Original Article

The effect of amount of lost tooth structure and restorative technique on fracture resistance of endodontically treated premolars

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Abstract

Aim: Endodontic treatment generally reduces the fracture resistance of teeth. The purpose of this study was to evaluate the fracture resistance and the mode of fracture of endodontically treated human premolars with different amounts of remaining tooth structure.

Materials and Methods: Seventy non-carious human premolars were randomly assigned into 7 groups. Group 1 (ST) did not receive any preparation. The teeth in groups 2-7 received root canal treatment and different preparations. Group 2 (MO-NF): Mesio-occlusal preparation without filling; Group 3 (MOD-NF): Mesio-occluso-distal preparation without filling; Group 4 (MO-F): Mesio-occlusal preparation with direct composite restoration (Z250); Group 5 (MOD-F): Mesio-occluso-distal preparation with direct composite restoration (Z250); Group 6 (CC-D): Mesio-occluso-distal preparation with cusp reduction and direct composite restoration (Z250); Group 7 (CC-InD): Mesio-occluso-distal preparation with cusp reduction and indirect composite restoration (Gradia GC). The fracture resistance (N) was assessed under compressive load in a universal testing machine (Zwick) perpendicular to the occlusal surface at a cross-head speed of 1 mm/min, and the mode of fracture was assessed under stereomicroscope.

Statistical analysis: Data was analyzed by Kruskal – Wallis and Mann – Whitney tests and the mode of fracture was analyzed by Chi-square test ($P < 0.05$).

Results: Statistical analysis showed that MO and MOD cavity preparations significantly reduced the fracture resistance of sound teeth. Direct composite restorations can improve the fracture resistance, and Groups 7 and 6 presented the highest fracture resistance values.

Conclusions: Teeth with adhesive restorations showed significantly higher fracture resistance values as compared with the non-restored ones.

Keywords: Adhesive restoration; endodontically treated; fracture resistance; premolars; teeth

INTRODUCTION

Caries, trauma, and cavity preparations reduce tooth structure that *per se* decreases the fracture resistance of tooth.[1,2] Abrasion, erosion,[2] non-carious lesions, and aging[3] are the other factors that have such an influence on fracture resistance of teeth. Among all factors, “extensive cavity preparations and endodontic treatment” are the most common reasons for tooth fragility. These procedures can decrease fracture resistance of teeth due to the removal of occlusal marginal ridges.[3]

Access cavity preparation in endodontic treatment compromises the fracture resistance of teeth, because the preparation is associated with reducing the pulp chamber walls and root dentin. These events result in increased cuspal deflection and cuspal fracture. Also, dental arch position, tooth anatomy, and changes in mechanical and physical properties of dentin can influence the fracture resistance of teeth.[4,5]

Several authors claim that adhesive restorative materials such as composite resins can reinforce the remaining tooth structure after endodontic therapy.[6,7] However, light-polymerizing direct adhesive materials can cause polymerization shrinkage stresses that result in subsequent microleakage and dentin sensitivity.[8] In order to reduce

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this negative influence, use of laboratory-prepared indirect resin restorations that adhere to the tooth structure is recommended. They can provide a favorable reinforcement for extensively damaged teeth.[9,10]

On the other hand, although dental amalgam is a material with a long clinical life,[7] it does not have such a reinforcing effect, because amalgam does not adhere to the tooth structure and deforms under compressive stresses.[11]

The purpose of this study was to evaluate the fracture resistance and mode of fracture of endodontically treated human premolars with different amounts of remaining tooth structure.

MATERIALS AND METHODS

Seventy sound human premolars free of any cracks or defects and indicated for extraction because of orthodontic treatment were selected for this study and were stored for no longer than 6 months. Teeth were stored in normal saline. The selection of teeth was based on having similar bucco-lingual (BL) and mesio-distal (MD) dimensions.

The selected teeth were divided into 7 groups ($n = 10$):

Group 1(ST): The teeth were left intact without any cavity preparation or root canal treatment and used as the negative control.

Groups 2-7: One clinician made all the preparations and restorations. Access cavities were prepared using a high-speed bur and water spray, and the canals were instrumented with K files (Kerr corporation) to an apical size 35 using the step-back technique. Irrigation with 10 ml of 5.25% sodium hypochlorite preceded each file introduced into the canal. Following biomechanical preparation, the canals were dried with absorbent paper points (Diadent Group International Inc., CheongJu City, Korea) and obturated with gutta percha (Diadent Group International Inc.) and AH 26 root canal sealer (silver free; Dentsply DeTrey, Konstanz, Germany) using cold lateral condensation. Then, Class II mesio-occluso-distal (MOD) cavities (Groups 3, 5, 6, and 7) and mesio-occlusal (MO) cavities (Groups 2 and 4) were prepared with the gingival cavosurface margin located 1.0 mm above the cement–enamel junction. The buccolingual width of each cavity, measured with a digital caliper (Mitutoyo Corp., Kawasaki, Japan), was half the inter-cuspal distance and extended into the pulp chamber. The depth of the cavities was 4.0 mm, without proximal steps and flat floor. All teeth were prepared as approximate as possible to the same size using a periodontal probe and standard burs (Universal Set; Intensiv) to measure the depth and width. The facial and lingual walls of the occlusal segment were prepared parallel to each other.

Group 2 (MO-NF): This group was kept unrestored after MO cavity preparation and endodontic treatment and was used as the positive control.

Group 3 (MOD-NF): This group was kept unrestored after MOD cavity preparation and endodontic treatment and was used as the positive control.

Group 4 (MO-F): After MO cavity preparation as in Group 2, the cavities were etched with 32% phosphoric acid (Uni-etch Bisco Inc., USA) for 30 s for enamel margins and 20 s for dentinal margins, respectively, rinsed for 20 s with an air/water spray, and gently air-dried to avoid desiccation. The primer (All bond 3, Bisco Inc.) was applied with a microbrush to the tooth surface for 20 s and then air-dried for 5 s. Light-curing adhesive (All bond 3, Bisco Inc.) was applied with another microbrush, the excess was gently air-thinned, and the surface was exposed to a light-emitting diode (LED)-polymerization unit with an intensity of 800 mW/cm^2 (Starlight pro; Mectron SpA, Carasco, Italy) for 40 s. A matrix retainer (Tofflemire matrix; Miltex Inc., York, Pa) was used and changed for each restoration. The matrix was tightened and held by finger pressure against the gingival margin of the cavity, so that the preparations could not be overfilled at the gingival margin. The composite resin (Z 250 Micro hybrid composite resin, 3M ESPE USA) was placed using the oblique incremental technique,[12] and each increment was no more than 1.5-mm thick to ensure adequate polymerization. Each increment was polymerized for 40 s (20 s of slow-rise function repeated 2 times) using the LED-polymerizing unit with a power light intensity of 800 mW/cm^2 in contact with the occlusal surface of the tooth. The matrix was removed, and, to ensure adequate polymerization of the deepest parts of the interproximal box, each restoration was further light-cured for 60 s from the buccal aspect and 60 s from the lingual aspect of the box.

Group 5 (MOD-F): MOD cavities were prepared as in Group 3, and the cavities were filled as in Group 4.

Group 6 (CC-D): After obtaining impressions of the teeth, the MOD cavities were prepared as in Group 3 and the cusps were then reduced for 2 mm. The impressions were used as indexes during the filling procedure. Cavities were filled as in Group 4.

Group 7 (CC-InD): In order for the prepared teeth to be restored with indirect composite resin, restorations impressions were made with a condensation silicone-based material (Speedex, Colten, Switzerland) using a custom-made impression tray. The impressions were poured with a type IV stone and separated from the dies after 1 h. After separation, the cast was carefully evaluated to ensure that the finish line was entirely visible and that there were no distortions, air bubbles, or undercuts prior to sending the cast to the dental laboratory. The dies were coated with separating medium (Gradia, GC Corporation, Tokyo, Japan) and onlays were fabricated with indirect composite resin (Gradia). Each layer of onlays was further polymerized in a light-heat polymerization oven (Gradia) for 10 s.

Each restoration was verified for fit accuracy and adjusted accordingly and then finished with a fine diamond rotary cutting instrument (Intensiv FG; Intensiv). The internal surfaces of both the onlays and the teeth were airborne-particle abraded with 50-μm silica-coated aluminum-oxide particles (Special sand, Kumapan; Consorzio Onda, Grugliasco, Italy). Then, the teeth were treated, as previously described for Group 4, by etching and using primer, and bonding agents. The onlays, after the airborne-particle abrasion, were cleaned with ethyl alcohol (95%), and silane and bonding agents were applied. The Duo Link cement (Bisco Inc.) was used as a luting agent, according to the manufacturer's instructions. The cement was then placed on the tooth, the onlay was seated in place, and the excess cement was removed with a brush. Cavosurface margins were coated with a glycerine gel (DeOx; Ultradent Products Inc.) to permit complete polymerization of the luting agent. Each restoration for the first 10 s was held under load and then polymerized with the LED-polymerizing unit from the occlusal, facial, and lingual directions for 20 s in each direction, 3 times each (for a total of 1 min in each direction).

After complete polymerization, the specimens were finished with carbide finishing burs (Dentsply Maillefer) to remove the excess cement, followed by repolishing with rubber cups and points (Identoflex; KerrHawe SA).

The selected teeth were then stored in distilled water at 25°C, and, subsequently, the root surfaces were marked 3 mm below the crown margin to simulate the biological width and covered with 0.3-mm-thick wax (Tenatex wax; Kemdent). The specimens were then embedded in autopolymerizing acrylic resin (Ortho-Jet; Lang Dental Mfg Co, Wheeling, Ill) surrounded by a cylindrical-shaped plastic mold (IKEA; Rome, Italy) with the long axis of the tooth parallel to that of the cylinder. After the first signs of polymerization, the teeth were removed from the resin blocks and the wax on the root surfaces was removed using a hand instrument. Light-body silicone-based impression material (Speedex) was injected into the resin base, and the teeth were reinserted into the resin base. Thus, the standardized silicone layer that simulated the periodontal ligament was created.[13,14]

The specimens were then placed into a Universal Testing Machine (Zwick, Germany) and loaded compressively at 1 mm/min. A vertical compressive force was applied with a 6-mm diameter stainless steel bar. The bar contacted the occlusal surface of the restoration and the buccal and lingual cusps of the teeth. The force necessary to fracture each tooth was recorded in Newton (N), and the data was subjected to Kruskal – Wallis and Mann – Whitney tests for the 7 experimental conditions. The fractured specimens were then examined under a stereomicroscope (Olympus SZ4045TRPT, Tokyo, Japan) with 10× magnification to determine the fracture mode.

Fractures were considered favorable if adhesive fracture occurred above the cervical line (CEJ) and was restorable. Non-restorable fractures under CEJ constituted unfavorable fractures.

RESULTS

The mean fracture resistance and the standard deviation for each of the 6 experimental groups are presented in Table 1.

Statistical analysis indicated that the fracture resistance of Groups 6 and 7 was significantly higher than that of the other groups ($P = 0.01$). Teeth restored with composite resin, indirect, and direct composite resin in Groups 4-7, respectively, showed increased fracture resistance as compared with that in the non-restored group (Groups 2 and 3) ($P = 0.00$). No statistically significant differences were found among Groups 4, 5, and 1 ($P = 0.25$), and Group 4 had greater fracture resistance than Group 5 ($P = 0.33$). Also, Group 3 had the least fracture resistance among those receiving a restoration.

Chi-square test revealed significant differences among all groups with respect to the mode of fracture. With regard to the fracture mode, the Groups 2 and 3 presented the highest incidence of catastrophic fracture. The specimens in the Groups 1, 4, 6, and 7 presented less severe fractures [Table 2].

DISCUSSION

The fracture resistance of premolars significantly decreased following endodontic treatment and cavity preparation,

Table 1: The mean fracture resistance (Newton) and standard deviation for each of the 7 experimental groups

Groups	Mean±SD (*N*)	CV	*P* value
(ST)	837±532/42[a]	0/63	0.002
(MO-NF)	508±93/33[b]	0/18	
(MOD-NF)	483±110/85[b]	0/21	
(MO-F)	761±501/96[a]	0/66	
(MOD-F)	741±195/01[a]	0/26	
(CC-D)	1815±295/709[c]	0/16	
(CC-InD)	1594±265/99[c]	0/16	

ST: Sound teeth, MO-NF: Mesio-occlusal-no filling, MOD-NF: Mesio-occluso-distal-no filling, MO-F : Mesio-occlusal filled, MOD-F: Mesio occluso distal-filled, CC-D: Cusp coverage-direct filling, CC_InD: Cusp-coverage-indirect filling, Similar letters indicate statistically similar values ($P>0.05$)

Table 2: Percentage (frequency) of mode of fracture for all groups (n=10)

Groups	Favorable (%)	Unfavorable (%)	*P* value
(ST)	90	10	0.001
(MO-NF)	20	80	
(MOD-NF)	0	100	
(MO-F)	70	30	
(MOD-F)	50	50	
(CC-D)	90	10	
(CC-InD)	100	0	

ST: Sound teeth, MO-NF: Mesio-occlusal-no filling, MOD-NF: Mesio-occluso-distal-no filling, MO-F : Mesio-occlusal filled, MOD-F: Mesio occluso distal-filled, CC-D: Cusp coverage-direct filling, CC_InD: Cusp-coverage-indirect filling

because of the loss of tooth structure.[15-18] Premolars are more susceptible to cusp fractures because of their unfavorable anatomical shape, crown root ratio, and crown volume. Therefore, a coronal restoration is necessary to support the remaining tooth structure.[19] Remaining tooth structure after preparation for indirect restorations is lesser than the amount of tooth structure remaining after preparation for direct materials.

In our study, the Group 1 presented 837 N fracture resistance value, which is different from the values reported by other studies, such as 2483 N by Cobankara *et al*.,[20] 1124.6 N by Soares *et al*.,[21] and 2451.3 N by Plotino *et al*.[22] Such differences among various studies can result from changes in the storage media of the teeth, the cross-head speed, type and design of load application, testing machine, and anatomical variability of teeth.[21]

Quality and quantity of the remaining tooth structure are the most important factors affecting fracture resistance; however, intact marginal ridges form a continuous circle of tooth structure in intact teeth that prevents cuspal fracture. Dentin is a suitable solid base for dental restorations, and its structural strength depends on the quality and integrity of tooth anatomical form. It means that, reducing the amount of remaining sound dentin reduces the support provided for the restoration.[20] Previous researches have shown that fracture resistance of a posterior tooth with access cavity is about one-third of a sound tooth. After MOD cavity preparation, deflection and strain of facial cusps are about 3 times greater than that of sound teeth, and stiffness reduces about 20%.

In the current study, the authors found statistically significant differences between fracture resistance and fracture mode of non-restored teeth with MO and MOD cavity preparations and fracture resistance of sound teeth, which is similar to the findings of other studies.[20,21]

However, studies by Re *et al*.,[23] reported interesting findings as they failed to find statistically significant differences between unrestored teeth with MOD preparation and sound teeth. In this study, restoring the MO and MOD cavities with direct composite resin improved the fracture resistance and fracture mode of teeth as high as that of sound teeth. Others suggested that composite resin has a cusp-reinforcing effect, which increases the fracture resistance of MOD cavity preparations.[24,25] This reinforcing effect of direct materials is related to the controlled "polymerization shrinkage" of composite resins. Joynt *et al*.,[15] suggested that incremental composite placement and curing can increase the fracture resistance of premolars with MOD cavity preparations.

In the present study, the greatest amount of fracture resistance was found in CC-D and CC-InD groups, which means that restoration technique and composite type (direct or indirect) do not lead to significant differences in the amount of required load for fracture. Also, these two groups did not have significant differences considering their fracture modes. Moreover, Plotino *et al*., found no significant difference in the fracture resistance of direct and indirect restorations.[22]

The difference in the fracture resistance of CC-D and CC-InD groups is related to the extensive MOD cavity preparation to provide divergent cavity walls for indirect restorations that necessitated removal of greater amounts of tooth structure, as mentioned by Soares *et al*.[21] However, this difference was not statistically significant in our study. Reduction in the amount of remaining tooth structure causes decreased fracture resistance.[21]

In this study, the fracture resistance of teeth restored with cuspal coverage restorations was even greater than that of sound teeth. Young teeth (extracted for orthodontic reasons), with a small amount of dentinal bulk and extended pulp chambers may be the cause of reduced fracture resistance of sound teeth. On the other hand, all teeth were extracted by forceps, which might have led to invisible coronal cracks.

One of the limitations of this study was that the samples were not thermocycled and were tested with static loading. Also, it is recommended to design future studies that use endodontically treated teeth without any cavity preparation as a positive control group.

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

- Preparation of access cavity and MO/MOD cavities can cause a significant decrease in fracture resistance of teeth
- Restoring the cavities with Z250 composite and all bond 3 bonding system increases the fracture resistance of teeth as high as that of the non-restored sound teeth
- Direct and indirect cusp coverage restorations cause a significant increase in fracture resistance as compared to the non-restored and conventionally restored teeth
- Conservative direct and indirect adhesive restorations

can be used to increase the fracture resistance of endodotically treated premolars as high as that of sound teeth.

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