The Effect of Different Restoration Techniques on the Fracture Resistance of Endodontically-treated Molars

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Clinical Relevance
To restore endodontically-treated molars, the use of indirect hybrid inlay restorations may be recommended due to their more favorable fracture failure modes compared with amalgam, resin composite and fiber-reinforced resin composite restoration techniques and their greater fracture resistance compared with amalgam restorations.

SUMMARY
Aim: This study compared the fracture resistance of endodontically-treated mandibular molars with mesio-occluso-distal (MOD) cavities restored using different restoration techniques. Methodology: Sixty sound extracted mandibular molars were randomly assigned to six groups (n=10). Group 1 did not receive any preparation. The teeth in Groups 2-6 received root canal treatment and a MOD cavity preparation. The teeth in Group 2 were kept unrestored. Group 3 was restored conventionally with amalgam. Group 4 was restored with a dentin bonding system (DBS, Clearfil SE Bond) and resin composite (CR) (Clearfil Photoposterior). Group 5 was restored with indirect hybrid ceramic inlay material (Estenia). In Group 6, polyethylene ribbon fiber (Ribbond) was inserted into cavities in a buccal-to-lingual direction and the teeth were then restored with DBS and CR. After finishing and polishing, the specimens, except for Group 2, were loaded to failure by a chewing simulation device (60,000 cycles x 50 N load, 1.3 Hz frequency) in an artificial environment at 37°C. Each tooth was subjected to compressive loading perpendicular to the occlusal surface at a crosshead speed of 1 mm/minute. The mean loads necessary to fracture were recorded in Newtons and the results were statistically analyzed. Results: The mean fracture values were as follows: Group 1: 2485.3 ± 193.9a, Group 2: 533.9 ± 59.4 b, Group 3: 1705.8 ± 135.7c, Group 4: 2033.3 ± 137.6cd, Group 5: 2383.2 ± 194.2de, Group 6: 2033.3 ± 137.6cd. The teeth in Groups 2-6 received root canal treatment and a MOD cavity preparation. The teeth in Group 2 were kept unrestored. Group 3 was restored conventionally with amalgam. Group 4 was restored with a dentin bonding system (DBS, Clearfil SE Bond) and resin composite (CR) (Clearfil Photoposterior). Group 5 was restored with indirect hybrid ceramic inlay material (Estenia). In Group 6, polyethylene ribbon fiber (Ribbond) was inserted into cavities in a buccal-to-lingual direction and the teeth were then restored with DBS and CR. After finishing and polishing, the specimens, except for Group 2, were loaded to failure by a chewing simulation device (60,000 cycles x 50 N load, 1.3 Hz frequency) in an artificial environment at 37°C. Each tooth was subjected to compressive loading perpendicular to the occlusal surface at a crosshead speed of 1 mm/minute. The mean loads necessary to fracture were recorded in Newtons and the results were statistically analyzed. Results: The mean fracture values were as follows: Group 1: 2485.3 ± 193.9a, Group 2: 533.9 ± 59.4 b, Group 3: 1705.8 ± 135.7c, Group 4: 2033.3 ± 137.6cd, Group 5: 2383.2 ± 194.2de, Group 6: 2033.3 ± 137.6cd.
2121.3 ± 156.5\(^4\), Group 6: 1908.9 ± 132.2\(^4\). There were statistically significant differences between the groups annotated with different letters. Thus, Group 1 (intact teeth) had the greatest fracture resistance and Group 2 (non-restored teeth) the poorest. No statistically significant differences were found between Groups 3 (amalgam), 4 (resin composite) and 6 (polyethylene ribbon fiber reinforced composite) (\(p>0.05\)). Group 5 (indirect hybrid ceramic inlay) had greater fracture resistance than Group 3 (\(p<0.05\)). Conclusions: Within the limitations of this study, although all of the restoration groups were stronger than the prepared-only group, none of the restoration techniques tested was able to completely restore the fracture resistance lost from MOD cavity preparation. However, use of indirect hybrid inlay restorations in these teeth may be recommended, because this restoration technique indicated more favorable fracture failure modes than other restoration techniques used in this study and particularly greater fracture strength than amalgam restorations. The promising result of indirect hybrid inlay restorations may need to be confirmed by long-term clinical studies.

INTRODUCTION

While not the primary cause for failure, the fracture of restored teeth may be most detrimental because it often results in extraction. This condition is more important in endodontically-treated teeth because, compared to teeth with healthy pulps, root-filled teeth are considered more susceptible to fracture, and fractures of restored endodontically-treated teeth are a significant clinical problem. Therefore, the root canal treatment should not be considered complete until an appropriate permanent coronal restoration has been placed. For this reason, endodontic practice and its success have been inextricably tied to the appropriateness and quality of the final restoration.\(^1\)\(^2\)

Endodontic treatment generally results in a reduction in resilience and fracture resistance of teeth.\(^3\)\(^4\) The primary factors for loss of tooth structure include dental caries, endodontic access preparation and root canal preparation. However, endodontic treatment does not cause teeth to become more brittle, and dehydration after endodontic treatment does not weaken the dentinal structure with respect to compressive or tensile strengths.\(^5\)\(^6\) A recent study reported that endodontically-treated teeth and their contralateral vital pairs exhibited similar biomechanical properties, such as punch shear strength, toughness and load required for fracture.\(^7\) These and other studies support the interpretation that it is the loss of structural integrity associated with the dental caries, access preparation and root canal preparation rather than changes in the dentin, that lead to a higher occurrence of fractures in endodontically-treated teeth compared with vital teeth.\(^8\)\(^13\)

The preparation of an endodontic access cavity compromises the strength of a tooth, because the preparation results in a deep and extended cavity, extending the amount of dentin to a critical extent.\(^1\)\(^4\) Consequently, loss of dentin, including anatomic structures such as cusps, ridges and arched roof of the pulp chamber, may result in tooth tissue fracture after the final restoration.\(^1\)\(^5\)\(^1\)\(^6\) In addition, endodontic access cavity preparations result in increased cuspal deflection during function and increase the possibility of cusp fracture.\(^1\)\(^7\)\(^1\)\(^8\) In most endodontically-treated teeth, there also is missing tooth structure caused by caries or existing restorations. Randow and Glantz\(^1\)\(^9\) reported that teeth have a protective feedback mechanism that is lost when the pulp is removed, which may also contribute to tooth fracture. Taken together, these studies indicate that restorations that enhance structural integrity would be expected to increase the prognosis of endodontically-treated teeth exposed to heavy masticatory loading forces.\(^2\)\(^0\) However, there is no consensus regarding the preferred type of final restoration for endodontically-treated posterior teeth. Many practical questions and controversies remain in this clinically important element of the treatment plan.

Some authors claim that only complete cast coverage will provide the needed protection and ensure the clinical success of the restoration.\(^2\)\(^1\)\(^2\) Others recommend the use of a complex amalgam restoration,\(^2\)\(^3\)\(^2\)\(^4\) indirect cast restoration covering the cusps (onlay)\(^1\)\(^6\) or composite materials.\(^2\)\(^5\)\(^2\)\(^6\)

Ceramic inlays have become popular, not only because of improved esthetics, but also because they provide tooth strength and allow for a reduction in the volume of resin composite that is used only as a luting agent.\(^2\)\(^7\)\(^2\)\(^9\) The use of newly developed, resin-based hybrid ceramics as alternatives to amalgam and direct resin composite restorations has increased in the posterior region. A hybrid ceramic material, Estenia (Kuraray Co, Osaka, Japan), is a recently developed, highly filled resin composite for indirect use. It is by far the hardest of the indirect resins. It provides the advantages of both ceramics (esthetic and durability) and resin composites (ease of use and low cost). No data are available with regard to its fracture strength.

In addition, in recent years, the development of fiber-reinforced composite (FRC) technology has also provided a significant opportunity to tailor materials’ response and to improve the behavior of existing materials.\(^2\)\(^0\) Ribbond (Ribbond, Seattle, WA, USA) is a reinforced ribbon made of ultra-high molecular weight polyethylene fiber that has an ultra-high elastic modulus. It is treated with cold gas plasma to enhance its adhesion to synthetic restorative materials, including chemical-
ly-cured or light-cured resin composites. The special fiber network of this material allows for the efficient transfer of forces acting on it. A finite-element stress analysis study reported that FRC post-core systems provide more adequate restoration by protecting the remaining tooth tissue with its elastic modulus close to dentin as compared to conventional rigid post-core systems. Although there are studies with fiber-reinforced composite in the literature, there is limited study about its effect on fracture resistance when used together with an extensive composite restoration. The reinforcement of composite restorations with fibrous assemblies can also change the effective fracture strength of the endodontically-treated teeth.

This in vitro study compared the effect of different restoration techniques, including amalgam, resin composite, indirect hybrid ceramic inlay and fiber-reinforced resin composite on the fracture resistance of endodontically-treated molars with MOD cavities.

**METHODS AND MATERIALS**

Sixty intact, non-carious, unrestored human mandibular molars freshly extracted for periodontal reasons with similar dimensions were selected. Any calculus and soft tissue deposits were removed from the teeth using a hand scaler (Gracey curette SG 17/18, Hu-Friedy, Chicago, IL, USA) and the teeth were stored in physiological saline at +4°C until used. The teeth were randomly assigned to six groups of 10 teeth each and subjected to the following procedures:

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

**Group 2 to 6:** Access cavities were prepared using a high-speed bur and water spray, and the canals were instrumented with K files to an apical size 35 using the stepback technique. Irrigation with 1 mL of 5.25% NaOCl preceded each file introduced into the canal. Following biomechanical preparation, the canals were dried with absorbent paper points (Diadent Group International Inc, ChongJu City, Korea) and obturated with gutta percha (Diadent) and AH Plus root canal sealer (Dentsply DeTrey, Konstanz, Germany) using cold lateral condensation. Then, Class II mesio-occluso-distal (MOD) cavities were prepared with the gingival cavosurface margin located 1.0 mm above the cemento-enamel junction. The buccolingual width of each cavity, measured with a digital caliper (Mitutoyo, Corp, Kawasaki, Japan), was half the intercuspal distance and extended into the pulp chamber. The depth of the cavities was 4.0 mm, without proximal steps and flat floor. The facial and lingual walls of the occlusal segment were prepared parallel to each other (Figure 1).

**Group 2:** This group was kept unrestored after MOD cavity preparation and endodontic treatment and was used as the positive control.

**Group 3:** The cavities were filled with high-copper amalgam (Cavex Avalloy-II spill, Lathe-cut silver alloy for dental amalgam, Holland), carved and polished after 24 hours.

**Group 4:** After priming for 20 seconds (Clearfil SE Primer) cavity surfaces were gently dried. Clearfil SE Bond was applied to the cavity surfaces and cured for 20 seconds. The cavities were then restored with a resin composite (Clearfil Photoposterior, Kuraray) using the incremental technique. The intensity of light in the light-curing unit (Lunar Curing Light, Benlioglu Dental Inc, Ankara, Turkey) was at least 500 mW/cm². Verification of the unit light intensity output was checked with the digital read-out light meter available with the unit every 10 samples during the study.

**Group 5:** After obtaining impressions of the cavity preparations, working models were fabricated. CR SEP II lacquer (Kuraray) was applied into the cavity preparation surfaces of the working models and dried with a gentle air stream. The cavity preparations were filled with incrementally placed hybrid ceramic material and hardened with a light-curing unit (Lunar Curing Light, Benlioglu Dental Inc, Ankara, Turkey) for three minutes followed by heat polymerization at 110°C for 15 minutes in an oven (KL-100, Kuraray) according to the manufacturer’s instructions. Then, the hybrid ceramic inlays were cemented with Panavia F (Kuraray) and light-cured for 60 seconds.

**Group 6:** After the priming and bonding procedures as in Group 4, the cavity surfaces were coated with flowable resin composite (Protect Liner F, Kuraray). Before curing, a piece of polyethylene ribbon fiber (8 mm long, 3 mm wide) (Ribbond) was cut and coated with adhesive resin. Excess material was removed and the fiber was
embedded inside the flowable composite in a buccal to lingual direction. After curing for 20 seconds, the cavities were restored with composite as described above.

One operator performed all of the preparations and restorations. The teeth were handled in moist gauze to prevent dehydration. In addition, a thin coat of wax was initially covered on the external root surface of all teeth. Plastic rectangular molds (4.5 cm x 2.5 cm margin and 2.5 cm high) were filled with autopolymerizing acrylic resin (Vertex, Zeist, Netherlands), and the teeth (4 teeth per mold) were vertically mounted to a level 1.0 mm apical to the CEJ, with the long axis of the tooth parallel to that of the mold. Then, after the wax on the root surfaces was eliminated using boiling water, the space formed between the root surface and the acrylic resin was filled with silicone paste (Dow Corning 3140 RTV coating, Dow Corning Corp, Midland, MI, USA) to 1 mm apical to the CEJ to simulate the periodontal ligament.

After finishing and polishing, all specimens, except Group 2, were put into an artificial oral environment for mechanical loading by the chewing simulation device. The specimens underwent 60,000 cycles x 50 N loading by the chewing simulation device at a frequency of 1.3 Hz.

The specimens were stored in 100% humidity at 37°C for one day before fracture testing. The specimens were then placed into a Universal Testing Machine (Instron, Canton, MA, USA) and loaded compressively at 1 mm/minute. A vertical compressive force was applied with a 6-mm diameter stainless steel bar. The bar contacted the occlusal surface of the restoration and buccal and lingual cusps of the teeth. The force necessary to fracture each tooth was recorded in Newtons (N) and the data was subjected to Kruskal-Wallis ANOVA and Mann-Whitney U tests for the six experimental conditions. The fractured specimens were then examined under 10x magnification using a stereomicroscope (Olympus, SZ4045TRPT, Tokyo, Japan) to determine the fracture mode.

### RESULTS

The mean fracture resistance (N) and standard deviation for each of the six experimental conditions are presented in Table 1.

Statistical analysis indicated that the fracture resistance of Group 1 was significantly higher than the other groups \( (p < 0.05) \). Teeth restored with amalgam, resin composite, indirect hybrid ceramic inlay and fiber-reinforced resin composite (Groups 3, 4, 5 and 6, respectively) showed increased fracture resistance when compared with the non-restored group (Group 2) \( (p < 0.05) \). No statistically significant differences were found among Groups 3, 4 and 6 \( (p > 0.05) \), and Group 5 had greater fracture resistance than Group 3 \( (p < 0.05) \). Also, Group 3 had the least fracture resistance of those groups receiving a restoration.

When the fracture modes were evaluated, all of the samples restored with amalgam (Group 3) demonstrated fracture with root involvement (Figure 2A). In Group 4 (resin composite), fractures involved more than half the crown of the tooth without root involvement (Figure 2B). The indirect hybrid ceramic inlay group (Group 5) tended to demonstrate only fractures

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**Table 1: The Mean Fracture Resistance and Standard Deviation for Each of the Six Experimental Conditions**

<table>
<thead>
<tr>
<th>Groups</th>
<th>n</th>
<th>Cavity</th>
<th>Restoration Type</th>
<th>Mean ± SD (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>10</td>
<td>intact</td>
<td>intact teeth</td>
<td>2485.3 ± 193.9*</td>
</tr>
<tr>
<td>Group 2</td>
<td>10</td>
<td>MOD non-restored</td>
<td>533.9 ± 59.4*</td>
<td></td>
</tr>
<tr>
<td>Group 3</td>
<td>10</td>
<td>MOD amalgam</td>
<td>1705.8 ± 135.7*</td>
<td></td>
</tr>
<tr>
<td>Group 4</td>
<td>10</td>
<td>MOD DBS + CR</td>
<td>2033.3 ± 137.6*</td>
<td></td>
</tr>
<tr>
<td>Group 5</td>
<td>10</td>
<td>MOD indirect hybrid ceramic inlay</td>
<td>2121.3 ± 156.5*</td>
<td></td>
</tr>
<tr>
<td>Group 6</td>
<td>10</td>
<td>MOD polyethylene fiber + FCR + DBS + CR</td>
<td>1908.9 ± 132.2*</td>
<td></td>
</tr>
</tbody>
</table>

*DBS, dentin bonding system; CR, resin composite; FCR, flowable resin composite. Similar letters indicate statistically similar values \( (p > 0.05) \).
of restorations rather than tooth structure (Figure 2C). In the fiber-reinforced resin composite group (Group 6), most of the observed failures were restoration fractures involving a portion of the tooth (Figure 2D).

**DISCUSSION**

The final success of endodontic treatment is dependent on the appropriate and timely coronal restoration of the endodontically-treated tooth, because the preservation of the remaining tooth structure after endodontic treatment is compromised.

Recent reports have indicated that the fracture resistance of endodontically-treated teeth was reduced because of tooth structure loss. Similarly, results of the current study also indicated that the strength of the teeth was reduced after cavity preparation. On the other hand, it is interesting to note that, in studies by Re and others and Blaser and others, there was no significant difference between fracture resistance of teeth that were intact and those that were prepared and unrestored.

Dentin provides the solid base required for tooth restoration. Its structural strength depends on the quality and integrity of its anatomic form, so the fundamental problem is the decreased quantity of sound dentin remaining that retains and supports the restoration. Consequently, an extensive MOD cavity preparation in an endodontically-treated tooth may cause cuspal fracture if the tooth is not restored. The results of the current study also showed that the restoration of an endodontically-treated tooth is important to achieve an increased resistance to fracture. Therefore, reinforcement of the cavity with a restorative material is necessary to support the remaining tooth structure.

Some studies on this subject have suggested that bonded composite restorations will better strengthen a tooth compared with amalgam, whereas others have not found a difference. Teeth with wide mesioocclusodistal (MOD) cavities restored with amalgam have frequently shown cusp failure due to the inability of this material to strengthen weakened cusps. Several studies have revealed a high fracture rate on endodontically-treated teeth restored with amalgam restorations. Accordingly, data from this study showed that endodontically-treated teeth restored with amalgam had lower fracture resistance compared to indirect-inlay restored teeth. However, in the current study, no statistically significant differences were found between the fracture strength of teeth restored with amalgam (Group 3), resin composite (Group 4) and fiber-reinforced resin composite (Group 6). According to Bell and others, the widely used restorative material amalgam does not bind the walls of the cusps together and thus does not strengthen the remaining tooth. Bell and others, in their study of cuspal failure in teeth restored with MOD amalgam, concluded that cusp fracture occurs as a result of brittle tooth structure fatigue caused by the propagation of microcracks under repeated loading.

Jagadish and Yogesh suggested that posterior resin composite has great potential as a cusp-reinforcing material. Studies by Gelb and others, Eakle and McCullock and Smith have also shown improved fracture resistance of teeth after using resin composites for MOD restorations. However, shrinkage of composite materials during polymerization is one of the prime factors that adversely affected the success of direct composite restorations. The polymerization reaction of light cured composites leads to the development of higher stresses when the resin composite is bonded to the cavity walls. Joynt and others suggested that the fracture resistance of premolars with MOD cavity preparations restored with resin composite may increase if an incremental resin placement and curing method is used. This is in accordance with the widely accepted belief that incremental composite placement results in reduced stress buildup at the tooth-restoration interface. Since layering concepts have been described as mandatory when working with resin composite materials, in this study, the authors used the incremental technique when placing resin composites.

In the current study, the authors found that there was no statistically significant difference between a resin composite restoration and a fiber-reinforced resin composite restoration. However, Belli and others found that the use of polyethylene ribbon fiber under composite restorations in root-filled teeth with MOD preparations produces greater fracture resistance than resin composite restorations. They suggested that polyethylene ribbon fiber had a stress-modifying effect along the restoration-dentin interface, and the bonding ability of fiber in combination with resin might have increased the fracture strength of the tooth by keeping both cusps together. The difference between both studies’ results may be because of the non-existence of standardized preparation and/or a standardized test model on this subject.

Estenia is a recently marketed indirect hybrid ceramic inlay material. No data are available with regard to its fracture strength. In the current study, there was a tendency for an Estenia indirect hybrid ceramic inlay to show greater fracture resistance than other restoration techniques; this difference was, however, not significant at the 95% level.

In addition to discussing fracture resistance values, it may be important to analyze the fracture modes in each experimental group. In the current study, although there was no difference between the amalgam, resin composite, fiber-reinforced composite restoration and
indirect hybrid ceramic inlay groups with respect to fracture strength, the indirect hybrid ceramic inlay group exhibited isolated fracture of the restoration, whereas the amalgam group showed serious fracture with root involvement.

Soares and others\textsuperscript{51} concluded that the method of root embedment to simulate the periodontal ligament has a significant effect on fracture resistance, and the artificial periodontal ligament may modify the fracture modes. Simulation of the periodontal ligament should be done with an elastomeric material that is able to undergo elastic deformation and reproduce the accommodation of the tooth in the alveolus, providing the non-concentration of stresses in the cervical region of the tooth. Moreover, it has been believed that the use of a rigid material (acrylic resin) to embed extracted teeth may lead to distorted load values and possibly affect the mode of failure of the specimens.\textsuperscript{12,53}

Therefore, in the current study, the roots were coated with a polyvinyl siloxane to simulate the periodontal ligament and surrounding anatomical structures and the roots were then embedded in acrylic resin.

The method of occlusal loading during the fracture test is another important factor. In this in vitro study, axial forces were applied to the center of the occlusal surface. Clinically, axial forces, in addition to lateral forces and fatigue loading, should be considered. Burke and others\textsuperscript{44} and Burke and Watts\textsuperscript{55} concluded that the best method for measuring the resistance of premolars to fracture is the use of a cylinder of a defined diameter. The use of a 6-mm steel sphere for resistance to fracture testing by Dietschi and others\textsuperscript{56} and Soares and others\textsuperscript{57} was shown to be ideal for molars, because it contacts the functional and non-functional cusps in positions close to those found clinically. Also, in the current study, the teeth were subjected to vertical compressive loading with a stainless steel sphere 6-mm in diameter.

The effect of masticatory stresses on teeth either restored or unrestored is variable. While sound teeth rarely fracture from mastication stress, cusp fracture may occur in teeth that have been weakened by caries and the cavity preparation required for restoration. While a fracture may not occur, deflection of a weakened cusp may open the tooth-restoration interface and lead to subsequent marginal leakage and secondary caries.\textsuperscript{5-12} Consequently, the applied forces on restorative materials during chewing may limit the service time of dental restorations. Therefore, in the current study, the teeth were loaded to failure (60,000 masticatory cycles) by the chewing simulation device before fracture testing. According to the literature, the wear produced by 240,000–250,000 masticatory cycles in a chewing simulator corresponded to the wear measured after one year of clinical service.\textsuperscript{46-59}

Therefore, to simulate a service time of three months, about 60,000 masticatory cycles have to be performed in a chewing simulator. However, the current authors' further study will report the effect of long-term chewing forces on fracture resistance of restorations placed in endodontically-treated teeth.

The clinical significance of these findings should consider that this study was carried out under in vitro conditions and the test was performed 24 hours after restoration. Longer-term thermal, chemical and physical stresses might further clarify the results. In addition, the method of continually increasing the load applied to the teeth in this study is not typical of the type of loading that occurs clinically. Ideally, more relevant test methods should be developed in which the behavior of in vitro tests would more closely mimic the clinical failure mechanisms of teeth and restorations. Further clinical investigations are recommended to verify the authors' in vitro results.

**CONCLUSIONS**

Within the limits of the current study, it can be concluded that:

1. MOD cavity preparations reduced fracture resistance of endodontically-treated teeth.
2. Although all of the restoration groups were stronger than the prepared-only group, none of the restoration techniques tested was able to completely restore fracture resistance lost during MOD cavity preparation.
3. Indirect hybrid ceramic inlay restorations in endodontically-treated molars with MOD cavities significantly increased fracture strength when compared with amalgam restorations.
4. When the fracture modes were considered, since indirect hybrid ceramic inlay restorations prevented unfavorable fractures of teeth under occlusal loading, it seems to be a more reliable restorative technique than amalgam, resin composite and fiber reinforced resin composite restorations for endodontically-treated molars with MOD cavities.

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**References**


