Effect of different onlay systems on fracture resistance and failure pattern of endodontically treated mandibular molars restored with and without glass fiber posts

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ABSTRACT: Purpose: To investigate the relationship between post and core build-up materials on the fracture resistance of endodontically treated teeth restored with different onlay restorations. Methods: 60 mandibular molars were endodontically treated and divided into three experimental groups that received one of the following onlay restorations: gold onlays, glass ceramic onlays (Empress I), or resin composite onlays (Gradia). Half of the specimens in each group received a fiber post (n=10). Two controls groups (n=10) were included: one group composed of sound mandibular molars, and the second group was composed of endodontically treated unrestored molars. Fracture tests were carried out by applying axial load using a universal loading machine until fracture. All fractured specimens were fractographically examined using a scanning electron microscope (SEM). Data were analyzed using two-way ANOVA and Tukey multiple comparison tests (α=0.05). Results: Statistical analysis showed that restoration of endodontically treated teeth with gold onlays improved fracture resistance when compared to glass ceramic or resin composite onlays. The presence of a fiber post significantly improved (P<0.045) fracture resistance of gold onlays from 2271 to 2874N while it did not influence the performance of the other two groups. Fractographic analyses revealed that the presence of fiber post resulted in more restorable fractures due to better stress distribution of the applied load. All onlay systems resulted in significant improvement of the fracture resistance compared to unrestored teeth (711N) but neither of them resulted in restoring the fracture resistance to match that of sound teeth (3212 N). (Am J Dent 2010;23:81-86).

CLINICAL SIGNIFICANCE: Placing a fiber post could improve the clinical performance of endodontically treated teeth restored with an onlay restoration especially when a gold onlay is used. The fracture resistance of endodontically treated teeth restored with onlays was higher than the average chewing load in the posterior region.

Introduction

Although endodontic treatment generally does not increase the brittleness of the treated tooth, a full coverage restoration is usually advocated to protect the tooth from fracture during function. Such practice is widely used especially when the remaining tooth structure is weakened by the absence of one coronal wall. As preservation of tooth structure is the main aim of minimally invasive dentistry, onlay restorations could be a more conservative alternative to full coverage restorations especially when the remaining coronal structure is intact.

Yamada et al. reported that endodontically treated maxillary premolars with mesio-occluso-distal (MOD) cavities could be successfully restored with cast metallic onlay and inlay restorations. Nowadays, ceramic onlays are popular due to their superior esthetics and biocompatibility and improved mechanical properties. All-ceramic restorations are generally adhesively cemented which increases the fracture resistance of the restored tooth and clinical studies have demonstrated acceptable results of posterior teeth restored with ceramic inlays and onlays. Direct composite onlays were also described and promoted a low cost alternative to ceramic crowns. A recent study advocated the use of indirect hybrid composite inlays to restore endodontically treated mandibular molars due to a more favorable failure mode and high fracture resistance compared with amalgam and direct resin composite. Nevertheless, fracture of endodontically treated teeth remains a common clinical occurrence. Many restoration designs have been suggested in an attempt to increase fracture resistance of endodontically treated teeth including complete or partial coverage restorations with and without post and core build-up material. Fiber-reinforced composite (FRC) posts were introduced to help improve stress distribution due to their elastic modulus closer to that of dentin when compared with metallic posts. Several in vitro studies reported higher fracture resistance and more favorable failure patterns for teeth restored with FRC posts, with different restorative systems. Similarly, in vivo studies showed a high success rate of endodontically treated teeth restored with FRC posts.

This study compared the fracture resistance and failure modes of endodontically treated mandibular molars restored with different types of onlay restorations and investigated the effect of placing a fiber post on their performance. The null hypothesis tested was that the fracture resistance and failure pattern of endodontically treated teeth was not influenced by the use of a fiber post nor by the type of onlay restoration.

Materials and Methods

Eighty human mandibular molars free from caries or previous restorations were selected for the study. Teeth were cleaned from external debris, examined using trans-illumination light to detect the presence of any cracks, and were stored in an incubator at 37°C at 90% relative humidity. A digital x-ray image was made for each tooth and the pulp chamber was

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accessed following standardized endodontic procedures. Sixty of these teeth were randomly selected for the experimental groups. After endodontic access was performed, canal patency was achieved by passing size #10 K-file into the root canal until its tip was visible at the apical foramen.

Root canals were instrumented using stainless steel K-files #10, 15, 20 and Glyde to the working length, which was established visually 1 mm from the anatomic foramen. Shaping was continued using rotary nickel-titanium instruments (ProTaper) according to the manufacturer’s instructions to F2 size (8% taper, 20/100 tip diameter). Root canals were regularly irrigated between instrumentation with 2 ml of 5.25% sodium hypochlorite. All root canal space was obturated using the warm vertical condensation technique, using calibrated gutta-percha points (F2) and an endodontic sealer (AH26). Each tooth was embedded in a block of self-polymerizing acrylic resin (Jet Ki) with the long axis perpendicular to the base of the block and with the acrylic resin ending 2 mm below the cement-enamel junction. Prior to embedding, a thin layer of glycerin was first applied with a micro-brush on the root surface and the tooth was carefully removed from the block after polymerization of the acrylic resin.

To simulate the presence of a layer of periodontal ligament, vinyl polysiloxane impression material (Flexitime) was injected into the acrylic resin molds and the tooth was inserted again under a fixed load of 200g until complete setting of the impression material resulting in a 0.5 mm thick layer.

Preparation of the specimens - MOD cavities were first prepared for the endodontically treated teeth by coarse diamond coated stone (Universal Prep set) using in a high-speed handpiece (Intramatic Lux 2 24LN) placed in a surveyor under water-cooling. The standardized dimensions of the tapered preparation were 4.0 mm in width and 3.5 mm in depth at the occlusal isthmus, all walls having 12° divergence towards the occlusal plane. A 1.5 mm occlusal reduction was performed on the buccal and lingual cusps resulting in horizontal flattening of the cusps. A 1 mm- wide chamfer finish line was then prepared on the entire periphery. Sixty of these teeth were then randomly distributed into three groups (n=20). Half of the specimens in each group received a fiber post according to the following procedures:

Root canal filling material was removed from the distal root with a Largo drill No.1 to a depth of 7 mm while keeping at least 4 mm of root filling intact to preserve the apical seal. The post-space was prepared with calibrated drills and 17% EDTA was used to clean the root canal walls. A translucent quartz-fiber post, DT Light-Post #1 was selected for restoration of the specimens. Each post was cut to the required length using a diamond stone ensuring at least 2 mm emergence outside the root canal orifice. Post surfaces were coated with a silane coupling agent (Calibra) for 60 seconds, then air-dried. The canal walls were etched with 34% phosphoric acid (Tooth conditioner gel) for 15 seconds, then rinsed and dried with paper points. Root surface was conditioned (Prime & Bond NT Duel Cure) according to the manufacturer’s instructions using a microbrush (Microbrush X) and excess primer was removed using paper points. The posts were then luted using a resin cement (Calibra), which was activated with a halogen light unit (Astralis 10) for 40 seconds with the tip of the unit directly in contact with the post. The remaining specimens that did not receive a fiber post were restored with a layer of flowable composite (UniFil Flow) which was placed on the pulpal floor and light polymerized for 20 seconds using the same unit.

The specimens were then restored with different types of MOD onlay restorations: gold platinum onlays (Midas), a glass ceramic (Empress 1), or a micro-filled hybrid resin composite (Gradia Direct) according to manufacturers’ instructions. A single-phase impression was made using vinyl polysiloxane impression material (Aquasil) and master dies were fabricated with type IV dental stone (Jad Stone). For the metallic and ceramic onlays, a wax pattern was built up using pattern inlay wax and was further processed using the lost wax technique.

For the resin composite restorations, a self-etching light-polymerized adhesive resin (G-Bon) was applied for 10 seconds after which it was air-thinned and light polymerized for 10 seconds according to manufacturer’s instructions. A flowable composite (UniFil Flow) was placed on the pulpal floor and light polymerized for 20 seconds followed by a 2 mm incremental build-up technique using a hybrid resin composite (Gradia Direct), each layer being light polymerized for 40 seconds. A template was used to achieve occlusal shape consistency.

The remaining 20 teeth were divided into two control groups: 10 sound mandibular molars were used to assess the fracture resistance of sound teeth while 10 teeth received the same root canal treatments and cavity preparation designs as the experimental groups but were not restored.

Cementation - For gold onlays, the inner surface was airborne particle abraded with 50 μm alumina powder, then rinsed with water spray and dried while the inner surface of the ceramic onlays was etched by applying hydrofluoric acid (IPS ceramic etching gel) for 20 seconds. After thorough rinsing and drying the inner surface of the ceramic onlays was coated with a silane monomer (Calibra) for 60 seconds.

All specimens were bonded using the total etch technique. The cavity walls were etched for 15 seconds with a layer of 34% phosphoric acid (Tooth conditioner gel), conditioned for 15 seconds (Prime & Bond NT Dual Cure), then a dual polymerization resin cement (Calibra) was used for cementation of the onlays according to the manufacturer’s instructions. The restorations were seated and held in position; gross excess was removed immediately with a micro-brush.

Fracture resistance test - Each specimen was inserted into the holding device and a controlled load was applied using a stainless steel rod with a 3 mm tip-diameter in a direction parallel to the longitudinal axis of the restored teeth using a universal loading machine (Triaxial Tester T400 Digital) at a crosshead speed of 1 mm/minute. All specimens were loaded until fracture and the maximum breaking loads were recorded in Newtons (N). All fractured specimens were ultrasonically cleaned and perfused with India ink to highlight the fracture lines. The failure mode was visually evaluated and classified as restorable or non-restorable (Figs. 1, 2). Restorable specimens were inspected for the presence of micro-cracks using a stereomicroscope (Zeiss OpMi) at different magnifications.
Fig. 1. Relation between placement of fiber posts in endodontically-treated teeth and the type of tooth fracture exhibited after vertical loading stresses. In the presence of a post, frequency of restorable restorations was significantly higher.

Fig. 2. Restorable fractures (A) were characterized by horizontal fractures, oblique fractures not reaching the cemento-enamel junction, or fractures of the restoration. Unrestorable fractures (B) were characterized by vertical fractures or oblique fractures violating the cemento-enamel junction.

Fig. 3. SEM image of cone cracks on the occlusal surface of a loaded onlay. The inner and outer cone cracks appear limited but are deeply extended into the structure.

The fracture origin of the specimen was identified using scanning electron microscopy (XL30®).

Data were analyzed using two-way ANOVA and Tukey multiple comparison tests (SPSS 12.0®) to examine the effects of onlay type and the presence/absence of a fiber post on fracture resistance (α=0.05).

Results

Statistical analysis revealed that sound teeth had the highest fracture resistance (3212 N) compared to other test groups (P< 0.001) while unrestored teeth proved to be the weakest (711 N). There was a significant interaction between the fracture resistance of endodontically treated teeth and the type of the onlay material (P< 0.0001). Insertion of a fiber post was a significant factor that improved the fracture resistance of teeth restored with gold onlays (P< 0.045) although it did not show any beneficial effect for the other materials tested. Moreover, Pearson chi-square test revealed that the presence of a fiber post was associated with higher percentage of restorable fractures compared to the specimens restored with the same onlay material but without a fiber post (P< 0.01), (Figs. 1, 2, Table).

Fractographic analysis revealed that gold onlays failed due to fracture of the supporting tooth structure while the onlay restoration remained intact. On the other hand, all-ceramic and composite resin restorations failed due to formation of cone cracks under the loading indenter which propagated apically to fracture the entire restoration (Figs. 3, 4).

Discussion

Based on the data of this study, the proposed hypothesis was rejected. This study was designed to measure the fracture resistance and failure pattern of mandibular molars restored with different types of onlay restorations in the presence or absence of the placement of translucent fiber-reinforced post. In order to produce a clinically relevant data, several factors were
considered. The tested specimens mimicked an unfavorable scenario resulting in the loss of tooth structure following standard endodontic treatment which required a Class II MOD cavity preparation.\textsuperscript{31} Using a surveyor insured that all cavity preparations were identical which guaranteed equal stress distribution for all specimens. A layer of rubbery impression material was used to simulate the function of the periodontium, as its presence was found to have a significant effect on the results of several fracture strength tests.\textsuperscript{32} Moreover, a resin bonding technique was selected for the cementation of the restorations which was proven to improve the strength of all-ceramic restorations.\textsuperscript{33} On the other hand, there are concerns that fracture strength tests do not mimic the in vivo situation where fatigue and biodegradation are the main sources of structural damage.

In accordance with previous studies conducted on full coverage crowns, insertion of fiber posts improved the fracture resistance of gold onlays which required a significantly higher load to be fractured.\textsuperscript{24,25,27} A recent study\textsuperscript{20} showed that the presence of a glass-fiber post under a full coverage crown enhanced its resistance to fracture. On the contrary, the presence of a fiber post did not result in improving the fracture resistance of the ceramic or resin composite onlay restoration. Such a finding could be related to the limited number of specimens used in each group which could have a negative influence on the power of the statistical test of choice or due to the presence of structural differences in the tested teeth which are known to directly influence their mechanical properties.\textsuperscript{34} The use of artificial teeth could solve this problem but on the other hand could totally ignore the influence of active bonding of the inserted restorations.\textsuperscript{25}

With consideration to the maximum chewing forces of the stomatognathic system (880 N),\textsuperscript{36,37} the lowest fracture load recorded for restored teeth in this study (1544.67 N) was almost double the previous value. Thus, it could be presumed that either of the tested groups could function sufficiently under normal functional loads. However, this study followed a cross-sectional design and as such does not take into account factors such as aging, cyclic loading, time or parafunctional habits that might modify force distribution patterns.\textsuperscript{38} On the other hand, teeth that did not receive proper restoration (control group) are expected to fracture under function (711 N).

Fractographic analysis confirmed the findings made in previous studies\textsuperscript{15,29,40} as it appeared to have a positive effect on fracture patterns observed for all groups. Meanwhile insertion of a fiber post did not improve the fracture resistance of the tested restorations, it resulted in higher percentage of restorable fractures which might be even of more clinical importance regarding the fate of the restored tooth after the event of fracture. This is particularly interesting in the case of gold onlays where prosthodontics textbooks generally do not advocate the placement of a fiber post.\textsuperscript{41} The results produced in this study clearly demonstrate that using a fiber post in combination with a gold onlay significantly increases its resistance to fracture by almost 27% and increased its percentage of favorable fractures from 20-80%. Insertion of a post could help distribution of the loading force over a larger surface area which includes the surface area of the prepared root canals.

The higher fracture load associated with gold onlays could be related to the ductility of the used alloy which allows for a higher degree of plastic deformation under the loading indenter without generation of cone cracks and structural damage which were proven to be the major source of damage for all-ceramic restorations resulting in direct failure at lower loads.\textsuperscript{42}

A finite element analysis (FEA) study\textsuperscript{43} showed that millinary molars restored with onlays are mainly subject to compressive interfacial stresses; another FEA study\textsuperscript{4} of ceramic inlay and onlay restorations in endodontically treated premolars reported that maximum shear stress was noted where enamel, dentin and restoration came together and at the axiogingival and axiopulpal line angles. Thus, the ductility of the used alloy allowed for a better stress distribution both under the loading indenter as well as along the entire cavity walls which was reflected on the ability of the tooth to sustain more occlusal load. At such high loads, the fiber post absorbs part of the delivered occlusal loads and redistributes these stresses along the entire root surface, which resulted in higher fracture resistance of the restored teeth. On the other hand, the insertion of a fiber post was not beneficial for all-ceramic or composite resin onlays as these restorations failed from the loading point and thus the post did not perform as a stress absorbing element in this situation. Insertion of a stress breaker between the loading indenter and the restoration could prevent the generation of high stress concentration areas.

In a clinical report,\textsuperscript{44} endodontically treated teeth restored with glass fiber posts and Gradia Direct resin composite restorations showed favorable clinical outcomes after 30 months of clinical service. The present study suggests that direct onlay restorations with Gradia have more or less the same fracture resistance and similar fracture patterns as Empress I all-ceramic onlay restorations. Further studies are required to test different types of resin composites, the longevity of such restorations, as well as other potential factors such as the influence of ferrule effect or the influence of the number of residual walls.\textsuperscript{45} Ferrari et al\textsuperscript{27} reported that the absence of structurally sound residual walls was associated with crown dislodgment and debonding of the fiber post under occlusal loading especially when the opposing dentition is a natural tooth. They concluded that it was crucial to preserve as much coronal residual dentin as possible during post preparation and placement which could be a direct advantage of onlay restorations compared to full coverage restorations which require a more aggressive preparation of the tooth structure.

Within the limitations of this study, restoration of endodontically treated mandibular molars with resin composite restorations and fiber posts may be considered as a new treatment strategy compared to the full coverage restoration especially when the reported failure load was much higher than the average chewing load in the posterior region. Insertion of a fiber post in combination with gold onlay restorations may improve the fracture resistance of the restored teeth.

\begin{itemize}
  \item a. Dentsply-Maillefer, Ballaigues, Switzerland.
  \item b. Lang Dental Manufacturing Co., Wheeling, IL, USA.
  \item c. Heraeus-Kulzer, Hanau, Germany.
  \item d. Intensiv SA, Viganello, Switzerland.
  \item e. Kavo, Biberach/Riss, Germany.
  \item f. RTD, Saint-Egreve, France.
\end{itemize}
Fracture resistance of onlay systems and glass fiber post-


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### Articles Accepted for Publication

- **Resin composite polyethylene fiber reinforcement: Effect on fracture resistance of weakened marginal ridges.**
  M.F. Ayad, A.A. Maghrabi & F. Garcia-Godoy

- **Controlled, prospective clinical split-mouth study of cast gold vs. ceramic partial crowns: 5.5 year results.**
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  M.M. Nayif, Y. Shimada, S. Ichinose & J. Tagami

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- **Microtensile bond strength of two-step etch-and-rinse adhesive systems on sound and artificial caries-affected dentin.**

- **Effect of DPSS laser on the shear bond strength of orthodontic brackets.**

- **Effect of chlorhexidine on bond strength of two-step etch-and-rinse adhesive systems to dentin of primary and permanent teeth.**
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