

# Cyclic Loading of Incisors Restored with Different Post Systems

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## Abstract

**Objective:** To evaluate the fatigue resistance of different post systems by submitting them to cyclic loading.

**Methods:** Human maxillary central incisors of similar dimensions were decapitated, root filled and embedded in acrylic blocks with simulated periodontal ligaments. Post spaces were prepared to a depth of 8 mm and restored with one of the following prefabricated posts: a 1.5 mm diameter titanium post (Mooser) (A), a 1.7 mm diameter zirconia ceramic post (Cosmopost) (B), a 1.4 diameter quartz fiber post (Aestheti-Plus) (C), and glass fiber posts (FRC Postec) of 1.5 mm (D) and 2.0 mm in diameter (E). All the posts were covered with metal copings, stored in 37°C water for 48 h, and then cyclically loaded with 25 N peak load at a 45° angle to the axial direction in a loading machine (Zwick 1465). Every 250 cycles (0.2 Hz frequency), the peak load was increased by 25 N until failure occurred. The equivalent load was calculated with the formula:  $P_{eq} = (\sum_{i=1}^n P_i \cdot N_i) / 1000$ , where  $P_i$  is the peak load, which is repeated for  $N_i$  cycles.

**Results:** Failure modes were yielding (A) and post fracture (B-E). ANOVA post hoc Tukey test showed significantly higher mean loading cycles and mean equivalent loads for (A) than for the other post groups ( $p < 0.001$  in each case). For both variables, no significant differences were found between (C) and (D) or (B) and (E) ( $p > 0.05$ ).

**Conclusion:** For severely damaged upper incisors without ferrule, metal posts demonstrated higher fatigue resistance than fiber-reinforced composite or zirconia posts and thus may be preferable over non-metal posts.

**Keywords:** Glass fiber post; Quartz fiber post; Titanium post; Zirconia ceramic post; Staircase; Fatigue resistance

## Introduction

The usage of root canal posts for the reconstruction of endodontically treated teeth (ETT) is under growing scrutiny since no clear evidence with regard to specific indications, type and design of the post material, operative technique, and cementation is available [1-4]. During the last years, more and more metal-free materials for prosthodontic crowns and bridges have become available. Subsequently, an increasing need for metal-free posts was the logical consequence. Therefore, posts made of zirconium oxide (zirconia) ceramics, quartz fibers, or glass fibers were introduced in the market over the last years and numerous clinical studies investigating survival rates of teeth restored with these posts revealed promising data at least at the short term [5-8]. The advantages of fiber-reinforced composite (FRC) posts over metal posts include their flexibility which may reduce the risk of root fracture and the possibility of easy post removal if access to the apical periodontium is needed or in the case of post fracture [3,9-12]. However, due to the limited number of long-term clinical studies a general recommendation for the replacement of metal posts by metal-free posts should be made carefully. In addition, the bonding effectiveness of the adhesive technique in the root canal is currently fundamentally questioned [13-16]. Clinical studies have shown that adhesively bonded fiber posts loosened more often than metal posts which were conventionally cemented with a zinc phosphate cement [4]. Follow-up studies after ten years revealed a more than twice as high failure rate of bonded glass fiber posts compared to conventionally cemented titanium alloy or cast posts [17,18]. Post fracture and debonding occurred most frequently and the highest failure probability was reported for anterior teeth lacking all coronal walls [17]. However, due to the associated aesthetic benefits of metal-free restorations the main indication for metal-free posts is the anterior region of the maxilla.

Despite many publications in this area, little is known about the fracture resistance towards increasing intermittent loading, which

reflects the clinical situation better than the maximum loading until the fracture occurs [19,20]. One reason for this is that the number of cycles to failure at physiological mastication loads is extremely high [21,22]. As an alternative, staircase loading with an incrementally increasing load for a specified number of cycles is being used for testing the component fatigue of ETT [23]. Therefore, the aim of this study was to evaluate the fatigue resistance of ETT restored with metal and metal-free posts under cyclic staircase loading. The null hypothesis tested was that there is no difference in the fatigue resistance of the different post systems.

## Materials and Methods

### Sample preparation

Extracted human maxillary central incisors of comparable dimensions were cleaned mechanically with scalers and stored in a 1% chloramine-trihydrate solution. Teeth with caries, fracture lines, resorptions, or open apices were excluded. The clinical crowns were removed from the cemento-enamel junction using a diamond saw at low speed and under water cooling. A stereomicroscope (Zeiss Stemi SV 8; Zeiss, Oberkochen, Germany) at a magnification of 12 x was used to exclude pre-existing dentinal cracks at the root surface. After numbering of the teeth the cross-sections of the roots were measured with a digital caliper (Garant; Hoffmann, München, Germany) at the

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level of the cutting surface in a mesio-distal and bucco-palatal direction. Roots of extreme small or large diameter were excluded. According to a randomization plan, the remaining samples were randomly distributed into five groups of seven roots each. Preparation of the root canals was performed using GT rotary files (Dentsply DeTrey, Konstanz, Germany) in a crown-down technique up to a size ISO 50. The working length was established at 1 mm from the anatomic apex. Between the instrument changes, the root canals were irrigated with 5 ml of 3% sodium hypochlorite solution and 15% ethylenediamine tetraacetic acid (Glyde File Prep; Dentsply DeTrey). After a final irrigation with 5 ml distilled water, the root canals were dried with paper points and filled with a root canal sealer based on calcium hydroxide (Apexit, Ivoclar Vivadent, Schaan, Liechtenstein) and gutta-percha points according to the lateral condensation technique. To imitate a human periodontium with uniform force distribution, the root surfaces were wrapped in one layer of latex rubber milk (Suter Kunststoffe, Jegenstorf, Switzerland) and embedded in acrylic resin blocks (Epoxy Die base and catalyst, Ivoclar Vivadent) with the coronal 3 mm being exposed.

### Post placement

Gutta-percha was removed with Gates-Glidden burs at the canal entrance. Standardized burs supplied by the corresponding post manufacturer were used to prepare a post space of 8 mm depth leaving at least 4 mm of the root filling in the apical portion. After a final cleansing with 5 ml of 3% sodium hypochlorite, the post spaces were dried with paper points. Five experimental groups were compared: (A) a 1.5 mm diameter titanium post (Mooser, Cendres & Mètaux SA, Biel/Bienne, Switzerland), (B) a 1.7 mm diameter zirconia ceramic post (Cosmopost, Ivoclar Vivadent), (C) a 1.4 mm diameter quartz fiber post (Aestheti-Plus, RTD, Saint Egreve, France), and glass fiber posts (FRC Postec, Ivoclar Vivadent) of 1.5 mm (D) and 2.0 mm in diameter (E). All the prefabricated posts were cleaned with 70% alcohol and cemented with zinc phosphate cement (Phospha CEM IC, Ivoclar Vivadent) according to the manufacturer's instructions. After post cementation, excess cement material was removed with a disposable brush. After shortening the posts up to 3 mm above the entrance of the root canal, standardized metal copings were placed on the coronal part of the posts (Figure 1). A core build-up and crown were deliberately

left out of the experimental design as this would complicate the interpretation of the results.

### Loading protocol

After water storage for 48 h at 37°C, the posts were subject to cyclic loading at an angle of 45° to the axial direction in a universal testing machine (Zwick 1465, Zwick Roell, Ulm, Germany). The cyclic loading at a 0.2 Hz frequency was performed according to a staircase methodology starting from an initial peak load of 25 N. To reduce excessive stress concentrations during loading, a 0.3-mm thick tin foil was positioned between the metal coping and the steel piston. Every 250 cycles, the peak load was incrementally increased by 25 N until failure of the post. Both, the number of cycles [n] and the maximum load at failure [N] were recorded. The equivalent load was calculated according to the formula:  $P_{eq} = (\sum_{i=1}^n P_i \cdot N_i) / 1000$ , where  $P_i$  is the peak load, which is repeated for  $N_i$  cycles.

### Statistical analysis

Statistical analysis was performed with SPSS for Windows version 19 (SPSS, Chicago, IL, USA). The level of significance was set at  $p < 0.05$ . Differences between the means of the groups were compared with one-way ANOVA followed by Tukey's post hoc test.

### Results

All the test samples survived the loading cycles without a visible (complete) root fracture. Predominant failure modes were yielding of the metal post (A) and post fracture in the metal-free post groups (B-E). The mean loading cycles and standard deviations were: 1475 ± 66 (A), 1045 ± 93 (B), 767 ± 69 (C), 761 ± 134 (D), and 1160 ± 143 (E). The mean equivalent loads and standard deviations were: 128 ± 10 N (A), 68 ± 12 N (B), 40 ± 6 N (C), 40 ± 12 N (D), and 83 ± 18 N (E). Figure 2 summarizes the results. For both variables, ANOVA post hoc Tukey test showed significant differences between the metal post (A) and the metal-free post groups ( $p < 0.001$ ). For both variables, no statistically significant differences were found between (C) and (D) or (B) and (E) ( $p > 0.05$  in each case). However, the zirconia ceramic post (B) withstood a significantly higher load than the fiber-reinforced composite posts (C) and (D) ( $p < 0.05$  in each case).

### Discussion

The null hypothesis that there is no difference in the fatigue resistance of the different post systems had to be rejected. In the present study, titanium posts showed significantly higher fatigue resistance than glass fiber, quartz fiber, and zirconia ceramic posts. Conventionally cemented titanium posts have been well investigated in the literature and have demonstrated a long-term clinical performance [4,18]. Disadvantages of titanium posts are grey discolorations of the roots and their high rigidity, which increases the risk of decementations and root fractures [24]. However, post fractures have been reported to be rare [18]. In the present study, the primary failure mode of the titanium post was yielding, while the non-metal posts did break during the cyclic loading. The yield strength is defined as the force required to cause a plastic deformation of the test sample [25]. The initial linear portion of the stress-strain curve is elastic and so after the load is removed, the sample will not have any permanent deformation. Increasing the load over the elastic region, the plastic area is reached resulting in some permanent bending [25]. The transition point between elastic and the plastic region is termed as the elastic limit [25]. Fiber posts have a higher elasticity (elastic modulus (E))=30-60 GPa) compared to the stiffer titanium alloy (E ~ 117 GPa) or zirconia ceramic posts

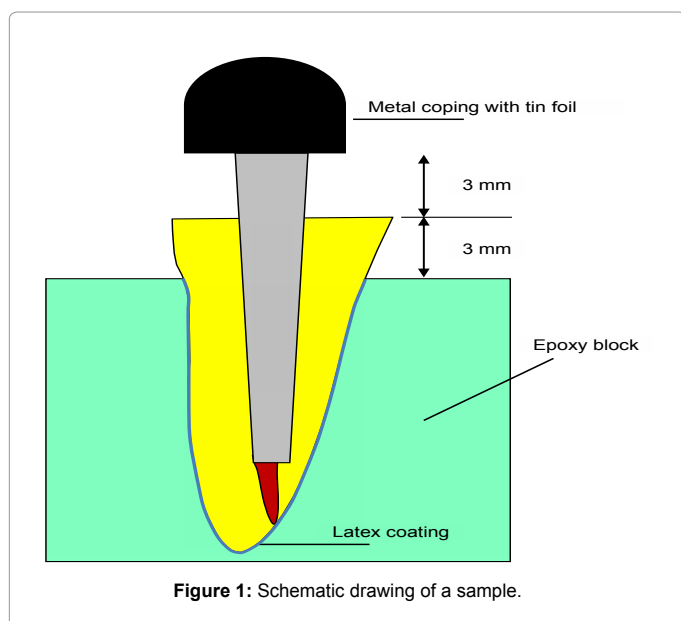
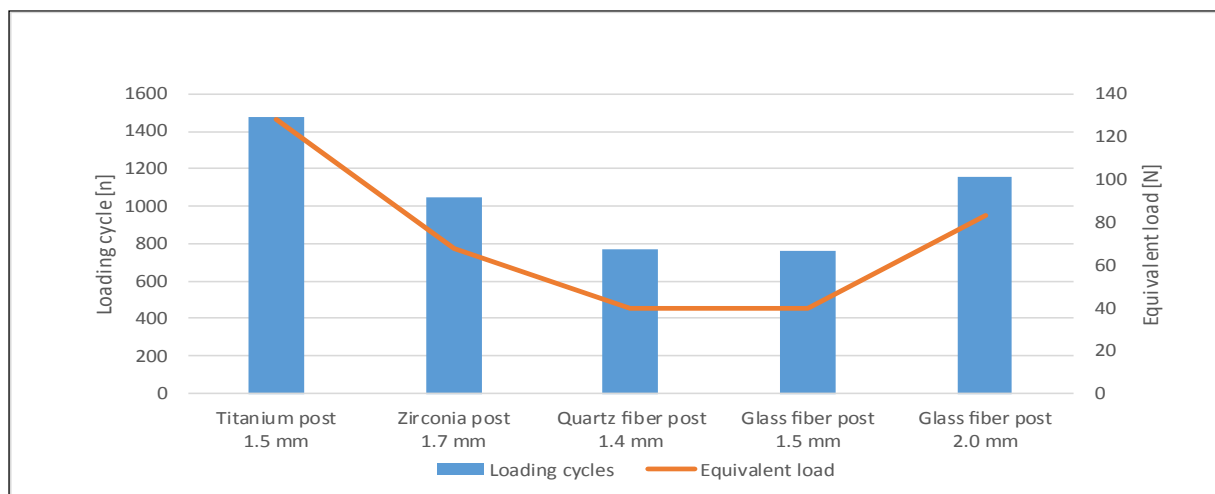


Figure 1: Schematic drawing of a sample.



**Figure 2:** Mean number of loading cycles and mean equivalent load (i.e. standardized to the number of cycles that reach maximum load) of different post systems after cyclic loading.

( $E=170-200$  GPa) [9,12,22,26]. On the one hand, the higher elasticity reduces the risk of root fractures but on the other hand, a less invasive preparation is sufficient for more rigid posts because of the smaller post diameter [26]. This assumption is only supported in parts by the present study. Although the 1.5 mm titanium post showed significant higher load values than the glass and quartz fiber posts with the same or thicker diameter, the even more rigid zirconia ceramic post showed a significantly decreased load rating. In the literature, little is known about the long-term survival of these all-ceramic posts [7,8] and in this context it is problematic that after luting zirconia ceramic posts can no longer be removed and thus offer no potential for reinterventions of ETT. In the case of a post fracture this will lead to the loss of the tooth.

In the present study, all the posts were non-adhesively cemented with zinc phosphate cement. Metallic posts are normally fixed within the root canal with a non-adhesive technique allowing the later removal of the post. Furthermore, the manufacturer states that zirconia ceramic posts can be cemented with conventional zinc phosphate or glass ionomer cements, thus reducing the risk of root fractures during post removal and retreatment. Zinc phosphate cement provides a dentin-like  $E$  between  $\sim 13$  GPa and 22 GPa [12,27], is ease of use, and has withstood the test of time. Disadvantages of conventional cements include their low tensile strength, their relatively high solubility, and at least in the case of zinc phosphate the lack of a bonding potential to root dentin [12]. Therefore, the retentive strength relies highly on an adequate adaptation of the post to the prepared root canal and the cement layer. In contrast, adhesive luting techniques could favor the retention of posts within the root canal [28]. Moreover, literature has reported that fiber posts should be fixed with an adhesive technique in all cases to ensure the reinforcement of the ETT and to withstand functional loads [27]. However, current studies indicate that the effectiveness of the adhesive technique within root canals is questionable. Some authors suppose that the measured push-out or pull-out bond strengths are basically caused by frictional retention of the post within the root canal [14-16]. Moreover, the adhesive interfaces may degrade during the clinical service [22]. Against this background, the strengthening effect of adhesively luted fiber posts on ETT is debatable and further research efforts are necessary.

A deeply damaged ETT is an unfavorable initial situation for a successful prosthetic restoration, especially if the remaining dentin is too less for a ferrule preparation (absence of a ferrule effect). In vitro and clinical reports indicate that such situations cannot simply be compensated by adhesive techniques using FRC posts and composite core build-ups [2,5,17,29]. The present study shows, that for largely destroyed upper incisors without a ferrule effect, an increasing coronal diameter of the FRC post helps to reduce the fracture risk to a certain extent. However, the residual dentin wall thickness needs to be carefully considered. It has been reported, that metallic posts are of advantage if the restoration is strongly loaded, e.g. in the case of patients with bruxism or malposition of upper anterior teeth [2,4]. In the present study the mechanical load was applied in an angle of 45 degree to simulate a worst case scenario with strong shear forces. The results suggest that in such a scenario a metallic post may be preferable over FRC and zirconia ceramic posts. However, long-term clinical trials with an adequate number of restored teeth, especially in the fracture prone upper incisal area, are necessary to prove that the newer metal-free posts are a durable alternative to metallic posts.

## Conclusion

Under the limitation of an in vitro study, it can be concluded that titanium posts demonstrated higher fatigue resistance than fiber-reinforced composite or zirconia ceramic posts. No significant difference has been observed between glass and quartz fiber posts of similar size. For severely damaged and endodontically treated teeth in the upper incisal area with absence of a ferrule effect, metal-free posts with a sufficient material diameter should be used. However, in such a scenario more rigid metallic posts may be preferable over non-metal posts.

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