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In vitro fracture resistance of endodontically treated premolar teeth restored with a direct layered fiber-reinforced composite post and core

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ABSTRACT

Methods for restoring endodontically treated teeth fall short of restoring the physiologic mechanical properties. Fracture of endodontically treated teeth is a common type of clinical failure. New treatment modalities or perfected versions of existing treatment concepts need to be tested to find a biomimetic solution. A novel method of restoring endodontically treated teeth is presented and compared *in vitro* with currently accepted restorative methods. Seventy-two extracted and endodontically treated maxillary premolar teeth were divided into six groups (n = 12) depending on restorative technique (Groups 1–6). Group 1: fiber-reinforced composite post (FRC), Group 2: direct layered short FRC post and core, Group 3: short fiber-reinforced obliquely layered composite restoration, Group 4: microhybrid composite restoration, Group 5: fiber-reinforced box, Group 6: control. Specimens were submitted to static fracture resistance test. Fracture thresholds and fracture patterns were evaluated. Group 6 exhibited the highest fracture resistance. Group 2 yielded the highest fracture resistance among the restored groups. The fracture resistance of Group 2 did not differ significantly from Group 6. Groups 1, 3, 4, 5 proved to be significantly different from the control group. There was no statistically significant difference among restored groups. Fracture patterns of tested groups were dominantly non repairable opposed to control groups mostly repairable fractures. Application of direct-layered short FRC post and core in endodontically treated premolars performed statistically similarly in the studied conditions as natural teeth. Therefore, it seems a promising alternative to current endo-restorative solutions. However, further testing is required.

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1. Introduction

Endodontically treated teeth (ETT) are structurally different from nonrestored vital teeth and require specialized restorative treatment.[1] According to Dietschi et al. [2], the major difference is not a consequence of tissue quality alteration, but the result of the loss of dental

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structures (e.g. marginal ridges, pericervical dentine and the arched roof of the pulp chamber) caused by caries, trauma or endodontic procedures. As a result of the compromised structural integrity, ETT are at an increased risk of fracture.[3,4] The fracture strength of these teeth is dependent on the amount and position of the remaining tooth structures and the choice of restorative material and technique.[5–13]

Several studies highlighted that postinsertion significantly increased the fracture resistance of nonvital premolars[10,14–16]; however, other studies only managed to prove the positive effect of postinsertion on the fracture pattern in premolar teeth.[17–19] The latter was also confirmed by Trope et al. [20] and Zicari et al. [21] who came to the conclusion that posts do not strengthen the tooth. These findings could be caused by the mismatch between fiber posts and the root canal diameter since according to modern minimal invasive principles postspace preparation should not contribute to radicular dentine removal.[22,23] Following a minimally invasive postspace preparation leaves us with unique and irregular spaces [24] which are difficult to fill out with a single conventional or even a flexible posts. A further problem with posts is that they are placed in the most central part of the postspace (neutral axis), leaving the space originally occupied by dentine to be filled by the mechanically inferior luting composite material. A more effective reinforcement location mechanically may be on the outer surfaces of the postspace close to the dentine walls where the highest tensile stresses occur.[25] This is the space which before the root canal preparation was most likely obtained by healthy radicular and pericervical dentine. So to reach a reinforced, mechanically homogenous unit it would be ideal if a restorative material could be directly bonded to the root canal dentine and it would have mechanical properties similar to that of dentine.

In a 2007 investigation by Garoushi and coworkers, it was found that anterior ETT showed better load-bearing capacity if restored with a short fiber-reinforced composite (SFRC) restorative material opposed to a fiber-reinforced composite (FRC) post.[26] These findings open the debate on the necessity of the FRC post concept and open a gateway for the promotion of new types of endo-restorative techniques.

The aim of this investigation was to compare the mechanical properties of novel methods for the reinforcement of ETT utilizing SFRC (EverX Posterior, GC Europe, Leuven); with previously tested and accepted restorative methods. The null hypothesis was that (1) there would be no difference in the maximal fracture resistance of the ETT restored teeth with the tested methods. (2) There would be no difference in the fracture patterns of the ETT restored with the tested methods.

2. Materials and methods

All procedures of the study were approved by the Ethics Committee of the University of Szeged, and the study was designed in accordance with the Declaration of Helsinki.

Seventy-two upper premolar teeth, extracted for periodontal or orthodontic reasons were selected for this investigation. Specimen selection, exclusion criteria, root canal treatment protocol, specimen preparation and mechanical testing were carried out as described by Frater et al. [27,28].

The freshly extracted teeth were immediately placed in 5.25% NaOCl for 5 min and stored in 0.9% saline solution at room temperature. Teeth were used within 6 months after extraction.

During specimen preparation the soft tissue covering the root surface was removed with hand scalers. The inclusion criteria were absence of caries or root cracks, the absence of previous endodontic treatments, posts or crowns, resorptions or evident lateral canals. Buccolingual and mesiodistal radiographs of all teeth were taken and examined to evaluate root integrity and the number of canals present. To standardize procedures and materials, all teeth used in this study had 1 root canal with a curvature of less than 5°, evaluated by Schneider's technique,[29] and teeth with a root length of 15 ± 1 mm and similar mesio-distal and bucco-lingual dimensions (±10%) were selected.

90% of the specimen ranged 9–10 mm in size, measured at the widest bucco-lingual dimension, and the rest measured were 6.5–8 mm. Regarding the mesio-distal dimension, 90% of the specimen ranged 7–7.5 mm, and the rest were 6.5–8 mm.

The teeth were randomly distributed over six study groups of 12 specimens each.

Access cavity was prepared by the same trained operator in five groups of the six, and one group was left intact to serve as control (Group 6).

Access cavity preparation was carried out with a round-end, tapered, medium grit, 0.8 mm tip diameter, 10 mm length diamond bur (850-014 M SSWhite, Lakewood, NJ, USA) with water cooling in the approximated centre of the occlusal surface according to standardized parameters: the access cavity involved one-third of the intracuspal distance in the bucco-lingual dimension and one-third of the mesio-distal distance, measured at the level of the central fissure.

The working length was established with the direct method by subtracting 1 mm from the real root length determined by introducing a number 10 K-file (Maillefer-Dentsply, Ballaigues, Switzerland) until it was visible through the apical foramen. The canals were instrumented using rotary ProTaper Universal files (Dentsply, Maillefer, Ballaigues, Switzerland). The ProTaper sequence (S1, S2, F1, F2) was used for the preparation at the working length.

Irrigation was performed after every instrument with 2 ml of 2.5% NaOCl solution and the canal space was filled with irrigant during the instrumentation phase. After the shaping and cleaning of the root canal, the roots were dried with 96% alcohol and paper points. Root canal filling was done by matched single-cone obturation with a master cone (F2 gutta-percha, Maillefer-Dentsply, Ballaigues, Switzerland) and sealer (AH plus; Dentsply De Trey GmbH, Konstanz, Germany). The access cavity was temporarily filled with Fuji Triage Pink (GC Europe, Leuven, Belgium). Fuji Triage Pink was applied to the apical part of the root in order to prevent leakage through the apex. The teeth were stored in an incubator (mco-18aic, Sanyo, Japan) for 1 week (at 37 °C, 100% relative humidity).

Groups 1 and 2 received a minimal invasive post space preparation with a depth of 8 mm, as measured from the CEJ on the buccal aspect of the tooth, but no post preparation drills recommended by the manufacturer were used in order to preserve the individual anatomy of the specimen teeth. Only the root canal filling was removed with size three Gates Glidden burs and ISO standard Hedstrom files leaving a minimum apical seal of 6–8 mm of gutta-percha in the canal. The Number 3 Gates Glidden bur was used on the full 8 mm length.

In Groups 3–5 the gutta-percha was only cut back 2 mm below the CEJ with an 0.1 mm diameter ball-shaped carbide bur (H1SM.205.010, Gebr. Brasseler GmbH & Co. KG, Lemgo, Germany), but no post space preparation was performed. After cutting back the gutta-percha, the orifice was sealed with resin modified glass ionomer cement (Fuji VIII, GC Europe, Leuven, Belgium).

All specimen received the same adhesive treatment. Prior to the adhesive treatment of the cavity and the root canal, enamel was acid-etched selectively with 37% phosphoric acid for 15 s and rinsed with water. The root canal and the coronal cavity were rinsed with 2 ml of water and dried with paper points and air. For bonding, a dual-cure one-step self-etch adhesive system (Gradia Core Self-Etching Bond, GC Europe, Leuven, Belgium) was used, according to the manufacturer's instructions using a microbrush-X disposable applicator (Pentron Clinical Technologies, LLC, USA). Excess adhesive was removed by suction drying (Evacuation Tip – Starryshine, Anaheim, CA, USA) within 0.5 cm from the occlusal cavity (without contact). Excess adhesive resin at the bottom of the canal was removed with a paper point. The adhesive was light-cured for 60 s using an Optilux 501 quartz-tungsten-halogen light-curing unit (Kerr Corp., Orange, CA, USA). The average power density of the light source, measured with a digital radiometer (Jetlite light tester; J. Morita USA Inc. Irvine, CA, USA) prior to the bonding procedure, was 840 ± 26.8 mW/cm^2.

Five different techniques were used to restore the specimens (Figure 1):

Group 1

The teeth received a prefabricated, conventional FRC post (GC Fiber post, GC Europe, Leuven, Belgium). Before the adhesive treatment, the conventional translucent FRC posts of 0.8 mm diameter (GC Fiber Post, GC Europe, Leuven, Belgium) was tried in and cut to a length 1 mm below the level of the occlusal cavity margins with a water-cooled diamond disc (Isomet 2000; Buehler Ltd., Lake Bluff, IL, USA) and cleaned with alcohol after try in. The posts received silanization of the surface (Ceramic Primer, GC Europe, Leuven, Belgium) following the manufacturer's recommendation. After silanization, the post surface was bonded with the same bonding agent used for the cavity. Luting of the posts and the core build-up was performed with a dual-cure resin composite core material (Gradia Core, GC Europe, Leuven, Belgium). Gradia Core was applied using its own automix cartridge with an 'elongation tip' for direct root canal application. After insertion of the post, 5 min of chemopolymerization time was provided to reduce polymerisation stress, then cement was polymerized with an Optilux 501 quartz tungsten-halogen light-curing unit for 60 s from each side (a total of 240 s/tooth). The outlines of the restoration were finished with dental composite (G-aenial Posterior P-JE, GC Europe, Leuven, Belgium).

Group 2

The teeth were reconstructed with a novel method of building a direct layered FRC post and core (DLFRC post and core) from SFRC (EverX Posterior, GC Europe, Leuven, Belgium). The DLFRC post and core was horizontally layered in 1–2 mm segments. An increment of SFRC was packed to the apical portion of the postspace using a microbrush-X disposable applicator (Pentron Clinical Technologies, LLC, USA). A light transmitting FRC post (0.8 mm GC Fiber post, GC Europe, Leuven, Belgium) was inserted into the postspace in order to aid the transmission of the light to the apically positioned layers. The 'light transmitting' post was withdrawn with 0.5–1 mm from the surface of the uncured SFRC layer not to have direct contact with it.

After each layer 80 s of light curing through the fiber post was carried out. After incrementally filling the root canal to the level of the CEJ with repeating the previously described procedure, SFRC was layered in the coronal cavity until 1 mm below the margin of the

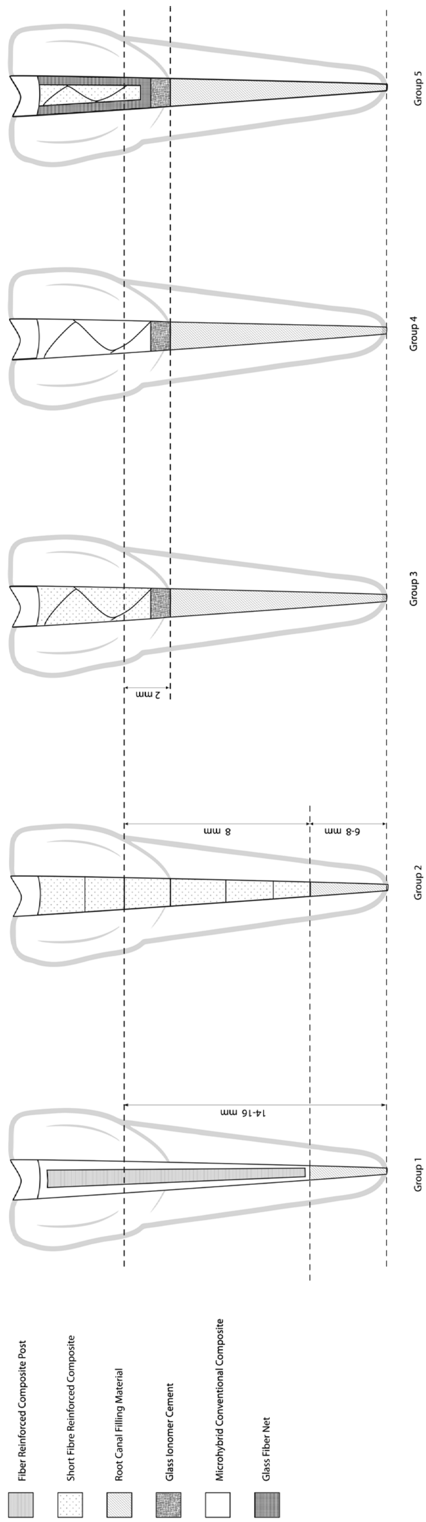

Figure 1. Restored study groups, layering concepts and restorative materials applied.

occlusal cavity in a concave shape. Each increment was light cured from the occlusal surface for 40 s. The outlines of the restoration were finished with dental composite (G-aenial Posterior P-JE, GC Europe, Leuven, Belgium).

Group 3

The cavities were restored with SFRC material applied in an oblique incremental technique. The material was placed in consecutive 2 mm thick increments. Each increment was light cured from the occlusal surface for 40 s. The last 1 mm thick occlusal layer was composite material (G-aenial Posterior PJ-E, GC Europe, Leuven, Belgium) covering the SFRC.

Group 4

The cavities were restored with microhybrid composite restorative material (G-aenial Posterior PJ-E, GC Europe, Leuven, Belgium) applied with an oblique incremental technique. The material was placed in consecutive 2 mm thick increments. Each increment was light cured from the occlusal surface for 40 s.

Group 5

The cavity walls were coated with flowable composite (G-aenial Flo, GC Europe, Leuven, Belgium) and before curing, a piece of preimpregnated glass fiber net (Everstick net, GC Europe, Leuven, Belgium) (10 mm long, 3 mm width) was cut and embedded inside the flowable composite first in buccal to lingual, then a mesial to distal direction. After curing for 40 s, another glass fiber band was adapted to the walls circumferentially, forming the FRC 'box'. The remaining central part of the cavity was restored with SFRC and a final layer of composite as described in Group 3.

Finally, for all specimens, glycerine gel (DeOx Gel, Ultradent Products Inc., Orange, CA, USA) was applied and final polymerization from each side for 40 s was performed. The restorations were finished with a fine granular diamond burr (FG 7406-018, Jet Diamonds, USA and FG 249-F012, Horico, Germany) and aluminum oxide polishers (OneGloss PS Midi, Shofu Dental GmbH, Ratingen, Germany).

After the restorative procedures, the specimens were stored in physiological saline solution (Isotonic Saline Solution 0.9% B. Braun, Melsungen, Germany) in an incubator (mco-18aic, Sanyo, Japan) for 1 week (at 37 °C, 100% humidity) before the fracture strength test. Prior to embedding, the root surface of each tooth was coated with a layer of liquid latex separating material (Ruber-Sep, Kerr, Orange, CA, USA) to simulate the periodontal ligament.[30] Specimens were embedded in methacrylate resin (Technovit 4004, Heraeus-Kulzer) at 2 mm from the CEJ to simulate the bone level. After embedding, all specimens were immediately subjected to a fracture resistance test using a universal loading device (5848 MicroTester1, Instron, Norwood, MA, USA). Each test was performed at a cross-head speed of 0.5 mm/min and load was applied at 45° using a 4.8 mm diameter stainless-steel ball-shaped stylus positioned to the central groove of the tooth providing two contacts with the triangular ridges and one with the more dominant marginal ridge. The maximum failure load was recorded in Newton's (N).

A force vs. extension curve was dynamically plotted for each tooth (Figure 2).

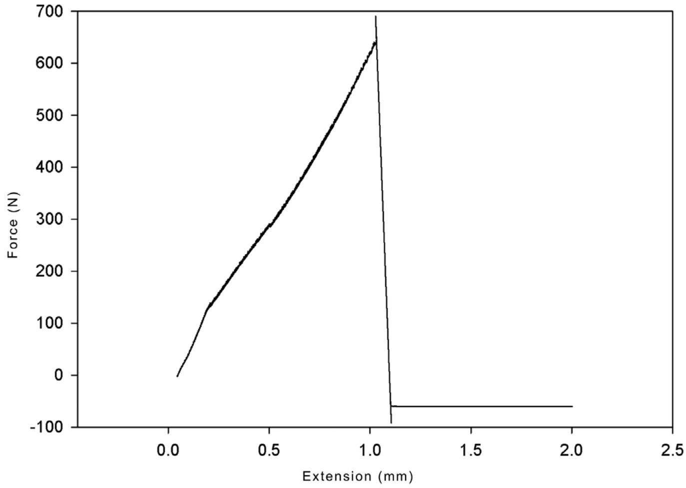

Figure 2. Representative force extension curve of fracture resistance tested on tooth sample for determination of maximum force of failure.

After mechanical testing, the specimens were examined for fracture patterns. According to Scotti and co-workers, distinction was made between restorable or nonrestorable fractures under optical microscope with a two-examiner agreement. A restorable fracture is above the CEJ, meaning that in case of fracture, the tooth can be restored, while a nonrestorable fracture extends below the CEJ and the tooth is likely to be extracted.[31]

Statistical analysis was conducted with SPSS 22.0 (IBM, USA). As the data were not normally distributed in all groups, the comparisons were performed with Kruskal–Wallis analysis of variance (ANOVA) with Dunn–Bonferroni *post hoc* pairwise comparisons. The level of significance was set at $p < 0.05$.

3. Results

Table 1 summarizes the fracture thresholds for the different study groups. The control group exhibited the highest fracture resistance. The application of the DLFRC post and core technique yielded the highest fracture resistance among the restored groups. The fracture resistance of Group 2 (DLFRC post and core group) did not differ significantly from the intact teeth (control group). The rest of the groups proved to be significantly different from the control group in terms of fracture resistance. There was no statistically significant difference when comparing the restored groups regarding their fracture resistance. Therefore, the null hypothesis regarding fracture resistance was rejected.

In terms of fracture patterns, the tested groups 2, 3, 4, 5 were identical (Table 2). Only the control group and the FRC post showed dominantly repairable fractures. Therefore, the null hypothesis regarding fracture patterns was also rejected.

4. Discussion

In this study, maxillary premolars were used as they present an unfavorable anatomy in crown volume and crown to root proportion, making them more susceptible to cusp

Table 1. Fracture thresholds of studied groups and the significance of their difference compared to the control group.

Group	Sig. compared to control (*p*, *post hoc*)	*N*	Minimum (*N*)	Maximum (*N*)	Mean (*N*)	SD
Control	–	12	605.85	1205.83	922.34	189.21
Group 1	0.005	12	208.28	802.61	501.30	186.65
Group 2	1.000	12	352.85	1171.19	727.98	287.37
Group 3	0.009	12	123.59	865.93	511.61	225.20
Group 4	0.005	12	216.67	748.44	456.24	189.75
Group 5	0.023	12	303.64	682.83	536.35	126.41

Notes: Group 1: glass fibre- reinforced post; Group 2: direct-layered glass fiber-reinforced composite core; Group 3: SFRC applied by an oblique incremental technique; Group 4: obliquely layered conventional composite and Group 5: torsion box with FRC net. As there was no significant difference among the restored groups in this respect, significances are shown as compared to the controls only.

Table 2. Fracture patterns.

	Control	Group 1	Group 2	Group 3	Group 4	Group 5
Reparable	0.66	0.58	0.33	0.33	0.33	0.33
Irreparable	0.33	0.42	0.66	0.66	0.66	0.66

Notes: The numbers indicate relative frequencies (n = 12 in each group). Group 1: glass fibre- reinforced post; Group 2: direct-layered glass fiber-reinforced composite core; Group 3: SFRC applied by an oblique incremental technique; Group 4: obliquely layered conventional composite and Group 5: torsion box with FRC net.

fractures than other posterior teeth when submitted to occlusal load application.[10] An oblique load (45° to the long axis of the tooth) was applied to the occlusal incline of the buccal cusp using a rounded loading tip, intended to simulate normal working side occlusal contacts.[3]

ETT demonstrate an increased risk of fracture, and therefore, an acceptable restoration, in addition to aesthetic considerations, should not only restore function, but should also aim to preserve and reinforce the remaining dental structures thus reducing the occurrence of catastrophic failures and increasing the longevity of the restoration.[32–35] However, there seems to be little evidence to guide the clinician toward the best restorative solution if only the access cavity needs restoring in a premolar tooth.[4,9]

According to several authors, posterior teeth with an endodontic access preparation and no other structural loss may succeed with a conservative bonded restoration.[8,36,37] In the present study, the specimen restored with composite restorations applied with the oblique layering technique (Group 4) showed the lowest fracture resistance values among the restored groups; however, this was not statistically significantly lower compared to the other restored groups. These findings are in accordance with some studies showing that restored root-filled maxillary premolars without a fiber post showed similar fracture resistance to those when an FRC post was placed.[38–40] This could be attributed to the minimal invasive access cavity preparation in this study, leading to still acceptable 'internal splinting' with adhesively bonded composite restorations. Also, the inconsistency in the findings of different FRC post-related studies may be attributed to the difference in postspace preparation procedures. Preparing the root canal to receive a post with pilot drills and removing radicular dentine on purpose, might lead to cracks and defects that can concentrate stress and increase the possibility of tooth fracture.[41] For this reason, a minimal invasive postspace preparation was performed in this investigation, leading to the preservation of the individual, irregular root canal anatomy and shape. Because of this the inserted, smaller rigid FRC post could not fill out the root canal entirely, possibly leading to greater amount of luting composite in the prepared space. This could account for the inferior findings in the present study regarding the post-restored group as Group 1 was not statistically superior to the other restored groups.

SFRC is a dental restorative composite resin [29,42,43] intended to be used in high stress bearing areas as a stress-breaker restorative material. Mechanical testing has shown major improvements in the load-bearing capacity, the flexural strength and also the fracture resistance of SFRC in comparison with conventional particulate filler composite resin.[44–48] In the current investigation, the group restored with obliquely layered SFRC (Group 3) reached higher fracture resistance figures compared to the ones restored with conventional composite (Group 4) or even the conventional FRC post group (Group 1); however, the difference was statistically not significant. This has been previously described in molar teeth with MOD cavities, where the SFRC-restored groups yielded better results than the conventional composite restored ones, yet the difference was not significant.[49]

While in the SFRC material the E-glass fibers are randomly oriented and possess isotropic features, leading to possible reinforcement in multiple directions, the E-glass fibers in the bidirectional pre-impregnated fiber-reinforced net (everStick Net) show orthotropic properties, therefore reinforcing the structure in two directions.[50,51] The threefold usage of FRC net (FRC box) together with the SFRC-restorative composite is aiming to reconstruct the integrity and strength of the opposing cavity walls. The values of the FRC box restorations showed an increase compared to Groups 1, 3 and 4, this technique could also not emulate the values measured in case of sound premolar teeth. However, in this study, there seems to be a clear tendency of increasing fracture resistance values toward the use of individualized FRC materials compared to conventional techniques (composite restoration or FRC postplacement). This observation is in accordance with the findings of Bijelic et al. [52]. The inferior, though not statistically different results of the FRC box group (Group 5) compared to the DLFRC post and core group (Group 2) can be explained by the coronal position of the FRC box, which can only keep the coronal part of the tooth together but does not reinforce the cervical and root part of the tooth.

Prefabricated FRC posts suffer from two main shortcomings in clinical settings: Insufficient bonding of the interfaces [53–55] and the fact that the post position is in the neutral axis of the root canal. Direct layering of SFRC into the root canal is intended to solve these drawbacks. Seyam et al. and other authors showed that a transparent post can transfer the light and aid the polymerization of composite resin in the root canal,[56–58] enabling layering in the hollow root canal space. However, there are investigations to oppose this statement [59,60]. The DLFRC post and core technique (Group 2) produced the highest fracture resistance values among the restored groups in the present study. These results seem to be in accordance with Garoushi et al. showing that the thicker the applied SFRC restoration the greater the fracture resistance is [61]. Although the numbers produced by Group 2 were not significantly higher than the rest of the restored groups, a positive tendency could be visible with the utilization of SFRC materials. Moreover, there was no statistically significant difference between the Group 2 and the intact teeth. This result suggests a move toward a biomimetic restorative concept. It has to be noted that the reported advantages come at the price of increased application time and technically more demanding clinical procedure as compared to Group 1. Development of materials, instruments and light curing equipment specifically for such purposes could be promising and could resolve the main shortcomings of the DLFRC post and core method as described in this investigation.

Regarding fracture pattern, the tested groups were identical with dominantly unfavorable, irreparable fractures. Only the control group and Group 1 presented a shift toward favorable, repairable fractures. Therefore, the null hypothesis regarding fracture pattern was rejected. The DLFRC post and core technique according to the findings of this investigation might hold the potential of reinforcing the root and particularly the pericervical area, which is highly beneficial when shear forces are also present (e.g. 45° loading). The DLFRC post and core concept theoretically could present a possibility to compensate for most of the known weaknesses of the presently accepted endo-restorative options with a not complicated, clinically feasible and reproducible methodology. Given these facts and the promising results in the current investigation, it is recommended to conduct further investigations particularly applying artificial ageing, cyclic loading until fracture, different cavity extensions and tooth groups *in vitro*.

The limitations of this investigation are the limited number of specimens, which makes it much more unlikely to exhibit statistical significance. It is also a limitation that maximal fracture resistance testing only indicates a certain physical property of the structure not giving information of the possibly clinically more relevant reaction to cyclic loading and ageing. Given the mentioned shortcomings the results and the novel method have to be implemented with caution. Therefore, the proposed techniques should require future testing in more clinically realistic situations. The proposed investigation could be deemed as a possible first, still critical step toward the development of clinically relevant future endo-restorative methods.

5. Conclusions

Within the limitations of this investigation, it can be concluded that natural teeth exhibit significantly higher fracture resistance then the endodontically treated and restored premolar teeth except for the DLFRC post and core restored group which did not show statistically significant difference compared to the control group. FRC posts exhibited more favorable fracture patterns then the other restored groups examined. The direct layered short fiber-reinforced post and core is a promising alternative to the accepted restorations of endodontically treated teeth, and as such should be further investigated.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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