
Aim: The purpose of this study was to evaluate the fracture resistance of endodontically treated maxillary central incisors restored with quartz fiber posts, composite cores, and crowns when different types of ferrule designs were incorporated.

Methods and Materials: Sixty maxillary incisors were divided into six groups: Group 1 (control): teeth with root canal treatments having a full crown prosthesis; Group 2: teeth with a 2 mm circumferential ferrule; Group 3: teeth with a 2 mm ferrule only in the vestibular region; Group 4: teeth with a 2 mm ferrule only in the palatal region; Group 5: teeth with a 2 mm ferrule in the vestibular and palatal region, having cavities in both proximal areas; and Group 6: teeth with no ferrule. The teeth in the experimental groups were restored with quartz fiber posts-composite cores and full metallic crowns. All experimental teeth were subjected to an increasing compressive force with a crosshead speed of 1 mm/min, until fracture occurred.

Results: The median fracture values of groups were as follows: Group 1: 574.4 N, Group 2: 472.4 N, Group 3: 474.3 N, Group 4: 480.7 N, Group 5: 463.1 N, and Group 6: 297.9 N. A statistically significant difference was found between Group 1 and Group 6 (p< 0.01).

Abstract
Conclusion: It was concluded different ferrule designs did not have any influence on the fracture resistance of teeth with fiber posts. The results of this study indicate fiber posts can safely be used for their reinforcing properties. Furthermore, there is no significant change in the resistance of teeth with fiber posts regardless of which ferrule design is incorporated. The property of these types of posts is an additional advantage in clinical practice.

Keywords: Post-core restorations, restoration of endodontically treated teeth, quartz fiber post, fracture resistance, ferrule design


Introduction

The restoration of endodontically treated teeth frequently poses a challenge for the clinician. Apart from substantial tissue loss which can be considered as one of the major obstacles, endodontically treated teeth are assumed to be more prone to fracture because of desiccation or premature loss of moisture supplied by a vital pulp.1

In cases of severe hard tissue loss, posts are frequently used as reinforcing elements in the prosthodontic restoration of endodontically treated teeth. Previously posts were believed to reinforce tooth structure and strengthen weakened endodontically treated teeth against intraoral forces by distributing torqueing forces within the radicular dentin to supporting tissue along their roots.2 Currently, posts are not believed to function as a reinforcing component of prosthodontic treatment but rather as an element supporting a core foundation when there is an insufficient clinical crown.3

In recent years more emphasis has been placed on the “ferrule effect” in the restoration of endodontically treated teeth with posts and cores. A ferrule has been described as a key element of tooth preparation when using a post and core.4 It is a generally accepted restorative strategy to include a ferrule in the design of the tooth preparation when restoring a endodontically treated tooth with a post and core and then restored with a crown.5 The availability of 2.0 mm of coronal tooth structure between the shoulder of the crown preparation and the tooth/core junction has been shown to provide a ferrule effect enhancing fracture resistance and preventing fracture and dislodgement of the post.6 It has been stated the ferrule can improve resistance to dynamic occlusal loading, maintain the integrity of the cement seal of the artificial crown retainer, and reduce the potential for concentration of stress at the junction of the post and core. Furthermore, “the ferrule effect” reduces the wedging of tapered posts or bending forces during post-insertion and helps to improve the marginal integrity of fixed partial dentures.7

In cases where coronal tooth structure is intended to be used to function as a ferrule, a circumferential supporting structure of uniform height may be difficult to achieve due to the variability of hard tissue damage. The type of hard tissue destruction in incisor teeth may show clinical variations; thus, teeth with hard tissue loss may necessitate the incorporation of different types of ferrule designs. Naumann et al.,7 based on clinical experience, indicated tooth fracture often followed specific patterns. Occlusal overload might cause facial sub-gingival tooth damage and leave palatal hard tissue intact whereas
perpendicular loading to the facial surface commonly resulted in a palatal sub-gingival level fracture.

The purpose of this in vitro study was to investigate the fracture resistance of endodontically treated maxillary central incisor teeth restored with quartz fiber posts and crowns when different types of ferrule designs were incorporated.

Methods and Materials

Preparation of the Specimens
Sixty recently extracted, caries-free, intact human maxillary central incisors were selected from 100 maxillary central incisors extracted for periodontal reasons. During the selection of teeth special care was taken to include those teeth whose coronal heights were 10 ± 1 mm and root lengths 13 ± 1 mm. All external debris was removed with an ultrasonic scaler. The selected teeth were stored at room temperature in a 0.1% thymol solution until testing. Endodontic access cavities were prepared using a water cooled air turbine handpiece.

The teeth were endodontically prepared using the “step-back” technique to a #70 size file (Flex R File, Union Broach, York, PA, USA) and irrigated with 2.5% sodium hypochlorite. During root canal preparation the working length was set at 1 mm short of the apical foramen. Each canal was obturated using the lateral condensation method with gutta-percha points (Dentsply, Maillefer, Tulsa, OK, USA) and AH Plus sealer (De Trey, Zurich, Switzerland). Following root canal obturation, the adequacy of endodontic fillings was confirmed by radiographs exposed from various angles. The endodontic access cavities were filled with a temporary filling material.

The specimens were stored in an incubator at 37°C for one week. All teeth were then prepared with a circumferential 1 mm shoulder meeting all-ceramic crown requirements. The prepared clinical crowns were removed providing different ferrule designs. The specimens were divided into six groups. The properties of the specimens included in each group were as follows: (Figure 1)

- **Group 1 (control group):** Root filled tooth specimens without endodontic posts receiving crowns.
- **Group 2:** Circumferential ferrule 2 mm above the cemento-enamel junction.
- **Group 3:** Hard tissue was removed providing a 2 mm ferrule on the buccal aspect (traumatic injury).
- **Group 4:** Hard tissue was removed providing a 2 mm ferrule on the palatal aspect (occlusal overload).
- **Group 5:** Hard tissue was removed providing a 2 mm ferrule on the buccal and palatal aspects with interproximal concavities (caries treatment).
- **Group 6:** No ferrule above the cemento-enamel junction (severe damage).

The temporary fillings were removed from all teeth. Root canal fillings were removed leaving at least 4 mm of gutta-percha in the apical portion. The endodontic access cavities in the control group were filled with a composite core material without any additional procedure.

D.T. Light-Post Double Taper No. 2 quartz fiber posts (Bisco Inc, Schaumburg, IL, USA)

Figure 1. Specimen design (approximal view of location of remaining tooth structure).
were selected, and root canal spaces in the experimental groups were prepared using the special #2 drill included in the kit. Post spaces were prepared so an 8 mm intraradicular post length would be achieved. Root canal walls were etched with Uni-Etch 32% phosphoric acid (Bisco Inc, Schaumburg, IL, USA) for 15 seconds, rinsed with an air water spray, and compressed air. All-Bond 2 bonding agent (Bisco Inc, Schaumburg, IL, USA) was applied to the moist dentin. Fiber posts were cemented with Duolink dual cure composite resin luting cement (Bisco Inc, Schaumberg, IL, USA).

Core build-up was performed using Bis-Core (Bisco Inc, Schaumberg, IL, USA) dual cured core build-up composite. During core build-up, special care was taken to provide an approximately 8 mm long crown length. A final preparation was made using water-cooled air turbine handpiece and burs.

Impressions were taken using a light-bodied silicone impression material (Oranwash, Zhermack, Italy), and 60 similar full metallic crowns 10 mm in height were fabricated using Ni-Cr alloy (Wiron 99, Bego, Germany). The crowns were cemented using zinc phosphate cement. Following cementation, a notch was scraped 3 mm below the incisal edge corresponding to the middle of the mesio-distal width. The prepared specimens were stored in 100% humidity for three days at room temperature.

All roots were blocked out with wax 2 mm below the finish line to imitate biologic width. The roots were covered with a 0.1 mm thick layer of autopolymerizing silicone to simulate a human periodontium. The teeth were embedded in an autopolymerizing acrylic resin (Meliodent, Bayer UK Ltd, Newbury, UK) orienting their long axes in a 135° angle with the loading force (Figure 2).

Testing Fracture Strength
Specimens were mounted on a universal testing machine (Instron, 3345, Norwood, MA, USA). The load head was placed on previously prepared notches in the cast crowns. A compressive force was applied at a crosshead speed of 1 mm/min until fracture occurred. The fracture loads were recorded in Newtons.

Data was analyzed using the Kruskal-Wallis test and Dunn's multiple comparison test. A significance level was set at p<0.05.

Figure 2. Schematic drawing of the specimen mounted in acrylic resin block; A: Quartz fiber post, B: Composite core, C: Cemented metal crown, D: Resin block, E: Silicon simulated periodontal ligament. Arrow indicates 135° of angle load applied to prepared notch on the palatal surface.
**Evaluation of Fracture Mode**

The modes of fracture were classified according to the criteria suggested by Andreasen and Andreasen. According to these criteria, fractures extending within 3-4 mm below the cemento-enamel junction are considered repairable whereas fractures exceeding this limit are regarded as catastrophic failures requiring extraction.

**Results**

Table 1 summarizes the median and mean fracture resistance values for the control and the experimental groups. The control group presented higher fracture strength than the other groups.

When the fracture resistances were evaluated, Group 1 (control group) had the highest result both as a mean and a median; the lowest mean and median values were obtained for Group 6. Statistical analysis showed a significant difference existed between Group 1 and Group 6 (p<0.05). The median fracture resistance for the control group was significantly greater than Group 6. There was no statistically significant difference in the fracture resistances of teeth with crown prosthesis without hard tissue loss and teeth with fiber post-composite core and crown prosthesis having different ferrule designs.

When the mode of failure was evaluated, no vertical root fractures were observed in any groups. The modes of fracture were either horizontal or oblique. Only one catastrophic root fracture occurred in Group 1, which had no posts, among all groups. The fracture modes are presented in Figure 3.

**Discussion**

In the present investigation extreme care was taken to provide an even distribution between the experimental teeth with respect to size. Teeth were randomly distributed among the testing groups. A standard protocol was followed during all the steps of the study. Despite this effort, it is impossible to achieve an exact uniformity among the experimental teeth. Although teeth may be selected of equal dimensions, there are multiple factors such as variation in moisture content and number of dentinal tubules. Heydecke et al. reported the main disadvantage of natural teeth is the relatively large variation in size and mechanical parameters, often resulting in large standard deviations.

This has also been observed in the present investigation. The variables in human teeth may include tooth conditions previous to the extraction, tooth age, tooth storage conditions, pulp status at the time of extraction, root anatomy, and root dimensions. Despite these drawbacks, the utilization of human teeth is the only and the most reliable methodology in fracture testing and has also been adopted by many authors who performed studies of a similar nature.

In the present study crowns were placed over the experimental teeth before subjecting them to compressive testing in order to more precisely simulate clinical conditions. The placement of

| Table 1. Fracture loads (Newton) of control and test groups. |
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| Groups | Median | Mean | Min | Max |
| Group 1 | 574.4 | 605.4±192.8 | 373.4 | 898.5 |
| Group 2 | 472.4 | 544.2±269.5 | 209.2 | 1061 |
| Group 3 | 474.3 | 489.2±179.4 | 228.2 | 744.6 |
| Group 4 | 480.7 | 474.4±139.5 | 301.8 | 675.7 |
| Group 5 | 463.1 | 460.3±136.2 | 287.5 | 699.3 |
| Group 6 | 297.9 | 313.9±150.8 | 115.8 | 611.7 |
a crown during testing has been questioned by some who indicate this practice may obscure the effects of different buildup techniques. However, to not place crowns would not reflect common clinical practice; therefore, crowns were placed prior to loading test. Similar comments were made by Heydecke et al.

Quartz fiber posts were specifically selected as the intraradicular supporting elements due to their low elastic modulus (18 to 47 GPa) similar to dentin. Furthermore, these post systems have gained widespread usage in recent years for their many beneficial properties such as esthetics and ease of application allowing the practitioner to complete the procedure in a single appointment. Ease of retrievability is an additional advantage. Burgess et al. also reported a preference for posts designed to be similar to the root form. Akkayan and Gülmez reported the light-transmitting property of the DT Light-Post system makes it possible to polymerize primer and cement through the post, and they related their significantly better results obtained with this post system to this characteristic.

Maxillary incisor teeth were selected due to their high susceptibility to trauma that may eventually require the placement of a crown restoration. Various types of hard tissue damage may occur in the tooth structure requiring variations in ferrule design appropriate for individual fracture

Figure 3. Location and frequencies of fractures in each of the six groups of specimens. Fractures ending above the grey line were classified as repairable.
scenarios. Naumann et al. stated tooth fracture often followed patterns. Occlusal overload may cause facial sub-gingival tooth damage and leave palatal hard tissue intact. Perpendicular loading to the facial surface of the tooth such as traumatic injuries, commonly results in a palatal sub-gingival level fracture, leaving vestibular hard tissue intact. Furthermore, interproximal cavities are generally observed on maxillary incisors. Therefore, different possibilities of hard tissue loss were tested, simulating various clinical conditions. The hypothesis at the beginning of the study was different ferrule designs would affect fracture resistances in different ways. To examine the effect of different designs more precisely, a group with tooth preparation (Group 1) and a group with no ferrule above the cemento-enamel junction (Group 6) were included in the study. The reason for this approach was to evaluate the effect of ferrule design factor more accurately.

The loading was applied to the experimental teeth at an angle of 135° to the long axis to simulate Class I occlusion. This mode of loading was adopted from the methodology utilized by those authors who also evaluated the fracture resistances of maxillary incisor teeth. Group 6 had the lowest mean fracture resistance values determined in the present study at 313.9 N which had no ferrule incorporated in the preparation. The maximal occluding force for males exerted by a maxillary incisor tooth has been reported as 146 ± 44 N. Quartz fiber posts can be assumed to be reliable options because even the lowest mean fracture resistance

value obtained in the present study exceeded the maximal force exerted upon incisors. This has been the case in the present investigation irrespective of the ferrule designs.

According to the results of the present study, specimens with no ferrule (Group 6) showed significant differences from those without endodontic posts receiving only a crown restoration (Group 1). This was rather expected because Group 1, with the lowest amount of hard tissue loss, represents the strongest foundation whereas Group 6 represents the weakest. This again implies the significance of overlying hard tissue in the achievement of a successful crown system. The fact no significant difference was determined among the groups with different ferrule designs suggests the position of the ferrule does not influence the resistance of the maxillary incisors to fracture. This result may be interpreted as quartz fiber posts exert a similar reinforcing effect regardless of the ferrule design. Consequently, the results may emphasize the practicality of quartz fiber posts in all sorts of clinically encountered cases and advocate their utilization without giving much consideration to the ferrule design. It is true further studies involving a higher number of specimens will strengthen these findings. It has been shown in some studies the ferrule effect significantly reduces the incidence of fracture in non-vital teeth by reinforcing the tooth at its external surface and redistributing the applied forces. In the present study no statistically significant difference was observed among the fracture resistances of teeth with different ferrule designs and those having no ferrule. This result is in agreement with the findings of other studies.

Among teeth with different ferrule designs examined in the present study, the highest fracture resistance was determined in the group having a 2 mm ferrule in the palatal region. In a study by Ng et al., using a similar methodology, the same kind of group showed the highest fracture resistance values. The results of both studies are similar in that respect. When the remaining axial wall (ferrule) is at the location where load is applied, it provides support against the post and core. In this study maxillary anterior teeth were used with the force applied from the palatal direction. For this reason, the ferrule at
the palatal region possibly reinforced the post and core which necessitated greater forces for fracture than those of the other experimental groups.

When the modes of fracture were assessed, the only catastrophic mode of failure was observed in the first group (control) in which no posts were placed. The fact no catastrophic failure was observed in the other groups may favor the use of quartz fiber posts. However, because of the small sample size used in the present study, definite conclusions cannot be drawn by relying on the available results. The modes of failure observed in the present study were favorable which would not require extraction of the teeth in clinical practice. These findings are consistent with the results obtained in different studies. Newman et al. also stated the creation of a mono-block dentin-post-core system through the dentinal bonding would allow better distribution of forces along the root. This may be considered as one of the beneficial properties of quartz fiber posts.

Lack of thermocycling and fatigue loading may be one of the shortcomings of the present study; thus, further investigations may focus on this aspect of occlusal loading.

Conclusion
Susceptibility of endodontically treated teeth with extensive hard tissue loss is one of the challenges faced by the clinician during the restoration process. The fact quartz fiber posts have a similar supporting effect irrespective of the ferrule design may be promising for use of these post systems.

References

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