Influence of endodontic treatment, post insertion, and ceramic restoration on the fracture resistance of maxillary premolars

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Abstract


Aim To investigate the effects of endodontic treatment, post placement and ceramic restoration type on the fracture resistance of premolars.

Methodology One hundred and twenty teeth maxillary premolars were allocated to four groups (A–D; n = 30). In group A, mesio-occlusal-distal-inlays with a buccal and palatal wall of 2 mm (MOD), in group B partial onlays with palatal cusp coverage and in group C total onlays with buccal and palatal cusp coverage were prepared. Group D served as untreated controls. Groups A–C were divided into three subgroups (n = 10): (i) teeth received solely the described preparations, (ii) teeth were root filled, (iii) teeth were root filled and quartz fibre posts were placed. Teeth were restored using Computer-assisted design/computer-assisted machining-ceramic-restorations and subjected to thermo-mechanical-loading; subsequently, the buccal cusp was loaded until fracture.

Results Group D revealed significantly higher fracture resistance [mean (standard deviation)] [738 (272) N] compared to all other groups (P < 0.05; post hoc test Dunnett). For groups A–C, fracture resistance was significantly affected by the restoration type (P = 0.043) and endodontic treatment/post placement (P = 0.039; 2-way ANOVA). Group A [380 (146) N] showed significantly lower fracture resistance compared to group B [470 (158) N] (P = 0.048; post hoc test Tukey). Compared to non-endodontically treated teeth [487 (120) N], root filled teeth revealed significantly lower fracture resistance [389 (171) N] (P = 0.031).

Conclusion The restoration of cavities with a remaining wall thickness of 2 mm using ceramic MOD-inlays is inferior with respect to the fracture resistance compared to partial onlay restorations. Root filled teeth without post placement show lower fracture resistance compared to non-endodontically treated teeth.

Keywords: ceramic inlays, ceramic onlays, fibre post, fracture resistance, post-endodontic restoration, thermo-mechanical loading.

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Introduction

Maxillary premolar teeth have an unfavourable anatomical shape, crown volume and crown/root proportion, thus making them more susceptible to cusp fracture compared to other posterior teeth (Mondelli et al. 1980, Schwartz & Robbins 2004). It has also been
assumed for maxillary premolars that non-functional cusps of restored teeth are more susceptible to fractures compared with functional cusps (Cavel et al. 1985, Burke 1992).

Root canal treatment and the preparation of mesio-occlusal-distal (MOD) cavities have been shown to reduce the fracture strength of teeth (Reeh et al. 1989, Hansen et al. 1990). Moreover, clinical experience has revealed that maxillary premolars with deep MOD cavities are susceptible to fracture when eccentric forces are applied (Steele & Johnson 1999). On the other side, adhesively luted composite or ceramic MOD-restorations have been shown to provide internal reinforcement of teeth without occlusal coverage (Ausiello et al. 1997, Bremer & Geurtsen 2001, St-Georges et al. 2003, Hannig et al. 2005). Moreover, these restorations preserve sound tooth structure and appearance. Controversy exists whether the restored teeth reach the fracture toughness of sound teeth (Ausiello et al. 1997, Hannig et al. 2005, Habekost et al. 2007) or not (Siso et al. 2007, Soares et al. 2008b).

Adhesively luted ceramic materials demonstrate a good aesthetic appearance and a functional treatment option and provide biocompatibility, resistance to wear and a similar coefficient of thermal expansion compared to teeth (Ritter & Baratieri 1999). Ceramic materials are more brittle but tend to stiffen the cusps compared to composite resin that has been considered to be more compliant and tends to distribute loading forces by deformation (Magne & Belser 2003). However, information about the extension limits of ceramic MOD inlay restorations and recommendations for ceramic total- or partial-coverage restorations is scarce (Ritter & Baratieri 1999). It has been suggested that adhesive inlay restorations might be an alternative restorative treatment for root filled teeth compared to cuspal coverage restorations if a normal occlusion (without parafunction) is present (Steele & Johnson 1999, Krejci et al. 2003). Initial cuspal deformation after subcritical loading was lower with ceramic inlays if compared to composite resins, thus indicating a cusp-stabilizing effect (Magne & Oganeyan 2009), and one laboratory study demonstrated an even higher fracture resistance with ceramic inlays compared to onlay restorations (Habekost et al. 2006).

Posts are frequently used to retain the coronal restoration of root canal filled teeth, but they do not reinforce the root (Sorensen & Martinoff 1984). Fibre posts have been suggested as a viable alternative compared to metal posts (Bateman et al. 2003, Schwartz & Fransman 2005) and are increasingly used in dental practice. However, the effect of post insertion on the fracture resistance of root filled teeth is controversial. One clinical study indicated a significantly higher survival rate for premolars with two or less remaining coronal walls that were restored with posts compared with teeth that were restored without posts. Moreover, teeth with one or two residual walls before abutment build-up that were restored without posts revealed significantly more vertical root fractures (Ferrari et al. 2007, Cugidiaco et al. 2008). For central incisors, laboratory studies demonstrated a higher fracture resistance for teeth restored using fibre posts compared to teeth that were restored without posts (Naumann et al. 2007, Salameh et al. 2008). Furthermore, teeth restored using fibre posts revealed predominantly restorable failure modes (Akkayan & Gulmez 2002, Salameh et al. 2008). However, another randomized prospective clinical trial demonstrated that fibre post placement was efficacious to reduce failures of post-endodontic restorations only for teeth with no residual coronal wall (Bitter et al. 2009). Moreover, laboratory studies did not show a significantly increased fracture resistance molars and premolars restored using fibre posts (Salameh et al. 2006, Sorrentino et al. 2007), although more unrestorable failure modes have been demonstrated for teeth restored without posts.

The aim of the present study was to investigate the effects of root canal treatment and quartz fibre post insertion as well as the ceramic restoration type on the fracture resistance of the buccal cusp of maxillary premolars with respect to the observed failure modes. The null hypotheses were (i) that the fracture resistance of intact maxillary premolars will not differ from the restored teeth and (ii) that root canal treatment and post placement as well as the restoration type will not affect the fracture resistance of maxillary premolars.

**Materials and methods**

For the present study, 120 sound human maxillary first premolars extracted for periodontal or orthodontic reasons with two separated root canals in all cases were used. After soft tissue removal, the teeth were stored in 0.5% chloramine solution (Pharmacy of Charité, Universitätsmedizin Berlin, Berlin) before use. Teeth showing cracks under magnification (10×) were excluded. Additionally, teeth falling below or above the size limits of 8.8–9.6 mm bucco-palatal distance, 6.2–6.8 mm mesio-distal distance and 4.9–5.7 interocclusal distance (from palatal cusp tip to buccal
(cusp tip) were excluded to avoid outliers. The roots of the teeth were embedded parallel to the long axis of the teeth into acrylic resin (Technovit 4071; Heraeus Kulzer, Wehrheim, Germany) up to 2 mm below the cemento-enamel-junction (CEJ) using copper rings. No simulation of the periodontal ligament was performed. The teeth were then randomly allocated to four groups ($n = 30$). Of each tooth, an impression was made using a heavy-bodied vinyl polysiloxane material (Express; 3M ESPE, Seefeld, Germany), which was sectioned and used as an anatomical guide during tooth reduction.

In group A, teeth received standardized cavity preparations for MOD inlays with a 6-degree divergence of the walls of the occlusal and proximal boxes (Fig. 1). Preparation and finishing were performed using tapered diamond rotary cutting instruments (847KR.314.023, 8847KR.314.023, 847KREF.314.023; Brasseler/Komet, Lemgo, Germany), with sufficient water cooling. To allow adjustment of preparation to anatomic variability, the teeth were prepared free-hand. The occlusal preparation was extended to a buccal and palatal wall thickness of 2 mm measured at the occlusal floor. The depth of the occlusal preparation was 2 mm. The cervical margins of the proximal boxes were located 1 mm below the CEJ and 2.5 mm below the occlusal floor. The bucco-palatal widths in the proximal boxes were similar to the occlusal isthmus width. Margins were not bevelled. In group B, MOD cavity preparations were performed as in group A. Additionally, a 2 mm reduction in the functional palatal cusp was performed to prepare a partial onlay.

In group C, the preparation was conducted as in group B, completed by an additional 2 mm reduction in the buccal cusp. In group D, teeth remained untreated (control).

Groups A–C were divided into three subgroups: (i) teeth received solely the described preparation forms for simulating teeth with vital pulps ($n = 10$); (ii) teeth were root filled treated before preparation ($n = 10$); (iii) teeth were root filled and quartz fibre posts (DT Light Post Size 2; VDW, München, Germany) were inserted prior to final cavity preparation ($n = 10$).

For root canal treatment, the middle and coronal thirds of the root canals were enlarged using sizes 1–4 Gates Glidden burs (VDW) in descending order. Subsequently, the instrumentation of the root canals was performed at a working length of 1 mm from the apical foramen using FlexMaster rotary instruments (VDW) in a crown-down technique. Apical enlargement was performed to size 35, .02 taper. Irrigation (Endoneedle; Vedefar, Dilbeek, Belgium) was performed using 1 mL of 1% NaOCl solution (Pharmacy of Charité) after every change of file size throughout the cleaning and shaping of the root canal. After drying canals with paper points, teeth were filled by means of cold lateral condensation using AH plus endodontic sealer (DeTrey Dentsply, Konstanz, Germany). Size 35 gutta-percha points (VDW) served as master cones and size 20 and 25 gutta-percha points were used as accessory points. Coronal surplus of the root canal filling was removed with a heated excavator; subsequently, the pulp chambers were temporarily filled with Cavit (3M ESPE) and stored for 24 h at 37°C in 100% humidity. In groups A2, B2 and C2, the access cavities were filled with an auto-curing resin composite and the corresponding total-etch adhesive system (Clearfil Core/New Bond; Kuraray, Osaka, Japan), and the preparations for the respective restoration forms were performed. In groups A3, B3, and C3, a quartz fibre post (DT Light Post) was inserted using Clearfil Core/New Bond. Post space preparation was performed in the palatal canal in all cases using the drills provided by the manufacturer at a length of 8 mm, thus leaving an apical seal of 4 mm of the root filling. Prior to post insertion, the post was cleaned using 2-propanol, and this was followed by the application of a silane coupling agent (Monobond S; Ivoclar Vivadent, Schaan, Liechtenstein). The root canal was etched using phosphoric acid (Total Etch:...
Ivoclar Vivadent) for 15 s, thoroughly rinsed and dried using paper points. Subsequently, the chemically cur- ing adhesive system New Bond was applied and excess was removed also using paper points.

Computer-assisted design/computer-assisted machining (CAD/CAM) ceramic restorations (CEREC; Sirona, Bensheim, Germany) were fabricated with the CEREC 3 D system using the software package provided (Version 2.80R2402; Sirona). Leucite reinforced glass ceramic (IPS Empress CAD; Ivoclar Vivadent) was used for fabrication of the ceramic restorations. Prior insertion, the ceramic restorations were etched using 9% hydrofluoric acid (Ultradent Porcelain Etch; Ultradent Products, South Jordan, UT, USA) for 60 s. Subsequently, restorations were rinsed under running water for 60 s and dried with air for 30 s. A silane coupling agent (Monobond S) was applied and allowed to dry for 3 min. The enamel margins of the prepared cavities were etched first using 35% phosphoric acid (Total Etch, Ivoclar Vivadent) for 30 s, followed by etching of the dentin for another 30 s; subsequently, the etching gel was rinsed with water for 30 s. Excite DSC (Ivoclar Vivadent) was applied onto the intaglio surface of the restoration and cavity preparation according to the manufacturer’s recommendations without light polymerization, and the restorations were placed using Variolink II (Ivoclar Vivadent) and light curing was performed from mesial, distal, and occlusal directions for 40 s each (Elipar Freelight 2; 3M ESPE). Margins of the restorations were finished using a 15-μm-grit diamond rotary cutting instrument (379 EF 018; Brasseler/Komet) followed by polishing discs (Soflex; 3M Espe).

After placement of the restorations, specimens were stored in water for 21 days at 37 °C and subsequently subjected to thermal-mechanical loading. Chewing simulation was performed with 500,000 cycles occlusal load of 49 N in horizontal direction (Willytec chewing simulator; Mechatronik, Feldkirchen-Westerhamm, Germany). The incline of the buccal and palatal cusps were loaded simultaneously with a spherical antagonist that was positioned centrally on the tooth. Subsequently, specimens were subjected to 5,000 thermal cycles in deionized water from 5–55 °C with dwelling time of 30 s in each bath and a transfer time of 2 s.

The fracture resistance of the buccal cusp was tested using a universal testing machine (Zwick; Roell, Ulm, Germany), and the load was applied using a steel ball (diameter 3.5 mm) in a 30° angle to the long axis of the tooth with a cross head speed of 0.5 mm min⁻¹. The applied force (N) at fracture was measured. Four categories were used for the description of the failure modes. Failure types I (fractures buccal in the restoration continuing into the tooth structure below the CEJ) (Fig. 2a) and II (fractures central in the restoration continuing into the tooth structure below the CEJ) (Fig. 2b) were classified as non-restorable failures.

![Figure 2](a–d) Representative images of the four observed failure modes. (a) Unrestorable fracture of the buccal part of the restoration and tooth structure below the cemento-enamel-junction (CEJ). (b) Unrestorable fracture central in the restoration and buccal in the tooth structure below the CEJ. (c) Restorable fracture central in the restoration. (d) Restorable fracture palatal between tooth structure and restoration.
Failure types III (fractures central in the restoration not continuing into the tooth structure) (Fig. 2c) and IV (fractures between restoration and tooth structure palatal but not continuing below the CEJ) (Fig. 2d) were regarded as restorable fractures. Failures during chewing simulation were comprised with a fracture resistance of 0 N into the analyses (Butz et al. 2001, Naumann et al. 2008).

Statistical analysis was performed using spss version 16.0 software (SPSS, Chicago, IL, USA). The alpha (Type I) error level was set to 0.05. To investigate differences in fracture resistance between all investigated groups, one-way ANOVA was computed, and this was followed by post hoc tests for multiple comparisons (Dunnett). In secondary analyses, contrasts were tested within the nine subgroups for those pairs of subgroups differing in only one of the two factors (endodontic treatment/post insertion and ceramic restoration type).

The effects of endodontic treatment/post insertion and ceramic restoration type on fracture resistance in groups A–C were analysed using two-way ANOVA followed by Tukey-HSD (honestly significant difference) post hoc test. The failure modes were analysed with respect to endodontic treatment/post insertion using Chi-square test.

**Results**

Two specimens from groups A2 and B2 failed during chewing simulation. One-way ANOVA revealed significant differences in fracture resistance between groups (P < 0.0005). The control group (D) showed significantly higher fracture resistance [738 (272) N] compared to all restored groups A–C (P < 0.05; Dunett). A descriptive presentation of the mean fracture resistance in each group is given in Table 1.

Within groups A–C, fracture resistance was significantly affected by restoration type (P = 0.043) and by endodontic treatment/post insertion (P = 0.039; 2-way ANOVA). Group A [380 (146) N] showed significantly lower fracture resistance compared with group B [470 (158) N] (P = 0.048; Tukey-HSD), but no significant difference to group C [453 (158) N]. No significant interaction could be observed between the factors restoration type and endodontic treatment/post insertion (P = 0.201). Endodontically treated teeth revealed significantly lower fracture resistance [389 (171) N] compared to non-endodontically treated teeth [487 (120) N] (P = 0.031; Tukey-HSD), but did not differ significantly from endodontically treated teeth.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Descriptive presentation of the mean fracture resistance (in N) and standard deviation (SD) of all investigated treatment groups (n = 10) and control group (n = 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>MOD-inlay</td>
</tr>
<tr>
<td>No endodontic treatment</td>
<td>402 (108)</td>
</tr>
<tr>
<td>Endodontic treatment</td>
<td>401 (216)</td>
</tr>
<tr>
<td>Endodontic treatment + post</td>
<td>336 (114)</td>
</tr>
</tbody>
</table>

MOD, mesio-occlusal-distal.

Table 2 Analyses of the failure modes in numbers in each group

<table>
<thead>
<tr>
<th>Failure mode</th>
<th>Unrestorable</th>
<th>Restorable</th>
<th>Not to assess</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>I</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td>Buccal in rest + tooth</td>
<td>Central in rest + tooth</td>
<td>Central in rest</td>
<td>Between tooth + rest palatal</td>
</tr>
<tr>
<td>A1: MOD</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>B1: partial onlay</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>C1: total onlay</td>
<td>3</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>A2: MOD</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B2: partial onlay</td>
<td>4</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>C2: total onlay</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>A3: MOD</td>
<td>8</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>B3: partial onlay</td>
<td>8</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>C3: total onlay</td>
<td>8</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>22</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

Superscript letters indicate significant differences between restored groups according to Chi-square test (P < 0.05). MOD, mesio-occlusal-distal.
Fracture resistance of maxillary premolars  Bitter et al.

with fibre post insertion [427 (124) N] (P = 0.574; Tukey-HSD). Subgroup analyses only revealed significantly different fracture resistance for one of the 18 comparisons. Group A3 [336 (114) N] showed significantly lower values compared to group B3 [514 (131) N] (D = 177.4,  P = 0.037; ANOVA). D denotes the difference of means.

The failure modes were significantly affected by endodontic treatment/post insertion (P < 0.0005; Chi-square test) and are displayed according to the groups in Table 2.

The failure modes of root filled teeth with post insertion differed significantly from teeth with endodontic treatment (P = 0.013) and from teeth without endodontic treatment (P < 0.0005; Chi-square test).Posted teeth revealed significantly more unrestorable failure modes (Table 2).

Discussion

In the present study, significantly lower fracture resistance for all restored groups could be found compared to sound controls, irrespectively of the ceramic restoration type. Thus, the first null hypothesis of the present study could be rejected. This is in accordance with previously published results (Habekost et al. 2006, Siso et al. 2007, Dejak & Mlotkowski 2008, Soares et al. 2008b). However, other authors reported similar fracture loads for sound teeth compared to adhesive MOD restorations (Ausiello et al. 1997, Hannig et al. 2005, Soares et al. 2008a). In this aspect, the dimension of the occlusal isthmus of the cavity plays an important role and was less in the mentioned studies compared to the presently investigated MOD preparation design. Moreover, cavity depth and occlusal isthmus widths have been shown to be critical factors for cusp fractures (Khera et al. 1991, Lin et al. 2001). Additionally, it should be considered that the cervical margin of the proximal boxes of the investigated cavities were located below the CEJ and not inside the enamel, which could have affected the stability of the restorations, in particular with regard to the thermo-mechanical loading regimen. Moreover, micro-leakage at cervical margins has been found to be significantly higher in dentine compared to enamel (Manhart et al. 2001, Mota et al. 2003).

Ceramic restoration type as well as endodontic treatment significantly affected the fracture resistance; and consequently, the second null hypothesis of the present study could be rejected too. MOD inlay restorations of non-endodontically treated teeth revealed significantly lower fracture resistance compared to total onlays and MOD inlay restorations of posted teeth showed a significantly lower fracture resistance compared to partial onlays in the present study. However, the subgroup analyses for pairwise comparisons revealed only a significant difference between MOD inlay restoration of posted teeth compared to partial onlays of posted teeth. Previously published results showed higher fracture resistance of MOD-inlays compared to partial or total onlays using a central load application (Habekost et al. 2006). The cited study analysed MOD inlays with an isthmus width of half of the intercuspid distance, which is considerably less compared to the present preparation design, and specimens were not subjected to thermo-mechanical loading. Moreover, it might be speculated that the insertion of a fibre post represents an additional adhesive interface in the restored tooth, which could participate in the propagation of microcracks, thus leading to a reduced fracture resistance of MOD-inlay restorations.

Endodontic treatment requires the removal of additional tooth structure including the roof of the pulp chamber, thus resulting in a decreased fracture resistance of restored root filled treated maxillary premolars compared to non-endodontically treated ones (Hannig et al. 2005, Habekost et al. 2007). This observation was only confirmed for total onlay restorations in the present study and could not be further supported by pairwise comparisons of the subgroup analyses. The experimental groups in the present study consisted of extracted human maxillary premolars, with two separated canals in all cases. Compared to molars, these teeth are more susceptible to fractures because of their anatomy (de Freitas et al. 2002). In contrast to other studies, where load application for testing fracture resistance was either in a central (Habekost et al. 2007, Salameh et al. 2007, Soares et al. 2008a,b) or a palatal direction (Hannig et al. 2005, Sorrentino et al. 2007), the present study investigated the fracture resistance of the buccal cusps by simulating extreme eccentric forces (Hofmann et al. 1998, Siso et al. 2007). Buccal cusp fractures have been described to occur more often compared to palatal cusp fractures (Cavel et al. 1985, Hansen et al. 1990), and teeth are more vulnerable to fractures when eccentric forces are applied (Hofmann et al. 1998). The specimens were mounted at a 30° angle to the long axis of the tooth. Consequently, the load was applied perpendicular to the incline of the buccal cusp, and no sliding of the loading device in relation to the cusp during force application could...
occur. This design has been judged as advantageous compared to conventional testing designs in which buccal and palatal cusps are loaded simultaneously by spherical or cylindrical devices (Hofmann et al. 1998, Hannig et al. 2005). However, differences in load application might influence the results, and thus, comparisons to other studies that used a different load application should be interpreted with caution. In the present study, no simulation of the periodontal ligament was performed. A recent review on the influence of test parameters on in vitro fracture resistance of post-endodontic restorations demonstrated that the majority of the reviewed articles did not simulate a periodontal ligament (Naumann et al. 2009), although a simulation of the clinical situation is appreciated. Nevertheless, an accepted standardized model for simulation of the periodontal ligament as well as of the mandibular and maxillary bone characteristics, which has been validated with respect to the clinical situation, has not yet been introduced (Naumann et al. 2009).

The failure mode analyses revealed that fractures of the ceramic restoration occurred before tooth structure fractured. This is corroborated by previously published results (Soares et al. 2008b). The generated stresses are concentrated within the ceramic material and could initiate crack formation and propagation that resulted in cohesive fractures of the ceramic material. Furthermore, ceramic restorations are known to concentrate stresses with higher peaks at central grooves (compare Fig. 2b–c), regardless of the contact location (Magne & Oganesyan 2009).

It has been demonstrated in laboratory studies that endodontically treated teeth restored with MOD CEREC inlays often failed as a result of severe fractures with exposure of the pulp or root canal (Hannig et al. 2005). Moreover, a finite element method revealed that debonding between restoration and the cavity wall could initiate crack formation and propagation that resulted in cohesive fractures of the ceramic material. Furthermore, ceramic restorations are known to concentrate stresses with higher peaks at central grooves (compare Fig. 2b–c), regardless of the contact location (Magne & Oganesyan 2009).

Within the limitation of the current study, it can be concluded that restored maxillary premolars are not able to reach the fracture resistance of sound teeth, irrespective of restoration type, endodontic treatment, or post placement. The restoration of cavities with a remaining palatal and buccal wall thickness of 2 mm using ceramic MOD inlays is inferior with respect to the fracture resistance compared to partial onlay restorations with palatal cusp coverage. The fracture resistance of endodontically treated teeth without post insertion is lower compared to non-endodontically treated teeth.

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