Fracture Resistance and Failure Mode of Endodontically Treated Premolars Restored with Different Adhesive Restorations

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Abstract

Introduction: The restoration of endodontically treated teeth is a topic that has been studied extensively but it is still a challenge for dental practitioners. The aim of this study was to evaluate fracture resistance, fracture patterns and fracture location of endodontically treated human maxillary premolars restored with direct and indirect composite resin and ceramic restoration. **Methods:** Eighty non-carious maxillary premolars were selected and divided into four groups (n=20). Endodontic treatment and mesio-occluso-distal preparations were carried out in all the groups except for the control group (group I). Subsequently, the prepared teeth were restored as follows: group II: indirect composite restoration; group III: ceramic restoration; group IV: direct composite restoration. The specimens were subjected to compressive axial loading until fracture occurred. The mode of failure was also recorded. **Results**: Group I had higher fracture resistance (1196.82±241.74) than the other groups (P<0.05) and group IV exhibited significantly higher values (962.10±165.52) compared to groups II (731.21±85.89) and III (758.18±108.10) (P<0.05). The fracture patterns were significantly different between the composite resin groups and the ceramic group (P<0.05). The most prevalent fracture pattern in the groups II and IV was mixed fracture and in the group III, restoration cohesive fracture was the predominant pattern. With regard to fracture location, the direct composite restorations exhibited more fractures below the CEJ compared to the indirect restorations (P<0.05). **Conclusions:** Use of direct composite restorations resulted in higher resistance against fracture, but their failure modes may be unfavorable.

Introduction

The clinical survival of teeth undergone endodontic treatment depends on the remaining tooth structure, the restorative material, the technique used and the interaction between the tooth, material and oral cavity (1). It has been reported that the majority of failures in endodontically treated teeth are due to inadequate restorative therapy (2). The remaining tooth structure and functional requirements are important in determining the optimum type of restoration (3). In the past, it was thought that posts can strengthen the root of an endodontically treated tooth, but it is widely held today that the primary purpose of post placement is to retain the core buildup material (4). For the posterior teeth that receive predominantly vertical forces, a post is indicated only when other conservative retention features, such as retention of pulp chamber cannot be used (5). With recent advances in adhesive systems, the

concept of minimal intervention dentistry has been introduced to preserve sound tooth structure (6). It has been claimed that adhesive restorations that have higher ability to transmit and distribute functional stresses through the bonding interface to the tooth may reinforce the remaining tooth structure (7). Some authors believe that large preparations require cusp coverage to decrease possibility of fracture (8,9). Couegnat et al. and Jiang et al. reported that an onlay-restored tooth exhibited more favorable stress distribution pattern compared to inlay-restored teeth (10,11). MOD onlay restoration is more conservative than a full crown, though both provide the same protection of the remaining tooth structure (12).

Direct composite restorations have been considered as one of the most favorable restorations, mainly due to their excellent esthetics, preservation of more sound tooth structure and the fact that the restoration is placed in a single visit (6,13). Indirect composite and ceramic restorations are among other common practiced restoration techniques. Their use is time-consuming and more expensive (14), however indirect restorations are expected to have better physical properties when compared to direct composite restorations because they are fabricated under relatively ideal laboratory conditions.

Apart from the polymerization method, the mechanical properties of restorative materials may also influence the behavior and fracture pattern of the tooth/restoration complex under test conditions (15).

Some previous studies evaluated the fracture resistance of teeth restored with direct and indirect restorations; however, there is no agreement among the researchers about the performance of the restorative materials and techniques (16-19). Due to the increasing use of adhesive restorations, it is important for clinicians to be aware of longevity and modes of failure of these restorations. The aim of this study was to evaluate the fracture resistance and failure modes in endodontically treated maxillary premolars with MOD cavities restored using three different types of onlay. The null hypothesis was that there is no difference in fracture resistance and failure behavior between a direct resin composite, an indirect resin composite, and a ceramic onlay.

Materials and Methods

A whole number of 80 non-carious single-rooted maxillary premolars with mature apices, extracted for orthodontic reasons were selected under a protocol approved by the Ethics Committee of Mashhad University of Medical Sciences (86239). Only teeth with similar bucco-lingual and mesio-distal dimensions, as determined with a digital caliper (Mitutoyo, Tokyo, Japan), and with no visible cracks, were included. A hand scaler was used for surface debridement of the teeth. The specimens were immersed in 5% formalin solution for 10 hours to control infection and stored in normal saline at room temperature until completion of the experiment. The teeth were randomly divided into 4 groups, each containing 20 teeth, so that the average tooth size in each group was as equal as possible. Endodontic and restorative procedures were carried out in all the groups except for the control group. A standard access cavity was prepared and the canals were prepared up to 1 mm from the radiographic apex by using passive step-back technique up to K-file #35 (Maillefer, Dentsply, Ballaigues, Switzerland) at the apical constriction. Gates-Glidden drills (Maillefer, Dentsply, Ballaigues, Switzerland) no. 2 and 3 were used to flare the coronal portion of each root canal. The root canals were obturated with cold lateral compaction of gutta-percha and AH-26 sealer (Dentsply Detrey, GmbH, Konstanz, Germany). Gutta-percha was removed to a depth of 1 mm below the Cemento-enamel junction (CEJ), forming an apical location for the composite resin (Filtek Z250, 3M ESPE, Seefeld, Germany) used to fill the access preparation. All the preparation and restorative procedures were carried out by one operator.

Class II MOD cavities were prepared with the gingival cavosurface margin located at the cementoenamel junction (CEJ). The residual thickness of buccal and palatal cusps at height of contour was 2±0.2 mm. The buccopalatal widths of mesial and distal boxes were similar to the occlusal isthmus width. The depth of gingival wall was 1.5 mm. After preparing MOD cavities, the palatal cusps were reduced up to 2 mm in order to cover them with restorative material later (fig. 1). For the indirect restorations, a tapered cylindrical cutting instrument with 6 degrees of divergence (#2131, KG Sorensen, Barueri, SP, Brazil) was used to prepare divergent walls. Names, compositions and manufacturers of the materials used in this study are shown in Table 1. The groups were treated as follows:

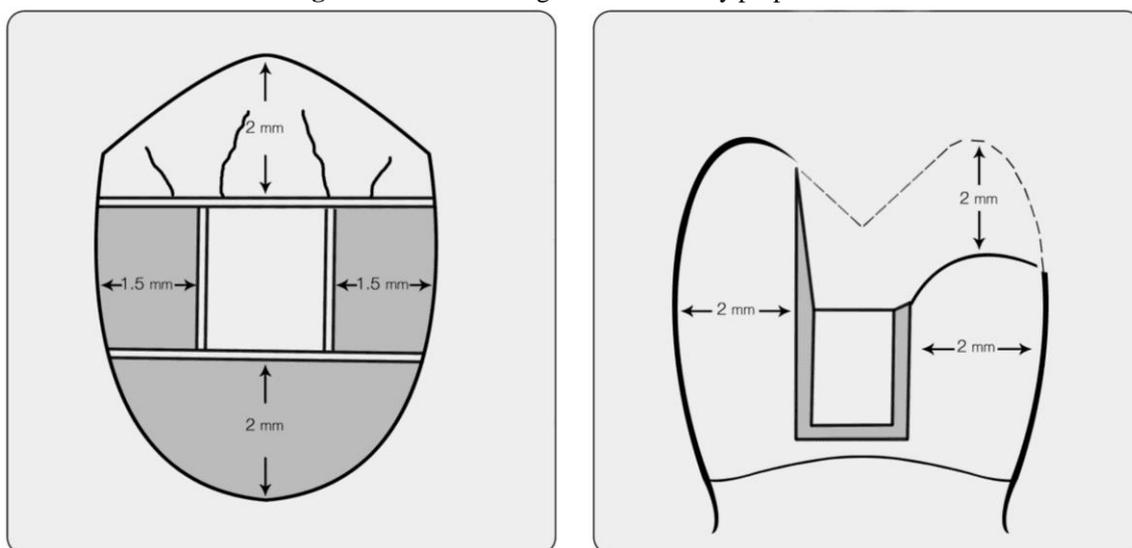**Figure 1.** Shematic diagram of the cavity preparation

Table 1. Chemical composition of restorative materials used in this study

Materials	Chemical Composition	Filler fraction(vol%)	Manufacturer
GC Gradia	Alumino-silicate glass Amorphous Precipitated Silica Prepolymerized filler UDMA	64-65	GCAmerica Alsip, IL, USA
GC Initial	Crystalline Silica Aluminum oxide Propylene Glycol		GC America Alsip, IL, USA
Filtek Z250	Zirconia-silica Bis-GMA, UDMA, Bis-EMA	60	3M, ESPE, Seefeld Germany

Bis-GMA: Bisphenole A diglycidyl ether dimethacrylate, UDMA: Urethane dimethacrylate,

Bis-EMA: Bisphenole A polyethylene glycol dietherdimethacrylate

Group I: Intact teeth as the control group; no treatment.

Group II: The teeth were restored with indirect composite onlays (GC Gradia America, Alsip, IL, USA). Following cavity preparation, an impression (C-Silicone, Speedex, Coltene, Altstatten, Switzerland) was made to produce a hard stone model for each tooth. The laboratory-processed resin onlays were fabricated according to manufacturer's instructions. After 24 hours, the internal surface of each onlay was sandblasted with 50-µm aluminum oxide particles, washed and air-dried; then the bonding agent was applied. Each preparation was etched with 37% phosphoric acid for 15 seconds, rinsed for 15 seconds and dried. The dentin adhesive system (Single Bond, 3M, ESPE) was applied in two coats and light-polymerized for 20 seconds with a halogen curing unit with 800 mW/cm2 light intensity (XL 3000, 3M ESPE). The resin luting cement (Rely X Adhesive Resin Cement, 3M ESPE) was mixed and applied to the surfaces of the composite onlay and tooth. The restoration was seated in place, and excess cement was removed from the margins. The same curing unit was applied to the occlusal, facial, and palatal directions for 40 seconds in each one.

Group III: The teeth were restored with GC Initial ceramic onlay (GC Gradia America, Alsip, IL, USA). The teeth were prepared and impressions were made in the same manner as those in the group II; then the ceramic onlays were fabricated according to manufacturer's instructions. The internal surface of each onlay was sandblasted and subsequently treated with 10% hydrofluoric acid (Dentsply, Milford, DE, USA) for 20 seconds. After rinsing and drying, the internal surface was silanized (Rely X Ceramic Primer, 3M ESPE) for 40 seconds. Other steps for cementation were the same as those in the group II.

Group IV: The teeth were restored with Filtek Z250 composite resin (3M ESPE, Seefeld, Germany). After the application of adhesive as previously described, a matrix retainer system was used. The composite resin was placed into the cavity using the incremental technique. Each 2.0-mm increment was light-cured for 20 seconds. After finishing the restoration, curing of occlusal, facial, and palatal aspects of each tooth was carried out for 40 seconds in each direction.

All the restored teeth were finished and polished with rubber cups and points (Identoflex, Kerr Hawe SA, Bioggio, Switzerland). Then the teeth were stored in distilled water at 37°C. After 24 hours, the specimens were subjected to 500 cycles of thermocycling at 5±2°C/55±2°C (13). Subsequently, all the teeth were mounted in cold-cured acrylic resin up to 2 mm apical to the CEJ. The specimens were positioned to maintain the loading axis perpendicular to the occlusal surface and submitted to compressive force at a crosshead speed of 0.5 mm/min in a mechanical testing machine (Z250 material testing machine, Zwick/Roell, Germany). Compressive loading was applied using a 2-mm diameter metallic device with a sharp pointed tip contacted the occlusal groove (Fig. 2). The compressive load at fracture was reported in Newton. After fracture, the specimens were evaluated under magnification (×40) using a stereomicroscope (Blue Light, La Habra, USA) for fracture patterns as follows: cohesive failure of the restorative material, adhesive fracture at the interface, cohesive fracture of the tooth, and mixed fracture of the specimens involving the tooth and the restorative material. A distinction was also made between fracture location above and below the CEJ. The data were analyzed using statistical software (SPSS 11.5). One-way ANOVA and a post-hoc Tukey's test were used to compare the fracture resistance; and failure modes were analyzed using Fisher's exact test. The significance level was set as P<0.05.

Results

The mean fracture strength values, standard deviations and maximum and minimum forces needed for fracture of all the specimens are shown in Table 2. The one-way ANOVA showed significant differences among the groups with respect to resistance to fracture (P<0.05). Tukey's test showed that group I presented higher fracture resistance values than the other groups (P<0.05). The fracture resistance of direct composite restorations (Group IV) was significantly higher than those for the groups II and III (P<0.05). The fracture resistance values of the groups II and III were statistically similar (P>0.05).

The distribution of fracture patterns is presented in Table 3. Fisher's exact test indicated that the fracture pattern was significantly different between composite resin restorations and ceramic restorations (P<0.05).

In relation to fracture location, Fisher's exact test showed significant differences among the groups (P<0.05) (Table 4). Direct composite restorations exhibited more fractures below the CEJ compared to indirect restorations.

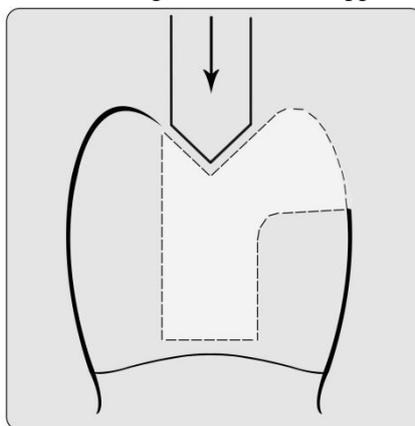**Figure 2.** Shematic diagram of the load application device

Table 2. Fracture resistance values (N)

Groups (n=20)	Mean (SD)	Minimum	Maximum
I	1196.82 (241.74) [a]	855.93	1645.87
II	731.21 (85.89) [b]	605.39	953.93
III	758.18 (108.10) [b]	612.84	962.80
IV	962.10 (165.52) [c]	781.29	1325.25

Different letters indicate statistically significant difference

Table 3. Distribution of fracture patterns in each experimental group

Groups (n=20)	Adhesive	Restoration cohesive	Tooth cohesive	Mixed
GC Gradia (II)	2	6	1	11
GC Initial (III)	5	11	2	2
Filtek Z250 (IV)	4	4	2	10

Table 4. Distribution of fracture location in treatment groups

Groups	Fracture above CEJ	Fracture below CEJ
Sound teeth (I)	11	9
GC Gradai (II)	19	1
GC Initial (III)	18	2
Filtek Z250 (IV)	11	9

Discussion

Considering the results obtained in this study, the null hypothesis has to be rejected as the direct composite resin proved to improve the fracture resistance; but increased the unrestorable fractures. In vitro aging of restorations can be induced with several methods, including storage in water or artificial saliva, and thermal or mechanical cycling, hypothesizing that the hydrolytic degradation of collagen and the adhesive is the most important mechanism to decrease bonding quality (20). In the current study, aging was conducted based on the regimen proposed by the ISO standard (ISO TR 11450) (21).

The present study was conducted on maxillary premolars because with an unfavorable crown volume and crown/root ratio, they are more susceptible to cusp fracture than other posterior teeth (22). The findings showed that the fracture resistance of premolars restored using adhesively bonded restorations, is lower compared to intact premolars. Several studies have also reported higher fracture resistance for intact teeth (20,23).

In this study, however, the direct composite resin onlays had lower fracture strength than natural teeth but it was higher than the indirect composite onlays. Mohandesi et al. also reported that Filtek Z250 exhibited higher fatigue strength when compared to Gradia indirect composite (24). This finding is likely to be attributed to the excellent properties of its polymer matrix (presence of hard and flexible monomers, adequate toughness and increase in cross-links), high percentage of filler particles and better combination of polymer matrix and filler particles in this composite resin (24). Filtek Z250 and Gradia indirect had 60% and 64-65% filler fraction, respectively (25,26). Previous studies indicated a strong correlation between compressive strength and filler volume fraction in dental composites (27). On the contrary, there was some evidence that strength started to decrease at very high filler levels (>60 vol%) because of increase in the modulus of elasticity (28).

Apart from the filler volume fraction, the degree of conversion in the cross-linked polymeric system also influences the mechanical properties of resin composites (29). Usually the indirect curing of the composite can increase the degree of conversion, which improved the physical and mechanical properties greatly. However, in some indirect systems the effect of heat curing was minimal (30). A previous study has also showed that indirect polymerization of Gradia composite has no significant effect on fatigue strength (24).

In the present study, no differences were found in the fracture resistance of indirect composite resin and ceramic onlays. These results are consistent with those

reported by Kuijs et al. (16). However, Brunton reported significantly less fracture resistance in ceramic onlays (17). This conflicting result can be attributed to tooth anatomical variances, specimen preparation, different materials employed for the restoration, tooth storage methods, type and design of the load application contact device and the test speed.

The most prevalent fracture pattern observed in ceramic onlays was cohesive failure in the restorative material, consistent with the results reported by Soares et al (31,32); these findings might be attributed to the high elastic modulus and friability of ceramic materials compared to composite resins (15,32). The stresses concentrate within the ceramic and result in cohesive fracture of the restoration.

This study showed no differences between the fracture pattern of direct and indirect composite resin restorations. The lower elastic modulus of composite resin produced less restoration stiffness, and greater distribution of stresses to adjacent tooth structure might occur (15), which can be the cause of higher incidence of mixed fractures in composite resin restorations observed in this study.

According to Table 3, 45% of fractures in the group IV were recorded below the CEJ level that was comparable to those in sound teeth (control group). Since the dentin and the composite resin have similar modulus of elasticity, the stress transmitted to coronal and root dentin and induced fracture with root involvement.

The majority of fractures in indirect restorations ended above the CEJ level. The differences observed between the direct and indirect techniques can be due to the cement layer. After placement of indirect restorations, the cement layer will be thicker than the bonding layer in the direct composite resin and results in a different transfer pattern of the loads to the dentin (10).

The fracture location of direct composite resin suggests that caution should be exercised before material selection for restoration of endodontically treated teeth with extensive loss of coronal structure. However, direct composite resin can be placed as a foundation for a subsequent definitive restoration (33,34). In addition, this can be used as an intermediary restoration in posterior endodontically treated teeth with uncertain prognosis. Jafari Navimipour et al. demonstrated that Composite resin restoration along with glass fiber could be an acceptable treatment option for restoring root-filled upper premolars (35).

The test used in the present study is widely employed in the literatures and this is an important source of information about restorative materials, but this methodology should be recognized as not completely similar to the type of loading that occurs in clinical situations. Clinically, tooth fractures are usually the result of the accumulation of repeated stress during oral function. A number of short-term clinical evaluations of direct and indirect composite resin and ceramic restorations demonstrated acceptable clinical performance (36,37); however, long-term clinical studies are needed to achieve definitive results.

Conclusion:

Under the limitations of this study, use of direct composite restorations in endodontically treated teeth resulted in higher fracture resistance compared to indirect resin composite or ceramic onlay; however, fracture in direct resin composite restorations led to higher share of unrestorable teeth.

Acknowledgment

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