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Ferrule-Effect Dominates Over Use of a Fiber Post When Restoring Endodontically Treated Incisors: An *In Vitro* Study

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Clinical Relevance

The use of a post for the restoration of nonvital incisors with a ferrule is not necessary. The additional time, materials, and risk involved in the placement of the post do not provide an increase in mechanical resistance. Post placement can be correlated with unrestorable fractures.

ABSTRACT

Objectives: The aim of this study was to investigate the restoration of broken-down endodontically treated incisors with the ferrule effect using glass ceramic crowns bonded to composite resin core buildups with or without a fiber post. A no-ferrule group with post was also included for comparison.

Methods and Materials: Thirty decoronated endodontically treated bovine incisors with a 2-mm ferrule were restored with a direct buildup using a nanohybrid direct composite resin (Miris 2 and Optibond FL) with or without a glass-fiber–reinforced post. An additional group of 15 teeth without a ferrule were restored with buildup and a fiber post. All teeth were prepared to receive bonded glass ceramic crowns (e.max CAD luted with Variolink Esthetic DC) and were subjected to accelerated fatigue testing. Cyclic isometric loading was applied to the incisal edge at an angle of 30° and a frequency of 5 Hz, beginning with a load of 100 N (×5000 cycles). A 100 N load increase was applied each 15,000 cycles. Specimens were loaded until failure or to a maximum of 1000 N (×140,000 cycles). Groups were compared using the Kaplan Meier survival analysis (log rank test at *p*=0.05).

Results: None of the tested specimens withstood all 140,000 load cycles. Specimens with

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posts but without a ferrule were affected by an initial failure phenomenon (wide gap at the lingual margin between the buildup/crown assembly and the root). There was a significant difference in mean survived cycles between the ferrule groups (Fp=73,332× and FNp=73,244×) and the no-ferrule group (50,121×; *p*=0.001). The addition of a fiber post was not significant in the presence of the ferrule (*p*=0.884). In both groups with posts, 100% of failures were unrestorable. The no-post group had 47% of restorable and possibly restorable failures.

Conclusions: The survival of broken-down nonvital incisors was improved by the presence of the ferrule but not by the fiber-reinforced post. Fiber posts were always detrimental to the failure mode and were not able to compensate for the absence of a ferrule.

INTRODUCTION

The restoration of severely broken-down and endodontically treated incisors (ETI) is a major challenge in daily practice. Endodontically treated teeth have significantly different mechanical properties compared to vital teeth. The main modifications in the biomechanics of the tooth are attributable to the loss of tissue following caries lesion, fracture, or cavity preparation, including the access cavity before endodontic therapy.[1,2]

There is a general agreement that the ferrule is the most important mechanical factor[3-5] for the strength of ETI. The presence of an adequate ferrule decreases the impact of the post and core system, luting agents, and the final restoration on the performance of endodontically restored teeth.[3] Teeth prepared with a ferrule have a tendency to fail in a more favorable mode.[6] The amount of suggested ferrule varies from 1 mm[7] to 1.5 mm[8] up to 2 mm.[3] The resistance seems to increase significantly with an increased ferrule height,[9] and a better prognosis can be expected if the ferrule is circumferential.[10]

Traditionally, direct posts are used to retain adhesive core buildups in ETI. Hence, studies about ETI typically compare different types of buildup methods that usually include posts. When deciding to use a direct post, glass-fiber–reinforced (GFR) posts seem to have many benefits (adhesion, tooth-like flexibility, esthetics, etc.).[4,11,12] However, despite all the benefits of GFR posts, their selection and indication are still not fully understood. Earlier publications have reported loss of retention as a major mode of failure for glass-fiber posts luted with resin cements.[13-15] In addition, the preparation of an access channel, canal enlargement during endodontic procedures, and the use of specific chemicals as well as the post placement itself significantly reduce tooth strength.[2]

In posterior teeth, placement of a post has already proven not to significantly improve fracture resistance compared with composite resin core without extra retentive features.[16,17] Whenever a post is used, fewer restorable fractures are expected.[16,18] The uselessness of a post was even demonstrated on premolars[18] using restorative composite and a proven classic adhesive. Pereira and others[19] demonstrated the importance of the ferrule on canines, while Lima and others[20] showed the uselessness of posts in incisors; however, both studies used a single-load-to-failure experiment and metal crowns. Post insertion for teeth showing a minor substance loss should be critically reconsidered.[11] Thus, there is still a lack of scientific information about restoration of ETI with bonded ceramic crowns. Progress in dentin bonding and the so-called biomimetic approach[21] have triggered new ways of restoring ETI using adhesive ceramic crowns, and it has become more acceptable to restore ETI with extensive loss of coronal structure without a post.

Hence, the objective of the present study was to investigate the restoration of ETI with a ferrule using glass ceramic crowns bonded to composite resin core buildups with or without a fiber post. A no-ferrule group with a fiber post was also included for comparison.

The null hypotheses were that 1) the use of a GFR post and 2) the presence of ferrule would not influence the accelerated fatigue strength of ETI and that 3) the presence of a GFR post would not affect the failure mode of the restored ETI tested in this *in vitro* study.

METHODS AND MATERIALS

Tooth Preparation

Forty-five bovine incisors (n=15) with similar dimensions and pulp space were selected and stored in thymol-saturated solution (Thymol, Aqua Solutions Inc, Deer Park, TX, USA). The sample size was determined by a pilot study, without performing a power analysis, following similar experimental designs of previous studies.[16,18] All teeth were decoronated, up to either 15 mm (ferrule group) or 13 mm (no-ferrule group) from the apex, and subsequently separated into three groups: FP = ferrule with GFR

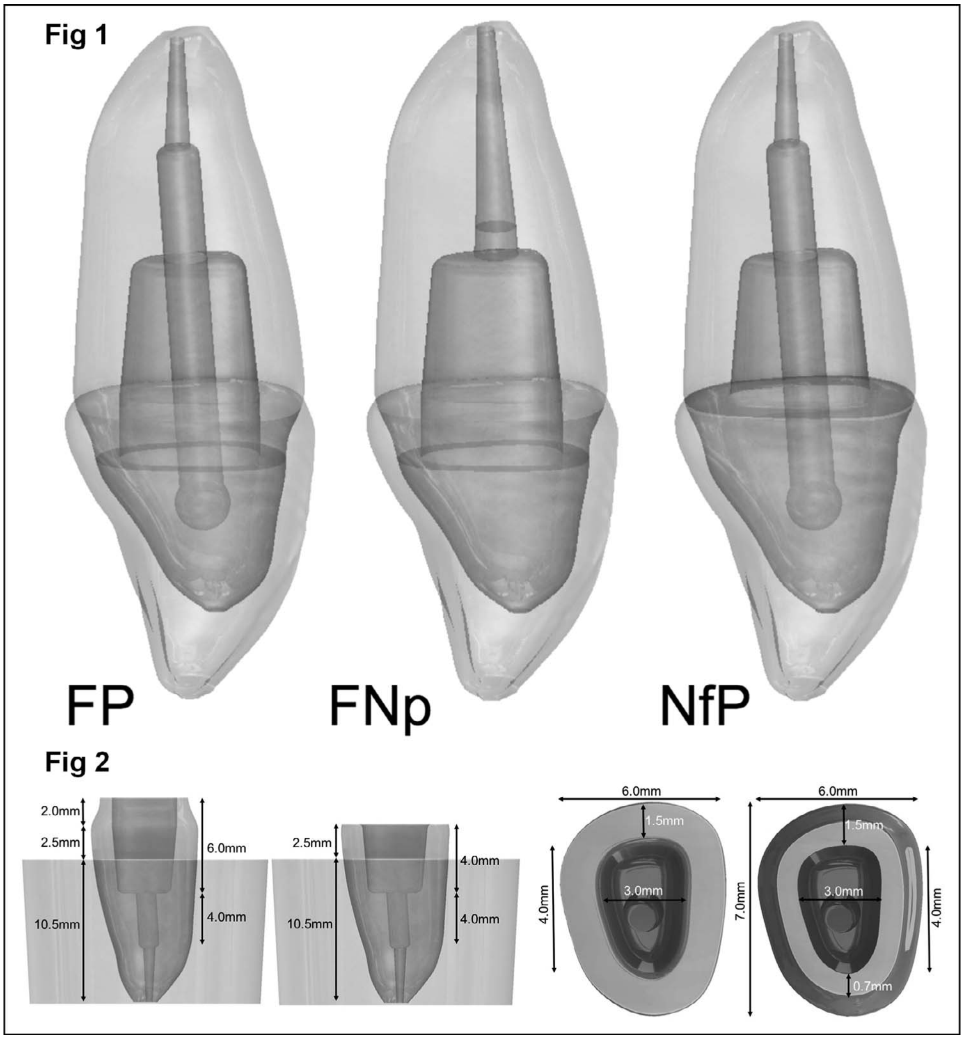


Figure 1. *Schematic views of restored endodontically treated incisors. (A): Group FP. (B): Group FNp. (C): Group NfP.*
Figure 2. *Schematic view of root dimensions before restoration.*

post and resin core buildup, FNp = ferrule and direct resin core buildup, or NfP = no ferrule with GFR post and resin core buildup (Figures 1 and 2). The specimens were mounted in a special positioning device with acrylic resin (Palapress Vario, Heraeus Kulzer, Armonk, NY, USA) embedding 11.5 mm of the root. For the ferrule groups, the specimens were prepared with a tapered round-ended diamond bur (Brasseler, Savannah, GA, USA), creating a 2-mm-high/1-mm-thick circular ferrule and a 0.8-mm horizontal circular chamfer (cervical limit). Table 1 presents the brand, company and qualitative composition information of materials used in the present study.

Endodontic Treatment

Standard chemomechanical endodontic protocol with ideal irrigants ensued.[22,23] The canals were instrumented to at least a size of 40/06 with K3XF rotary files (Sybron Endo, Orange, CA, USA) by crowning down and maintaining patency with a 10k file between rotary files. The canals were irrigated with 17% EDTA (Roydent, Johnson City, TN, USA) for one minute followed by 5.25% NaOCl (Chlorox, Oakland, CA, USA) for one minute as a final rinse.[24,25] The efficacy of irrigation was amplified by Endo Activator (Dentsply, Tulsa Dental Specialties, Tulsa, OK, USA) each with EDTA and NaOCl. After the canals were dried with paper points, one coat of Thermaseal Plus (Dentsply) was placed circumferentially around the lumen all the way to the working length with a 10 K-file. Then 0.6-taper K3XF gutta-percha cones (Sybron Endo) were coated with Thermaseal Plus and used for warm vertical obturation; the gutta-percha was thermoplasticized with a 0.6-taper Buchanan heated plugger (Sybron Endo) and then packed down with stainless-steel Buchanan hand pluggers (Sybron Endo).

Table 1: *Material Application, Brand Name, Composition, and Manufacturers of the Materials Used in the Study*

Application	Brand Name	Composition	Manufacturer
Acrylic resin for tooth mounting	Palapress Vario	*Powder*: methyl methacrylate copolymer *Liquid*: methyl methacrylate, dimethacrylate	Hereaus Kulzer (Wehrheim, Germany)
Dual cure self-adhesive universal resin cement for post cementation	RelyX Unicem 2	*Base paste*: methacrylate monomers containing or not containing phosphoric acid groups, silanated fillers, initiator components stabilizers, rheological additives *Catalyst paste*: methacrylate monomers; alkaline (basic) fillers; silanated fillers; initiator components; stabilizers; pigments; rheological additives	3M ESPE (Seefeld, Germany)
Fiber post	Parapost Fiber Lux	60% glass fiber, 40% resin	Coltène Whaledent (Altstätten, Switzerland)
Glass ionomer barrier	Vitrebond Plus	*Liquid*: resin-modified polyalkenoic acid, HEMA (2-hydroxyethymethacrylate), water and initiators (including camphorquinone) *Paste*: HEMA, BIS-GMA, water, initiators, a radiopaque fluoroaluminosilicate glass	3M ESPE
Silicatization	Rocatec Soft	High-purity 30-μm aluminum oxide, modified with silica	3M ESPE
Total-etch adhesive system	Optibond FL	*Primer*: 2-hydroxyethyl methacrylate ethanol, 2-[2-(methacryloyloxy)ethoxycarbonyl]benzoic acid, glycerol phosphate dimethacrylate *Adhesive*: 2-hydroxyethyl methacrylate, 3-trimethoxysilylpropyl methacrylate, 2-hydroxy-1,3-propanediyl bismethacrylate, alkali fluorosilicates(Na)	Kerr (Orange, CA, USA)
Composite resin for core/buildup	Miris 2	Methacrylate, barium glass, silanized, amorphous silica, hydrophobed	Coltène Whaledent
Silanization	Monobond Plus	Alcohol solution of silane methacrylate, phosphoric acid methacrylate, sulfide methacrylate.	Ivoclar Vivadent (Schaan, Liechtenstein)
Self-etch adhesive system	Adhese Universal	Phosphoric acid methacrylate, methacrylated carboxylic acid polymer, hydrophilic monofunctional methacrylate, hydrophilic/hydrophobic crosslinking dimethacrylate, hydrophobic crosslinking dimethacrylate	Ivoclar Vivadent
Resin cement for restoration luting	Variolink Esthetic Dual Cure	*Monomer matrix*: urethane dimethacrylate, inorganic fillers (ytterbium trifluoride and spheroid mixed oxide), initiators, stabilizers, pigments	Ivoclar Vivadent
Acid for ceramic surface treatment	IPS Ceramic Etching Gel	5% hydrofluoric acid	Ivoclar Vivadent
Glass ceramic for restoration	IPS e.max CAD	SiO_2, Li_2O, K_2O, P_2O_5, ZrO_2, ZnO, Al_2O_3, MgO, coloring oxides	Ivoclar Vivadent

Preparation of Root Canal and Internal Ferrule

For post groups, gutta-percha was removed 8 mm deep into the pulp chamber from the cervical limit with a Reamer pilot drill size no. 3 (Ivoclar Vivadent, Schaan, Liechtenstein) using a hand piece at 1000 to 2000 rpm. For all groups, a so-called internal ferrule was prepared in the form of a box using a conical-shaped bur 4 mm deep from the cervical limit of the crown preparation.

Post Groups Preparation

The post spaces were prepared with ParaPost drills specifically designed for the ParaPost Fiber

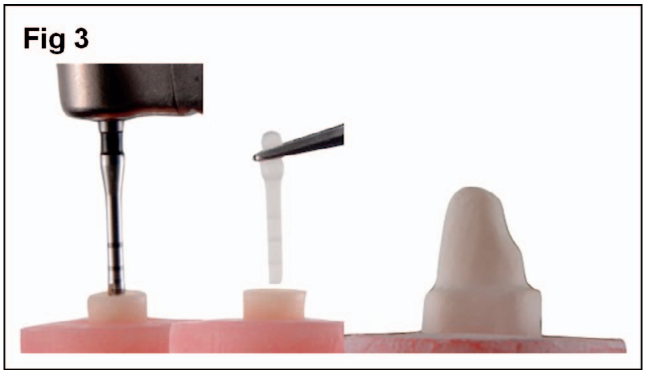


Figure 3. *Post insertion and buildup.*

Lux (no. 6, 1.5-mm diameter, Coltène Whaledent, Altstätten, Switzerland) (Figure 3). Using a cutting disc, the apical portion of the posts was removed to obtain a length of 11 mm (8 mm below and 3 mm above the cervical limit of the crown preparation). Prior to the luting procedure, the posts were cleaned with alcohol and air-dried. The post space walls were lightly coated with cement (RelyX Unicem 2 Automix, 3M ESPE, Seefeld, Germany), and the post was inserted. Cement excesses were cleaned, leaving 4 mm of post height in the cement. The cement system was light cured for 40 seconds (VALO Curing Light, Ultradent Products, Inc, South Jordan, UT, USA). After post cementation, the exposed dentin walls and the post were sandblasted with 30-μm silicated Al_2O_3 powder (Rocatec Soft, 3M ESPE). Silane (Ceramic Primer, 3M ESPE) was applied to the post head and air-dried. For dentin bonding purposes, 35% phosphoric acid (Ultra-Etch, Ultradent Products) was used for etching for 10 seconds, dentin walls and post rinsed and gently dried, followed by application of the adhesive system (Optibond FL Primer and Adhesive, Kerr, Orange, CA, USA) and light curing for 40 seconds (VALO Curing Light). All buildups were obtained with five to six 2-mm-thick increments of Miris 2 (Coltène Whaledent), each polymerized at 1000 mW/cm^2 (VALO Curing Light) for 40 seconds. An air-blocking barrier (KY Jelly, Johnson & Johnson Inc, Montreal, QC, Canada) was used to cover the preparation surface, and additional polymerization was carried out for 10 seconds per surface. Special care was taken to shape the Miris 2 buildup ideally in order to avoid any further corrections of the preparation surface and margins. All buildups were 11 mm high (4 mm internal and 7 mm above the cervical limit of the crown preparation).

No-Post Group Preparation

After internal ferrule preparation, a 1-mm-thick GI barrier (Vitrebond Plus, 3M ESPE) was placed followed by sandblasting (Rocatec Soft), acid etching of all exposed dentin (Ultra-Etch), and application of the adhesive system (Optibond FL Primer and Adhesive). The same buildup technique and materials were used as for the two post groups.

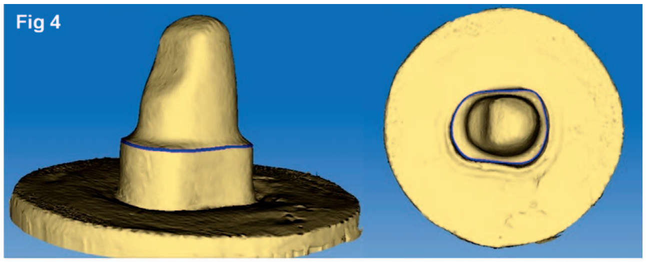
Design and Manufacturing of Restorations

All bonded ceramic crowns were fabricated using the Cerec 3 CAD/CAM system (Sirona Dental Systems GmbH, Bensheim, Germany). Digital impressions of the prepared teeth were performed with Cerec Blue Cam, using a contrast powder (IPS Contrast Spray Chairside, Ivoclar Vivadent). The specimens were fitted with a crown of standardized thickness and anatomy with 11-mm inciso-cervical length and 9-mm mesio-distal width. All crowns were milled in lithium disilicate ceramic (IPS e.max CAD, Ivoclar Vivadent) using the "crown mode" with the sprue located at the lingual surface. After milling, lithium disilicate restorations were glazed, crystallized, and fired according to the manufacturer's protocol (Programat CS, Ivoclar Vivadent) using IPS Object Fix Putty and IPS e.max CAD Crystall/Glaze Spray (Ivoclar Vivadent). The steps of digital design as well as the final restoration are presented in Figures 4 through 6.

Adhesive Luting of the Crowns

The dual-cure resin cement Variolink Esthetic DC (Ivoclar Vivadent) was used. Before luting, each restoration was fit on its respective tooth to check its marginal adaptation. All crowns were cleaned in an ultrasonic bath in distilled water followed by etching with 5% hydrofluoric acid (IPS ceramic etching gel, Ivoclar Vivadent) for 20 seconds and postetching cleaning for one minute in distilled water in an ultrasonic bath. Silane (Monobond Plus, Ivoclar Vivadent) was applied with a microbrush and heat dried at 100°C for five minutes in a minioven (D.I.-500, Coltène Whaledent).

The tooth preparation and buildups were sandblasted with 30-μm silicated Al_2O_3 powder (Rocatec Soft) and coated with Adhese Universal (Ivoclar Vivadent). Variolink Esthetic was then applied to the fitting surface of the crown and seated on the tooth with approximately 500*g* of pressure. Cement excesses were removed and followed by light polymerization three times for 20 seconds on each surface (buccal and lingual) with an LED light



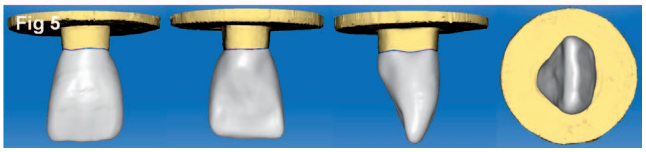


Figure 4. *CAD data set of preparation with preparation line.*
Figure 5. Standardization of crown design using Cerec software. All crowns were 11 mm high and 9 mm in mesial–distal width.

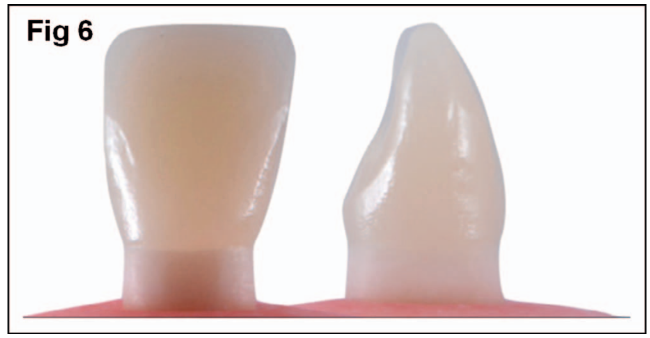


Figure 6. *Final assembly after cementation.*

(VALO Curing Light). Air-blocking barrier (KY Jelly) and additional polymerization was carried out for 10 seconds per surface. The margins were finished with hand instruments (scalpel and scaler). The samples were stored in distilled water at room temperature (24°C) for a minimum of 24 hours following adhesive restoration placement and then subjected to accelerated fatigue testing.

Accelerated Fatigue Test

Masticatory forces were simulated in an artificial mouth using a closed-loop electrodynamic system (Acumen 3, MTS Systems, Eden Prairie, MN, USA). The chewing cycle was simulated by an isometric contraction (load control) applied through a flat composite resin antagonist (Z100, 3M ESPE). The force was applied at a palatal angle of 30° with the flat surface contacting three-fourths of the incisal edge (Figure 7). The load chamber was filled with distilled water to submerge the sample during testing. A cyclic load was applied at a frequency of 5 Hz, starting with a load of 100 N (warm-up of 5000 cycles), followed by stages of 200, 300, 400, 500, 600, 700, 800, 900, and 1000 N at a maximum of 15,000 cycles for each force. Samples were loaded until fracture or to a maximum of 140,000 cycles.

Analysis

All fatigue tests were monitored using a macro video camera and recorded continuously in order to determine the crack propagation mode (initial gap, root fracture, and final fracture). The numbers of endured cycles, load to failure, and failure mode of each specimen were recorded. After the test, each sample was evaluated by transillumination (Microlux, Addent, Danbury, CT, USA) and an optical microscope (Leica MZ 125, Leica Microsystems, Wetzlar, Germany) at 10:1 magnification. A visual distinction was made among three fracture modes, considering the reparability of the tooth: catastrophic, that is, root fracture that would require tooth extraction; possibly reparable, that is, cohesive/adhesive failure with fragment and minor damage, chip, or crack of underlying tooth structure; or reparable fracture, that is, cohesive or adhesive failure of restoration only.

The fatigue resistance of the groups was compared using the Kaplan-Meier survival table (for cycles). At each time interval (defined by each load step), the numbers of specimens intact at the interval and the number of specimens fracturing during the interval were counted, allowing the calculation of survival probability at each interval. A *post hoc* log rank test was used to analyze the influence of the ferrule, post system, and core buildup material on the fracture resistance of the ETI at a significance level of 0.05 (corrected for multiple comparisons when indicated).

Additionally, the fracture load and number of cycles at which the specimen failed was compared using one-way analysis of variance (ANOVA) fol-

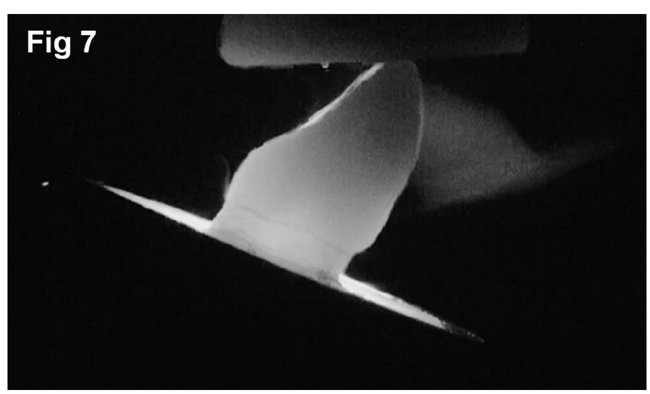


Figure 7. *Specimen in the load chamber. Cyclic isometric loading was applied to the incisal edge at an angle of 30°.*

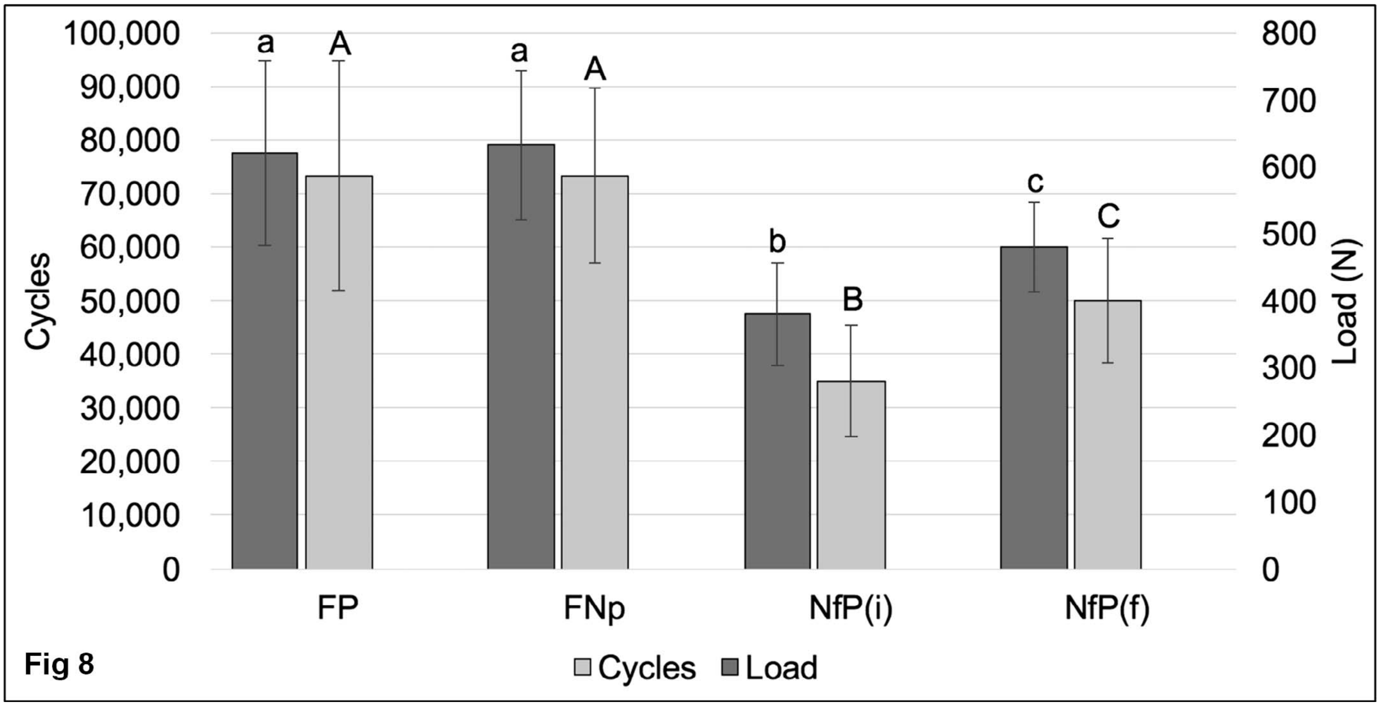


Figure 8. *Mean fracture loads (dark gray) and average number of survived load cycles (light gray) and their standard deviations, respectively.*

lowed by the Tukey test at a significance level of 0.05. For all statistical analyses, the level of significance was set at 95%. The data were analyzed with statistical software (SPSS 23, SPSS Inc, Chicago, IL, USA).

RESULTS

None of the specimens withstood all 140,000 load cycles. As all specimens fractured, the mean fracture load/cycles could be calculated (Figures 8 and 9). During cyclic loading, initial failures were detected in 81% (12/15) of the specimens in the no-ferrule group and 14% (2/15) and 7% (1/15) for a ferrule with a post and a ferrule without a post, respectively. The initial failure phenomenon can be described as the opening of a wide gap between the buildup/crown assembly and the root. The gap was always located at the lingual margin. Because clinical detection of such initial failures appears to be questionable, the analysis of survival was conducted for both the "final failure" (NfP[f]) and the "initial failure" (NfP[i]). The initial failure (i) values were recorded by reviewing the motion picture (high-definition macro mode) of the entire test for each specimen. Initial failure was easily detected by a significant high-pitched noise and simultaneous opening of a wide gap with emission of debris and air bubbles. The final failure (f) values were obtained by the testing machine when the sample completely fractured, causing the test to stop by activating the predetermined trigger parameters (axial displacement and axial acceleration).

The Kaplan-Meier survival graphs for all groups are displayed in Figure 9. The log-rank test showed significantly higher survival of groups with a ferrule

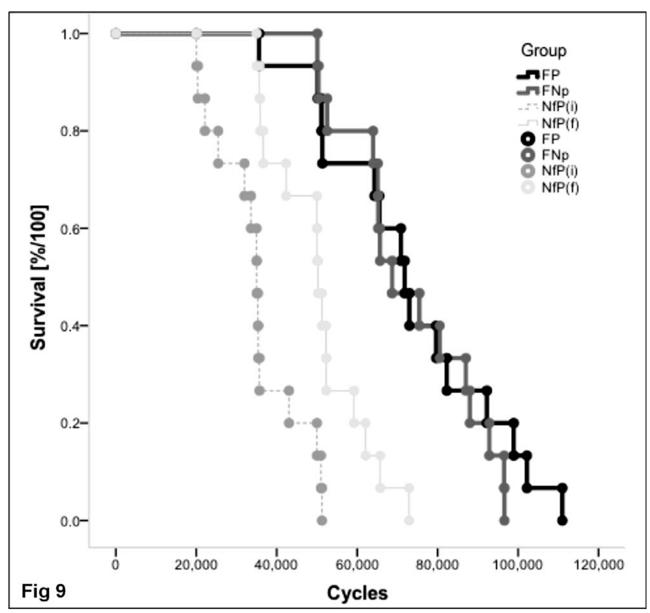
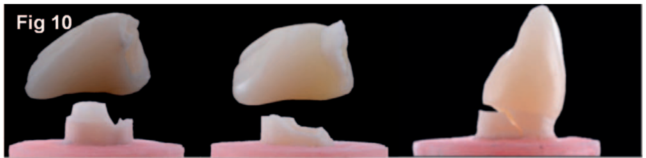


Figure 9. *Kaplan-Meier survival graphs for groups FFp, FNp, and NfFp. For better comparison, the survival graph of group NfFp was divided into initial failure and final failure.*



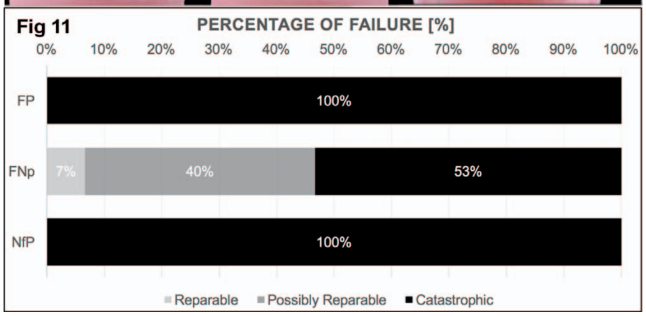


Figure 10. *All specimens were analyzed and classified in one of the three failure modes: "reparable" fracture (cohesive or cohesive/adhesive fracture of restoration only), "possibly reparable" (cohesive/adhesive failure with fragment and minor damage, chip, or crack, of underlying tooth structure) or "catastrophic" (tooth/root fracture that would require tooth extraction).*
Figure 11. Percentage of specimens per group for each fracture mode.

compared to groups without a ferrule ($p<0.001$). No difference could be found between groups with ferrule ($p=0.488$). Also when considering the initial failure, the log-rank test showed the same results; that is, a significantly higher survival of the ferrule group compared to the no-ferrule group ($p\leq0.001$) and no statistical difference between ferrule groups ($p=0.508$).

One-way ANOVA and the Tukey test revealed that the mean fracture load for the FP group (620.00±137.32 N; $p=0.984$) showed no statistical difference when compared with the FNp group (633.33±111.2697 N; $p=0.984$). Ferrule groups were significantly higher than the NfP group (380.00±77.4596 N [i], 480.00±67.6123 N [f]) considering the initial and final failure ($p<0.001$). The same results were found when the number of survived cycles was statistically compared (FP group to FNp group: $p=1.000$; FP group to NfP group: $p<0.01$; FNp group to NfP group: $p<0.01$). Figure 8 shows the mean values of fracture loads and survived cycles and their standard deviations, respectively.

Failure Mode Analysis

Groups with fiber post showed 100% catastrophic failures, while the no-post group presented 47% noncatastrophic failure. Possible fractures of the roots were made visible by transillumination in order to classify the specimen correctly (Figure 10). Figure 11 provides the number of specimens and percentage of each specific fracture mode for each group.

DISCUSSION

This study evaluated the effect of ferrule on the adhesive rehabilitation of ETI with glass ceramic crowns. A core buildup made with composite resin was compared with and without the use of a fiber-reinforced post system, and a no-ferrule group with fiber post was added for comparison. The first null hypothesis was accepted because there was no significant difference on fracture loads and survival rates when comparing ferrule groups with or without glass-fiber posts. The second null hypothesis was rejected because the presence of the ferrule increased the fatigue resistance of the ETI. Since the no-post group (FNp) presented 47% of noncatastrophic failures compared to 100% of catastrophic failure in both groups with post (FP and NfP), the third null hypothesis was also rejected.

Bovine teeth were used because of a lack of availability and large natural anatomic variations of extracted human teeth (age, size, and shape). Using standardized specimens is of paramount importance and allows minimizing confounding variables and gaining sensitivity in testing. Bovine dentin is often used for *in vitro* tests and is generally considered similar to human dentin in composition and geometric root configuration.[26,27] Because of the high standardization level that can be obtained using bovine roots and CAD/CAM technology, several confounding variables were avoided. However, the slight variations in internal dimensions (after internal ferrule preparation) of the root and the cementation process must still be considered as a possible limitation of this experiment.

All reviewed articles used single-rooted human or bovine teeth, and a constant load was applied at an angle to the long axis until fracture of the specimen occurred. Maximum loads that teeth could withstand and fracture patterns were analyzed and compared. However, the clinical significance of results obtained from *in vitro* static testing has been questioned[28] because a monostatic load does not represent the clinical situation in which repetitive mechanical loading and thermal changes are inherent. Therefore, in order to acquire more clinically relevant data with regard to the ferrule effect, the accelerated fatigue test was performed. This test consists of a stepped-load protocol, using a closed-loop electro-dynamic machine that allows a physiological representation of mastication.[30] This stepped-load protocol is a compromise between the conventional load-to-failure protocol and the time-consuming low-load fatigue test.

The cyclic loads were phased, increasing the load in 100 N steps up to 1000 N at a frequency of 5 Hz. A flat composite resin surface was used as an antagonist instead of stainless steel, as suggested in other similar fatigue studies,[29,30] in order to prevent localized and intense point loads and unrealistic surface damage. Healthy humans exhibit maximal isometric bite forces in the incisor region ranging between 243 N (women) and 287 N (men).[31] Even higher forces may be encountered in bruxism, trauma (high extrinsic loads), or intrinsic masticatory accidents (under chewing loads but delivered to small area due to a hard foreign body, such as a stone or a seed). It is difficult, however, to draw direct correlations between the load range applied in this study and its significance *in vivo*. Due to the application of far higher forces in this study, it can be expected that an accelerated life cycle of the restored tooth may have been simulated.

In view of the present results, the use and effect of glass-fiber posts can be questioned. No significant difference could be observed between groups FP and FNp. These findings are in accordance with a previous study[20] in which fiber post insertion did not increase the fracture resistance of severely broken-down ETI with a ferrule. The results of this investigation confirm the general consensus that the presence of a ferrule (reminiscent of coronal dentin) is the most important factor and increases the resistance of the tooth.[32]

The combination of coronal dentin, shock-absorbing properties of the core buildup, and the use of a three-step etch-and-rinse adhesive appear to be the major advantages of this approach. It seems to more closely mimic the structure and biomechanical behavior of a natural tooth, in contrast to the concept of post-and-core buildups, in which a post is actually located at the position of the mechanically functionless pulp. Coronal dentin (ferrule) increases the intrinsic resistance of the core. Optimized approaches in bonding procedure, such as immediate dentin sealing and high strength of the nanohybrid composite resin, may have increased the assembly strength within the ferrule groups regardless of the presence of the post. All elements (crown, buildup, and tooth) have to form a cohesive assembly requiring a capable adhesive system and cement, which ideally mimics the properties of the dentin–enamel junction.

An initial failure phenomenon was observed essentially associated with the presence of a post without a ferrule. A sudden failure of the adhesion at the lingual margin could be easily observed thanks to high-definition video. It was immediately accompanied by the opening of a wide gap starting at the margin between the buildup/crown assembly and the root, intensifying and well preceding total failure. Such a phenomenon was also observed in other studies on endodontically treated molars restored with fiber posts.[16] From a clinical perspective, this type of failure is extremely critical because it is impossible to detect, can initiate bacterial contamination of the root-canal system (often referred to as "coronal leakage" or "coronal microleakage"), and can be a potential cause of periodontic and endodontic failure.[33] In addition, recurrent caries or fractured restorations may lead to recolonization of the root-canal system.[34] Schwartz and Robbins[34] concluded in their literature review that there are some questions about the flexibility of the glass-fiber post, suggesting that a flexible post allows too much movement of the core, resulting in increased microleakage under the crown. A reasonable explanation for the lack of initial failure on the FP group is the fact that the ferrule itself was responsible for increasing the resistance of the assembly and changing the bending behavior of the tooth/restoration. The absence of initial failure phenomenon in the ferrule groups is a significant advantage because patients would more rapidly consult in case of complication.

Fiber posts are popular because of their elastic modulus, similar to that of dentin,[35] which should improve the stress distribution within the root[36,37] and reduce the risk of vertical root fractures.[38] However, in view of the results in the present study, the use of a glass-fiber post should be questioned. In addition, the use of the fiber post was not able to compensate for the absence of a ferrule. A further problem with fiber posts was revealed with the rate of catastrophic failures (100% in FP and NfP compared to 53% in FNp). This result is in accordance with Zicari and others,[39] who stated that teeth restored with longer glass-fiber posts showed more nonrepairable failures.

Based on this preliminary study, there are several clinically relevant elements that can be drawn. Avoiding placement of a post significantly facilitates clinical procedures without interfering with longevity, as far as the right materials are selected. Anterior teeth with at least 2 mm of ferrule may be restored conservatively with a bonded restoration using a restorative composite resin as a core buildup, which should increase the chances for a restorable failure without decreasing the resistance of the restored tooth. The amount of ferrule that is available to the clinician can vary substantially. The present data suggest that the operator should use the available tissue to provide a ferrule whenever possible. There is still a lack of data regarding the best treatment option in the absence of a ferrule. Before opting for crown lengthening or even extraction, the clinician should consider obtaining more coronal tooth structure through orthodontic extrusion when possible. However, further research will determine whether newer restoration designs, such as endocrowns, or new materials, such as fiber-reinforced composites, may be able to compensate for the absence of a ferrule and prevent more invasive surgical interventions.

CONCLUSIONS

Within the limitations of this *in vitro* study, the following conclusions can be drawn when restoring ETI:

1. Insertion of a fiber-reinforced post does not enhance the load-bearing capacity and survival of all-ceramic crowns.
2. In presence of a GFR post, catastrophic failure of the specimen was often preceded by the cyclic opening of a wide gap at the margin between the buildup/crown assembly and the root (initial failure). This significantly affected the survival rate.
3. The least amount of unrestorable failures was found with direct core buildups from a light-curing composite without a fiber-reinforced post.
4. The absence of a ferrule was not compensated for by the use of a fiber post.

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Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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