Accelerated fatigue resistance and color stability of endodontically treated bleached maxillary incisors restored with and without a post

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Abstract

Purpose: The present study aimed to assess fatigue resistance and color modifications of endodontically treated incisors (ETIs) submitted to internal bleaching and restored using three different techniques.

Materials and methods: Forty-five maxillary central incisors received endodontic treatment and were internally bleached. After the completion of bleaching, the ETIs were divided into three groups (n = 15) according to the different restoration procedures: 1) glass-ionomer cement base covered with composite resin (GI); 2) short fiber-reinforced composite resin base with composite resin (SF); 3) composite resin restoration over a fiberglass post (FP). Specimens were subjected to accelerated fatigue testing: frequency of 5 Hz, beginning with a load of 100 N for 5000 cycles and a 25-N load increase applied every 1700 cycles until a load of 1200 N was reached. Samples were loaded until fracture. The Kaplan-Meier survival analysis with the log-rank post hoc test were performed (α = 0.05). Tooth color was measured 4 weeks after the bleaching treatment and again after the final restoration procedure using a spectrophotometer and the Commission Internationale de l'Eclairage (CIE) L*a*b* system. L* values of the specimens were analyzed using the Shapiro-Wilk and paired sample *t* tests (α = 0.05).

Results: All groups showed similar survival mean cycles until failure (*P* = 0.332) and presented a major number of nonrestorable failures. The GI group presented the lowest number of nonrepairable fractures (GI = 68%, SF = 79%, FP = 86%) and showed the most stable L* value (*P* = 0.987).

Conclusions: The fatigue survival of internally bleached ETIs was not affected by the restorative technique utilized. Retaining the glass-ionomer base and covering the surface with composite resin should provide optimal color stability.

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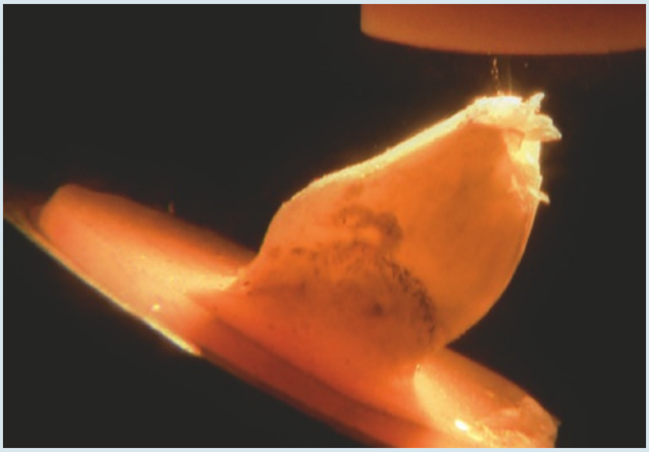
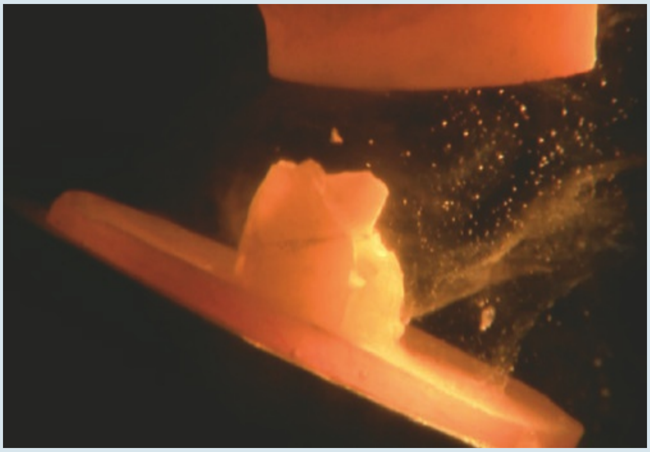




Introduction

Loss of tooth vitality due to dental trauma is the main reason for the endodontic treatment of intact incisors.[1] As a result of traumatic injury, pulpal hemorrhage and/or pulp necrosis can generate intrinsic tooth discoloration.[2] In view of the biomechanical integrity of nonvital traumatized teeth, dental bleaching is the most conservative alternative to assure the functional, mechanical, and esthetic recovery of the tooth.[1,3-5] Optimal bleaching of discolored nonvital teeth is obtained when the bleaching agent is applied for a long period of time;[6] therefore, the walking bleach technique is considered the best treatment option.[1]

Restorative procedures of endodontically treated incisors (ETIs) have been recognized as one of the greatest challenges of clinical dentistry due to the increased risk of biomechanical failure.[7,8] Endodontic access and preparation can result in a significant loss of dental tissue and structural weakness, with consequent loss of restoration retention.[9] In addition, intracoronal bleaching can contribute to restoration failures, in turn making the tooth itself more susceptible to fracture[10-13] and reducing its adhesion to restorative materials.[14-16] Therefore, preserving intact coronal and radicular tooth structure and maintaining cervical tissue are considered crucial to optimize the biomechanical behavior of ETIs.[17-20]

The improvement of the mechanical properties of composite resin associated with the development of adhesive systems has allowed the direct bonded restoration of ETIs to reach values of fracture resistance and stiffness similar to those of unaltered teeth.[19,21] The use of a fiber post to restore a relatively intact ETI, however, is questionable. The existing literature has proven that posts do not improve the fracture resistance of teeth; studies have shown similar failure modes and performance of posts when compared with ETIs restored only with composite resin.[12,13] The only benefit of a fiber post has been related to the retention of the filling material within the remaining tooth structure.[22,23] One may question whether the mechanical retention provided by a post could be substituted by appropriate dentin bonding. In addition, it is still a controversial topic whether sound dentin should be removed to prepare the root canal to receive a post in order to increase the stability of the restoration foundation. In recent accelerated fatigue studies on ETIs, fiber posts have demonstrated a systematic association with catastrophic failure (root fracture).[24,25]

As color relapse is considered one disadvantage of an internal bleaching procedure,[26-28] the restoration of an internally bleached ETI should not only prioritize the tooth biomechanical behavior but also provide adequate color stability. Differences in the final outcome of internal bleaching may be expected due to the very different optical behavior of the restorative materials. Glass-ionomer cement (GIC) is expected to improve tooth opacity when compared with translucent materials such as fiber-reinforced composites. Further studies are needed to determine whether the choice of the access cavity restorative material would affect post-bleaching color stability.

Therefore, the aim of the present study was to assess the fatigue resistance and color modification of maxillary central ETIs submitted to the walking bleach technique and restored with three different procedures. The restorative protocols tested were: 1) GIC base replacing the missing dentin and covered with a composite resin restoration; 2) short fiber-reinforced composite resin replacing the missing dentin and covered with a composite resin restoration; and 3) composite resin restoration over a luted fiberglass post. The null hypotheses were that no significant difference would be found in accelerated fatigue resistance and that no difference would be found in final color modification among the restorative techniques.

Materials and methods

Specimen preparation

Forty-five intact human maxillary central incisors were carefully selected and stored in thymol-saturated solution (Thymol; Aqua Solutions) after approval for the study was received from the Ethical Review Committee of the University of Southern California (protocol HS-17-00705). The incisors were endodontically treated, internally bleached, and randomly assigned to three test groups (n = 15). They were then submitted to accelerated fatigue testing.

Using slow-speed, round, and GK269 burs (Kerr) to smoothen the internal walls, a standard lingual access was prepared to simulate root canal treatment in each tooth. Patency was achieved using no. 10-K files (Dentsply Sirona). Coronal flare was created using a Gates Glidden no. 2 drill (Dentsply Sirona), and the canals were chemomechanically debrided using S1 and S2 ProTaper Gold rotary files, with F1 (20.07) Variable Taper as the finishing file (ProTaper NiTi Rotary; Dentsply Sirona). The canals were irrigated with 5.25% sodium hypochlorite (regular bleach with Clorox CHLOROMAX; Proctor & Gamble) to within 2 mm of the apex. A final rinse with 17% ethylenediaminetetraacetic acid (EDTA; Vista Dental Products) was performed, and the canals were dried using paper points (Kerr Endodontics Absorbent Points; Kerr). Gutta-percha cones compatible with ProTaper Gold F1 files were used for obturation with AH Plus Sealer (Dentsply Sirona). Gutta-percha was down-packed, and the canals were back-filled with a warm vertical obturation technique to the orifice level, then condensed.

A cervical barrier was placed over the orifice at the buccal level of the cementoenamel junction (CEJ), reproducing the spatial configuration of the CEJ (scalloped buccal contour and proximal ‘wings’).[1] To create this barrier, the gutta-percha material was removed 2 mm below the CEJ and then the GIC (Ketac Molar; 3M) was applied. After GIC setting, the barrier design was defined using a spherical diamond bur (Brasseler USA) at low speed in a buccolingual movement to create barrier wings against the proximal walls, preventing the diffusion of the bleaching material into the critical proximal zone. The bleaching procedure was then performed with 3% hydrogen peroxide (Essential Oxygen) mixed with sodium perborate (Sultan Healthcare) for three consecutive 1-week applications. During that time, the teeth were temporarily sealed with a cotton pellet and with GIC and stored in distilled water at room temperature.

After the three bleaching sessions, the bleaching paste was removed by aspiration and irrigation with 1% sodium hypochlorite (Regular bleach with Clorox CLOROMAX) and rinsed with water. The pulp chamber was completely filled with GIC and stored for 4 weeks in distilled water at room temperature. After this delay, the teeth were restored according to the specific procedures for each group and were mounted with acrylic resin (Palapress vario; Heraeus Kulzer), embedded up to 2 mm below the CEJ.

Restorative procedures

In order to evenly distribute the teeth according to their size, the incisors were sorted into ‘small’ (18 to 23 mm) and ‘large’ (24 to 30 mm) categories and subsequently reassigned randomly to one of the three experimental groups (n = 15).

In the GI group, specimens were restored with a GIC/composite resin laminate technique. A spherical diamond bur was used to remove the GIC base to a depth of 2 mm and the enamel margin was beveled. The entire lingual surface was etched with 35% phosphoric acid (Ultra-Etch 35%; Ultradent), enamel for 30 s, and dentin for 10 s, followed by abundant rinsing and drying. A three-step etch-and-rinse bonding agent (OptiBond FL; Kerr) was applied and polymerized for 20 s at 1000 mW/cm^2 (VALO LED Curing Light; Ultradent). Composite resin (Inspiro Direct, shade SW; Edelweiss DR) was then used to fill the residual space, followed by polymerization for 20 s under an air-blocking barrier (KY Jelly; Johnson & Johnson).

In the SF group, a short fiber-reinforced composite resin (everX Posterior; GC Europe) was used to replace the GIC base material (but the GIC barrier was maintained). Every time GI material was removed, this procedure was performed under ×10 magnification using an optical microscope (Leica MZ 125; Leica Microsystems), and its total elimination was confirmed by radiographic analysis. After removal of the GIC base, the exposed dentin and enamel were etched with 35% phosphoric acid (10 s for dentin and 30 s for enamel), abundantly rinsed, and dried. The same three-step etch-and-rinse bonding agent (OptiBond FL) was applied and polymerized. The pulp chamber was filled with a single increment of short fiber-reinforced composite resin. Regular composite resin (Inspiro Direct) was used for the last 1-mm–thick increment and polymerized for 20 s under an air-blocking barrier.

In the FP group, all GIC material was removed (base and barrier) and an intraradicular fiberglass post (ParaPost Fiber Lux, no. 6, 1.50-mm diameter; Coltène) was placed. The post space was prepared by retaining at least 5 mm of root filling at the apical level using ParaPost drills specifically designed for the ParaPost post used (see above). Using a cutting disc, the head of the post was removed to fit the pulp chamber space and to terminate 2 mm above the buccal level of the CEJ. Prior to the luting procedure, the posts were cleaned with alcohol and air-dried. First, the enamel was etched with 35% phosphoric acid for 30 s, rinsed, and dried. All dentin walls were dried (including the canal, with paper points) and treated with a non-rinse conditioner (ParaBond NRC; Coltène) for 30 s, followed by drying with paper points and brief air-drying. Adhesive resin (ParaBond Adhesive A+B; Coltène) was then applied for 30 s, followed by drying with paper points, brief air-drying, and filling with cement (ParaCore Dentin; Coltène). The post was then inserted, and cement excesses were cleaned, leaving a uniform space around the coronal portion of the post. The cement system was light cured for 40 s. The same adhesive was applied to the enamel and polymerized. Regular composite resin was used to fill the residual space and polymerized for 20 s under an air-blocking barrier.

Accelerated fatigue test

A closed-loop electrodynamic system (Acumen III; MTS Systems) was used to simulate masticatory forces. The chewing cycle was simulated by an isometric load applied through a flat antagonist, 10-mm–diameter composite resin disc (MZ100; 3M). The force was applied at a palatal angle of 30 degrees with the flat surface of the disc contacting a minimum three-fourths of the incisal edge width (Fig 1). The load chamber was filled with distilled water to submerge the sample during testing. All tests were performed with a sine-wave cyclic load that was applied on the specimens at a frequency of 5 Hz. After a warm-up of 5000 cycles, the cyclic load started with 100 N and was submitted to an incremental increase of 25 N each 1700 cycles until a load of 1200 N was achieved (maximum 45 increments). Samples were loaded until fracture or to a maximum of 76,500 cycles.

A macro video camera was used to continually record all fatigue tests. Data regarding the number of endured cycles, load to failure, and failure mode of the specimens were analyzed. Fracture mode was evaluated using transillumination (Microlux; AdDent) and an optical microscope (Leica MZ 125) at ×10 magnification. A visual distinction was made among three fracture modes, considering the reparability of the tooth: 'reparable' (ie, cohesive or adhesive failure of coronal structure only); 'possibly reparable' (ie, cohesive/adhesive failure involving the root but no deeper than the level of the mounting resin); or 'catastrophic' (ie, cohesive root fracture that would require tooth extraction – below the level of the mounting resin).

The fatigue resistance of the groups was compared using the Kaplan-Meier survival estimator for number of cycles survived. A pairwise comparison among the three groups was performed using the log-rank post hoc test at a significance level of $\alpha = 0.05$. Statistical analyses were performed using R i386 3.0.2 software (R statistical software; R Foundation for Statistical Computing).

Color measurement

An intraoral spectrophotometer (Vita Easyshade; Vita Zahnfabrik) was operated by the same researcher in the same room under constant laboratory illumination conditions. The color analysis was performed on the central region of the labial surfaces of the crowns of the maxillary incisors. In order to standardize the position of the color measurement, individual specimen carriers were made using a silicone impression material (Perfit Puffy; Zhanmed), which were used for all measurements during the experiment.

Fig 1 Specimen in the load device. Cyclic isometric loading was applied to the incisal edge at a 30-degree angle.

Before each measurement, specimens were removed from the saline solution and dried with a gauze. The spectrophotometer was then calibrated. The color measurements were performed at two different moments: after the bleaching color stabilization interval (4-week delay after the completion of the bleaching treatment), and again after the access cavity final restoration.

The Commission Internationale de l'Eclairage L*a*b* system (CIELab 2000) was used to evaluate the color modifications. The L* value, which represents the lightness from black to white, was used to compare the bleaching color effect before and after the tested restorative approaches. Specimen lightness of the groups was compared using the Shapiro-Wilk normality and paired sample *t* tests ($\alpha = 0.05$). Statistical analyses were performed using R i386 3.0.2 software.

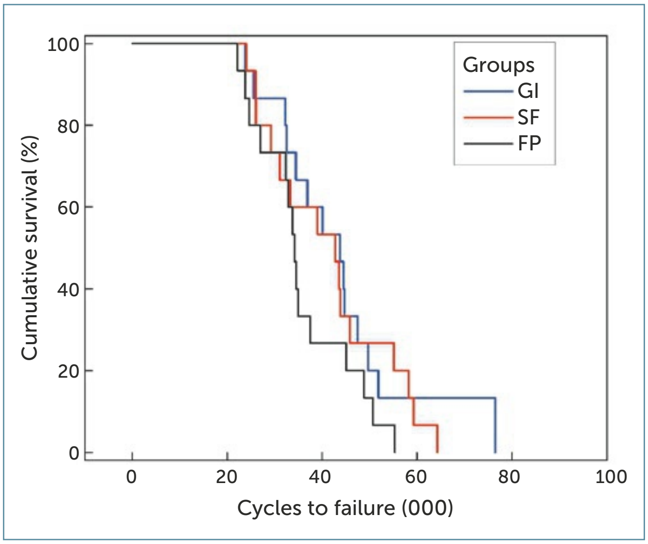


Fig 2 Fatigue resistance survival curves (Kaplan-Meier survival estimator) for all groups. GI: glass-ionomer cement; SF: short fiber-reinforced composite resin; FP: fiber post.

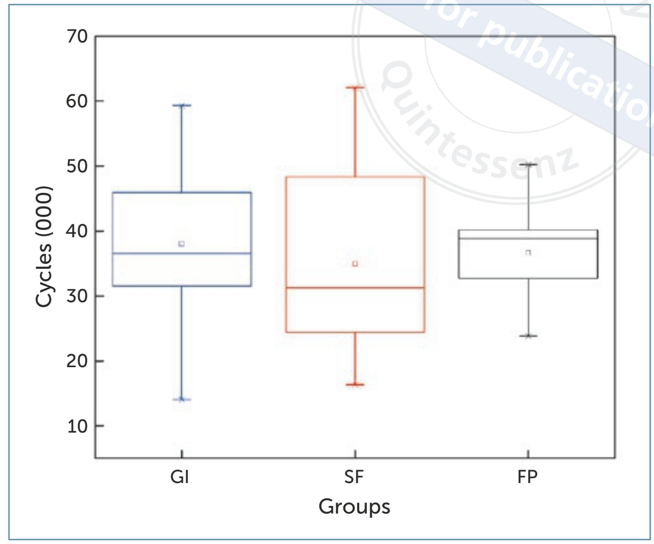


Fig 3 Box plot of number of survived load cycles for all groups. GI: glass-ionomer cement; SF: short fiber-reinforced composite resin; FP: fiber post.

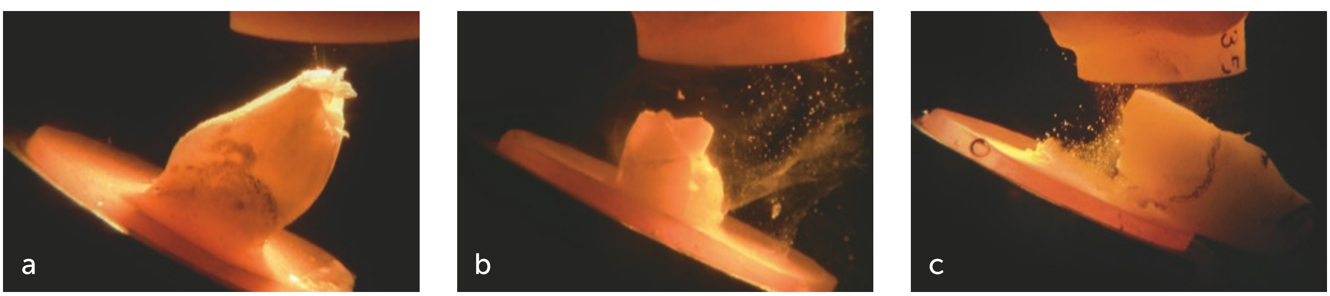


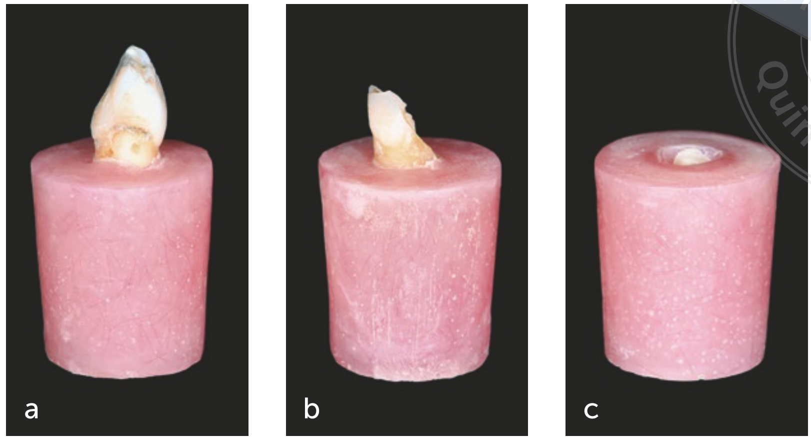
Fig 4 Classification of failure mode of the tested specimens. Video image captured at the moment that the test finished. (a) 'Reparable' fracture (cohesive or cohesive/adhesive fracture of tooth structure or restoration). (b) 'Possibly reparable' fracture (cohesive/adhesive failure with fragment and minor damage, chip or crack of underlying tooth structure). (c) 'Catastrophic' fracture (tooth/root fracture that would require tooth extraction).

Results

Only one specimen (from the GI group) survived 76,500 load cycles. The Kaplan-Meier survival graph for all groups is presented in Figure 2. The mean fracture cycles calculated from the fractured specimens and their corresponding loads are presented in Figure 3. The log-rank post hoc test did not yield significant outcomes (P = 0.332).

Failure type is illustrated in Figures 4 and 5 and its distribution is presented in Figure 6. All of the three groups presented a major number of nonrestorable failures. The GI group seemed to present a more favorable outcome, with the lowest number of catastrophic fractures (68%) when compared with the SF (79%) and FP (86%) groups. The GIC base also created some kind of palatal reinforcement, as demonstrated in Figure 7.

Fig 5 Classification of failure mode of the tested specimens. (a) 'Reparable' fracture. (b) 'Possibly reparable' fracture. (c) 'Catastrophic' fracture.



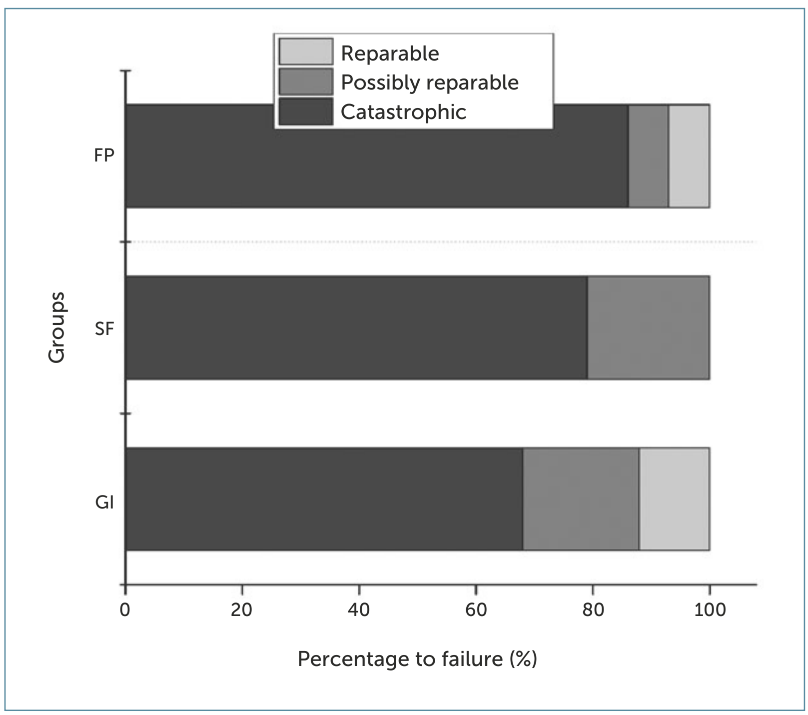


Fig 6 Percentage of specimens per group for each fracture mode. GI: glass-ionomer cement; SF: short fiber-reinforced composite resin; FP: fiber post.

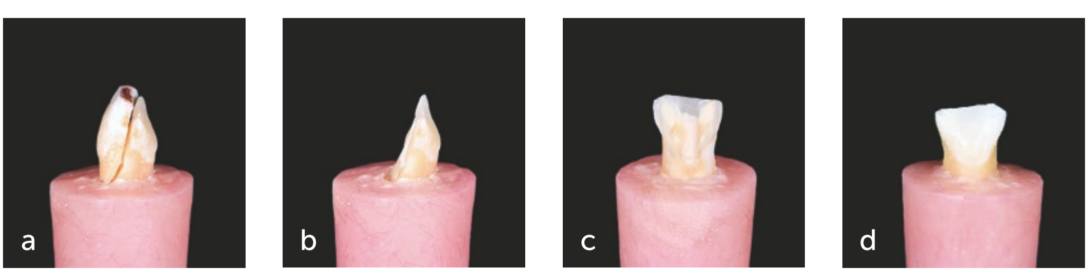


Fig 7 Specimens from the GI group displaying an intact composite resin lingual surface that forced the initial crack to start from a very coronal position, almost at the incisal edge. (a) Proximal view with the labial fragment in position. (b) Proximal view of the remaining fractured specimen. (c) Labial view showing the intact GI base. (d) Lingual view showing an intact composite resin restoration.

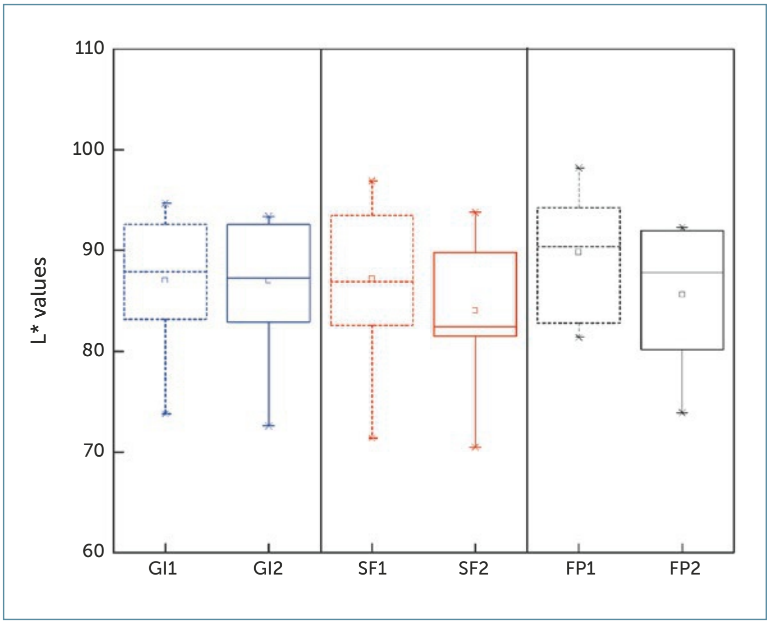


Fig 8 Box plot of the L* values of the specimens for all groups. Color measurements were performed after internal bleaching color stabilization, ie, before (1) and after (2) the access cavity final restorative procedure. GI: glass-ionomer cement; SF: short fiber-reinforced composite resin; FP: fiber post.

The L* values are presented in Figure 8. In both the SF and FP groups, the internal bleaching luminosity effect decreased significantly after the completion of the final restoration. For the SF specimens, the L* mean value decreased from 87.21 to 84.00 (P = 0.000), and for the FP specimens, the luminosity reduced from 89.82 to 85.60 (P = 0.000). When the access cavity of the specimens was restored with the GIC/composite resin laminate technique, the internal bleaching outcome was stable, with L* mean values of 87.03 before and 87.02 after the restorative procedure (P = 0.987).

Discussion

The present study evaluated the effect of three restorative approaches on the survival of relatively intact, internally bleached ETIs. The null hypotheses were that no significant difference would be found in accelerated fatigue resistance and that no difference would be found in final color modification among the restorative techniques. The first null hypothesis was accepted because there was no significant difference in survival rates when comparing the three treatment modalities. The second null hypothesis was rejected because the luminosity of both the SF and FP specimens was reduced after access cavity restoration.

One of the major challenges of the present in vitro study was the limited availability and extreme variability of extracted human teeth (age, size, and shape). Using standardized specimens is of paramount importance as it allows the minimization of confounding variables and the increase of sensitivity in testing. Nevertheless, many confounding variables could be eliminated by having absolute control, not only of the restorative steps (absence of existing restorations, standardized size of endodontic preparation, etc), but also by normalizing the load configuration and load protocol. The accelerated fatigue test represents a compromise between the conventional load-to-failure protocol and the time-consuming low-load fatigue test. The cyclic loads were applied in increments, with the load increased in 25 N steps up to 1200 N at a frequency of 5 Hz. In order to prevent localized and intense point loads and unrealistic surface damage, a flat composite resin surface was used as an antagonist.[24,25] In the anterior region, the isometric bite force ranges between 243 N (females) and 287 N (males),[17] even though higher forces may be encountered in the presence of bruxism, trauma (high extrinsic loads) or intrinsic masticatory accidents. In the present study, higher forces were required to break the specimens. The first failures occurred at 425 N; however, one specimen in the GI group survived until 1200 N. Average failure loads ranged between 550 and 650 N.

In view of the present results, the use of glass-fiber posts can be questioned. No significant advantage could be observed. Fiber posts have already proven their lack of positive effect in previous studies on severely broken-down ETIs with or without ferrule.[24,25] The results of the present investigation confirm that this conclusion can be extended to relatively intact ETIs. This is a significant finding, as the presence of intact coronal structure usually renders post insertion more difficult and may lead to some clinicians removing coronal tissue in order to place the post. However, maintaining intact coronal tissue is paramount in the treatment of ETIs.[17-21] This has been proven by the general consensus and abundant data on the advantages of the ferrule effect. Due to the moderately conservative preparation approach in the present investigation, a 'natural' ferrule effect was obtained by the substantial amount of intact circumferential dentin and enamel. This, in turn, may have 'masked' the effect of the restorative approach.

Placing a post is not without risks, in particular in the presence of limited coronal access.[7-9] If the three restorative methods presented herein were ranked according to simplicity, efficiency, minimal risks (including failure mode), and cost, the GIC approach would certainly be the most favorable; it does not require the removal of the existing barrier. The glass-ionomer base was used as a dentin replacement and was covered with a 2-mm–thick composite resin layer over the entire lingual surface as an additive reinforcement measure. This technique was used in order to create some kind of palatal reinforcement[17] and to compensate for the flexible behavior of the ETIs.[12,13] This is demonstrated in Figure 7, which shows a specimen with an intact composite resin lingual surface that forced the initial crack to start from a very coronal position, almost at the incisal edge.

Recently, so-called bulk-fill composite resins were introduced, including short fiber-reinforced restorative composite resins. The physical and mechanical properties of these materials show promising results.[11,14,15,24] However, perhaps due to the very limited amount of material used in the present study, and also because this reinforced composite was located in the center of the tooth (near the neutral zone), the effect could not be detected. In fact, when anterior teeth are subjected to bending from a lingual load, the tooth is separated into two distinct areas: the palatal half is subjected to tensile stresses and the labial half to compressive ones. The center of the tooth (near the pulp) is located at the transition between those two areas and exhibits neutrality (stresses close to 0).[18]

Internal bleaching is a predictable, quick, simple, and cheap procedure; however, the longevity of its color outcome has been questioned. Color relapse can occur after 1 to 5 years of treatment and seems to be related to the initial tooth color and to the access cavity restorative procedure.[5,26,27,29] It is known that cases in which the teeth become gray, light yellow or black are easier to bleach than those with dark-yellow discoloration. Additionally, the easier it is to obtain the bleaching effect, the more stable the long-term outcome.[28] Internal bleaching color relapse has been associated with the permeation of extrinsic pigments through the marginal defects of access cavity final restorations. The GIC/composite resin laminate technique has been demonstrated to be the restorative procedure that presents the best color stability over time when compared with nonadhesive restorative materials.[28] The findings of the present study confirm this fact, even when compared with other adhesive restorative procedures such as short fiber-reinforced composite resin or fiber post, both covered with composite resin. The GIC/composite resin laminate technique was the only restorative approach that did not decrease the luminosity obtained after internal bleaching. The GIC opacity was certainly responsible for this result.

From a clinical perspective, a delay of 3 to 4 weeks is generally required before applying adhesive restorative procedures to a bleached tooth,[14-16] whether it is externally or internally bleached.[3] This not only permits the recovery of the bond strength but also allows for color stabilization before the restorative treatment.[3-6] Hence, the tooth needs to be restored temporarily during that time. Glass ionomer is a good choice because it is easy to place and provides a decent seal with appropriate color and opacity. The present study also demonstrated that keeping this glass-ionomer base and simply replacing the surface of the defect with composite resin will not affect the mechanical behavior of the restored tooth when compared with the more complicated alternatives such as the placement of a post.

Conclusion

Based on the findings of the present in vitro study, it is possible to conclude that the fatigue survival of relatively intact, internally bleached maxillary central incisors was not affected by the restorative technique utilized. Additionally, the GIC/composite resin laminate technique (GI group) was the only restorative procedure that could maintain the short-term bleaching outcome. Therefore, the use of a glass-ionomer base as a dentin replacement covered with composite resin is the most conservative restorative approach and seems to be the best treatment choice from both a biomechanical and esthetic standpoint.

Clinical relevance

The present in vitro study suggests that the mechanical stability of intact, internally bleached ETIs is not improved by the use of fiber posts or short fiber-reinforced composite resin. The simplest and most conservative restorative approach (one that uses an opaque GIC as a dentin replacement in the endodontic access and composite resin at the surface) should be used because it does not compromise strength and provides better color stability.

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