Fracture resistance of endodontically treated premolars restored with lithium disilicate CAD/CAM crowns or onlays and luted with two luting agents

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The purpose of the present study is to evaluate the fracture resistance of endodontically treated maxillary premolars restored using CAD/CAM onlays or crowns and luted with two types of resin cement. Forty all-ceramic crowns and twenty onlays were fabricated on maxillary premolars using the Cerec 3 system (n=10). The abutments were randomly subjected to two different procedures: Endodontic treatment was performed on forty teeth restored through a mesio-occlusal-distal (MOD) cavity preparation with composite resin fillings; twenty teeth without endodontic treatment served as control. In endodontically treated teeth restored using IPS e.max CAD crowns or onlays, the fracture loads were lower than those of the control. Endodontic treatment of teeth restored using CAD/CAM crowns does not impair the fracture load but shows more severe fractures than teeth restored using CAD/CAM onlays. This suggests that a CAD/CAM onlay might be an effective method for the restoration of endodontically treated premolars with MOD cavity defect.

Keywords: Fracture resistance, Ceramic, CAD/CAM crown

INTRODUCTION

Endodontically treated teeth generally lose some dental structure and suffer from reduced fracture resistance owing to caries, trauma, and endodontic and root canal preparations1-4). Although the integrity of the teeth can be restored through the application of silver amalgam, a bonded composite, or glass-ionomer cement, the fracture incidence still remains high under a clinical setting5-7). Ceramic or composite inlays have been adopted for a reinforcement of prepared teeth without cuspid coverage. Recent studies have shown that endodontically treated teeth restored using ceramic inlays have a similar fracture strength as sound teeth controls8-12), but, in comparison, might suffer from more severe fractures11). During endodontic treatment, all onlays and crowns are thought to reduce the teeth fracture susceptibility13).

With the increasing demand for esthetic procedures, all-ceramic restorations have become more and more popular in dental clinics owing to their lifelike appearance, durability, and biocompatibility14). However, their drawbacks include fracture susceptibility, an inadequate marginal fit, and an abrasive wear of the natural opposing teeth14,15). Therefore, several all-ceramic systems have been introduced to alleviate these drawbacks14,16). Computer aided design/computer aided manufacturing (CAD/CAM) systems are widely used in dentistry. CAD/CAM ceramic materials are manufactured under optimized conditions, which can minimize the voids and volume defects16,17). More and more materials have recently become available for CAD/CAM restoration18).

Among the materials used in all-ceramic restorations, lithium disilicate glass ceramic (IPS e.max CAD, Ivoclar Vivadent) not only exhibits a favorable translucency and shade variety, but also has a greater flexural strength than that of other monolithic ceramic blocks used for CAD/CAM restoration17-19). Monolithic lithium disilicate CAD/CAM crowns have been reported to be an effective option for all-ceramic crowns, and can maintain their structural integrity over a two-year period20). In vitro studies have shown that monolithic lithium disilicate crowns demonstrate significantly higher reliability than porcelain-layered Y-TZP crowns21,22). Guess et al. reported that IPS e.max CAD molar crowns show a 2,500 N mean fracture load with a single load-to-failure, which is higher than masticatory forces21). In spite of promising clinical results, the mechanical performance of monolithic lithium disilicate crowns can be affected by several factors, including the abutment condition, the preparation designs, and the luting method used. The fracture load and fracture mode of monolithic lithium disilicate crowns may be influenced by the endodontic treatment itself. In addition, the fracture load can also be influenced by the luting cement through the affecting stress transferred to the abutment20,11).

This study aims at evaluating the fracture load and modes in endodontically treated maxillary premolars restored using monolithic lithium disilicate crowns or onlays, and luted with two types of resin cement. Teeth without endodontic treatment served as a control.

MATERIALS AND METHODS

Sixty extracted caries- and crack-free human premolars were stored in a 0.1% thymol solution after the calculus

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deposits and soft tissues were cleaned. These teeth were randomly divided into six groups (n=10) of IPS e.max CAD glass ceramic material according to the abutment conditions, preparation designs, and luting method used (Table 1). The materials are shown in Table 2.

The teeth were embedded in autopolymerized acrylic resin blocks 2 mm beneath the cemento-enamel junction following published protocols. In the TCA, TCU, TOA, and TOU groups, the teeth first underwent endodontic treatment using standardized canal enlargement and a filling procedure. The canals of each tooth were prepared using K-flexofile at up to a #40 file size (Dentsply, USA) using a step-back technique. The root canals were irrigated with 1% sodium hypochlorite (NaOCl) and physiological saline during preparation. All canals were obturated with gutta-percha points (Dentsply, USA) and an AH26 Plus sealer (Dentsply, USA). Mesio-occlusal-distal (MOD) cavities were then uniformly prepared using a periodontal probe to measure their dimensions. A 6° divergence of the walls of the occlusal and proximal boxes was prepared using a tapered diamond with a convergence angle of 6°. The depth of the occlusal isthmus reduction was 3 mm. The proximal portions of the preparations ended 1 mm occlusal to the CEJ. The occlusal cavity corresponded to 50% of the intercuspal distance. Finally, the MOD cavities were filled with a flowable composite resin (Filtek Flow, 3M ESPE, St. Paul, MN, USA) with a single bond (Single Bond, 3M ESPE) (Fig. 1). All forty premolars restored with crowns were prepared based on the standardized criteria using a custom-made paralleling device with a vertical brake and speed adjustment: A 2-mm reduction was performed on the occlusal surface. 5-mm occlusogingival height, a 1.5-mm wide shoulder placed 0.5 mm occlusal to the CEJ, and a 6° axial taper. All twenty premolars restored with onlays were prepared in the same manner (Fig. 2), and a 2-mm reduction was performed on the occlusal surface. The proximal portions of the preparations ended at 0.5 mm occlusal to the CEJ. The depth of the occlusal isthmus reduction was 4 mm. The occlusogingival

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Table 1  The groups of samples

<table>
<thead>
<tr>
<th>Groups</th>
<th>abutment condition/preparation design/ the luting method</th>
</tr>
</thead>
<tbody>
<tr>
<td>WCA</td>
<td>teeth without endodontic treatment/crown/ RelyX ARC</td>
</tr>
<tr>
<td>WCU</td>
<td>teeth without endodontic treatment/crown/ RelyX Unicem</td>
</tr>
<tr>
<td>TCA</td>
<td>endodontically treated teeth/crown/ RelyX ARC</td>
</tr>
<tr>
<td>TCU</td>
<td>endodontically treated teeth/crown/ RelyX Unicem</td>
</tr>
<tr>
<td>TOA</td>
<td>endodontically treated teeth/onlay/ RelyX ARC</td>
</tr>
<tr>
<td>TOU</td>
<td>endodontically treated teeth/onlay/ RelyX Unicem</td>
</tr>
</tbody>
</table>

Table 2  Materials used in this study

<table>
<thead>
<tr>
<th>Materials</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cerec 3</td>
<td>Sirona, Bensheim, Germany</td>
</tr>
<tr>
<td>IPS e.max CAD</td>
<td>Ivoclar Vivadent, Schaan, Liechtenstein</td>
</tr>
<tr>
<td>RelyX ARC</td>
<td>3M ESPE, St Paul, MN, USA</td>
</tr>
<tr>
<td>RelyX unicem</td>
<td>3M ESPE, St Paul, MN, USA</td>
</tr>
</tbody>
</table>

Fig. 1  Two types of abutments. A, C teeth without endodontic treatment; and B, D endodontically treated teeth. d=intercuspal distance.

Fig. 2  Standardized preparation dimensions, proximal view. A crown, B onlay. d=intercuspal distance.
heights of both cuspids was 2 mm. The isthmus shoulder stayed 0.5 mm above the CEJ limit. Width of shoulder was 1.5 mm. Axial taper was made with 6-degree\(^{11,22}\).

Forty lithium disilicate crowns and twenty lithium disilicate onlays were fabricated using a Cerec 3 CAD/CAM system from IPS e.max CAD glass ceramic. The teeth were then covered with an optical reflection medium for acquiring the digital impression of the abutment. All of the prepared crowns and onlays were designed and milled using the associated Cerec 3 system software, and received a standardized firing program. Finally, the fit surface of the restorations was etched with 5% hydrofluoric acid for 20 s as recommended by the manufacturers.

The crowns were luted using RelyX ARC (total etch and dual-polymerizing resin cement) or RelyX Unicem (a self-adhesive and dual-polymerizing resin cement) according to the manufacturer's instructions. The crowns were then seated using finger pressure and held under 1.5 kg of static pressure using a rounded end steel cylinder. A sharp explorer was used to remove any excess cement from the margins. Each surface was light polymerized for 20 s at an irradiation intensity of 1,100 mW/cm\(^2\) (Mini L.E.D, SATELEC, France). One hour after cementation, the specimens were placed in 37\(^\circ\)C distilled water and kept for 1 week\(^{12}\). The fracture resistances of the teeth were evaluated under a vertical compression load using a stainless steel sphere (diameter, 4 mm) at a speed of 0.5 mm/min. The fracture load (N) was recorded using a sphere making contact with the center of each crown. The fracture mode was analyzed and determined based on previous publications\(^{24,25}\). Mode I indicates a minimal fracture or crack of the crown; mode II indicates that less than half of the crown is lost; mode III indicates a crown fracture through the midline; mode IV indicates that more than half of the crown is lost; and mode V indicates a severe fracture of the crown and/or tooth.

The study was carried out with the patients' consent and approved by the ethical committee of Shanghai Ninth People's Hospital affiliated to Shanghai Jiao Tong University, School of Medicine (serial number: 2012.98).

The fracture loads were analyzed using SPSS 11.5 statistical software. A one-way and a two-way analysis of variance (ANOVA) were used, and a 95% level of significance was deemed acceptable.

## RESULTS

There was a linear correlation between the applied load and time taken for the fracture experiments (Fig. 3). The mean values and standard deviations (SD) of data from the fracture resistance test of the six groups are shown in Table 3. In addition, the significant difference of all tested groups also was shown in Table 3. The two-way ANOVA analysis showed significant differences among the abutments \((p<0.01)\) regardless of the luting cement applied (Table 4). For teeth without endodontic treatment, the fracture modes were mostly crown fractures (types III and IV, shown in Table 5). For the endodontically treated teeth restored using onlays, mode II was the main fracture type (Table 5). However, more severe fractures (type V; Table 5) were observed in the endodontically treated teeth restored using crowns. The typical fracture modes are shown in Fig. 4.

For teeth without endodontic treatment, during the fracture resistance test, the crack lines tended to travel

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**Table 3** The fracture load for different groups (Mean±SD)

<table>
<thead>
<tr>
<th>Groups</th>
<th>Fracture load (N)</th>
<th>Fracture load (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WCA</td>
<td>1981.90±81.12</td>
<td>—</td>
</tr>
<tr>
<td>WCU</td>
<td>1931.04±95.81</td>
<td>—</td>
</tr>
<tr>
<td>TCA</td>
<td>—</td>
<td>1786.91±64.60</td>
</tr>
<tr>
<td>TCU</td>
<td>—</td>
<td>1794.13±78.34</td>
</tr>
<tr>
<td>TOA</td>
<td>—</td>
<td>1746.27±145.00</td>
</tr>
<tr>
<td>TOU</td>
<td>—</td>
<td>1768.12±157.35</td>
</tr>
</tbody>
</table>

There was significant difference between tested groups in different arrays. Significant at \(p<0.05\).

**Table 4** Two-way ANOVA

<table>
<thead>
<tr>
<th>Source</th>
<th>df effect</th>
<th>df error</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cements</td>
<td>1</td>
<td>56</td>
<td>0.638</td>
<td>0.428</td>
</tr>
<tr>
<td>Abutments</td>
<td>1</td>
<td>56</td>
<td>42.240</td>
<td>0.000*</td>
</tr>
<tr>
<td>Cements-abutments</td>
<td>1</td>
<td>56</td>
<td>0.930</td>
<td>0.339</td>
</tr>
</tbody>
</table>

*Significant at \(p<0.01\); df=degree of freedom.
along the luting cement interface when the monolithic lithium disilicate ceramic crowns were restored (Fig. 5A). However, when endodontic treatment was applied, the crack lines reached the tooth through the luting agent in the teeth restored using crowns (Fig. 5B), and went along the luting agent in the teeth restored using onlays (Fig. 5C).

Table 5  The distribution table of the fracture modes of the all-ceramic crowns

<table>
<thead>
<tr>
<th>Groups</th>
<th>Fracture modes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>WCA</td>
<td>0</td>
</tr>
<tr>
<td>WCU</td>
<td>0</td>
</tr>
<tr>
<td>TCA</td>
<td>0</td>
</tr>
<tr>
<td>TCU</td>
<td>0</td>
</tr>
<tr>
<td>TOA</td>
<td>0</td>
</tr>
<tr>
<td>TOU</td>
<td>0</td>
</tr>
</tbody>
</table>

Fig. 4  Typical fracture modes.
A, crowns restored on teeth without endodontic treatment; B, crowns restored on teeth with endodontic treatment; and C, onlays restored on teeth with endodontic treatment.

Fig. 5  Representative specimens after fracture resistance.
A, ceramic crown restored on teeth without endodontic treatment; B, ceramic crown restored on teeth with endodontic treatment; C, ceramic onlay restored on teeth with endodontic treatment. a, crown; b, luting agent; and c, tooth. The arrows indicate crack lines.

DISCUSSION

The mean maximum posterior masticatory forces in human beings vary from 200 N to 540 N\(^{26,27}\). In the present study, for vital or endodontically treated premolars restored using all-ceramic crowns or onlays, the mean fracture loads were higher than the above mean maximum masticatory forces. The high fracture force of IPS e.max CAD materials may be caused by optimized industrial manufacturing conditions and subsequent minimal voids and volume defects\(^{16,20}\). Other causes may be from the fully anatomical design, or the use of monolithic lithium disilicate ceramic materials. In monolithic lithium disilicate ceramic crowns, the occlusal area where the load is applied has a thickness of 2 mm. As the thickness increases, the load causing a bulk fracture increases accordingly\(^{21,28}\).

The fracture resistance of all-ceramic crowns or onlays can be affected through the change in stress transmission from many factors, such as the ceramic material, luting agent, and human dentin\(^{15,26,27}\). Generally, all-ceramic crowns luted with zinc phosphate cement have poorer mechanical properties than the crowns luted with adhesive resin\(^{29-31}\), because brittle zinc phosphate cement can induce the stress...
concentrated on the luting interface. On the contrary, compared to traditional cements, resin cements are a less stiff material and can absorb the stress, thus increasing the fracture loads of all-ceramic crowns. Some studies have shown that resin cements have no effect on the fracture resistance of ceramic restorations. However, other studies have pointed out that the elastic modulus of resin cement plays a positive role in the strength of ceramic crowns. In our study, the elastic modulus of resin cement is 5.5 GPa for RelyX ARC and 7.8 GPa for RelyX Unicem, but neither produced an influence on the fracture loads of IPS e.max CAD all-ceramic crowns and onlays. This may be explained by the fact that the inherent fracture resistance of IPS e.max CAD material surpasses that produced from the resin cement. Furthermore, according to the manufacturers, the innovative lithium disilicate glass-ceramic IPS e.max CAD offers 2.5- to 3-times (360 MPa) the fracture load of other glass ceramics.

The abutment is another factor in a crown fracture analysis. In the present study, compared with sound teeth with intact pulp chambers, endodontically treated teeth possess lower fracture strength of the crowns, which is independent of the luting agent used. Although endodontic treatment does not weaken the inherent biomechanical properties of teeth, the preparation of an endodontic access cavity or MOD cavities may cause dentin loss, thereby reducing the original strength. Filling MOD cavities with bonded composite resins might influence the stress distribution during the crown fracture process, leading to a different fracture resistance. By comparison, however, abutments with intact pulp chambers can withstand and transfer a load effectively, thus generating a higher fracture load of a crown. However, for teeth that have undergone endodontic treatment, the abutments may not effectively transfer such loads. The stress is therefore gradually concentrated on the bonded composite resins of the MOD cavities, which might decrease the fracture loads of the ceramic crowns. In addition, there are different mechanical properties between dentin and composite resin, which might play a role on the ultimate fracture failure of the crowns. This hypothesis was proved by our analysis on fracture modes. For teeth that have not undergone endodontic treatment, their fracture modes are principally a crown fracture, which is confined only in the cement-ceramic interface. However, fracture modes of teeth that have undergone endodontic treatment clearly produce a severe fracture with crown and tooth breakdown.

In the restoration of endodontically treated teeth, the onlays did not increase the fracture resistance compared with the use of crowns. Although the endodontic treatment of teeth restored using onlays can retain more tooth tissue than when using crowns, which might enhance the fracture load of all-ceramic restorations, the inherent fracture resistance of IPS e.max CAD material might surpasses that produced from the greater amount of tooth tissue. In the endodontic treatment, restoration by onlays proved to be less than half of the fracture modes that were seen as a crown leak (Fig. 4C), which might be caused by the concentrated stress on the MOD cavity edge after removal of the bonded composite resins. That means MOD cavity might increase the thickness of onlay at the loading point. For the restoration of endodontically treated teeth, the fracture mode of the onlays makes them superior to crowns in the laboratory. A lithium disilicate CAD/CAM onlay may therefore be more reliable for the reinforcement of endodontically treated premolars with MOD cavities.

One limitation of this study is that the cyclic loading fatigue in a wet environment was not applied in the fracture analysis of the all-ceramic crowns. Cyclic loading under wet conditions may cause a propagation of small cracks within the crowns, which might weaken the fracture resistance of the crowns.

CONCLUSION

Several conclusions can be inferred from this in vitro study. (1) After restoration using lithium disilicate CAD/CAM crowns, teeth without endodontic treatment show better prognosis than teeth with endodontic treatment which is independent of the luting agent used. (2) A CAD/CAM onlay might be an effective method for the restoration of endodontically treated premolars with MOD cavity defect.

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