strength of the material,<sup>36</sup> offers better resilience and fracture toughness in comparison to ceramics by enhancing the dissipative characteristic and subsequently the resistance to fracture.

Also, according to the manufacturer, the flexural strength would be around 175 MPa and compression strength around 500 MPa. When subjected to compression, the glassy polymer undergoes a craze initiation that will eventually develop into a crack when the force exceeds the creep limit of the material, craze initiation serves as a sign of failure.<sup>37</sup> In the present study, SEM images of the fractured specimens revealed the presence of a radial crack originating at the point of application of the occlusal load, and that fanned out as it propagated apically. These findings are in accordance with Aboushelib et al.<sup>38</sup> who tested survival of ceramics and polymers under fatigue. Moreover, and according to the manufacturer, Ambarino® disks have a modulus of elasticity of 10 GPa, which is inferior to the elastic modulus of dentin. This may explain the mode of failure observed since the core fractured mostly by macro-crack propagation without involving the residual coronal dentin thus resulting in a favorable failure mode.

According to the manufacturer, Trilor® is formed of an epoxy resin matrix (25% vol) and multidirectional glass fibers reinforcement (75% vol) that simulate in multi-

dimensional configuration the texture of a fabric, with a flexural strength of 540 MPa and an elasticity modulus of 26 GPa. Fibers are silanized before being embedded in the resin matrix. Fiber-reinforced materials are known to gain their mechanical properties from the matrix and the fibers as well as the strength of the bond at the interface between them. Good interfacial bonding can ensure efficient load transfer from the matrix to the reinforcing fibers, thus enhancing the mechanical behavior of the composite materials.<sup>39</sup>

Grandini et al.<sup>40</sup> observed under SEM the surface of fiber posts cut with a diamond bur. The tips of the posts were irregular, and some bur marks were observed close to the surface borders. They assumed that it was because the posts were not cut against a surface, which would create a mechanical resistance load opposed to the cut direction. This might occur when a block of fiber is milled on a milling machine. Potential stress could actually occur on the cutting surface of the post and core and cutting of the fibers might have affected the interface between the fibers and the matrix and compromised the mechanical properties of the initial blocks. This agrees with the findings of Baran et al.<sup>41</sup> who concluded that in case of failure of fiber reinforced materials, cracks do not propagate for a long distance within the matrix before reaching the fiber interface. The strength gradient at the interface between the matrix and filler will represent the crack-growth rate better than the crack propagation rate determined for the matrix alone. Following local matrix and interface failure surrounding a dispersed fiber, the fiber itself ruptures; then, the load is transferred to neighboring fibers, which in turn rupture. After a critical density of single-fiber failures is attained, the fracture of the body takes place. Failures may also be localized within a specific domain, and this damage is termed "brush-like cracking", from which the ultimate failure of the body proceeds.<sup>42</sup> These findings are in accordance with the SEM images observed on the crack surface of Trilor<sup>®</sup> posts and cores after failure. It might, therefore, be concluded that the milling procedure might have compromised the mechanical properties of group 2 (BLC).

More studies should be conducted and include factors such as full-coverage crowns, the aging process, and bond strength tests to better simulate *in vivo* conditions.

## CONCLUSION

Within the limitations of this *in vitro* study, the following conclusions can be drawn:

- One-piece post and core can be milled successfully from FRC blocks and high-density-polymer material disks using CAD/CAM technology
- High-density-polymer material custom made posts and cores behaved better with regard to fracture resistance than prefabricated fiber post with composite core build up and custom made FRC posts and cores.

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