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ORIGINAL ARTICLE

The effect of the post length and cusp coverage on the cycling and static load of endodontically treated maxillary premolars

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Abstract In endodontically treated teeth, cuspal coverage plays a fundamental role in reducing the risk of fracture. However, the adhesive techniques with or without fiber post increased the possibilities in restoring root-filled teeth. The aim of this study was to determine the effect of the fiber post and/or post length and/or cuspal coverage on the fracture resistance of endodontically treated maxillary premolars. Seventy intact single-rooted maxillary premolars were selected and divided in seven groups of ten each: "intact teeth" (control), "inlay without fiber post" (G1), "inlay with long fiber post" (G2), "inlay with short fiber post" (G3), "onlay without fiber post" (G4), "onlay with long fiber post" (G5), and "onlay with short fiber post" (G6). Except for intact teeth, all specimens were prepared with a mesio–occluso–distal (MOD) cavity, endodontically treated and restored with or without long or short post, with or without cusp coverage. All specimens were thermal-cycled, exposed to a cyclic loading, and then submitted to the static fracture resistance test. Fracture loads and mode of failure were evaluated. A statistically significant difference in fracture resistance was found between group 1 and the other groups ($p<0.001$). $\chi 2$ test showed statistically significant differences in the patterns of fractures between the groups ($p<0.001$). The highest number of favorable fractures was observed in groups 3 and 4. Similar fracture resistance was detected in maxillary premolars endodontically treated with MOD cavity preparations, restored with either direct resin composite with fiber post or cusp capping. The "short post" direct restoration may be a valid alternative in the restoration of root-filled premolars.

Keywords Post length · Cusp coverage · Premolars · Endodontically · Nanohybrid composite

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Introduction

Endodontically treated teeth with extensive loss of coronal structure may have a considerably reduced capacity to resist functional forces, and this may be a primary concern. The most significant changes in the biomechanics of endodontically treated teeth are attributed to the loss of tissue either at radicular [1, 2] or coronal level [2, 3]. These factors point out the importance of highly conservative endodontic and restorative procedures. Traditionally, custom cast and cores covered by metal or porcelain fused to metal crowns were considered the standard restoration approaches. The introduction of adhesive techniques and the use of fiber-reinforced resin-based composite posts, used with composite resin build-up, have facilitated the preservation of maximum sound tooth structure. Moreover, post and core should have the same elastic modulus as root dentin in order to distribute forces along the long axis of the post [4].

To date, only few prospective clinical studies comparing the outcome of different types of direct or indirect adhesive restorations of endodontically treated teeth are available. An in vivo study [5] found fiber posts and direct composite restorations to be more effective than amalgam in preventing root fractures, but not secondary caries, of root-filled premolars. Another prospective in vivo study [6] showed similar survival rates between endodontically treated premolars restored with fiber posts plus direct composite restoration and full coverage with metal ceramic crowns over a 3-year period. Resin composites have the ability to bond with the tooth structure, increasing the fracture resistance of posterior endodontically treated teeth. Therefore, they may be considered a valid potential alternative restorative technique [7–9]. Direct composite restoration techniques present several limitations, such as polymerization shrinkage stress [10], difficulty in obtaining proximal contacts [11], limited anatomic reproduction [12], and finishing and polishing issues [13]. To overcome such problems, indirect adhesive restorative techniques may be considered [14, 15] even if recent low-shrinking composite materials could reduce cavity wall deflection representing a new option in direct restoration of severally destroyed teeth [16]. Moreover, contraction stress on adhesive interfaces could be reduced by soft-start curing protocols [17, 18] and composite-layering techniques [19].

Most published studies on restoration techniques for non-vital premolars with class II (MOD exclusively) defects report on various minimally invasive coronal direct approaches without the use of posts [20–24]. The role of the fiber post in providing reinforcement has been demonstrated even in the presence of sufficient residual coronal dentin [25, 26]. Indeed, within the radicular dentin, the post serves as distributor of stress applied to the core and prosthetic crown. However, this technique has some limitations: the post-space preparation tends to weaken the radicular structure, since a certain amount of dentin tissue needs to be removed in order to place the post [3]. Moreover, several studies also reported a poor bond strength in the deeper areas of the post space [27]. The conservative approach and the preservation of sound tooth structure contribute to increase the survival rate of endodontically treated teeth to a great extent. This is also due to the fact that the cavity preparation for indirect restorations requires the removal of more sound tooth structure if compared with direct restorations [28].

Today, controversy still exists on whether fiber posts and/or cusp coverage are more effective than cusp capping alone in restoring root premolars. The aim of this in vitro study is to evaluate the effect of post placement, post length, and cusp capping on fracture resistance of these teeth. The null hypothesis was that there was no significant difference among experimental groups restored with either short or long posts, with or without cusp capping.

Materials and methods

Seventy noncarious recently extracted single-rooted maxillary premolars with mature apices, extracted for orthodontic reasons, were selected. The inclusion criteria were nearly similar crown and root sizes, and no cracks under transillumination. A hand scaling instrument was used for surface debridement of the teeth, followed by cleaning with a rubber cup and slurry of pumice. Endodontic treatment was carried out in all samples except for the control group (intact teeth). Samples were endodontically instrumented using Pathfiles (1–2–3) and ProTaper (S1–S2–F1–F2–F3; Dentsply Maillefer, Ballaigues, Switzerland) to the working length, enlarging the apex to size 30, 0.09 taper. The working length was established under 10× magnification (ProErgo, Carl Zeiss, Hoberkocken, Germany) when the tip of the file became visible at the apical foramen. Irrigation was with 5% NaOCl (Niclor 5, Ogna, Muggiò, Italy) alternated with 10% EDTA (Tubuliclean, Ogna, Muggiò, Italy) using a 2-ml syringe and 25-gauge needle. Specimens were obturated with gutta-percha (Gutta Percha Points Medium, Inline, Turin, Italy) using the DownPack heat source (Hu-Friedy, Chicago, IL, USA) and endodontic sealer (Pulp Canal Sealer EWT, Kerr, Orange, CA, USA). Backfilling was performed with the Obtura II system (Analytic Technologies, Redmond, WA, USA).

After 24 h, samples were randomly divided into seven groups (n=10, Table 1). Class II mesio–occluso–distal (MOD) cavities were prepared with the gingival cavosurface margin located 1 mm coronal to the cement–enamel junction (CEJ). The buccolingual dimension of mesial and distal boxes was 4 mm. Thus, residual thickness of buccal and lingual cusps at height of contour was 2±0.2 mm. In the groups with cusp capping, both buccal and lingual cusps were reduced up to 2 mm and the cavosurface angle in all the walls was>90°.

Group 1: samples were treated with All Bond 2 (Bisco, Schaumburg, IL, USA). Enamel margins were etched with 32% orthophosphoric acid (Bisco, Schaumburg, IL, USA) for 40 s, while dentin was etched for 20 s. Samples were then washed with a water syringe and then gently air-dried with an air syringe, preventing the dentin from dehydrating. Three drops of primers A and B was mixed and three coats of primer and adhesive material were applied into the cavity with a small brush. Excess primer adhesive solution was gently removed with a gentle stream of air and then a layer of pre-bonding resin was applied and gently air-dried. After fixation of matrix band with a retainer, A2-shaded nanohybrid resin composite (Venus Diamond, Heraeus Kultzer,

Table 1 Fracture resistances of the groups expressed in Newton and failure modes of samples

Group	*N*	Characteristics	Mean+SD	Minimum	Maximum	Non-restorable failures (*n*)	Restorable failures (*n*)
Control	10	Intact teeth	998.64+287.86	371	1,322	2	8
1	10	Post (−), cusp capping (−)	359.29+137.50	220	611	9	1
2	10	Post (−), cusp capping (+)	763.25+187.87	549	892	9	1
3	10	Long post (+), cusp capping (−)	806.94+160.30	585	1,036	5	5
4	10	Short post (+), cusp capping (−)	617.87+192.29	273	960	4	6
5	10	Long post (+), cusp capping (+)	819.45+97.78	602	1,262	10	0
6	10	Short post (+), cusp capping (+)	804.47+214.82	675	974	9	1

SD standard deviation, (+) the corresponding procedure was performed, (−) the corresponding procedure was not performed

Hanau, Germany) was placed by using an oblique layering technique. Each layer, 1.5–2 mm thick, was light-cured for 20 s with a light-emitting diode (LED) curing lamp at 1,200 mW/cm^2 (Translux Power Blue, Heraeus Kultzer, Hanau, Germany). After removal of matrix band and retainer, post-curing was carried out on buccal and lingual aspects of the boxes for 40 s on each side.

Group 2: samples were treated as described in group 1. In this group, the reduced cusps were covered by 2-mm thicknesses of composite resin on each cusp.

Group 3: the dowel space was prepared to a depth of 7 mm measured from the pulpal chamber floor (“long post”) by using the drills from the respective post manufacturer (Dentsply Maillefer, Ballaigues, Switzerland). For the fiber post cementation, samples were treated with All Bond 2 (Bisco, Schaumburg, IL, USA). The root canal walls were etched with 32% orthophosphoric acid (Bisco, Schaumburg, IL, USA) for 30 s, washed with a water syringe with an endodontic needle and then gently air-dried with an air syringe. Excess water was removed from the post space by using paper points, preventing the dentin from dehydrating. Three drops of primers A and B was mixed and 3 coats of primer and adhesive material were applied into the root canals with a small brush. Excess primer adhesive solution was gently removed with a gentle stream of air and then a layer of pre-bonding resin was applied, gently air-dried and excess removed with a paper point. For post cementation, a dual curing cement (NanoCore Dual, Dentalica, Milano, Italy) was used. It was applied into the canal by using tube with needle and the appropriate plug (KerrHawe SA, Bioggio, Switzerland) and by injecting the materials into the post spaces with a specific Composite Gun (KerrHawe SA, Bioggio, Switzerland). Fiber Post ISO 100 (Dentsply Maillefer, Ballaigues, Switzerland) were cemented to full depth in the prepared post spaces. The surface of the fiber post was cleaned with 96% ethanol. After initial set, photopolymerization was effected with a LED curing light for 40 s (Translux, Haereus Kultzer, Hanau, Germany) at 1,200 mW/cm^2. The cavity restoration was performed as described in group 1.

Group 4: the dowel space was prepared to a depth of 3 mm measured from the pulpar chamber floor (“short post”) by using the drills from the respective post manufacturer (Dentsply Maillefer, Ballaigues, Switzerland). Post cementation was performed as described in group 3; cavity restoration was performed as described in group 1.

Group 5: dowel space preparation and fiber post cementation were performed as described in group 3; cavity restoration was performed as described in group 2.

Group 6: dowel space preparation and fiber post cementation were performed as described in group 4; cavity restoration was performed as described in group 2.

All the restored specimens were finished, polished, and then stored in distilled water at 37°C for 7 days. All specimens were subjected to 3,000 thermal cycles between 5°C and 55°C for 60 s each. All specimens were embedded in light-curing acrylic resin with thin layer of polyvinilsiloxane around the root to simulate the periodontal ligament. Specimens were then exposed to a cyclic loading for 20,000 cycles (Mini Bionics II; MTS Systems, Eden Prairie, MN, USA), with an inclination angle 30° to the long axis of the tooth, at a frequency of 8 Hz, starting with a load of 20 N for 5,000 (preconditionong phase of the experiment), followed by stage of 50 N at a maximum of 20,000 cycles. A 10-mm diameter steatite ceramic ball was used. The site of loading was the central fissure of the occlusal surface in the direction of the buccal cusp. The specimens were then submitted to the static fracture resistance test using a universal testing machine (Instron, Canton, MA, USA) with a 2-mm diameter steel sphere crosshead welded to a tapered shaft and applied to the specimens at a constant speed of 2 mm/min and at an angle of 30° to the long axis of the tooth. Fractured specimens were assessed for failure modes: “restorable failures” including adhesive failures above the CEJ, and “non-restorable failures” including vertical root fractures below the CEJ.

Data were expressed as mean±standard deviation (SD) and frequency (%). The Kolmogorov–Smirnov statistical test for normality revealed a normal data distribution. The statistical analysis was conducted with a model of one-way analysis of variance test (ANOVA) and a post-hoc Dunnet test for multiple comparisons. $\chi 2$ test was used to compare the failure modes of the specimens. Differences were considered statistically significant when $p<0.05$. All statistical analyses were performed by using the SPSS12.0 Windows software (SPSS, Chicago, IL, USA)

Results

The mean values of fracture resistance of all the groups are listed in Table 1. ANOVA test for repeated measures showed the presence of statistically significant difference between groups ($f=9.11$; $p<0.001$). The post-hoc multiple-comparison analysis showed a statistically significant difference between group 1 [post (−), cusp capping (−)] and the other groups.

The evaluation of mode of failure of all the groups is reported in Table 1. The $\chi 2$ test showed statistically significant differences in the patterns of fractures between the groups ($\chi 2=27.311$; d$f=4$; $p<0.001$). The highest number of restorable fracture (80%) was observed in group 1. Similar modes of failure were detected in group 3 and group 4, while in other groups, most of the fractures were non-restorable.

Discussion

The results of this in vitro study lend support to the null hypothesis, since post length and cusp coverage did not significantly differ in affecting fracture resistance of endodontically treated premolars.

The present study was conducted on maxillary premolars because these teeth have an anatomic shape which facilitates the fracture of cusps under occlusal loads [29]; this was also confirmed by previous studies where a higher incidence of cusp fracture in the oral cavity was found in the upper premolars [30, 31]. Moreover, several other studies on tooth fracture resistance used premolars to facilitate the comparison of results [32].

The coronal destruction from dental caries, the presence fractures, previous restorations, and the endodontic techniques used may contribute to increase the risk of fracture in endodontically treated teeth [33]. The loss of anatomic portion of the tooth crown, such as pulp chamber roof or marginal crest, decreases fracture resistance. According to another study [3], endodontic procedures have only a small effect on the tooth: they cause a reduction of only 5% in the relative rigidity due to the endodontic access opening. Restorative procedures and, particularly, the loss of marginal ridge integrity, contribute to a great extent to negatively affect the tooth rigidity. In addition, the loss of water content in the dentin after endodontic therapy may reduce tooth resilience, consequently increasing the susceptibility to fracture [25, 26]. The clinical survival of endodontically treated teeth depends on the remaining tooth structure, the technique used, the interaction between material, teeth and oral cavity, and the restorative material [34]. In this study, a low-shrinking resin composite was used. This composite can reduce the stresses generated along the adhesive interface during polymerization and affects resistance and failure mode of the samples [10].

This study adopted thermal cycling as an in vitro aging process that simulates the thermal stresses that normally occur intraorally. There are two hypotheses on the way this process may work and its possible effects: hot water may accelerate hydrolysis of interfacial composite resin components, and the coefficient of thermal expansion mismatch will definitely generate stresses upon temperature changes at adhesive interfaces, thus, decreasing fracture resistance.

Intraorally, teeth are subjected to cyclic loading through mastication; in order to simulate this clinical situation, cycling fatigue test was conducted before static loading [35, 36]. Load cycling has been established as an essential research tool for testing adhesive restorations because the cyclic loading pattern is comparable to actual physiological function.

The current study found that fracture resistance was significantly decreased in maxillary premolars endodontically treated with direct restorations, but with no fiber post. Fiber post insertion within the direct restoration reinforced the weakened remaining coronal structures, probably because of the larger distribution of loads along the adhesive interface [37]. Posts with a modulus of elasticity similar to dentin, when submitted to a compressive load, can better absorb the forces concentrated along the root which may decrease the probability of fracture [38]. On the other hand, different studies showed that root-filled maxillary premolars without fiber posts showed similar fracture resistance to those with a post. This may be attributed to the fact that more tooth structure is removed during post placement and that an additional adhesive interface could participate in the propagation of microcracks, thus leading to a reduced fracture resistance [39–42]. A study conducted by Soares et al. [43] concluded that the use of glass fiber posts did not reinforce the tooth restoration complex. When major dental structure was lost, posts did not restore the lost fracture resistance, and, in case of moderate structure loss, the use of posts actually reduced fracture resistance. These inconsistencies may be attributed to the type of crown restorative material, the type of teeth, and the direction of the load applied, which are different in these studies.

In our study, the "short post" restorations without cusp capping demonstrated a similar fracture resistance to "long post" restorations. These results are in accordance with a recent study [44] which concluded that the fracture load was not influenced by the post length. On the contrary, another paper [45] argued that roots restored with 10-mm post and core had a greater resistance to fracture than 8-mm and 6-mm post and core restorations. These conclusions could be explained by the differences among the specimens tested: the current study used maxillary premolars with MOD cavity loaded at an angle of 30° in relation to the long axis of the roots; on the contrary, Giovani et al. [45] tested maxillary canines after removing the clinical crowns and restoring with post and core system, and specimens were loaded at an angle of 135° in relation to the long axis of the root.

The literature well documented that coronal coverage significantly reduced the risk of tooth fracture in teeth subjected to root canal treatment [46–48]. Some authors also concluded that endodontically treated teeth recovered the lost resistance to fracture after receiving an indirect metallic restoration with cusp protection. Similar results were found with cusp coverage with amalgam [29] which significantly increased the fracture resistance of the teeth as compared to teeth restored without cusp coverage. These findings are confirmed in the current study where the coverage of the cusps with composite led to higher fracture resistance in MOD preparation of root-filled maxillary premolars. A previous finite element analysis study [49] showed that stress value in the restorative material and remaining tooth structure was mainly influenced by the restorative material used and the cavity design. When cuspal-coverage treatment is considered, the cuspal height should be reduced to at least 1.5 mm to significantly decrease the stress value [50]. The use of restorative material with low modulus of elasticity, such as resin composites, had more favorable biomechanical performance for restorations involving cuspal replacement because of the lower transmission of the load to the underlying tooth structure [51].

Our study also showed that the fracture load of cuspal-covered teeth was not statistically significant if compared to that seen in premolars restored with fiber post inlay restoration. Considering the splinting of cusps by composite restoration, our results suggest the possibility of decreasing cuspal fracture caused by cuspal deflection even without cusp coverage. A recent in vitro study [52] confirmed these findings, showing that root-filled maxillary premolars, restored with direct resin composite with or without fiber post and cusp capping, had similar fracture resistance under static loading. These results lend further support to the observations of Mannocci et al. [6]. They reported that the clinical success rates of endodontically treated premolars with limited tooth structure loss, restored with fiber posts and direct composite restorations without cuspal overlay, were equivalent to a similar treatment of full coverage with metal ceramic crowns after 3 years of clinical service. In contrast to our results, recent findings [43] showed that reduction of cusps and coverage by composite resin decreased fracture resistances in mandibular premolars. However, it should be noticed that the amount of reduction in that study was greater than in our study. Another recent paper [42] verified that ceramic MOD inlay restorations of posted teeth had a lower fracture resistance compared to partial ceramic onlays of posted teeth. These findings contrast with our results probably because of the different material employed for the post-endodontic restoration.

In the present study, the insertion of a "short" or "long" fiber post under an onlay composite restoration did not enhance the fracture resistance of endodontically treated maxillary premolars. This indicates that, despite reducing both the vestibular and palatal cusps during the cavity preparation, the stress is still sufficiently well distributed along the adhesive interface. An increase in the adhesive area did not affect the fracture resistance.

Regarding failure mode, the combination of the fiber post with an inlay adhesive restoration led to a higher incidence of more favorable failure types ($p<0.001$). In groups 3 and 4, the post insertion might create a higher incidence of more favorable and re-restorable failure modes. This is consistent with the results of other studies [24, 43, 53]. It might be speculated that the higher percentage of favorable fractures found in the current study is probably due to the use of resin composite; indeed, a low-shrinkage composite could reduce both cavity wall deflection and stress on adhesive interface. Interestingly, some authors have also suggested that the deflection of the remaining walls increases the tooth resistance [54]; a reduced stress on the adhesive interface could justify an increase in restorable failures modes [52].

Conclusion

Within the limits of this laboratory investigation, endodontically treated maxillary premolars with MOD cavity preparations restored with direct resin composite with fiber post or cusp capping demonstrate similar fracture resistance. The "short post" direct restoration represents a valid alternative in the restoration of root-filled premolars because of its less invasive approach and its increased fracture resistance if compared to direct MOD inlay restorations. However, the fracture resistance of fiber-posted premolars was proportional to fiber post length. Further long-term clinical studies are needed to confirm these findings.

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Conflict of interest The authors declare that they have no conflict of interest.

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