Fracture Resistance of Endodontically Treated Premolar with Deep Class II: In Vitro Evaluation of Different Restorative Procedures

Hong Zhang\textsuperscript{a,b}
\textsuperscript{a} Key Laboratory of Bionic Engineering, Ministry of Education, Jilin University, Changchun 130022, PR China
\textsuperscript{b} School of Stomatology, Jilin University, Changchun 130021, PR China

Zhimin Zhang \textsuperscript{b}
\textsuperscript{b} School of Stomatology, Jilin University, Changchun 130021, PR China

Lihua Hong \textsuperscript{b}
\textsuperscript{b} School of Stomatology, Jilin University, Changchun 130021, PR China

Qian Cong\textsuperscript{a,c,*}
\textsuperscript{a} Key Laboratory of Bionic Engineering, Ministry of Education, Jilin University, Changchun 130022, PR China
\textsuperscript{c} State Key Laboratory of Automotive Simulation and Control, Jilin University, Changchun 130022, PR China
*Corresponding author (Email: congqian@mail.jlu.edu.cn)

Aobo Du \textsuperscript{b}
\textsuperscript{b} School of Stomatology, Jilin University, Changchun 130021, PR China

Ying Wang \textsuperscript{b}
\textsuperscript{b} School of Stomatology, Jilin University, Changchun 130021, PR China

Abstract
To assess the impact of CMR method on the resistance to fracture of endodontically treated premolars with deep class II preparations under dynamic loading. Root canal management was executed on 50 human maxillary premolars. Class II cavities were primed with the mesial margin located 2 mm beneath the cemento-enamel junction (CEJ). The teeth were assigned into five groups (n=10) at random, including an unprepared group (G1), two groups where teeth were restored with endocrowns (G2), and cervical margin was relocated 1 mm above CEJ with bulk-fill composite (CMR)(G3). In the remaining two groups, teeth were repaired using Glass fiber posts (G4) and conventional full crowns (G5), CAD/CAM lithium disilicate ceramic crowns were made for both types of crowns and adhesively cemented (Variolink II). Teeth underwent thermalcycling (3000 30 s cycles of 5ºC/55ºC) and fatigue loaded (1,200,000 cycles at 49 N and 1.7 Hz) in a custom-built fatigue simulator. Following thermomechanical loading, the restored teeth underwent a 90-degree vertical load, with a cross-head speed of 0.5 mm/min. The mode of fracture and load required were logged. For thermomechanical loading experiments, all groups displayed statistically significant results. The highest and lowest fracture value was recorded in groups G1 and G2 respectively. The major fracture observed in the samples was a vertical fracture from the occlusal fissure, splitting the restoration. Most restorations in the endocrown groups (G2 and G3) exhibited favorable fractures while, in the conventional crown groups (G4 and G5), there was an increase in the percentage of unfavorable failures (fractures beyond bone level). Endocrowns with CMR showed a significantly increased fracture resistance when compared to conventional full crowns and, consequently, offer a viable alternative for deep class II endodontically treated premolars.

Key words: Endodontically Treated Premolars, Cervical Margin Relocation, Fracture Resistance, Preparation Design

Resistencia a la Fractura del Premolar Tratado Endodónticamente con Clase Profunda II: Evaluación in Vitro de Diferentes Procedimientos de Restauración

Resumen
Evaluar el impacto del método CMR en la resistencia a la fractura de premolares tratados endodónticamente con
Preparations of class II with deep crown preparations under load. The management of the root canal was realized in 50 premolars human superiors. The cavities of class II were imprinted with the mesial margin located 2 mm below the cemento-enamel junction (CEJ). The teeth were assigned in five groups (n = 10) at random, including a group without preparation (G1), two groups in which the teeth were restored with endocrowns (G2 and G3) and the cervical margin was repositioned 1 mm above the CEJ with a composite material (CMR) (G3). In the two remaining groups, the teeth were restored by using rubber dam post and core (G4) and complete crowns (G5), which were bonded with adhesive (Variolink II). The teeth were combined to a cyclic fatigue test (1200 cycles of 30 s of 5°C / 55°C) and were loaded by fatigue (1,200,000 cycles at 49 N and 1.7 Hz) in a fatigue simulator made of steel to the measurement. Tras la carga termomecánica, los dientes restaurados se sometieron a una carga vertical de 90 grados, con una velocidad de cruzeta de 0.5 mm / min. Se registró el modo de fractura y carga requerida. Para los experimentos de carga termomecánica, todos los grupos mostraron resultados estadísticamente significativos. El valor de fractura más alto y más bajo se registró en los grupos G1 y G2, respectivamente. La mayor fractura observada en las muestras fue una fractura vertical de la fisura oclusal, dividiendo la restauración. La mayoría de las restauraciones en los grupos de endocrown (G2 y G3) mostraron fracturas favorables, mientras que en los grupos de coronas convencionales (G4 y G5), hubo un aumento en el porcentaje de fracasos desfavorables (fracturas más allá del nivel del hueso). Las endocrowns con CMR mostraron una resistencia a la fractura significativamente mayor en comparación con las coronas completas convencionales y, en consecuencia, ofrecen una alternativa viable para los premolares con tratamiento endodóntico profundo de clase II.

Palabras clave: Premolares Tratados Endodónticamente, Reubicación del Margen Cervical, Resistencia a la Fractura, Diseño de Preparación

1. Introduction

Endodontically treated premolars with class II preparations are susceptible to fracture. The conventional method for repairing an endodontically treated tooth with class II consists of rebuilding with a post and core or full crown. Studies have reported a certain amount of risk for root fractures that potentially arise after preparation for a post and ferrule. Minimally invasive repair with an endocrown has previously been proposed as an alternate method for endodontically treated posterior teeth[1-4]. This procedure is based on reconstruction of tooth utilizing both coronal and core restoration in a crown consisting of only one-piece, which is anchored to the pulp chamber and cervical margins. In vitro studies have shown the fracture load values of bonded endocrowns are equivalent to those of classical crowns.

When restoring sizeable posterior faults with proximal caries lesions spreading beneath the cemento-enamel junction (CEJ), and with cavity margins situated underneath the gingival tissues, the restoration treatment plan often involves one of two strategies, either through surgical crown enlargement[5] or orthodontic tooth extraction [6]. The difficulties in these identified approaches usually arise from the challenge of preparing the tooth in subgingival areas, which is achieved through a series of events all with their own difficulties, including creating impressions, the cementation of adhesive within the restoration site, and the final stages of finishing and polishing the margins of the tooth [7]. The vast majority of the issues mentioned above are associated with substandard insight, poor accessibility to the deep areas of the cavity and inadequate or impossible separation of the operating field using a rubber dam. This results in inadequate moisture regulation and blood and/or saliva contamination. To improve the clinical techniques, making them easier and less fault-prone, Dietschi and Spreafico (1998) developed a procedure called cervical margin relocation (CMR). This method utilizes the use of a composite resin in the deepest proximal areas, with the aim of repositioning the cervical margin supragingivally. This is thought to aid separation and increase the ability to take impressions and cementation of adhesive in the indirect restorations[8, 9].

The endocrown plus CMR method is considered, as a noninvasive alternative to the conventional approaches used. However, clinicians may have differing preferences based on their experience as there is no obvious features of the method that suggest it can optimally restore endodontically treated premolar with deep class II. The most suitable materials and procedures that should be used in these situations are a topic much debate among clinicians. This is in part due to the little scientific evidence in the literature. This study has attempted to calculate the fracture strength of endodontically treated premolars with deep class II, repaired using four different techniques, in addition determining the mode of failure when an vertical compressive force is applied.
2. Materials and Methods

2.1. Specimen selection and samples preparation

Fifty intact, caries-free human maxillary premolars of comparable size at the cemento-enamel junction (CEJ), were selected for this study. All samples were stored in thymol solution (0.1%) between extraction and use. Preparation of the root canal was achieved using ProTaper Next rotary instruments (Dentsply Maillefer, Ballaigues, Switzerland) with an apical size of ISO 30. The root canals were filled with vertically condensed gutta-percha (BeeFill, VDW, Munich, Germany) and an epoxy sealant (AH-Plus®, Dentsply De Trey, Konstanz, Germany). These teeth were prepared with standard conventional class II mesio-occlusal cavities with dimensions of 2 mm buccolingually, and a 1.5 mm wide gingival margin located 2 mm below the CEJ, verified using a periodontal probe. The bur was changed after every five preparations. Teeth were distributed randomly into five groups (n=10) (displayed in Fig. 1 and described below).

**Group 1:** Negative control, Structurally sound, unprepared teeth.

**Group 2:** Endocrown.

For the endocrown group, a 2 mm decrease in the lingual and buccal cusps were implemented. The “endo” preparation was made up of a circular butt margin with a central retention cavity depth of 5 mm from the cavosurface boundary with rounded internal line angles.

**Group 3:** Endocrown with CMR.

The deep mesio-margin was elevated using resin composite to simulate the cervical margin relocation technique. The cervical boxes of the MO-cavities were situated 1 mm above the CEJ post placement of the proximal composite layers. The materials used for CMR were Bulk-fill composite (SonicFill, Kerr, Orange, CA, USA) bonded with Tetric N-Bond (Ivoclar Vivadent, Schaan, Liechtenstein). Restoration margins were finished and polished with the OptraPol composite finishing kit (Ivoclar Vivadent, Schaan, Liechtenstein). The endocrown preparation was the same as Group 3.

**Group 4:** Conventional crown with glass fiber post.

The root canal was enlarged and widened with the bur supplied with the post system, with appropriately positioned cursors. Roots were adhesively cemented with a tapered glass fiber post (RTD Post #1.2, St. Egreve, France) and fixed in place using dual resin cement (RelyX ARC, 3M ESPE, St Paul, MN, USA), with an apical gutta-percha seal of 5 mm, and a composite resin core (Filtek Z250, 3M ESPE, St Paul, MN, USA) was accomplished. Finally, there was preparation of a 1mm wide circumferential shoulder finish line at the CEJ and a 3 mm ferrule.

**Group 5:** conventional full crown.

Tetric N-Bond self-etch adhesive (Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the class II cavity, followed by air drying for 5 s and light curing for 10 s. Composite resin (Filtek Z250, 3M ESPE, St Paul, MN, USA) was placed in the cavity using the oblique incremental procedure, and each increment was cured with an LED light curing unit for 40 seconds. Then, each tooth underwent preparation for a full crown using a no. 2135 sized diamond wheel bur (KG Sorensen, Cotia, SP, Brazil). The dimensions of the preparations were as follows: a 1.0 mm shoulder margin, a 3 mm core height with rounded line angles and a 6° taper on each side.

The CEREC 3D system (Sirona Dental Systems GmbH, Bensheim, Germany) and lithium disilicate (e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein) were used for all ceramic conventional crowns with post,
endocrowns and conventional full crowns. After the ceramic restorations were fitted and polished, the exterior of the installments were etched with 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent, Schaan, Liechtenstein) and silane coupling agent pretreated (Monobond S; Ivoclar Vivadent). The adhesive surfaces of the teeth were pretreated and etched using dentin primer (Syntac, Ivoclar Vivadent) and dentin adhesive (Syntac, Ivoclar Vivadent). All ceramic crowns were fixed with a dual cure resin cement (Variolink II, Ivoclar Vivadent) following to manufacturer’s standard protocols.

2.2. Load to fracture

Simulation of the periodontal ligament was simulated by coating the roots of all the samples with a 0.3mm polyether imprint material (Impregum Penta Soft, 3M ESPE). Next, the roots were implanted in a self-curing acrylic resin (Shanghai Dental Material Company, Shanghai, China) so that repair margins were positioned around 3 mm over the artificial bone level. Repeated thermal and mechanical stress was applied to all specimens using a computer-controlled masticator (custom made; Jilin University) for 1,200,000 cycles, using tungsten carbide spheres (5.0 mm radius of curvature) of 49 N at 1.7 Hz. Thermal stress, simulating approximately 5 years of clinical service, was simultaneously applied via 3,000 thermocycles between 5 °C and 50 °C[10].

All specimens were mounted to the vertical axis of the tooth for fixation with a universal testing apparatus (NTS, Technology Co., Ltd., Japan), driving a static compression force onto the tooth using a 5mm steel sphere contacting the buccal and lingual cusps for axial loading. Excessive stress concentration on the surface of the tooth was avoided by placing aluminum foil (0.5mm thickness) between the crown surface and the steel sphere. The crosshead speed was set at 0.5 mm/min until the occurrence of a fracture, and the corresponding load value recorded (Fig. 2). Fractures were defined into two categories, favorable failures were defined as repairable fractures of the tooth/restoration above the level of bone recreation, and unfavorable failures were classed as unrepairable fractures beneath the level of bone simulation.

The findings were assessed with SPSS (Version 21.0; Abacus Concepts Inc, Piscataway, NJ). Differences between groups were evaluated using the Least Significant Difference test and ANOVA with significance level set to p <0.05.

![Fig.2. Fracture load of all groups.](image)

2.3. Results

Of the specimens assessed, none failed during the testing of fatigue resistance. The values for mean fracture strength, along with standard deviations, and results of the ANOVA analysis and Least Significant Difference test are presented in Table 1 and data depicted in Fig. 3. One-way ANOVA indicated that only the fracture loads of control group (Group 1) were significantly greater than those of the experimental groups, with no difference detected between treatment groups (Table 1). There was no difference statistically (p>0.05) in fracture resistance between Groups 3-5, however there was trend with Group 3 (Endocrown with CMR) showing higher values (1156.45 N) than Group 4 (1147.23 N), which was higher than Group 5 (1130.82 N). In this study, Group 2 showed the least resistance to fractures compared with other groups and the alterations were statistically significant (P <0.05). The mode of failure for all groups are displayed in Table 2. The results showed that 70% of the samples in Group 3, 60% of the specimens in Group 2, 30% of the specimens in Group 4 exhibited favorable fractures, whereas only 20% of the specimens exhibited favorable fractures in Group 5.
Table 1. Mean and standard deviation of fracture resistance (N).

<table>
<thead>
<tr>
<th>Groups</th>
<th>n</th>
<th>Mean±SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>10</td>
<td>A1502.8±109.03</td>
<td>1340.41</td>
<td>1694.34</td>
</tr>
<tr>
<td>Group 2</td>
<td>10</td>
<td>B988.38±135.88</td>
<td>786.66</td>
<td>1141.76</td>
</tr>
<tr>
<td>Group 3</td>
<td>10</td>
<td>C1156.45±116.99</td>
<td>979.99</td>
<td>1333.86</td>
</tr>
<tr>
<td>Group 4</td>
<td>10</td>
<td>C1147.23±135.38</td>
<td>903.54</td>
<td>1262.48</td>
</tr>
<tr>
<td>Group 5</td>
<td>10</td>
<td>C1130.82±82.60</td>
<td>982.22</td>
<td>1281.46</td>
</tr>
</tbody>
</table>

Groups with different letters show a statistically significant difference (P<0.05). SD=Standard deviation

Table 2. Frequencies of failure modes in the five groups.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Repairable (%)</th>
<th>Irrepairable (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>9 (90%)</td>
<td>1 (10%)</td>
</tr>
<tr>
<td>Group 2</td>
<td>6 (60%)</td>
<td>4 (40%)</td>
</tr>
<tr>
<td>Group 3</td>
<td>7 (70%)</td>
<td>3 (30%)</td>
</tr>
<tr>
<td>Group 4</td>
<td>3 (30%)</td>
<td>7 (70%)</td>
</tr>
<tr>
<td>Group 5</td>
<td>2 (20%)</td>
<td>8 (80%)</td>
</tr>
</tbody>
</table>

3. Discussion

This study aimed to evaluate the resistance to fracture and patterns of failure in maxillary premolars with proximal defects underneath the cemento-enamel junction (CEJ) that were restored using four different options. Endodontically treated premolars with deep class II are prevalent in the clinic and lead to a decreased fracture resistance [11]. The typical method used to repair these teeth would be to utilize a post and core, as well as full-crown coverage. However, post preparation can weaken the root significantly, and ultimately lead to root fracture leading to patient dissatisfaction. Restoration using an endocrown has been muted as an alternate method for posterior teeth treated endodontically [1, 3, 4, 12, 13]. There is controversy surrounding the use of CEREC endocrown to restore premolars. The survival rate of endocrowns on premolar was reported by Bindl et al. to be lower than that of molars [12, 14]. Contrary to this, some FE analysis and in vitro research have showed that endocrown and classical crowns performed comparably under normal occlusion [15, 16]. A recent clinical report also reported restoration of maxillary premolars using endocrown.

To replicate the authentic clinical environment and acquire clinically relevant results, the study implemented a vigorous loading and fatigue assessment, performed on a masticatory simulator [17]. The dynamic loading force was kept consistent throughout a simulated 5-year period [18]. The use of a polyether layer to cover the roots of the tooth, as an artificial periodontium, made it possible to simulate the physiological movement of teeth inside the alveole [19, 20]. Fracture restoration mainly depends on the technique and materials used for the restoration of the coronal cavity [21]. In this study, the untreated negative control group showed the greatest resistance to fracture, consistent with previous studies that reported restored teeth have a significantly reduced resistance to fracture [22]. The results of this study also demonstrated a decreased fracture resistance of endocrown restored with CMR, but that was still higher than the endocrown groups without CMR. Dietzchi and Spreatico first proposed the notion of coronal relocation of cavity margins cervically spreading into the dentin structure (CMR) [8]. Similar names, such as “coronal margin relocation” “deep margin elevation”
CMR are slightly advantageous in terms of fracture resistance, which is significantly greater resistance than any of the restoration techniques. No significant alteration was observed in terms of fracture resistance between conventional crown with and without post, which is in disagreement with a previous study that found that posts contributed significantly to the reinforcement of endodontically treated teeth, through the support of the remaining tooth structure against vertical compressive forces [28-32]. The different findings of these studies may be because due to a discrepancy in the degree of the defected proximal box, when only one proximal box defect is located below the CEJ as in this study, the reinforcement role of the post is unclear. Similarly, a clinical study by Fokkinga showed no observable difference in survival probabilities between single teeth treated endodontically with or without a post[33]. The fracture resistance of endocrown demonstrated in this study was significantly different from those restored with a glass fiber post and full crown. This conflicting finding may be associated with the structure or deep location of the gingival wall, which will damage the axial wall, influence the retention form of the endocrown and lead to the decrease of the bond area, which is the most significant factor affecting the resistance to fracture of the endocrown.

Fortunately, the CMR used in this study may contribute to recovery of the performance of the endocrown. Among the treatment groups, endocrowns with CMR showed a similar fracture resistance as compared to a conventional crown with post and full crown. The deep gingival wall was elevated with CMR before placing the crown, and the CMR material and tooth could function as a cohesive unit. Hence, stress was redistributed to increase the fracture resistance. The material used for CMR may alter the fracture resistance, and a mixture of flowable and conventional restorative composites is proposed[34]. In the current study, the CMR material was performed using bulk-fill composites instead of conventional resin-based composites. The low shrinking and high strength of Bulk-fill composites in the elastic layer explain the high fracture resistance in both the conventional crown with post and conventional full crown. This result supports the conclusion that not all endodontically treated teeth need post restoration, with the quantity of residual dentin walls needing to be taken into account [35].

The mode of failure consisted of either restorable and unrestorable failures. The restorable failure mode consisted of a cervical root fracture and resulting post failure. Conversely, the fracture line below the bone level was classified as an irreparable failure. The results indicate that the fracture patterns recorded for endocrown with CMR and endocrown without CMR group were more favorable, with more restorable vertical fractures from the occlusal fissure that split above the bone level. The patterns of the fracture mode recorded for the conventional crown with post and conventional full crown group were much less favorable. The difference between the fracture routes of the endocrown and conventional crown could be owing to the difference in the residual tooth structures. As the remaining cervical dentin decreased in the conventional crown with post and conventional full crown groups, the concentration of stress must be transmitted from the tooth cervical to the apical, which may be why the fracture line frequency below the bone level was greater. Fracture modes are related to several factors. From this and previous studies, it can be concluded that in the majority of circumstances, the mechanical failure of restored premolars is mostly due to the weakening of the residual tooth structures rather than restoration technique. In the conditions used for this in vitro study, it was found that the endocrown with CMR, the conventional crown with post and conventional full crown showed comparable resistance to fracture, and the intact maxillary premolars possessed significantly greater resistance than any of the restoration techniques. However, to truly take conclusions from these findings, long-term follow-up clinical studies are needed.

4. Conclusions

Within the limits of this study, endocrown in deep class II, root-filled, maxillary premolars offer no significant advantage over all-ceramic restorations. Nonetheless, CAD/CAM lithium disilicate endocrown with CMR are slightly advantageous in terms of fracture resistance than other conventional restoration techniques.
Acknowledgements

This research was partially supported by the companies Ivoclar vivadent (Schaan, Liechtenstein), and 3M ESPE (Seefeld, Germany) by providing the study with materials.

References


