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Influence of adhesive techniques on fracture resistance of endodontically treated premolars with various residual wall thicknesses

ABSTRACT

Statement of the problem. The choice of restorative method is commonly based on the cavity configuration and the residual number of cavity walls. However, the residual wall thickness could be a valuable clinical parameter in the choice of restoration for endodontically treated teeth.

Purpose. The fracture resistance of endodontically treated premolars was compared with different wall thicknesses restored with direct composite resin with and without cuspal coverage and with and without fiber post insertion.

Material and methods. This study included 104 intact human maxillary premolars extracted for periodontal or orthodontic reasons. Standardized MOD cavities were prepared with different palatal wall thicknesses (1.5, 2, and 2.5 mm) and a buccal wall thickness of 2 mm. Teeth were restored with or without a fiber post and with or without cuspal coverage. Specimens were subjected to thermocycling (3000 cycles, 5 to 55°C) and embedded in polymerized acrylic resin. Teeth were submitted to cyclic fatigue followed by a static fatigue test with an Instron machine; a compressive force was applied 30 degrees to the long axis of the teeth until fracture. The results were statistically analyzed by ANOVA (α=.05).

Results. Residual wall thickness (P=.004), the type of adhesive restoration (P<.001), and fiber post insertion (P<.001) significantly influenced the fracture resistance of endodontically treated premolars.

Conclusion. In specimens with a cavity wall thickness >2 mm, direct intracuspal composite resin restorations supported by a fiber post achieved comparable fracture resistance. With a residual wall thickness <2 mm, only cuspal coverage with or without a fiber post provided satisfactory fracture resistance.

Clinical implications. Within the limits of this study, the remaining wall thickness could be an important clinical parameter in deciding how to restore endodontically treated premolar teeth. Cuspal coverage composite resin restorations should provide improved fracture resistance in maxillary premolars, especially when the residual wall thickness is <2 mm.

INTRODUCTION

Preventing the fracture of endodontically treated teeth is essential in clinical practice. Indeed, the loss of tissue either at the radicular or coronal level leads to significant changes in the biomechanics,[1–4] leading to a high incidence of fractures in endodontically treated teeth[1]. Therefore, conservative endodontic and restorative procedures are important. Posts are necessary as foundations for prosthetic crowns in patients with substantial hard tissue loss. Of the various post systems available, metal or fiber posts are commonly recommended for clinical use.[5] The introduction of adhesive techniques and the use of fiber-reinforced posts in conjunction with composite resin foundation restorations have facilitated the preservation of tooth structure.[6] Moreover, if the post and core has the same elastic modulus as root dentin forces will be

distributed along the long axis of the post, improving the fracture resistance of endodontically treated teeth in vitro.[7–9] The function of a fiber post is to improve the retention of the definitive restoration and to distribute occlusal stressors along the remaining tooth structure. Posts do not strengthen endodontically treated teeth,[10,11] especially anterior teeth,[12] although some studies have suggested that cast metal posts result in reduced stresses in the dentin.[13]

However, endodontically treated teeth restored with direct techniques, with or without posts, may sometimes present residual compromised cusps that could eventually fracture. In these patients, reduction and coverage with a complete crown is usually indicated to prevent coronal fracture.[14,15] However, the concept of minimal intervention dentistry to maximize preservation of the tooth structure is gaining popularity in the restoration of endodontically treated teeth.[13] Tooth structure preservation is directly correlated with fracture resistance,[16,17] reducing the occurrence of catastrophic failures and enhancing the longevity of the restoration. In vivo and in vitro studies support the use of direct intracuspal adhesive techniques for the restoration of endodontically treated teeth if a normal occlusion without parafunction is present.[18,19] This approach has the advantage reinforces teeth without occlusal coverage.[20–22] To date, few prospective clinical studies have evaluated the different types of direct or indirect adhesive restorations of endodontically treated teeth. Mannocci et al[23] found fiber posts and direct composite resin restorations to be more effective than amalgam in preventing root fractures, but not secondary caries, of endodontically treated premolars. Another prospective in vivo study[24] showed similar 3-year survival rates between endodontically treated premolars restored with fiber posts and direct composite resin restorations and complete coverage with metal ceramic crowns.

The thickness of the residual cavity wall could be a simple but effective parameter for clinically evaluating the remaining tooth structure, and consequently, for the selection of the most appropriate type of restoration for endodontically treated teeth. However, this parameter has not been investigated extensively. The choice of restorative method is commonly based on the cavity configuration and the residual number of cavity walls.[25,26] However, because the residual cavity wall thickness represents the quantity of remaining enamel and dentin and is directly correlated with the residual sound tissue,[27] wall thickness evaluation could provide more information to the clinician regarding the fatigue resistance of an endodontically treated tooth. Therefore, the aim of this in vitro study was to evaluate the effect of cavity wall thickness on the fracture resistance of endodontically treated teeth restored with a variety of adhesive techniques. The null hypothesis tested was that residual wall thickness does not influence the fracture resistance or fracture mode of endodontically treated premolars restored with or without fiber posts and with or without cusp coverage.

MATERIAL AND METHODS

This study included 104 noncarious single-rooted maxillary premolars with mature apices recently extracted for orthodontic or periodontal reasons. The inclusion criteria were an absence of restorations, similar crown and root sizes, and no cracks under transillumination. Selected teeth were stored in 0.5% chloramine T trihydrate at 4°C. After cleaning the tooth surfaces, endodontic treatment was performed on all specimens, except those in the control group (intact teeth; n=8). Specimens were endodontically instrumented with Pathfiles (1-2-3) and ProTaper (S1-S2-F1-F2-F3) (Dentsply Maillefer, Ballaigues, Switzerland) to the working length, enlarging

the apex to a size 30, 0.09 taper. The specimens were irrigated with 5% NaOCl alternated with 10% ethylenediaminetetraacetic acid (EDTA) with a 2-mL syringe and 25-gauge needle. Specimens were obturated with gutta percha by using the DownPack heat source (Hu-Friedy, Chicago, Ill) and an endodontic sealer (Pulp Canal Sealer EWT; Kerr, Orange, Calif). Backfilling was performed with the Obtura III system (Analytic Technologies, Redmond, Wash).

After 24 hours, all specimens were randomly assigned to 3 groups (W1,5; W2; W2,5; 32 teeth each) based on the thickness of the residual palatal wall (1.5, 2, and 2.5 mm) after cavity preparation, measured with a caliber at the occlusal floor of the cavity. The specimens were treated as reported by Scotti et al[22] In each tooth, a Class II mesio-occluso-distal (MOD) cavity was prepared. In order to compensate for different coronal anatomy, all teeth were prepared by hand by 1 experienced operator. The preparation was extended until the gingival cavosurface margin was 1-mm coronal to the cement-enamel junction (CEJ). The residual thickness of the buccal cusps at the height of the contour was 2±0.2 mm. Within each group, the specimens were further randomly assigned to 4 subgroups (eight 8 teeth each), based on the restoration type (Table I). In the groups with cusp coverage (overlay), both cusps were reduced with a completely flat enamel margin of up to 2 mm.

In the fiber post groups, the dowel space was prepared with drills from the post manufacturer (Dentsply Maillefer, Ballaigues, Switzerland) to a depth of 7 mm, measured from the pulpal chamber floor . All adhesive procedures were performed with All-Bond 3 (Bisco, Schaumburg, Ill) according to the manufacturer's instructions. For fiber post cementation, a dual- curing cement (NanoCore Dual, Dentalica, Milano, Italy) was used. Dual curing cement was applied into the canal by using a tube with a 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). Size 1 RTD Fiber Posts (RTD, Saint Egreve, France) were cemented to the full depth in the prepared post spaces. After initial preparation, photopolymerization was performed with an LED curing light for 40 s (Translux, Haereus, Hanau, Germany) at 1200 mW/cm^2.

After fixing the matrix band with a retainer, A2-shaded nanohybrid composite (Venus Diamond, Heraeus Kultzer, Hanau, Germany) was placed by using an oblique layering technique. Each layer, 1.5 to 2 mm thick, was polymerized for 20 seconds with an LED-curing lamp at 1200 mW/cm^2 (Translux Power Blue, Heraeus Kultzer, Hanau, Germany). The matrix band and retainer were then removed, and postpolymerization was performed on the buccal and lingual aspects of the boxes for 40 seconds on each side. All the restored specimens were finished, polished, and then stored in distilled water at 37°C for 7 days. All specimens were subjected to 3000 thermal cycles between 5 and 55°C for 60 seconds each. All specimens were embedded in light-curing acrylic resin to 1 mm below the CEJ, with a thin layer of polyvinyl siloxane (Aquasil, Dentsply Italia, Rome, Italy) around the root to simulate the periodontal ligament. Specimens were then exposed to cyclic loading (Mini Bionics II; MTS Systems, Eden Prairie, Minn) with an inclination angle of 30 degrees to the long axis of the tooth and at a frequency of 8 Hz, starting with a load of 20 N for 5000 cycles, followed by a stage of 50 N for 20 000 cycles. A 10-mm-diameter metallic ball was used. The site of loading was the central fissure of the occlusal surface of the restoration in the direction of the buccal cusp. The specimens were then submitted to the static fracture resistance test by using a universal testing machine (Instron, Canton, Mass) 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

degrees to the long axis of the tooth. The forces necessary to fracture each tooth were measured in Newtons (N).

Restorable and nonrestorable fractures were distinguished by using an optical stereomicroscope with agreement by 2 examiners. Restorable failures included fractures above the cement-enamel junction, meaning that the tooth could be restored even in individuals with major coronal tissue loss. Nonrestorable failures included fracture patterns that extended below the cement-enamel junction, in which a surgical approach would be required to perform an adhesive restoration.

A statistical analysis of variance (3-way ANOVA, including 2-way and 3-way interactions, $p<.05$) was performed to evaluate the influence of the residual wall thickness (factor T at levels 1.5, 2 and 2.5 mm), the restoration (factor R at inlay and onlay levels), and the fiber post (factor P at 2 levels) on the fracture resistance of the tooth. An χ^2 test was used to compare the failure modes of the specimens. Differences were considered statistically significant at values of $P<.05$.

RESULTS

The mean fracture resistance values and the modes of failure observed in the groups are listed in Table I. The normal probability plot showed that the residuals followed a normal distribution. None of the tested restorations showed similar fracture resistance values to the control group, even those with residual walls of 2.5 mm. Within the restored specimens, ANOVA (Table II) showed that the thickness of the residual wall ($P=.004$), the type of adhesive restoration ($P<.001$) and the fiber post insertion ($P<.001$) significantly influenced the fracture resistance of endodontically treated premolars with a 1% significance level.

The first-order interaction plot (Fig. 1), which graphically represents the interaction between the factors (thickness, restoration, and fiber post), showed that only the interaction between the restoration and the fiber post insertion significantly influenced the fracture resistance ($P<.001$; large nonparallelism between solid and dashed lines).

The interval plot (Fig. 2) showed that the type of adhesive restoration was the most significant factor in providing fracture resistance to endodontically treated premolars. Regardless of wall thickness and post placement, teeth with cusp cupping (factor restoration at level "onlay") showed the greatest fracture resistance.

The χ^2 test showed statistically significant differences in the patterns of fractures between the subgroups ($\chi^2 = 18.133$; $P<.001$). The highest numbers of restorable fractures were in the subgroups that received fiber post insertion with inlay direct restoration, regardless of the residual wall thickness. Similar modes of failure were detected in subgroups B and D, in which specimens were restored without a fiber post.

DISCUSSION

The present study evaluated the influence of wall thickness on the fracture resistance in endodontically treated maxillary premolars with fiber-post insertion and cuspal coverage. The results of this in vitro study led to partial rejection of the null hypothesis because the residual wall thickness significantly affected the fracture resistance, but not the failure mode, of endodontically treated premolars.

The restoration of endodontically treated teeth remains a major concern in dentistry. Endodontic therapy is primarily performed on teeth with crowns previously damaged by caries, restorative failure, or fracture. Moreover, decay and trauma often induce extensive loss of tooth

structure, which may lead to reduced fracture resistance.[1] The clinical survival of these teeth depends on several parameters, such as dental type, occlusal load and lateral excursive contacts, restorative material used, and remaining tooth structure.[1, 28] The thickness of the residual cavity wall is a simple but effective parameter for clinical evaluation of the remaining tooth structure, and consequently, selection of the most appropriate type of restoration for the endodontically-treated tooth. However, this parameter has not been investigated extensively.

Intraorally, teeth are subjected to cyclic loading through mastication, and dental restorations most commonly fail due to fatigue.[29] Therefore, to simulate this clinical situation in this study, a cycling fatigue test was conducted before static load with parameters similar to those described previously.[30] Load cycling is essential to test adhesive restorations, since the cyclic loading pattern is comparable to the actual physiological function of mastication. However, the experimental methods used for in vitro analyses do not accurately reflect intraoral conditions. Intraorally, teeth are subjected to cyclic loading through mastication and are immersed in a wet environment that is subject to chemical and thermal changes. Moreover, a number of factors may affect the resistance to fracture, such as differences between specimens, tooth embedment methods, type and direction of load application, crosshead speed, and simulation of thermally or mechanically induced fatigue.

The results indicated that the fracture resistance of endodontically treated maxillary premolars was significantly influenced by the residual wall thickness. This parameter is directly correlated with the residual sound tissue: the more residual sound tissue, the higher the tooth resistance. Therefore, minimal intervention dentistry aiming to maximize preservation of tooth tissue is fundamental. The first-order interactions (Figure 1) evidenced a slight difference between the 1.5- and 2-mm groups, but not between the 2- and 2.5-mm groups, probably due to a

greater amount of dentine under the enamel. The presence of dentine within the composite and enamel improves the stress distribution because of the similar elastic modulus of dentine and composite materials.[22]

In the present study, the type of restoration had a marked influence on fracture resistance, independently of the residual wall thickness. Similar results were also achieved in recent studies on premolars restored with direct cusp coverage restorations.[21,31]

The fiber post also improved fracture resistance in the presence of sufficient residual coronal dentine.[32] The post distributes stress and loads applied to the core and prosthetic crown within the radicular dentine.[33] In this study, fiber-post insertion significantly increased the fracture resistance of direct intracuspal restorations independently of the wall thickness. Direct restorations with a fiber post commonly reinforced the weakened remaining coronal structures and the tooth, probably due to better distribution of functional stresses along the adhesive interface.[34] In contrast, some studies have shown that root-filled maxillary premolars without fiber posts had a similar fracture resistance to those with a post.[35-37] This may be attributed to the fact that a greater portion of tooth structure is removed during post placement. Soares et al[3] found that the use of glass fiber posts did not reinforce the tooth restoration complex when major dental structure was lost, and, in cases of moderate structure loss, the use of posts actually reduced fracture resistance.

The contrasting results reported in this study may depend on the different types of crown restorative material, the type of teeth, and the directions of the load applied. This study found that at a remaining wall thickness of endodontically treated teeth of at least 2 mm, the fiber post direct restoration yielded a fracture resistance similar to that of cuspal coverage restoration.[22] Thus, teeth with a wall thickness of 1.5 mm require a cusp coverage restoration to significantly

increase fracture resistance. The results of this study suggest that cusp coverage represents an important and effective method for the prevention of fracturing of endodontically treated premolars. These results agree with other reports that restored teeth had a significantly lower resistance to fracture.[38,39]

In the current study, onlay restorations had a mean decrease in fracture resistance of 35% compared to intact teeth, regardless of the remaining wall thickness. It is well-documented that coronal coverage significantly reduces the risk of tooth fracture in teeth undergoing root canal treatment.[10,13,27,40] According to Aquilino and Caplan,[13] although ceramic or composite onlays could protect against fractures, no reports support their use in the restoration of posterior teeth. Some laboratory studies concluded that endodontically treated teeth recovered the lost resistance to fracture after receiving an indirect restoration with cusp protection.[22] The tendency of onlay composite restorations to receive higher load might be attributed to the dispersion of compressive stresses. Similar results were found for cusp coverage with amalgam,[40] which significantly increased the fracture resistance of the teeth compared to those restored without cusp coverage. In contrast to the study by Soares et al,[41] cuspal reduction restorations reduced fracture resistance in mandibular premolars, probably because of the large amount of sound tooth tissue removed during specimen preparation.

Other authors have stated that cusp coverage does not strengthen premolars restored with composite onlay[32] or molars with ceramic restorations.[42] This may be due either to the different axial direction of the compressive load used in these studies, or to the different indirect restoration, which involved only a buccal cusp. Moreover, in this study, the insertion of a fiber post within the cuspal coverage restoration did not significantly increase fracture resistance,

probably due to the adequate dispersion of compressive stresses already provided by the composite overlay.[21,26,30]

Regarding failure mode, the combination of the fiber post with an inlay adhesive restoration led to a higher incidence of more favorable failure types ($P<.001$). This is consistent with the results of other similar studies.[26,42,43] Furthermore, the residual wall thickness did not influence the fracture mode, as reported elsewhere.[26] This finding is probably due to the stress distribution provided by the materials and techniques employed for the restoration, which influence the fracture pattern more than does the quantity of sound tissue.[44]

The current study has some limitations: although the methodology chosen cannot perfectly reproduce clinical conditions, it does result in fewer variables and allows for a more specific evaluation of the performance of various composite restorations on endodontically treated premolars with different wall thicknesses. This study focused on the fracture resistance of restored teeth, but additional in vitro investigations could be done to determine other clinical aspects related to occlusal loading before tooth fracture. A recent study[45] suggested that marginal leakage precedes loss of retention or fracture of the restoration and, therefore, may be regarded as a precursor to the failure of the treated tooth. Thus, further research to identify microleakage at the composite-tooth interface after cyclic loading would help reveal whether marginal leakage is occurring, where, and to what extent.

CONCLUSIONS

Within the limits of this investigation, the results suggest that wall thickness is an effective clinical parameter in selecting an appropriate adhesive restoration technique for endodontically treated premolars. In fact, when the residual cavity wall thickness is >2 mm, less

invasive treatments such as direct intracuspal composite restoration supported by fiber-post insertion can provide sufficient fracture resistance to occlusal loads. In contrast, when the residual wall thickness is <2 mm, the cuspal coverage through a composite adhesive restoration, with or without a fiber post, represents the treatment of choice because it is the only option that provides satisfactory fracture resistance. Further clinical trials are required to confirm these findings.

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Table I. Specimen characteristics, grouping, mean fracture resistance values (Newtons) and fracture modes of the various groups.

GROUP (*n*)	**RESIDUAL WALL THICKNESS**	**SUBGROUP (*n*)**	**CHARACTERISTICS**	**FRACTURE RESISTANCE** (mean ± SD)	**NON-RESTORABLE FRACTURE (%)**
W1,5 (*n*=32)	1.5 mm	W1,5 A (*n*=8)	Post (-), cusp coverage (-)	260.51 ± 82.69	87.5
		W1,5 B (*n*=8)	Post (+), cusp coverage (-)	445.71 ± 103.19	62.5
		W1,5 C (*n*=8)	Post (-), cusp coverage (+)	793.11 ± 196.56	87.5
		W1,5 D (*n*=8)	Post (+), cusp coverage (+)	775.98 ± 173.30	87.5
W2 (*n*=32)	2 mm	W2 A (*n*=8)	Post (-), cusp coverage (-)	313.77 ± 69.61	75
		W2 B (*n*=8)	Post (+), cusp coverage (-)	660.59 ± 149.48	50
		W2 C (*n*=8)	Post (-), cusp coverage (+)	801.16 ± 175.28	87.5
		W2 D (*n*=8)	Post (+), cusp coverage (+)	868.58 ± 139.76	87.5
W2,5 (*n*=32)	2.5 mm	W2,5 A (*n*=8)	Post (-), cusp coverage (-)	368.22 ± 130.27	87.5
		W2,5 B (*n*=8)	Post (+), cusp coverage (-)	676.06 ± 155.56	50
		W2,5 C (*n*=8)	Post (-), cusp coverage (+)	821,18 ± 121.45	75
		W2,5 D (*n*=8)	Post (+), cusp coverage (+)	871,77 ± 150.74	87.5
Control (*n*=8)	-	-	Intact teeth	1098.64 ± 287.86	20

Table II. ANOVA of empirical fracture resistance values.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-Statistics	P
Thickness	2	238703	119351	5.91	.004
Restoration	1	3247018	3247018	160.84	<.001
Fiber post	1	590008	590008	29.23	<.001
Thickness–Restoration	2	50737	25368	1.26	.290
Thickness–Fiber post	2	66634	33317	1.65	.198
Restoration–Fiber post	1	364051	364051	18.03	<.001
Thickness–Restoration–Fiber Post	2	6296	3148	0.16	.856
Error	84	1695753	20188		
Total	95	6259199			

LEGENDS

Fig. 1. First-order interaction plot of fracture resistance.

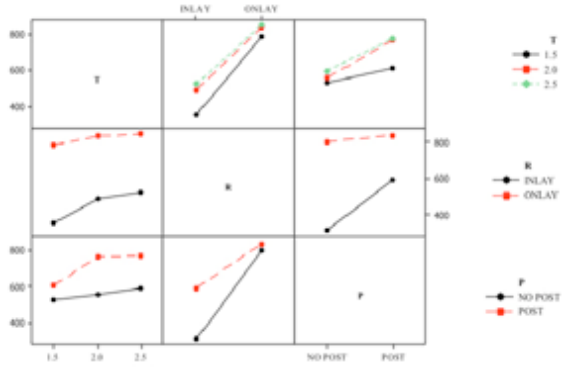

Fig. 2. Ninety-five percent confidence intervals of mean fracture resistance values.

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