The fracture behavior of premolar teeth with class II cavities restored by both direct composite restorations and endodontic post systems

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\section*{Abstract}

\textbf{Purpose:} The aim of the study was to evaluate the influence of different posts on the fracture load and fracture mode of endodontically treated premolars with class II cavities and direct composite restorations in an ex vivo setting.

\textbf{Methods:} Forty-eight single-rooted human premolars were endodontically treated and prepared with standardized MO (mesio-occlusal) cavities. Eight teeth each received either no post or were restored with titanium screws (BKS), glass fiber posts (DentinPost), or quartz fiber posts (DT Light SL). Sixteen teeth were restored with zirconium dioxide posts (CeraPost). BKS-screws and eight zirconium dioxide posts were cemented conventionally with glass ionomer cement; Panavia F resin cement was used for all others. The specimens were restored with direct composite restorations. Eight sound premolars served as the controls. After thermomechanical fatigue testing, the samples were loaded until fracture occurred at an angle of 45°. All specimens were evaluated for fracture lines.

\textbf{Results:} The sound teeth showed the significant highest fracture load (792.50 \pm 210.01 N). The group restored with quartz fiber posts differed not significantly from the control. In the groups with fiber posts and titanium screws significant higher fracture load values occurred as in the group with direct composite restorations without posts. The groups with fiber posts did not show a more favorable fracture mode than the other groups.

\textbf{Clinical significance:} The use of an intraradicular post in premolars with class II cavities can significantly increase the resistance towards extra-axial forces.

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\section{Introduction}

Restoration of endodontically treated teeth is, in many clinical situations, possible without posts due to modern adhesive systems. However, in cases with substantial hard tissue loss resulting from cavities or trauma, posts are at least necessary for providing sufficient retention of core materials.\textsuperscript{3} Concerning post materials, new developments have also arisen in recent years. In addition to post systems based on the traditional materials (e.g. precious gold alloys or titanium), tooth-like colored materials (e.g. ceramics and composites) have also been introduced.\textsuperscript{2,3} Zirconium dioxide and glass (or quartz) fiber-reinforced composites (FRC), in particular, are the foundation of many modern post-and-core concepts.\textsuperscript{4}
2. Materials and methods

2.1. Specimen preparation

A total of 56 sound, single-rooted premolars from the upper and lower jaws with similar size and shape were collected from the Dental School and Clinics of Saarland University, as well as from a group of private practitioners and orthodontists; the specimens were stored in a solution of water and 5% thymol at room temperature. Teeth were removed from the thymol solution only for the purpose of processing as specimens in the study.

The root surfaces were cleaned using a scaler and randomly divided into seven groups of eight specimens each. One group (n = 8) remained untreated and served as the control group. Following trepanation with a diamond bur and water-cooling, the root canals of the remaining 48 teeth were instrumented manually in a step-back technique to an apical size of ISO 40 (Hedström, VDW, Munich, Germany). Canals were dried with absorbent paper points and obturated with gutta-percha (Roeko, Langenau, Germany) and sealer (AH plus, Dentsply DeTrey, Konstanz, Germany) using cold lateral condensation.

All teeth were embedded in an acrylic resin (Palapress Vario; Heraeus Kulzer GmbH, Hanau, Germany) cube (1.6 mm x 1.6 mm), using a custom-made silicone mould (Adisil; Siladent-technik GmbH, Munich, Germany). The acrylic level was adjusted 2 mm below the buccal cemento-enamel junction.

2.2. Restorative procedures: preparation of coronal dental hard tissue

The preparation of the mounted teeth was performed using a parallelliometer-drilling device (Degussa Dental AG, Hanau, Germany) under permanent water-cooling. MO-cavities were prepared in the teeth using 2° tapered diamond burs (preparation bur: 6847 KR 018; finishing bur: 8959 KR 018; Brasseler, Lemgo, Germany) with rounded angles for the occlusal cavity. The approximal box was prepared with a 5° tapered diamond bur (preparation bur: 845 KR 025; finishing bur: 8845 KR 025, Brasseler) and a depth limited to 1 mm coronally from the mesial cemento-enamel junction. The bucco-lingual width of the approximal box was 4 mm at the bottom and 4.5 mm at the occlusal face. The mesio-distal width was 2.5 mm. The occlusal isthmus was placed 1.5 mm above the bottom of the approximal box and had a diameter of 3 mm at the apical and 3.5 mm at the occlusal face of the cavity. The position of the occlusal cavity varied slightly depending on the required central position of the access cavity.

2.3. Restorative procedures: placement of posts and direct composite restoration

The materials for the restorative procedures are listed in Table 1. Group 2 was restored without any post. In the remaining five groups, the following posts were used: in group 3, a titanium screw (BKS); in groups 4 and 5, a pre-fabricated zirconium dioxide post (CeraPost); in group 6, a glass fiber-reinforced composite post (Dentinpost); in group 7, a quartz fiber-reinforced composite post (DT Light SL).

In all roots, 11-mm deep post spaces were prepared as measured from the bottom of the approximal cavity. For all post systems, the system-specific preparation instruments were used according to the manufacturer’s recommendations. In group 3, a thread was cut using the system-specific thread cutter (118BKS.000.2, Brasseler).

The root canal surfaces in groups 4–6 were roughened with a special instrument (196D, roughness 52 µm; Brasseler).

Prior to fixation, all screws and posts were cleaned with ethanol and dried with an air blow. The root canals were rinsed with 0.5% sodium hypochlorite and dried with paper points.

The posts in groups 3 and 4 were cemented in the conventional way using automatically mixed (Rotomix; 3M ESPE, Seefeld, Germany) glass ionomer cement, which was applied to the total post surface. Subsequently, the post was seated in place using finger pressure. Excess cement was removed using a sharp instrument and cotton pellets.

In groups 5–7, the dentinal surfaces were conditioned by applying a self-etching primer (ED primer). This was left for 60 s, and a gentle air blow was used to evaporate the dissolution fluid. Resin cement (Panavia F) was mixed for 30 s and applied to the total post surface. Subsequently, the post was seated in place using finger pressure. Excess cement
was spread with a brush in a thin layer covering the coronal portion of the posts to guarantee a better bonding to the filling composite. Finally, light curing took place for 20 s.

After placement, all screws and posts were reduced to a total length of 15 mm. The direct restorations were built up using the micro-hybrid composite, HerculeXXV. Therefore, enamel (45 s) and dentin (15 s) were total-etched with 37.5% phosphoric acid (Gel Exchant; KerrHawe, Bioggio, Switzerland) rinsed for 15 s, and air-dried with a 5 s jet of compressed air. Optibond FL primer was applied onto the cavity surface with a microbrush (Dentsply DeTrey, Konstanz, Germany) and gently dried with an air syringe. Optibond FL adhesive was applied onto the cavity surfaces, gently dried, and light-cured for 20 s. HerculeXXV was added in cavities in increments, each approximately 2 mm thick; each increment was cured for 40 s.

Finally, the restorations were adjusted and polished with corresponding rotating instruments (9400, 9401, 9402, Brasceler, Lemgo, Germany).

2.4. Thermomechanical aging

The samples were subjected to thermocycling (Willytec, Gräfelfing, Germany) with 100,000 cycles at 5–55 °C and a dwell time of 30 s. Due to the transfer time of 5 s, the total time for one complete cycle was 70 s.

The mechanical aging was done in a chewing simulator (Willytec) with a stainless steel spherical antagonist (diameter, 4 mm) at an angle of 45° and with contact on the mesial fossa. Eight specimens were loaded simultaneously in 1,200,000 cycles with 50 N with a crosshead speed of 10 mm/s downward and 70 mm/s upward. During the aging process, the specimens were permanently kept in a wet environment (Aqua dest.).

2.5. Determination of load-bearing capacity

The samples were fixed in a metal holder in a universal testing machine (Zwick/Roell, Ulm, Germany) with the long-axis of the roots under an angle of 45° to the direction of the load. A stainless steel spherical antagonist (diameter, 4 mm) was used to load the samples until failure at a crosshead speed of 0.5 mm/min, with the force transferred to the composite restoration in the middle of the mesio-distal width of the buccal cusp on an interposed polycarbonate foil, 0.5 mm in thickness (Durian; Scheu Dental GmbH, Isarloh, Germany).

A sudden decrease in force of more than 30 N was regarded as an indication of failure, and the maximum force up to this point was recorded as the force at fracture.

2.6. Evaluation of fracture patterns

All samples were then removed from the acrylic and assessed for failure modes by visual inspection in combination with ink staining (Parker, Baden-Baden, Germany) and the fracture lines were documented on a schematic tooth drawing. Evaluation of post fractures followed fracturing the roots in their vertical axis using a metal instrument after cutting mesially and distally grooves in the root dentin.

"Favorable failures" were defined as repairable failures, including retention failures and fractures of the root above the level of bone simulation. "Unfavorable failures" were defined as irreparable failures as root fractures below the level of bone simulation.27

2.7. Statistical methods

Due to the chosen sample size, the statistical analysis of force at fracture data was performed using non-parametric tests (i.e. Kruskal-Wallis and Mann-Whitney-U). The level of significance was set at p < 0.05. The data for fracture patterns are reported as descriptive. All analyses were performed with SPSS, version 14.01 (SPSS GmbH Software, Munich, Germany).

3. Results

With the exception of sample number 5 of group 4, all samples tested survived $12 \times 10^5$ cycles of dynamic loading and $10^4$ thermal cycles in the artificial oral environment.
3.1. Analysis of load-bearing capacity

Table 2 shows the results of load-bearing capacity testing. Specimens fractured at failure loads of 261–1,030 N. In group 1 (control), the highest fracture loads were measured (792.50 ± 210.01 N). The highest fracture loads among the groups with different types of post-endodontic restorations were in group 7 (DT Light SL). The lowest fracture loads were noted in the groups with zirconium dioxide post.

The differences between the groups restored with fiber posts or titanium screws and the group without any post were statistically significant; however, only the fracture loads measured in group 7 differed not statistically significant from the control (Table 3).

3.2. Analysis of fracture patterns

In the control group with sound premolars, only “unfavorable failures” were observed. Five of these root fractures occurred in the middle one-third of the root. All other specimens fractured above or 1–2 mm below the simulated bone level. No fracture patterns were seen.

In all test groups the majority of failures were classified as “unfavorable” (Table 4).

4. Discussion

In contrast to many ex vivo studies on endodontically treated teeth, a “worst case scenario” with substantial hard tissue loss was not simulated in this study, rather, a less frequently occurring situation with minor loss of dental hard tissue. Naturally, endodontically treated teeth show a higher degree of substantial loss of hard tissue, and these situations are more challenging to the practitioner performing restorations. Nevertheless, an evidence-based restorative treatment protocol for premolars with minor loss of hard tissue is needed, and our estimation cannot be derived from the published scientific literature.

Clinical failures of dental restorations most commonly result from fatigue. Therefore, all specimens were artificially aged, applying dynamic thermal and mechanical loading with similar parameters as found in the scientific literature. Dynamic and static loading were performed at an angle of 45° to the long-axis of the roots. Dynamic loading was applied to the mesial fossa, whereas during the static loading, the force was transferred to the middle of the mesio-distal width of the buccal cusp to simulate a clinical situation with dynamic occlusion. This thermomechanical cycling resulted in a simulation of 5 years in clinical service.

In general, the data on the mean force at fracture demonstrates a high standard deviation ranging from 17% to 37%. It is a common problem that the use of human teeth results in a large variation in test results, compared with artificially manufactured teeth. This may be related to individual variations of the physical properties of dental hard tissue and tooth dimensions.

To judge the failure risk of variously restored non-vital premolars by their load-bearing capacity determined in an ex vivo setting, it is important to consider what forces can be expected in actual clinical situations.

Ferrario et al. measured single tooth bite forces in healthy young adults and reported on results of 250 and 290 N for the first and second premolars in men. Higher bite forces must be expected in subjects with functional disturbances, such as bruxism. During static loading, the force was applied slowly with a crosshead speed of 0.5 mm/min. This corresponds to the load in a parafunctional situation rather than to a chewing type load or an impact type load.

In this study, in all restoration groups, the above-mentioned bite forces were exceeded; however, only those treatment techniques employing quartz fiber posts reached the load-bearing capacity of sound premolars. So, uncertainty remains when predicting the performance of the alternative restorations in individuals with functional disorders.
Different post systems were used in combination with direct composite restorations, being aware of the fact that minimally invasive intracoronal restorations without posts delivered promising results in ex vivo and clinical studies. However, a direct comparison between these two approaches is rarely to be found in scientific literature. Nevertheless, two published studies from Sorrentino et al. and Siso et al. indicated that a reinforcing effect of an additional post placement is possible when restoring premolars with MOD cavities directly with composite. These results were confirmed in the present study, showing an increased load-bearing capacity when using fiber posts or titanium screws additionally to direct composite restorations. This finding is in contrast with the results from a previous study investigating the fracture behavior of crowned endodontically treated premolars with class II cavities. In an identical experimental setting, the additional placement of posts did not result in increased fracture loads. Therefore hypothesis 1 cannot be accepted. A limitation of the present study is the standardized cavity preparation and loading angle; in a clinical setting varying amounts of remaining tooth structure and loading situations may occur. However, in a clinical study on endodontically treated premolars with class II cavities, adhesive restorations with fiber posts were found to be effective over an observation period of 5 years. Placing rigid posts made from zirconium dioxide delivered no enhanced fracture strength values. Comparing the fracture modes, all tested groups showed unfavorable failures in the vast majority. The superiority of posts with a dentin-like modulus of elasticity, in general, which was stated by a number of publications and is attributed to more advantageous stress distribution to the residual tooth structure, could not be reproduced for the tested situation. The reason for unfavorable failures was not attributed to the rigidity of the endodontic posts or their cementation mode alone. Hypothesis 2 can be accepted partially. Within the limitations of this study, it can be concluded that

1. The use of intraradicular posts can increase the fracture resistance of endodontically treated premolars with MO-cavities and direct composite restorations. 
2. Endodontically treated premolars with MO-cavities, can be restored to the load-bearing capability of sound premolars when using quartz fiber posts.
3. The placement of posts in endodontically treated premolars results in a higher number of unfavorable failures compared to a restoration without the use of posts.

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References


