Effect of Restorative, Endodontic, and Fatigue Treatments on the Cuspal Deflection of Maxillary Premolars Subjected to Different Cyclic Occlusal Forces: An In Vitro Study

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This study aimed to determine the effect of adhesive direct composite restorations, endodontic treatments, and fatigue treatments on the cuspal deflection of maxillary premolars subjected to different cyclic occlusal forces. Thirty intact maxillary second premolars were selected. Ten teeth were left untreated (group IN), 10 teeth were subjected to endodontic and restorative treatment (group FL), and the remaining 10 teeth were subjected to endodontic, restorative, and fatigue treatments (group FT). All teeth were subjected to 5 occlusal compressive loading forces (98, 147, 196, 245, and 294 N) with a universal testing device. A total of 15 experimental groups were obtained with 3 tooth conditions (IN, FL, FT) and 5 different occlusal loading values. Deflection amounts (μm) were measured with laser sensors and recorded, and obtained data were statistically analyzed with one-way analysis of variance at a significance level of .05. Mean cuspal deflection values (μm) and SDs of experimental groups ranged as follows: IN-98 (24.4 ± 19.8), IN-147 (34.8 ± 28.9), IN-196 (43.8 ± 34.7), IN-245 (54.5 ± 46.4), IN-294 (60.3 ± 50.6), FL-98 (56 ± 49.1), FL-147 (62.6 ± 49.6), FL-196 (72.4 ± 52.1), FL-245 (81.3 ± 56), FL-294 (92.2 ± 60.9), FT-98 (77.2 ± 80.9), FT-147 (83.4 ± 81.3), FT-196 (92.6 ± 83.7), FT-245 (102.7 ± 85.4), and FT-294 (124.2 ± 89.5). Mean values of three main experimental groups were as follows: IN (43.5 μm), FL (72.9 μm) and FT (96.0 μm). Significant differences were found between the three main groups and relevant subgroups (P < .001). Highest cuspal deflection values (CDV) were obtained in FT groups. Lowest CDV were obtained in IN groups. FL groups showed higher deflection values than IN groups. CDV increased progressively as the teeth were restored and subjected to fatigue treatment. (Int J Periodontics Restorative Dent 2015;35:221–229. doi: 10.11607/prd.1802)

Endodontic treatment causes irreversible changes in the architectural anatomy of teeth. The chemical and mechanical properties of enamel and dentin also are modified.1–3 Several in vivo,4,5 ex vivo,6 and in vitro7–9 studies have demonstrated that endodontic treatment makes teeth more brittle due to the dehydration of dentin.10 Loss of soft (pulp chamber) and hard (marginal ridges) tissues due to caries causes an increase in cuspal height and a reduction in the thickness of cavity walls.11–13 These structural deficiencies may lead to a greater risk of tooth fracture. As reported by Morin et al14 and Panitvisai and Messer,15 mesio-occlusodistal (MOD) cavities represent the worst case in terms of fracture risk when nonadhesive (ie, conventional) restorations are employed.

Aspects of endodontically treated and adhesively restored teeth have been investigated in both noninvasive14,15 and invasive16 studies with use of different materials and techniques. In a noninvasive study, Panitvisai and Messer15 found that the cuspal deflection increases as the cavity turns from occlusal to
mesio-occlusal (MO)/occlusodistal (OD) or MOD, and recommended a full crown coverage.

In their in vitro study, Cobankara et al applied cyclic loading on intact mandibular molars until fracture occurred and reported that restorative materials such as amalgam, direct composite, ceramic inlay, polyethylene ribbon fiber, or composite resin could not adequately compensate for the loss of fracture resistance; however, ceramic inlays gave the best results. A similar result was found in a study of Hitz et al, in which mandibular first molars were subjected to thermal cycling and loaded until failure. They found that the resistance against fracture was lower than that of intact teeth, even in teeth restored with ceramic inlays.

Fatigue is a process involving nucleation, propagation, and coalescence of cracks; however, limited information is available about the behavior of endodontically treated teeth restored with MOD restorations after cyclic fatigue treatment.

Method and materials

Assignment of experimental groups

Occlusal surfaces of 30 maxillary second premolar teeth were to be subjected to five different occlusal loading force values (98, 147, 196, 245, 294 N) in three different tooth conditions (n = 10): intact (IN), filled with composite resin after endodontic treatment (FL), and filled with composite resin after endodontic treatment and subjected to fatigue treatment (FT). Thus, a total of 15 experimental groups were obtained (Table 1).

<table>
<thead>
<tr>
<th>Tooth condition (n = 10)</th>
<th>Occlusal loading force applied (N)</th>
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<tbody>
<tr>
<td>IN</td>
<td>98 147 196 245 294</td>
</tr>
<tr>
<td>FL</td>
<td>98 147 196 245 294</td>
</tr>
<tr>
<td>FT</td>
<td>98 147 196 245 294</td>
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</table>

IN = intact; FL = filled with composite resin after endodontic treatment; FT = filled with composite resin after endodontic treatment and subjected to fatigue treatment.

Tooth selection and preparation

A total of 30 human maxillary second premolars were extracted for orthodontic reasons from patients ages 15 to 29 years old who gave informed and signed consent for the study. All selected teeth had similar dimensions, no caries, no restorations, and no cracks that might affect the deflection amount under compressive loading. The teeth were examined visually, radiographically, and by means of transillumination in order to eliminate any defective ones. After being extracted, selected tooth specimens were stored in 0.9% sodium chloride (NaCl) saline solution at 20°C and were kept in that solution during all preparations and testing procedures to prevent dehydration.

 Thirty cylindrical resin blocks containing 30 tooth specimens were prepared as follows: (1) A cylindrical, open-ended, hollow brass matrix, 3 cm in diameter and 4 cm long, was obtained; (2) one of its open-ended sides was placed onto a glass surface and fixed with sticky wax (Dentsply). (3) Freshly poured autopolymerizing acrylic resin (Meliodent, Heraeus Kulzer) was injected into the matrix cavity. (4) Roots of each tooth specimen were embedded into the resin-filled cylindrical brass matrices 2 mm below the cementoenamel junction (CEJ), with their long axes positioned perpendicular to the horizontal plane.

Embedded tooth specimens were transferred to a milling machine equipped with a parallelometer (Fresart, Artiglio) and smooth surfaces of 3 to 4 mm² were formed onto the middle thirds of buccal and lingual surfaces using a cylindrical diamond bur (Fig 1). These surfaces were coated with a thin opaque varnish layer to provide an effective reading for the laser device.
Endodontic instrumentation and cavity preparation

Endodontic access cavities were prepared for tooth specimens in the FL and FT groups in a standard configuration. Instrumentation of root canals was performed with nickel-titanium (NiTi) rotary files (ProFile, Dentsply Maillefer), and sodium hypochlorite (NaClO) was used for irrigation. Canal obturation was performed with a vertically condensed gutta-percha technique and with a canal filling paste (Pulp Canal Sealer, Kerr).

Following endodontic procedures, the marginal ridges of all tooth specimens were reduced with a cylindrical diamond bur (Fig 2). The width of the occlusal cavity isthmus was set equal to one-third of the intercuspal distance, and the buccolingual width of each proximal box was equal to one-third of the tooth width. Heights of proximal cavities were set so that the floor of preparation was located 1 mm above the CEJ. Sharp internal edges of the cavities were rounded and no bevel was made on the outer edges of the preparations.

After completion of cavity preparations, tooth specimens were restored with composite resins. Enamel and dentin surfaces of prepared cavities were etched with 36% orthophosphoric acid (DeTrey Conditioner 36, Dentsply) for 40 and 20 seconds, respectively. Etched surfaces were thoroughly rinsed with abundant water spray and gently dried with air spray. The one-bottle light-curing total-etch bonding system (XP Bond, Dentsply) was applied onto etched surfaces and light cured (Swiss Master Light, EMS) for 20 seconds with a light intensity of 800 mW/cm².

A thin layer of flowable composite resin (Esthet-X flow, Dentsply) was applied onto the cavity floor as a build-up material and light cured as previously described for the bonding agent. Cavity margins were refined with fine-grit burs to eliminate excess flowable composite. Self-locking matrices (AutoMatrix, Dentsply) were attached around tooth specimens, and the cavities were filled with microhybrid composite resin (Esthet-X HD, Dentsply) using an incremental layering technique. Each resin layer with a maximum thickness of 2 mm was light cured as previously described for the bonding agent. Completed restorations were finished and polished with PoGo polishers (Dentsply). All specimens were stored in a physiologic saline solution for 24 hours.

Cyclic fatigue treatment procedure

The fatigue treatment procedure in group FT was performed using a custom-made device consisting of a water chamber at 37°C. Cyclic forces varying between 10 and 200 N were applied onto occlusal surfaces of tooth specimens (50,000 cycles) at 2 Hz frequency level.
Loading procedure

A universal testing machine (Instron 1195; Instron) was used to apply compressive loads to occlusal surfaces of tooth specimens (Fig 3). The resin blocks comprising tooth specimens were placed and clamped perpendicular onto the horizontal plane of the machine. A cylindrical stainless steel bar was fixed at the removable upper piece of the machine. The bar and the resin blocks were uniaxially positioned so that the side of the bar simultaneously contacted the lingual slopes of buccal cusps and the buccal slopes of lingual cusps of tooth specimens. Five different loading forces (98, 147, 196, 245, and 294 N) were respectively applied onto occlusal surfaces of 30 tooth specimens.

Measurement of cuspal deflection

The cuspal deflection was measured by means of a laser sensor system (Laser Twin Sensor, LMI Technologies). Two laser beams were simultaneously directed to the buccal and lingual sides of tooth specimens just onto the smoothed surfaces coated with an opaque varnish layer (OVL). The OVL served as a guide plane for avoiding measurement errors due to the fact that laser beams can penetrate the opalescent enamel layer. Deflections values were measured 10 seconds after load was applied to obtain the stabilization of deflected cusps, and the sum of both buccal and lingual cusp deflection amounts were recorded for each tooth. Deflection measurements were repeated for each loading force, and obtained length values (µm) were recorded.

Statistical analysis

Data obtained from testing were analyzed with the SPSS 15.0 for Windows statistical software program (SPSS). The analysis of variance (ANOVA) test was used to determine differences among groups. Differences were considered statistically significant at a confidence level of 95% (P < .05).

Results

Mean cuspal deflection values (µm) and SDs of experimental groups are presented in Table 2. Descriptive statistics (mean, maximum, minimum, and SDs) are depicted in Table 3. Comparisons among groups using ANOVA are presented in Table 4. Graphic charts of 15 experimental groups and 3 main groups are shown in

<table>
<thead>
<tr>
<th>Load (n)</th>
<th>Intact</th>
<th>Filled</th>
<th>Fatigue treated</th>
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<tbody>
<tr>
<td>98</td>
<td>24.4 ± 19.8</td>
<td>56.0 ± 49.1</td>
<td>77.2 ± 80.9</td>
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<tr>
<td>147</td>
<td>34.8 ± 28.9</td>
<td>62.6 ± 49.6</td>
<td>83.4 ± 81.3</td>
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Figs 4 and 5, respectively. Obtained values ranged as follows: IN-98 (24.4 ± 19.8), IN-147 (34.8 ± 28.9), IN-196 (43.8 ± 34.7), IN-245 (54.5 ± 46.4), IN-294 (60.3 ± 50.6), FL-98 (56 ± 49.1), FL-147 (62.6 ± 49.6), FL-196 (72.4 ± 52.1), FL-245 (81.3 ± 56), FL-294 (92.2 ± 60.9), FT-98 (77.2 ± 80.9), FT-147 (83.4 ± 81.3), FT-196 (92.6 ± 83.7), FT-245 (102.7 ± 85.4), and FT-294 (124.2 ± 89.5). Mean values of the three main experimental groups were as follows: IN (43.5 μm), FL (72.9 μm), and FT (96.0 μm). Significant differences were found among three main groups and relevant subgroups (P < .001; Table 4).

Discussion

Posterior teeth deflect under compressive loading due to their structural design. Endodontic access cavities and loss of proximal walls due to caries, especially in MOD cavities, may increase their tendency to deflect under chewing.
forces. Coronal restorations preventing residual tooth structures from such stresses are highly recommended.

In the past, full-crown coverage was indicated as the gold standard for postendodontic restoration treatment. Contrary to nonadhesive restorative materials, which require full cuspal coverage, minimally invasive and conservative adhesive materials or restorations have become increasingly popular in actual restorative dentistry.

Little is known about the long-term behavior of restorations, since acrylic resin-tooth interfaces are vulnerable to progressive damage by occlusal loads, as was substantiated by scanning electron microscopy analyses revealing typical fatigue fracture patterns. Fatigue can be defined as the failure of mechanical properties after repeated applications of stress, at a level well below the ultimate fracture strength of the material or interface.

In most in vitro studies, destructive methods are used to evaluate the resistance of the tooth-restoration complex. Nevertheless, the anatomical variability may strongly influence the results of such investigations due to the size and morphology differences of natural teeth. In vitro fractures induced by compressive loading in adhesively restored teeth may occur with values ranging from 302 to 502 N. There is little accordance in the literature about biting forces because a wide range of clenching force values are reported, ranging from 338 N to 720 N up to 1,221 N, whereas older studies report lower values between 13 and 66 N up to a maximum of between 147 and 261 N. However, some authors suggest that tooth fracture seems to occur mostly due to a fatigue phenomenon: Over time, repeated stress can greatly reduce the resistance to fracture, even under forces far below the loading force normally required to break a healthy tooth.

Nowadays, several in vitro studies about postendodontic restorations are available in the literature with both destructive and nondestructive techniques. Some interesting clinical trials also were carried out to assess the reliability of adhesive techniques and materials comparing them with the traditional prosthetic procedures. Measurements of cuspal deflection under load have been used in order to investigate both polymerization shrinkage and the mechanical properties of the tooth-restoration complex.

In particular, the evaluation of nondestructive evaluation of teeth deflection in terms of cuspal deflection under axial load seems to be a valuable method for predicting the capacity of the tooth-restoration complex to withstand intraoral stresses. The rationale for this approach is that, since there...
is a linear relationship between fatigue and static loading, \(^{41,42}\) the lower the amount of deflection, the lower the fatigue of the tooth-restoration complex and the better the prognosis. \(^{43}\)

The present study focused on the last aspect to assess differences of postendodontic adhesive restorations immediately after placement and after cyclic fatigue treatment, to provide information about the changes in mechanical behavior of the tooth-restoration complex over time. The original nondestructive protocol employed in the present study adopted a load range between 98 and 294 N, which is similar to the range normally registered under physiological condition for maxillary premolars. \(^{36}\) Maxillary premolars were selected for the present study because they hold the highest risk of fracture, as reported in the literature. \(^{40}\) Since cuspal deflection was tested on the same tooth samples in condition of integrity and following endodontic treatment/coronal restoration, the variability bias from tooth to tooth was eliminated or strongly reduced. \(^{15,36,37,1}\)

Several papers\(^5,7,14,15,36,38,40,43\) reported a remarkable difference in static load resistance between sound teeth and restored ones, so a restricted number of samples was considered sufficient to assess the null hypothesis.

According to the selected method of measurement, small flat surfaces were created on the buccal and lingual sides of each sample to enable the laser beams to measure more accurately each cuspal displacement without being misled by tooth anatomy. Otherwise, the convex shape of tooth surfaces could have caused unreliable data following a possible vertical micromovement of the tooth during load. Total deflection was recorded as the sum of the deflection of both cusps, without considering the concept of “cuspal independence” reported by Sakaguchi et al. \(^{45}\)

The preparation of endodontic access cavities by removing marginal ridges was meant to simulate the worst condition for the prognosis of the teeth. However, no deflection test was performed on open MOD cavities, as the weakening of cusps was reported several times in the literature. \(^5,9,14,15,40,43\) Such a test could have led to a great loss of samples without being really significant.

The flowable composite layer was used to reduce polymerization shrinkage on residual cusps. \(^{41}\) The 24-hour delay in deflection testing after endodontic and restorative treatments was meant to let the restorations complete their polymerization reactions and settle the stress of composite contraction.

Load application followed the long axis of the tooth in order to simulate the normal occlusal relationship of maxillary second premolars with their antagonist teeth and to standardize as much as possible the test conditions. In addition, since deflection was studied to investigate fatigue, angulated load was avoided, as it was less likely to occur in the oral cavity than axial load.

The results obtained in the present study indicate an increase in deflection under compressive load in all endodontically treated and adhesively restored teeth compared to the intact ones. Greater deformation values were found after mechanical fatigue treatment. Standard deviation values were quite high compared to the mean deflection values, as a consequence of anatomical variability: Each tooth actually reacts differently under load, depending on its size, morphology, and age.

All restored teeth deflect more than the intact ones; bonded coronal restorations then contribute to partly recover the initial properties. Such an increase in cuspal deflection was smaller immediately after restoration placement, and the differences between the groups are greater at higher load values. Significant differences were found between the three experimental conditions. This fact can be related to the different mechanical properties (ie, e-modulus) of dental tissues versus composite material and to the formation of microcracks as load was applied repeatedly. \(^{19}\)

Comparing the results of previous similar studies, \(^5,15,38,39,43\) slight differences in deflection values can be found. A variety of factors involved may contribute to this fact, such as different types of deflection sensors (strain gauges or differential transformers versus laser sensors), load range, load application mode, restorative material, and MOD preparation design. The results are comparable to those obtained in similar studies \(^36,37\) with different composite materials.
Although data comparison with similar studies is difficult, the study by Cobankara et al.\textsuperscript{17} confirmed a lower fracture resistance after cyclic loading treatment in teeth restored with ceramic or composite materials compared to intact ones, concluding that the most interesting option was represented by ceramic inlays. Analogous results were observed by Hitz et al.\textsuperscript{18} in a similar study. Different conclusions were drawn in a work by Kuijs et al.,\textsuperscript{16} in which ceramic and direct and indirect composite employed in the replacement of maxillary premolar cusps were compared by measuring the fracture load after fatigue treatment. The three materials performed in a similar way, suggesting that the treatment choice should be based on criteria other than fatigue resistance.

Fennis et al.\textsuperscript{19} compared the response to fatigue of composite restorations in premolars with a MOD cavity and a simulated buccal fracture, with or without lingual cuspal coverage. Although the group with cuspal coverage showed better survival rates against fatigue, the fractured specimens of this group were mostly unrepairable due to cracked ends below the CEJ. The authors suggested caution in reducing residual cusps.

The cuspal deflection values obtained in restored teeth might provide ideas in the selection of actual adhesive systems and composite materials as alternatives to prosthetic solutions, even in borderline situations such as postendodontic MOD cavities. Even if deformation values become greater after fatigue treatment, restorations appear to be able to withstand the stress during function.

Further investigations are needed to assess the behavior of composite or ceramic inlay restorations under compressive forces. The results of the present in vitro study should be confirmed in clinics by monitoring the behavior of tested restorative materials in randomized clinical trials.

Conclusions

The highest cuspal deflection values (CDVs) were obtained in the FT groups. The lowest CDVs were obtained in the IN groups. FL groups showed higher deflection values than IN groups. CDVs increased progressively as the teeth were restored and subjected to fatigue treatment.

Acknowledgments

The authors reported no conflicts of interest related to this study.

References


