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RESEARCH AND EDUCATION

Survival of extensively damaged endodontically treated incisors restored with different types of posts-and-core foundation restoration material

Priscilla Cardoso Lazari, DDS, MS,[a] Marco Aurélio de Carvalho, DDS, MS,[a] Altair A. Del Bel Cury, DDS, MS, PhD,[b] and Pascal Magne, DMD, PhD, PD[c]

ABSTRACT

Statement of problem. Which post-and-core combination will best improve the performance of extensively damaged endodontically treated incisors without a ferrule is still unclear.

Purpose. The purpose of this in vitro study was to investigate the restoration of extensively damaged endodontically treated incisors without a ferrule using glass-ceramic crowns bonded to various composite resin foundation restorations and 2 types of posts.

Material and methods. Sixty decoronated endodontically treated bovine incisors without a ferrule were divided into 4 groups and restored with various post-and-core foundation restorations. NfPfB=no-ferrule (Nf) with glass-fiber post (Pf) and bulk-fill resin foundation restoration (B); NfPfP=no-ferrule (Nf) with glass-fiber post (Pf) and dual-polymerized composite resin core foundation restoration (P); NfPt=no-ferrule (Nf) with titanium post (Pt) and resin core foundation restoration; and NfPtB=no-ferrule (Nf) with titanium post (Pt) and bulk-fill resin core foundation restoration (B). Two additional groups from previously published data from the same authors (FPf=2mm of ferrule (F) and glass-fiber post (Pf) and composite resin core foundation restoration; and NfPf=no-ferrule (Nf) with glass-fiber post (Pf) and composite resin core foundation restoration), which were tested concomitantly and using the same experimental arrangement, were included for comparison. All teeth were prepared to receive bonded glass-ceramic crowns luted with dual-polymerized resin cement and were subjected to accelerated fatigue testing under submerged conditions at room temperature. Cyclic isometric loading was applied to the incisal edge at an angle of 30 degrees with a frequency of 5 Hz, beginning with a load of 100 N (5000 cycles). A 100-N load increase was applied every 15 000 cycles. The specimens were loaded until failure or to a maximum of 1000 N (140 000 cycles). The 6 groups (4 groups from the present study and 2 groups from the previously published study) were compared using the Kaplan-Meier survival analysis (log-rank post hoc test at α=.05 for pairwise comparisons).

Results. None of the tested specimen withstood all 140 000 cycles. All specimens without a ferrule were affected by an initial failure phenomenon (wide gap at the lingual margin between the core foundation restoration/crown assembly and the root). NfPfP, NfPt, and NfPtB had similar survival (29 649 to 30 987 mean cycles until initial failure). NfPfB outperformed NfPt and NfPtB. None of the post-and-core foundation restoration materials were able to match the performance of the ferrule group FPf (72 667 cycles). In all groups, 100% of failures were catastrophic.

Conclusions. The survival of extensively damaged endodontically treated incisors without a ferrule was slightly improved by the use of a fiber post with a bulk-fill composite resin core foundation restoration. However, none of the post-and-core techniques was able to compensate for the absence of a ferrule. The presence of the posts always adversely affected the failure mode. (J Prosthet Dent 2018;119:769-76)

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[a]Predoctoral student, Department of Prosthodontics and Periodontology, Piracicaba Dental School, State University of Campinas, Piracicaba, Brazil.
[b]Professor, Department of Prosthodontics and Periodontology, Piracicaba Dental School, State University of Campinas, Piracicaba, Brazil.
[c]The Don and Sybil Harrington Professor of Esthetic Dentistry, Division of Restorative Sciences, Ostrow School of Dentistry, University of Southern California, Los Angeles, Calif.

Clinical Implications

The results of this in vitro study suggest that titanium and glass fiber posts combined with different composite resin core foundation restorations performed similarly and were not able to compensate for the absence of a ferrule. The ferrule should be preserved, if possible, as it will improve the survival of endodontically treated incisors.

The restoration of endodontically treated incisors (ETI) is still a controversial topic.[1,2] After biomechanical alterations related to the endodontic procedures, the fracture strength of the root-post-core assembly is important to maintain the mechanical stability of the restoration.[1]

A ferrule is crucial for the optimal biomechanical behavior of ETI.[2-6] However, ETIs do not always offer enough tooth structure to generate a ferrule. Therefore, other elements (the use of a post as well as the core foundation restoration material itself) that could compensate for the absence of a ferrule should be investigated. Cast post-and-cores have been widely used[7,8] when minimal or no coronal tooth structure is available for antirotational features or bonding.[8] Furthermore, because of the high elastic modulus of the material, this approach is associated with catastrophic types of failure.[9]

Currently, enhanced adhesive procedures are possible through the use of adhesive luting systems in combinations of prefabricated posts and direct core foundation restorations.[10] The effect of the post-and-core materials on the fracture strength of ETIs has been investigated in several in vitro studies, and conflicting results have been reported.[11-17] Prefabricated posts seem to demonstrate less fracture resistance than cast post-and-cores but present more favorable failure mode, allowing repair of the restoration.[18-20] Inserting posts with an adhesive luting system seems to result in greater retention, less microleakage, and higher resistance to root fracture.[21]

Core foundation restorations must have favorable physical properties to facilitate their resistance to masticatory forces and to enhance performance of the crowns.[10,22] Composite resins are commonly used as materials for core foundation restorations.[15,14,19] More recently, bulk-fill composite resins have been introduced and can be applied in 4- to 5-mm thicknesses without the need for an incremental technique but polymerized in a single step.[23] The manufacturers of bulk-fill composite resins claim that materials have greater depth of polymerization and lower polymerization-induced shrinkage stress than conventional composite resin.[24] Another alternative is the 2-in-1 material used to

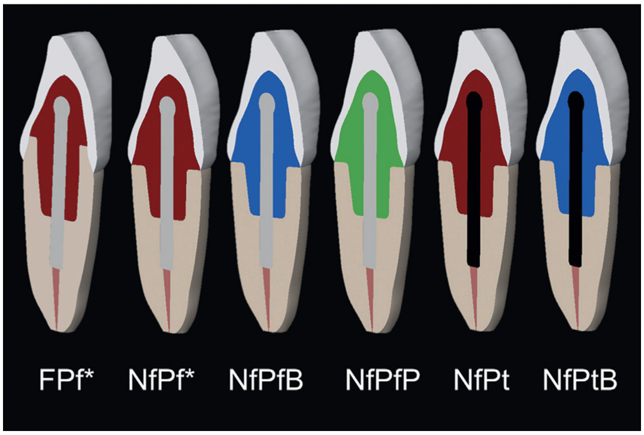

Figure 1. Experimental groups with different post-and-core foundation restorations. FPf*, 2 mm ferule (F) with glass-fiber post (Pf) and composite resin core foundation restoration; NfPf*, no-ferrule (Nf) with glass-fiber post (Pf) and composite resin core foundation restoration; NfPfB, no-ferrule (Nf) with glass-fiber post (Pf) and bulk-fill composite resin core foundation restoration (B); NfPfP, no-ferrule (Nf) with glass-fiber post (Pf) and dual-polymerized composite resin core foundation restoration; NfPt, no-ferrule (Nf) with titanium post (Pt) and composite resin core foundation restoration; and NfPtB, no-ferrule (Nf) with titanium post (Pt) and bulk-fill composite resin core foundation restoration (B) *Additional groups from previously published data concomitantly tested under identical experimental conditions.

cement the post and build the core with the same dual-polymerized material.[25] The "monoblock bond interface" between dentin and post and crown could produce a restoration with long-term survival and high strength.[26] However, few studies have compared this method with traditional ones.[13,26]

To increase the knowledge database about materials or combination of materials to restore ETIs without a ferrule, the purpose of the present study was to investigate the use of glass-ceramic crowns bonded to different composite resin core foundation restorations with glass fiber or titanium posts. The null hypotheses were that no significant difference would be found in accelerated fatigue resistance and that no difference would be found in failure mode among the restorative techniques.

MATERIAL AND METHODS

Sixty mandibular bovine incisors (I1) with similar dimensions and pulp spaces were selected and stored in a thymol-saturated solution (Thymol; Aqua Solutions Inc). All teeth were decoronated at 13 mm from the apex and subsequently separated into 4 groups: NfPfB; NfPfP; NfPt; and NfPtB (Fig. 1) (where NfPfB=no-ferrule [Nf] with glass-fiber post [Pf] and bulk-fill resin foundation restoration [B]; NfPfP=no-ferrule [Nf] with glass-fiber post [Pf] and dual-polymerized composite resin core foundation restoration (P); NfPt=no-ferrule [Nf] with titanium post [Pt] and resin core foundation restoration;

Table 1. Overview of properties of material used for core foundation restorations

Parameter	Miris 2: Light-Polymerized, Nanohybrid Composite Resin	Tetric Evoceram Bulk-Fill: Light-Polymerized, Nanohybrid Composite Resin	Paracore: Dual-Polymerized, Glass-Reinforced Composite Resin
Matrix	Methacrylate	Dimethacrylate	Methacrylate
Matrix (weight%)	ND	19.7	ND
Filler	Silanized barium glass, amorphous hydrophobic silica	Barium glass, ytterbium trifluoride, mixed oxide	Fluoride, barium glass, amorphous silica
Filler content (weight%)	80.0	62.5	74
Prepolymers (weight%)	ND	17.0	ND
Flexural strength (MPa)	120	120	120
E-Modulus (MPa)	13 000	10 000	ND
Compressive strength (MPa)	ND	ND	280
Vickers hardness (MPa)	ND	620	ND
Water absorption 7 days (mg/mm^3)	ND	21.1	18

ND, not disclosed by manufacturer.

and NfPtB=no-ferrule [Nf] with titanium post [Pt] and bulk-fill resin core foundation restoration [B]). Two additional groups from previously published data from the same authors tested concomitantly were included for comparison (FPf=2mm of ferrule [F] and glass-fiber post [Pf] and composite resin core foundation restoration; and NfPf=no-ferrule [Nf] with glass-fiber post [Pf and composite resin core foundation restoration). The specimens were mounted with acrylic resin (Palapress vario; Kulzer GmbH) by embedding 10.5 mm of the root. The properties of the composite resin materials of the 3 core foundation restorations are presented in Table 1.

A standard endodontic protocol was used.[27,28] The canals were instrumented to at least size .40/.06 with K3XF rotary files (Sybron Endo) and irrigated with 5.25% NaOCl (Chlorox) for 1 minute followed by a final rinse with 17% EDTA (Roydent) for 1 minute.[29,30] Gutta percha cones (0.6 taper K3XF; Sybron Endo) were then coated with Thermaseal Plus (Dentsply Sirona) and used for warm vertical obturation.

Gutta percha was removed to 8 mm into the pulp chamber from the finish line with a Reamer pilot drill size no. 3 (Ivoclar Vivadent AG). An extensively damaged ETI was simulated by a box preparation, using a cone-shaped bur, 4 mm from the cervical limit, 3 mm wide, and 4 mm buccolingually (Fig. 2). In cases where the root was already severely damaged, the area inside the root could be used for bonding. In this study, the authors proposed an adhesive approach using the internal tooth structure.

The post spaces were prepared with drills specifically designed for either glass-fiber posts (ParaPost Fiber Lux) or titanium posts (ParaPostHX; number 6; 1.5-mm diameter; Coltène). The post was cut to a length of 11 mm (8 mm below and 3 mm above the cervical limit). Prior to the luting procedure, the posts were cleaned with alcohol and air dried.

For the core foundation restoration with light-polymerized composite resin, groups NfPfB, NfPt, and NfPtB, the post space walls were lightly coated with self-etching self-adhesive resin cement (RelyX Unicem 2 Automix; 3M ESPE), and the post (either fiber or titanium) was inserted. Only the 4-mm apical part of the post was cemented to the root. Excess cement was cleaned, leaving an empty space between the post and the internal walls to be restored with the specified core foundation restoration material (Fig. 2). The cement was light polymerized for 40 seconds (VALO LED Curing Light; Ultradent Products, Inc). After post cementation, the exposed dentin walls and the post were cleaned with airborne-particle abrasion (27-µm silicated Al_2O_3 powder, CoJet; 3M ESPE). Silane (Ceramic Primer; 3M ESPE) was applied to the post head and air dried. The dentin was etched with 35% phosphoric acid (Ultra-Etch; Ultradent Products, Inc) for 10 seconds, then rinsed for 20 seconds, and gently dried, followed by application of the adhesive system (Optibond FL Primer and Adhesive; Kerr Corp), and light polymerized for 40 seconds. The core foundation restorations were made with either composite resin (Miris 2; Coltène) or bulk-fill composite resin (Tetric EvoCeram Bulk Fill; Ivoclar Vivadent AG). To build an 11-mm-high core (4 mm below and 7 mm above cervical limit) for composite resin, 5 increments were polymerized for 40 seconds each. For the bulk-fill composite resin, only 2 increments were polymerized for 40 seconds each. An air-blocking barrier (KY Jelly; Johnson & Johnson Inc) was used to cover the preparation surface, and an additional 20-second polymerization was carried out (10 seconds per side, buccal and lingual).

For the core foundation restoration with dual-polymerized glass-reinforced composite resin, group NfPfP, the nonrinse conditioner and mixed adhesive components (ParaBond NRC and Adhesive A and B, respectively; Coltène) were applied to the post space walls and cervical dentin (internal tooth structure space), rubbing for 30 seconds each step. The excess was removed by gently air drying for 2 seconds. The dual-polymerized glass-reinforced composite resin was dispensed into the prepared root canal, and the post was inserted and light polymerized for 20 seconds. The foundation restoration was added and light polymerized

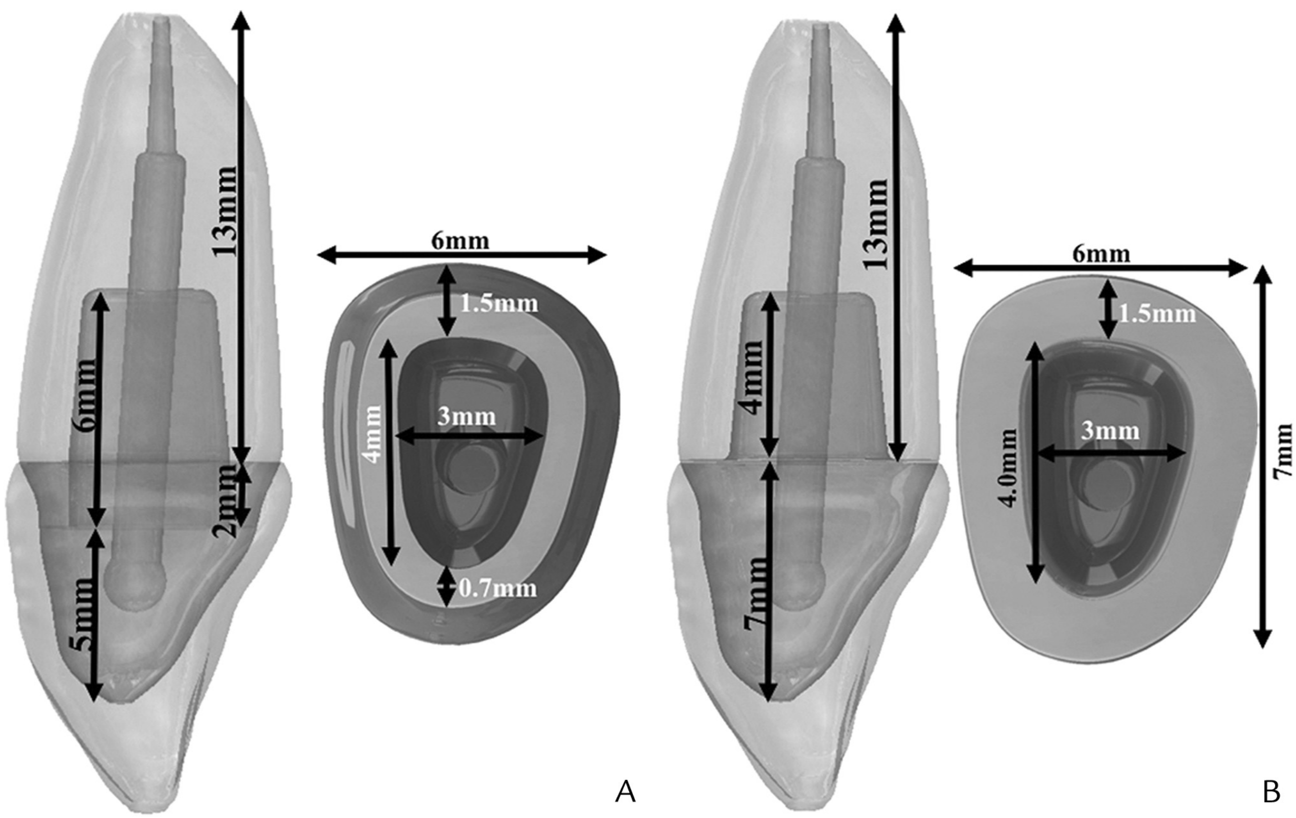

Figure 2. Occlusal and proximal views of root with preparation dimensions standardized for all groups with ferrule (A) and without ferrule (B). The internal tooth structure concept is an attempt to compensate for absence of ferrule by bonding to extended internal area (4×3×6 mm in ferrule group and 4×3×4 mm in no-ferrule group) because of extensively damaged root.

for 40 seconds (20 seconds each side, buccal and lingual). An air-blocking barrier was used as previously reported.

All bonded ceramic crowns were fabricated using the Cerec 3 computer-aided design and computer-aided manufacturing (CAD-CAM) system and Cerec Blue Cam (Dentsply Sirona) in lithium disilicate ceramic (IPS e.max CAD; Ivoclar Vivadent AG). The specimens were fitted with a crown of standardized thickness (0.8 mm on cervical area), an incisocervical length of 11 mm and a mesiodistal width of 9 mm.

All crowns were cleaned in distilled water in an ultrasonic bath for 1 minute, etched with 5% hydrofluoric acid (IPS ceramic etching gel; Ivoclar Vivadent AG) for 20 seconds, and cleaned again in the ultrasonic bath for 1 minute. Silane (Monobond Plus; Ivoclar Vivadent AG) was applied with a microbrush and heat dried at 100°C for 5 minutes (DI-500; Coltène).

The tooth preparation and core foundation restorations were cleaned with airborne-particle abrasion and coated with an adhesive (Adhese Universal; Ivoclar Vivadent AG). The dual-polymerized composite resin cement (Variolink Esthetic DC; Ivoclar Vivadent AG) was then applied to the intaglio surface of the crown and seated on the tooth with a force of approximately 4.9 N. Excess cement was removed and followed by light polymerization 3 times for 20 seconds on each side (buccal and lingual). Air-blocking barrier and additional polymerization was carried out for 20 seconds. Specimens were stored in distilled water at room temperature (24°C) for a minimum of 24 hours after luting and then subjected to accelerated fatigue testing.

Masticatory forces were simulated using a closed-loop artificial mouth electrodynamic machine (Acumen III; MTS Systems). The mastication load was applied through a flat composite resin antagonist (Z100; 3M ESPE) at a palatal angle of 30 degrees with the flat surface contacting 3/4 of the incisal edge (Fig. 3). The specimen was submerged in distilled water in the load chamber 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, a maximum of 15 000 cycles for each (total of up to 10 load stages). Specimens were loaded until fracture occurred or to a maximum of 15 000 cycles for each load stage or a total of 140 000 cycles for the entire procedure.

All fatigue tests were monitored using a macro video camera and recorded continuously to determine the crack

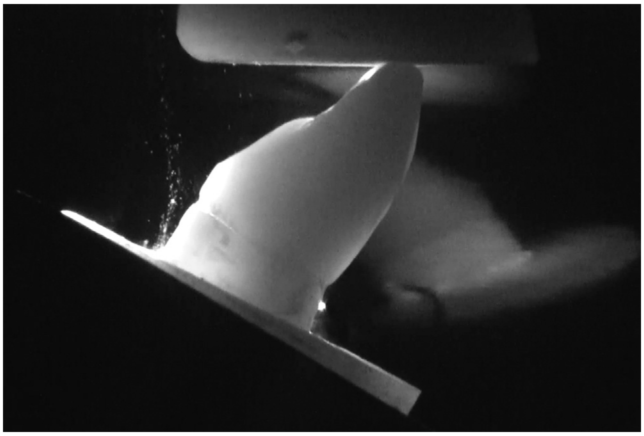

Figure 3. Cyclic isometric loading applied to incisal edge at an angle of 30 degrees. Initial failure as wide lingual gap between crown margin and tooth.

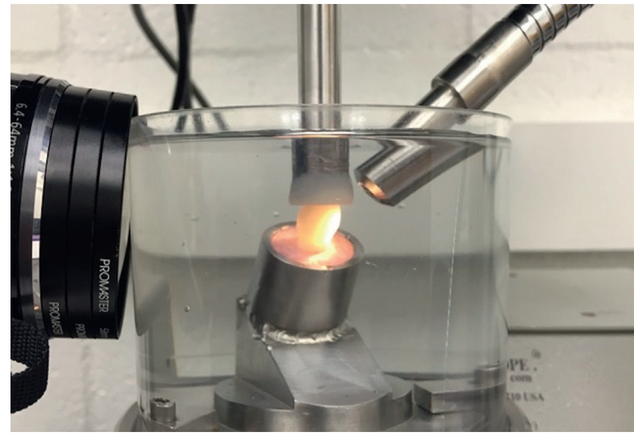

Figure 4. Specimen in load chamber. Macro camera and transillumination light used to identify crack propagation mode (initial and final failures).

propagation mode (initial gap and final failure) (Fig. 4). The number of cycles endured and the failure mode of each specimen were recorded. After the test, each specimen was evaluated by transillumination (Microlux; AdDent, Inc) and optical microscopy (Leica MZ 125; Leica Microsystems GmbH) at ×10 magnification. A visual distinction was made among 3 fracture modes, considering the reparability of the tooth: catastrophic (root fracture that would require extraction); possibly reparable (cohesive/adhesive failure with fragment and minor damage of root structure); or reparable fracture (cohesive or adhesive failure of restoration only).

The fatigue resistance of the groups was compared using the Kaplan-Meier survival estimator for endured cycles until initial and final failures. A post hoc log-rank test at a significance level of α=.05 was used for pairwise comparison among the 6 groups and between initial and final failure within each group (corrected for multiple comparisons when indicated). Data were analyzed using statistical software (IBM SPSS Statistics v23; IBM Corp).

Additional data from a previous study[6] by the same authors under identical experimental conditions and concomitantly tested approximately the same post preparations, design of core foundation restorations, and crowns were combined with the present data for additional computation and comparison. The previous study included 2 groups with a glass-fiber post and the same light-polymerizing composite resin core foundation restoration (Miris 2): FPf (2 mm ferrule) and NfPf (no ferrule).

RESULTS

Because none of the specimen withstood all 140 000 cycles, the mean number of cycles endured until failure could be calculated. Previously published results of groups tested concomitantly were combined with the new data, and the fatigue resistance and failure mode are presented in Figures 5-7.

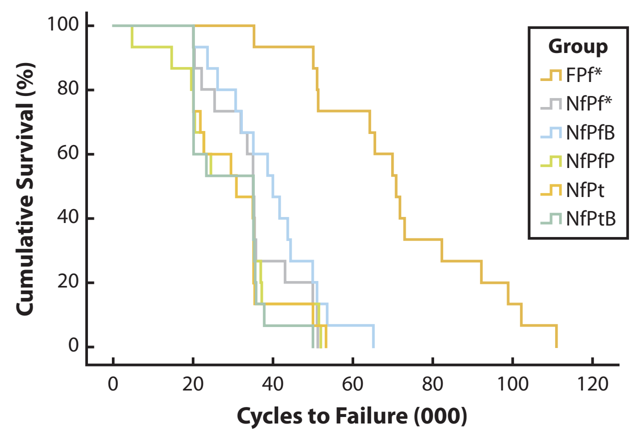

Figure 5. Fatigue resistance survival curves (Kaplan-Meier survival estimator) for all six groups. *Additional groups from previously published data concomitantly tested in identical experimental conditions. B, bulk-fill composite resin core foundation restoration; F, ferrule; Nf, no ferrule; P, dual-polymerized composite resin core foundation restoration; Pf, glass-fiber post; Pt, titanium post.

The complete failure of the specimens was possibly preceded by an initial failure in the form of a cyclic opening of a wide gap at the margin between the core foundation restoration/crown assembly and the root (Supplemental Video 1). This initial failure phenomenon was detected in 14% of specimens in group FPf, 81% in NfPf, 86% in NfPfB, 87% in NfPfP, 93% in NfPt, and 100% in NfPtB. The initial gap was always located at the lingual margin of the crown (Fig. 3). Because the clinical detection of such failures appears to be questionable, analysis of survival was conducted for both the initial and the final failure.

The Kaplan-Meier survival curves are displayed in Figure 5 and the means of cycles endured until initial failure in Figure 6. The log-rank test showed a significantly higher survival rate of the group with ferrule, FPf (P<.001). The no-ferrule group, NfPfB, presented better

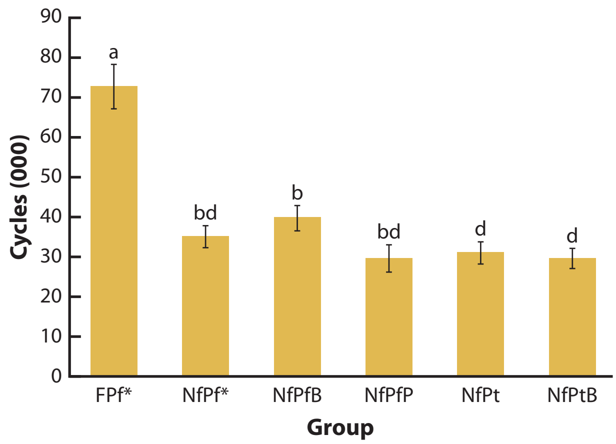

Figure 6. Mean survived cycles until initial failure and standard errors after Kaplan-Meier survival test. Log-rank post hoc test (P<.05) with different letters indicating statistically significant differences. *Additional groups from previously published data concomitantly tested in identical experimental conditions. B, bulk-fill composite resin core foundation restoration; F, ferrule; Nf, no ferrule; P, dual-polymerized composite resin core foundation restoration; Pf, glass-fiber post; Pt, titanium post.

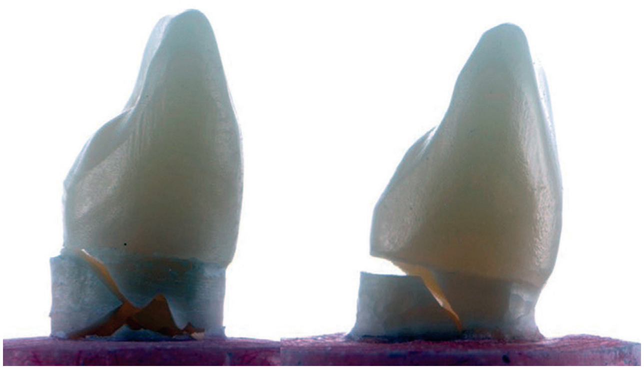

Figure 7. All specimens were classified as catastrophic (tooth/root fracture that would require tooth extraction).

Table 2. Log-rank (Mantel-COX). P values of pairwise log-rank post hoc comparisons (Kaplan-Meier survival estimator followed by log-rank test for cycles until initial failure among all 6 groups)

Group	FPf[a]	NfPf[a]	NfPfB	NfPfP	NfPt	NfPtB
FPf [a]						
NfPf [a]	<.001[b]					
NfPfB	<.001[b]	.202				
NfPfP	<.001[b]	.919	.069			
NfPt	<.001[b]	.520	.046[b]	.994		
NfPtB	<.001[b]	.258	.013[b]	.643	.992	

B, bulk-fill composite resin core foundation restoration; F, ferrule; Nf, no ferrule; P, dual-polymerized composite resin core foundation restoration; Pf, glass-fiber post; Pt, titanium post. [a]Additional groups from previously published data concomitantly tested in identical experimental conditions. [b]Statistically significant difference between groups (P<.05).

Table 3. Mean cycles endured until initial and final failures with standard errors obtained by the Kaplan-Meier survival estimator

Group	Cycles until initial failure ±SE	Cycles until final failure ±SE	P (log-rank test)
FPf [a]	72 667 ±5548	73 332 ±5551	.916
NfPf [a]	35 026 ±2687	50 121 ±2993	<.001[b]
NfPfB	39 761 ±3168	56 479 ±3475	<.001[b]
NfPfP	29 657 ±3381	58 254 ±2889	<.001[b]
NfPt	30 987 ±2739	51 437 ±2566	<.001[b]
NfPtB	29 649 ±2455	59 178 ±3706	<.001[b]

B, bulk-fill composite resin core foundation restoration; F, ferrule; Nf, no ferrule; P, dual-polymerized composite resin core foundation restoration; Pf, glass-fiber post; Pt, titanium post; SE, standard error. P values of log-rank post hoc pairwise comparison between initial and final failure within each group. [a]Additional groups from previously published data concomitantly tested in identical experimental conditions. [b]Statistically significant difference between groups (P<.05).

survival rate than the NfPt (P=.046) and NfPtB (P=.013) groups (Table 2). The means and standard errors of endured cycles until initial and final failures as well as the pairwise statistical level between initial and final failures are presented in Table 3.

Failure mode analysis showed 100% of catastrophic failures (crack vertically propagated in the cervical and middle portions of the root) (Fig. 7).

DISCUSSION

A worst-case scenario (extensively damaged no-ferrule condition) was considered in the present study to determine the fatigue strength of different materials. The null hypotheses were that no significant differences would be found in accelerated fatigue resistance and that no differences of failure mode would be found among the restorative techniques. In view of the statistical analysis, the first null hypothesis was rejected. The fatigue resistance of ETIs was slightly improved using a fiber post with a bulk-fill composite resin core foundation restoration compared with that of the titanium post groups. The second null hypothesis was accepted; the failure modes were similar across materials (100% catastrophic failure after fatigue test).

The experimental fatigue protocol of this study is based on a study by Fennis et al[31] that represents a reasonable balance between the single load-to-failure test and more sophisticated and time-consuming fatigue tests.[22] In the load-to-failure test, the specimen is forced to fail under displacement control of the load apparatus, providing useful data under extreme conditions but limited clinical relevance. With the present protocol and because of the presence of the post, the final failure (corresponding to the end of the fatigue test by the machine) was typically preceded by initial failure (cyclic opening of a wide gap at the lingual margin) (Supplemental Video 1). It was decided not to interrupt the fatigue test when initial failure occurred but subject the specimen to fatigue until complete failure (machine detects alterations and stops the test). Every cycle was continuously recorded using a macro video camera to identify the crack propagation mode and chronology.

The elastic behavior of the post may be interpreted as a disadvantage because the cyclic bending between the crown and core foundation restoration can induce microcracks in the core material or in the resin cement, leading to failure of the restoration.[18] Initial failure of the crown-tooth interface at the crown margin has been assumed to be the earliest sign of failure in post-core-restored teeth and depends on the adhesive strength of the crown-tooth interface.[3,32] Clinically, a restoration that has experienced initial failures could remain in place, apparently intact, for some time. However, the leakage between the restoration and tooth will facilitate bacterial infiltration and possibly cause secondary caries and jeopardize the integrity of the endodontic seal.[32] As it progresses undetected, this initial failure may proceed into the tooth, leading to core fracture and subsequently vertical tooth fracture.[3] Few studies have described the initial failure phenomenon in ETIs.[3,13,32] Single-load-to-failure studies are unable to provide such insight, but accelerated fatigue tests seem to be more sensitive to such a phenomenon.[6,10]

Bulk-fill composite resins have low shrinkage and tooth-strengthening effects.[23] In this study, the combination of fiber post and bulk-fill composite resin increased the number of cycles required to cause initial failure of the restoration compared with the titanium groups. Akkayan and Gülmes[11] reported similar results, as titanium posts groups presented lower resistance to fracture than fiber posts. However, these results differ somewhat from those who reported that, when no coronal tooth structure is left, the prefabricated metal posts show higher fracture strength than the fiber posts.[14,20]

In a previous study by Magne et al[6] under identical conditions and tested concomitantly, a ferrule group was used to verify the ferrule influence on the fatigue resistance of the ETI. The previous results were used in the current study to investigate whether the use of different post and core foundation restorations could compensate for the absence of a ferrule. The results revealed the superior performance of the FPf group (Fig. 4), showing the insertion of a post did not increase the fracture resistance enough to compensate for the absence of ferrule.

In addition to fracture resistance, the possibility of retreatment and preservation of the underlying tooth structure when failure occurs needs to be considered. Several studies reported that cast post-and-core restorations with prefabricated metallic posts increase the risk of catastrophic fractures.[5,32,33] Opposing results are reported when using fiber posts.[34] Their elastic moduli should improve the stress distribution within the root[35,36] and reduce the risk of vertical root fractures.[5] However, the present study presented 100% of catastrophic failures, regardless of the material of the prefabricated post. This result is in accordance with those of some recent studies that also reported catastrophic failures with fiber posts.[4,10,37]

Further research should explore alternatives to post-and-core restorations and possibly a no-post approach to obtain more resistant and nondestructive outcomes. Even though a fiber post presented an optimized elastic modulus compared with that of a titanium post or cast post-and-core, vertical catastrophic failures were not prevented. Optimized approaches to restore the extensively damaged no-ferule root in order to compensate for the absence of a ferule is still a major need in dentistry.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. The fatigue survival of the fiber post with bulk-fill in the composite resin core foundation restoration group was significantly higher ($P<.05$) than in the groups with titanium posts.
2. The use of a post was not sufficient to compensate for the absence of a ferrule ($P<.001$).
3. The failure of no-ferrule specimens with posts were always preceded by the cyclic opening of a wide gap at the lingual margin between the core foundation restoration/crown assembly and the root (initial failure). This significantly affected the survival rate compared with the final failure ($P<.001$).
4. The presence of posts always negatively affected the failure mode.

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Corresponding author:
Dr Pascal Magne
Division of Restorative Sciences
Ostrow School of Dentistry
University of Southern California
925 W 34th St
Los Angeles, CA 90089
Email: magne@usc.edu

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