

# Resistance to fracture of endodontically treated teeth restored with different post systems

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**Statement of problem.** Very little is known about the resistance to fracture of endodontically treated teeth restored with newly developed esthetic post systems.

**Purpose.** This in vitro study compared the effect of 1 titanium and 3 esthetic post systems on the fracture resistance and fracture patterns of crowned, endodontically treated teeth.

**Material and methods.** A total of 40 recently extracted human maxillary canines with their crowns removed were endodontically treated. Four groups of 10 specimens were formed. Teeth were restored with titanium, quartz fiber, glass fiber, and zirconia posts and numbered as groups 1, 2, 3, and 4, respectively. All posts were cemented with Single Bond dental adhesive system and dual-polymerizing RelyX ARC adhesive resin cement. All teeth were restored with composite cores, and metal crowns were fabricated and cemented with glass ionomer cement. Each specimen was embedded in acrylic resin and then secured in a universal load-testing machine. A compressive load was applied at a 130-degree angle to the long axis of the tooth until fracture, at a crosshead speed of 1 mm/min. One-way analysis of variance and a Tukey test were used to determine the significance of the failure loads between groups ( $P < .001$ ). A non-parametric  $\chi^2$  test was conducted for evaluation of the mode of failure ( $P < .001$ ).

**Results.** The mean failure loads (kg) were 66.95, 91.20, 75.90, and 78.91 for groups 1 to 4, respectively. Teeth restored with quartz fiber posts (group 2) exhibited significantly higher resistance to fracture ( $P < .001$ ) than the other 3 groups. Teeth restored with glass fiber and zirconia posts (groups 3 and 4) were statistically similar ( $P > .05$ ). Fractures that would allow repair of the tooth were observed in groups 2 and 3, whereas unrepairable, catastrophic fractures were observed in groups 1 and 4 ( $P < .001$ ).

**Conclusion.** Within the limitations of this study, significantly higher failure loads were recorded for root canal treated teeth restored with quartz fiber posts. Fractures that would allow repeated repair were observed in teeth restored with quartz fiber and glass fiber posts. *J Prosthet Dent* 2002; 87:431-7.

## CLINICAL IMPLICATIONS

*Within the limitations of this study, endodontically treated teeth restored with D.T. Light quartz fiber posts were less prone to fracture than teeth restored with any of the other 3 post systems tested. If teeth restored with D.T. Light quartz fiber and ParaPost Fiber White glass fiber post systems fracture, the results of this study suggest that the resultant fracture will be minor enough to allow an additional attempt to repair the tooth.*

Endodontically treated teeth are known to present a higher risk of biomechanical failure than vital teeth.<sup>1-3</sup> Sedgley and Messer<sup>4</sup> concentrated upon the loss of tooth structure, whereas others reported the effect of decreased moisture content and subsequent brittleness of root canal treated teeth<sup>5-7</sup> as causes of fracture. Caputo and Standlee<sup>2</sup> stated that posts are needed to allow the clinician to rebuild enough tooth structure to retain restorations. The price for added retention, however, may be an increased risk of dam-

aged tooth structure. In this respect, some of the current literature still disputes the reinforcement potential of posts.<sup>2,8-10</sup> Creugers et al<sup>11</sup> reviewed related literature that spanned more than 20 years and reported that survival rates have varied largely in endodontically treated teeth restored with different post-and-core systems. No consensus existed on which technique and materials are best suited for use.<sup>11,12</sup>

Sorensen et al<sup>13</sup> reported that a post system with the propensity to cause root fractures should be avoided. Several studies indicated that when remaining tooth structure was conserved with tapered posts, catastrophic root fractures resulted.<sup>13-15</sup> Cooney et al<sup>16</sup> also noted that tapered posts produced wedging stress-

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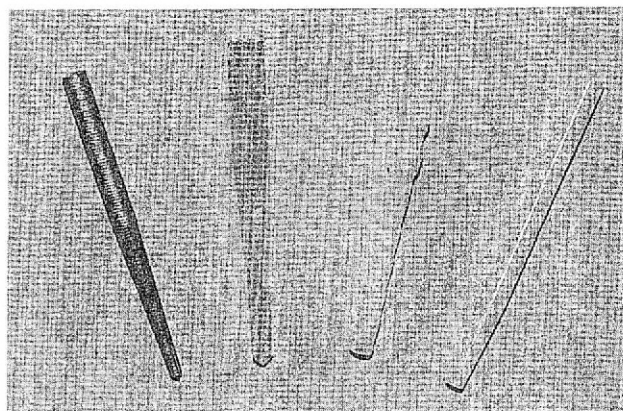


Fig. 1. Posts systems from left to right: Filpost, D.T. Light-Post, ParaPost Fiber White, and CosmoPost.

es near the apex, resulting in root fractures. Some authors have emphasized the necessity to use posts made with biomechanical properties similar to those of teeth.<sup>17,18</sup> Assif and Gorfil<sup>19</sup> reported that when root canal treated teeth were restored with posts and cores, stresses were concentrated at the coronal third of the root, especially at the interfaces of materials with different moduli of elasticity. Many investigators have reported that the design as well as the material of the post and core affect the resistance to fracture of endodontically treated teeth restored with post-and-core systems.<sup>3,9,19-21</sup>

Until recently, all available prefabricated posts consisted of metal alloys that resulted in a final heterogeneous combination of dentin, metallic post, cement, and core material. Fredriksson et al<sup>22</sup> proposed that the major disadvantage of these systems was the stresses concentrated in uncontrolled areas that were sometimes vital to the root. The restoration of endodontically treated teeth with metal-free, physiochemically homogeneous materials that have physical properties similar to those of dentin has become a major objective in dentistry. Christel et al<sup>23</sup> observed that zirconia posts, introduced in the late 1980s, exhibited high flexural strength and fracture toughness; Kwiatkowski and Geller<sup>24</sup> reported the ability of such posts to be silanated and bonded with a resin cement. Fiber-reinforced post systems were later introduced.<sup>20,25-27</sup> Goldberg and Burstone<sup>26</sup> reported that glass fiber-reinforced post systems were composed of unidirectional glass fibers in the resin matrix that strengthened the structure of the post without compromising the modulus of elasticity. Translucent quartz fiber post systems recently were introduced as an alternative to achieve optimal esthetics; they can be light-polymerized during cementation.<sup>27</sup>

Rosentritt et al<sup>28</sup> compared the fracture strength of endodontically treated teeth restored with titanium, zirconia, and fiber-reinforced posts and concluded that

the fracture strength of zirconia posts was superior to that of titanium posts and both were superior to fiber-reinforced posts. In a study by Mannocei et al,<sup>27</sup> intermittent loading of teeth restored with quartz fiber, carbon-quartz fiber, and zirconia posts was evaluated. Fiber-reinforced posts were able to reduce to a minimum the risk of root fractures and displayed significantly higher survival rates than teeth restored with zirconia posts. Another study investigated stiffness and the elastic limitations of zirconia, titanium, and carbon fiber posts and concluded that zirconia posts exhibited superior characteristics.<sup>29</sup> According to the results of Butz et al,<sup>30</sup> the fracture strength of teeth restored with zirconia posts and composite cores were significantly lower than those restored with zirconia posts and heat-pressed ceramic cores.

There is limited information in the literature on comparisons of post systems with different moduli of elasticity and their effect on the fracture resistance of root canal treated teeth. This study was conducted to compare the fracture resistance and mode of fracture of endodontically treated teeth restored with titanium, zirconia, and 3 newly developed fiber-reinforced post systems.

## MATERIAL AND METHODS

The fracture resistance and fracture mode of crowned, endodontically treated teeth restored with titanium, quartz fiber, glass fiber, and zirconia post systems was characterized through the application of a compressive load on a universal testing machine (Fig. 1). Forty freshly extracted maxillary canines free of cracks, caries, and fractures were selected for the study. All external debris was removed with an ultrasonic scaler, and the teeth were stored in saline solution when not under testing. The anatomic crowns of all teeth were sectioned horizontal to the long axis, at the cemento-enamel junction (CEJ), with the use of a water-cooled diamond fissure bur (DiaSwiss FG; Geneve, Switzerland) with an air-turbine at 300,000 rpm. Buccolingual and mesiodistal dimensions were determined with an electronic micrometer (Absolute Digimate Calipers; Mitutoyo, Sussex, United Kingdom), and the teeth were assigned to 4 groups of 10 teeth each. The root dimensions were assessed with 1-way analysis of variance (ANOVA) to demonstrate any significant differences between the groups ( $P > .05$ ).

The canals of all groups were prepared chemomechanically. Gates Glidden drills (Maillefer; Ballaigues, Switzerland) in sizes 2 and 3 were used to obtain straight-line access in the middle and the coronal third of all specimens. The specimens then were stepback prepared to a size 55 file (Flex R File; Union Broach, York, Pa.). Silicone stoppers were placed around the file shaft to control the working length of the files, and

the accuracy of the internal canal dimensions were ensured. After intermittent rinsing with 2.5% sodium hypochloride, the canals were dried with paper points (Union Broach), and the roots were obturated with lateral condensation of gutta-percha and AH 26 eugenol-free sealer (De Trey; Konstanz, Germany). The master gutta-percha point was coated with sealer and seated in the canal to the full working length. A finger spreader (Kerr; Romulus, Mich.) was inserted into the canal to a level approximately 1 mm short of the working length. Lateral condensation with non-standardized fine gutta-percha points (De Trey) was performed until the entire canal was obturated.

The most similar sizes available among the post systems used in this study were chosen. The length of the glass fiber posts was 15 mm, whereas posts from the other 3 systems measured 20 mm. Each post was marked at a distance of 11 mm from its apical end. A line was drawn around the post at this level, and all posts were sectioned horizontally with a water-cooled diamond fissure bur. This standardized the post lengths and established similarity between post diameters of the tapered designs. Gutta percha was removed from the root canals with Peeso drills (Maillefer; Baillagues, Switzerland) to a depth of 8 mm, and post spaces were prepared in all groups with the special preparation drills of each system.

Titanium posts (Filpost; Filhol Dental, Cork, Ireland) 1.60 mm in diameter were used in group 1. The special reamer of the system, used to prepare the post spaces, also created retention grooves in the canal walls. Quartz fiber posts (D.T. Light-Post; Recherches Techniques Dentaires, RTD, St. Egreve, France) were placed in group 2. A post size of 3 was selected, measuring 1.70 mm in diameter at the prepared length of 11 mm. The system was designed to have a tapered form; the degree of taper gradually decreased at the 1.00 mm apical end, from 1.30 to 1.20 mm in diameter. Glass fiber posts (ParaPost Fiber White; Coltene/Whaledent Inc, Mahwah, N.J.) were placed in group 3. A post size of 6 was selected, measuring 1.50 mm in diameter. This was the largest diameter provided by the manufacturer. Zirconia posts (CosmoPost; Ivoclar, Schaan, Liechtenstein) 1.70 mm in diameter were used in group 4.

All posts were cemented with an adhesive system (Single Bond Dental Adhesive System; 3M Dental Products, St Paul, Minn.) and dual-polymerizing adhesive resin cement (RelyX ARC; 3M Dental Products) according to the manufacturer's guidelines. The root canal walls were etched with 35% phosphoric acid (Scotchbond etchant; 3M Dental Products) for 15 seconds, washed with water spray, and gently air-dried. Two consecutive coats of Single Bond Adhesive were applied in the canals. After the material had dried for 5 seconds, excess was removed with a dry paper

point, and the adhesive was light-polymerized for 10 seconds. RelyX ARC adhesive resin cement was mixed for 10 seconds and applied in the canal walls with the use of a periodontal probe. A thin layer of cement also was placed on the post surface, and the post was inserted into the canal. Excess cement was removed, and the remainder was light-polymerized for 40 seconds.

Dentin was prepared with the use of the Single Bond adhesive system, and a light-polymerized composite core (Valux Plus; 3M Dental Products) was fabricated on one of the prefabricated posts. A beveled crown preparation was made on the composite core material with use of a water-cooled diamond bur. A matrix was formed on the prepared core with foil from the Adapta System (0.6 mm; Bego, Bremen, Germany). The matrix was filled with the composite material, seated on the root of another specimen along the long axis, and light-polymerized. Every other composite core was produced with the same procedure. One coat of die spacer (Picosep; Renfert, Hilzingen, Germany) was applied on the composite core. Preheated liquid wax (Pico Sculpturing Wax; Renfert) was inserted into a size 35 polycarbonate crown (Polycarbonate Crown Forms; 3M Dental Products) with the use of modeling tips (Waxlectric; Renfert), and the crown was seated directly on the core along the long axis. Upon completion of the cooling-down phase, excess wax was scraped and the polycarbonate crown was removed. The same procedure was applied for all specimens.

A marking line was scraped 3 mm below the incisal edge of the canine wax pattern on the palatal surface. A palatal step design (0.3 mm deep and 1 mm wide) was formed on each specimen. Wax patterns, custom-cast with a Ni-Cr alloy (Wiron 99; Bego), were luted to the cores with a glass ionomer cement (Vitremere Luting Cement; 3M Dental Products).

Specimens were stabilized on a fixator (Bego) with vertically moving rods, from the most coronal tip of each crown, with sticky wax (Pico sticky wax; Renfert). Root surfaces were marked 2 mm below the CEJ and covered with 2 0.1 mm Adapta foils. Specimens then were embedded in autopolymerizing acrylic resin (Meliodent; Bayer Dental, Newbury, United Kingdom) surrounded by aluminum cylinders. After the first signs of polymerization, teeth were extracted from the resin blocks by moving rods in an upward direction, and Adapta spacers were removed from the root surfaces. Silicon-base impression material (Speedex; Coltene, Altstätten, Switzerland) was injected into acrylic resin molds, and the teeth were reinserted into resin cylinders. Standardized silicone layers that simulated periodontal ligament thus were created.

Specimens were secured in a universal load-testing machine (HA 100; Dartec, Surrey, United Kingdom)

Table I. Mean failure loads (kg) for each group

	n	Mean (kg)	SD	SD Error	95% Confidence Interval for Mean	
Filpost	10	66.95	8.26	2.61	61.04	72.86
D.T. Light-Post	10	91.20	10.01	3.17	84.04	98.36
ParaPost Fiber White	10	75.90	5.76	1.82	71.78	80.02
CosmoPost	10	78.91	7.95	2.51	73.22	84.60
Total	40	78.24	11.76	1.86	74.48	82.00

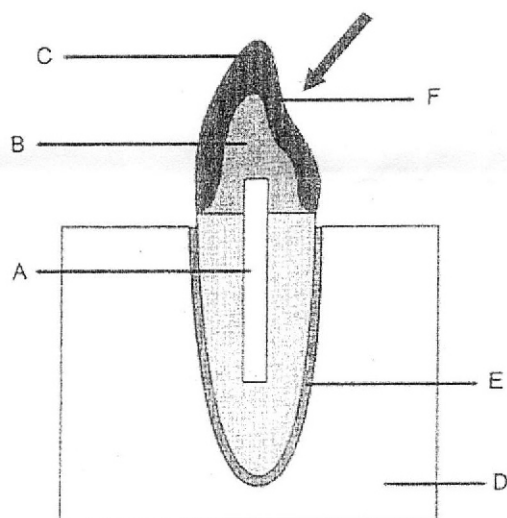


Fig. 2. Schematic drawing of specimen mounted in acrylic resin block: prefabricated post (A), composite core (B), cemented metal crown (C), resin block (D), silicone simulated periodontal ligament (E), and arrow indicating 130 degree angle load applied to prepared step on palatal surface (F).

with the use of a device that allowed loading of the tooth lingually at 130 degrees to the long axis. The load head was placed on the specially formed palatal step (Fig. 2). A compressive force was applied at a crosshead speed of 1 mm/min until fracture occurred. The fracture loads were determined, and the mode of fracture was recorded and classified as favorable (would allow repair) or catastrophic (non-restorable).

One-way ANOVA and a Tukey test were used to determine the significance of the failure loads between groups ( $P < .001$ ). A nonparametric chi-square test was conducted for statistical evaluation of the mode of failure ( $P < .001$ ).

## RESULTS

Mean failure loads were calculated for all groups (Table I). The highest fracture resistance was recorded for group 2 teeth (quartz fiber) at 91.20 kg, followed by group 4 (zirconia), group 3 (glass fiber), and group 1 (titanium) at 78.91 kg, 75.90 kg, and 66.95 kg, respectively (Fig. 3). Between-group differences in the

Table II. One-way ANOVA on failure loads (kg)

	Sum of squares	Df	Mean square	F	Pr > F
Between groups	3013.502	3	1004.501	15.172	.001
Within groups	2383.514	36	66.209		
Total	5397.016	39			

Table III. Significant differences in groups identified with 1-way ANOVA and Tukey's test ( $P < .001$ )

	Subset for alpha = .05		
	1	2	3
Filpost (titanium)	66.95		
ParaPost Fiber White (glass fiber)		75.90	
CosmoPost (zirconia)		78.91	
D.T. Light-Post (quartz fiber)			91.20

fracture resistance of teeth were significant ( $P < .001$ ) except for groups 3 and 4 ( $P > .05$ ) (Table II and III).

Teeth restored with quartz and glass fiber posts displayed favorable fractures ( $P < .001$ ); those restored with titanium and zirconia posts demonstrated catastrophic fractures (Table IV). The fracture patterns of all groups are presented in Figure 4. Oblique root fractures were apparent in group 1 specimens (titanium), with fracture lines more apical on the labial than palatal surface. The most catastrophic failures were found in this group. No fractures were seen in the middle or apical third of the roots in group 2 specimens (quartz fiber). In 3 specimens of this group, posts were bent at the apical end, and failure was observed at the core/root interface, although no serious damage to the root was incurred. In group 3 (glass fiber), 4 different failure types were recorded. Four of the fractures were oblique, extending apically, and involved the middle third of the root. Three specimens showed failure at the tooth/post/core interface combined with an oblique fracture line on the labial surface of the root. Dislodgement of the metal crown accounted for the failure of 2 specimens, and cervical root fracture was observed in 1 specimen. In group 4 (zirconia), all posts fractured. Most fractures involved the composite core and extended onto the mesial root surface below the crown margin. In 3 specimens, the cores separated from the posts at failure.

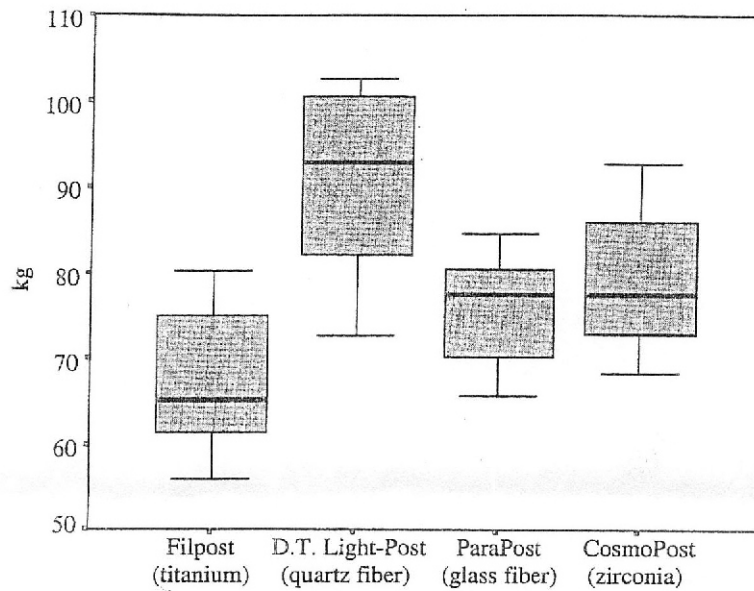


Fig. 3. Mean failure loads of post systems tested. Standard deviation represented by thin T bars.

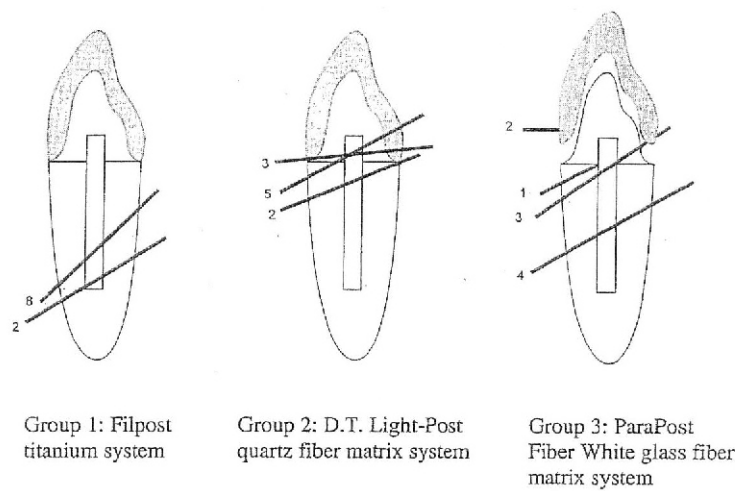


Fig. 4. Fracture patterns in specimen groups.

Table IV. Analysis of mode of failure with nonparametric  $\chi^2$  test ( $\chi^2=15.04, P<.001$ )

	Group 1 Filpost (titanium)	Group 2 D.T. Light-Post (quartz fiber)	Group 3 ParaPost Fiber White (glass fiber)	Group 4 CosmoPost (zirconia)
Favorable fractures	0	8	6	3
Catastrophic fractures	10	2	4	7

DISCUSSION

Studies that compared the mechanical properties of different post systems suggest that the ability of each post-and-core system to protect the root from biomechanical failures may vary greatly.<sup>19,27,29</sup> Asmussen et al<sup>29</sup> questioned whether a post system with better mechanical properties was more desirable.

This study compared the resistance to fracture of teeth restored with 4 different post systems. Natural teeth were used for the preparation of the specimens. The dimensions of the experimental teeth were evaluated statistically in order to eliminate the possible variations in size. All roots received endodontic treatment, and care was taken to fabricate standard cores

and metal crowns. A standardized silicon layer simulating periodontal ligament was created to allow limited freedom of movement.<sup>8</sup> The most similar post sizes among the tested systems were chosen. Variations in post length were eliminated by sectioning all posts at the 11 mm length prior to cementation. This procedure also enabled the formation of groups with similar post diameters (range 1.50 to 1.70 mm). The manufacturer's instructions were followed carefully when posts were cemented to validate the treatment procedures. Despite these measures, several factors limit the direct application of this study to *in vivo* situations.

Sorensen and Engelman<sup>13</sup> reported that the key factor in failure threshold was coronal extension of the tooth structure above the crown margin. Libman and Nicholls<sup>21</sup> studied the effects of different ferrule heights (0.5 to 2.0 mm) on the load resistance of teeth restored with cast posts and cores. They concluded that a ferrule height of at least 1.5 mm is required to ensure a favorable restoration prognosis. In the present study, a weak system with zero ferrule length was tested.

Guzy and Nicholls<sup>8</sup> reported that, for incisor teeth, a loading angle of 130 degrees was chosen to simulate a contact angle found in class I occlusions between maxillary and mandibular anterior teeth. In the present study, the teeth were loaded lingually at 130 degrees to the long axis and standardized palatal steps were fabricated to mark the level of loading on each metal crown. However, submitting specimens to cyclic loading and then establishing their reaction to fatigue more accurately simulates intraoral conditions than increasing a single load until fracture.<sup>30</sup>

In the present study, group 1 specimens (titanium posts) exhibited the lowest mean resistance to fracture with the most catastrophic fractures. According to the manufacturer, the Filpost system incorporates retention by interlocking the cement between the undercuts found on the post surface and the grooves created in the canal wall during post space preparation. Several studies have shown that the surface design and wedge-like action of this post type were responsible for increased stress concentration at the tapered apical end, resulting in catastrophic root fractures.<sup>13,15,16</sup> The results of this study confirm those findings.

Group 2 specimens (quartz fiber posts) demonstrated the highest mean resistance to fracture with fractures that would permit repair of the tooth. The manufacturer claims that the slightly double-tapered posts, which closely resemble the morphology of the root form, absorb stress rather than transferring it and thus protect endodontically treated teeth against fracture. Burgess et al<sup>14</sup> reported a preference for posts designed to be similar to the root form. The light-transmitting property of the D.T. Light-Post system

makes it possible to polymerize primer and cement through the post; this characteristic also may have contributed to the significantly better results obtained in group 2.

It has been reported that one potential disadvantage of parallel-sided post systems is weakening of the apical part of the root during post space preparation. This post design may have accounted for the significant difference in fracture resistance between groups 2 and 3. On the other hand, favorable (restorable) fractures were observed in both quartz fiber and glass fiber post specimens. These findings agree with previous studies on the effect of post design on fracture mode.<sup>9,13,15,20</sup>

Tjan et al<sup>17</sup> reported that when a zirconia post is used with a direct composite core, large stress-bearing composite cores in combination with subgingival margins should be avoided. Zirconia posts with heat-pressed ceramic cores have been suggested for use because their similar thermal expansion coefficients may result in favorable shrinkage and fit of the restoration.<sup>19,28,30</sup> In the present study, zirconia posts with a flexural strength of 820 MPa were used with composite cores. This may account for the fracture under compressive load of all teeth restored with zirconia posts. A similar result was reported by Butz et al.<sup>30</sup> Asmussen et al<sup>29</sup> noted that because of the rigidity of ceramic posts, it may be difficult to remove a cemented zirconia post from a failed restoration. Teeth restored with zirconia posts and all-ceramic cores may demonstrate increased resistance to fracture.

The modulus of elasticity of the different post systems used in this study should be taken into account. The high modulus of elasticity of titanium compared to dentin may be responsible for the catastrophic fractures of Group 1 specimens at low failure loads. Conversely, quartz fiber posts have a low elastic modulus (18 to 47 GPa) similar to that of dentin, which may explain the favorable fracture patterns and high fracture loads observed with group 2 specimens. Mannocci et al<sup>27</sup> also reported that quartz fiber posts were able to reduce to a minimum the risk of root fractures. Glass fiber posts exhibited a modulus of elasticity much better matched to that of teeth than zirconia and titanium.<sup>19,28</sup> Due to the high modulus of elasticity of zirconia, forces were transmitted directly to the post/tooth interface without stress absorption.<sup>27,29</sup> This feature may account for the catastrophic fractures observed in group 4 specimens.

The mean fracture loads of teeth restored with glass fiber and zirconia posts were not significantly different. The parallel-sided and serrated design of the glass fiber posts, which reduced the thickness of the remaining root structure, may have enabled group 3 specimens to exhibit properties similar to those of group 4 specimens. In this sense, it can be speculated

that posts should have an elastic modulus as close as possible to that of the root dentin to reduce stress concentration and thus the rate of failure.

## CONCLUSIONS

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

1. The titanium system demonstrated the least resistance to fracture loads and the most catastrophic failures.

2. Significantly higher fracture resistance was observed in teeth restored with the quartz fiber matrix system than teeth restored with the other 3 systems tested.

3. The mean fracture loads of the glass fiber matrix system and zirconia system did not differ. However, they were significantly higher than the loads recorded for the titanium group and lower than the loads recorded for the quartz fiber matrix group.

4. All specimens in the zirconia group fractured. Statistical analysis of the mode of fracture showed that the quartz fiber and glass fiber groups fractured favorably (fractures able to be repaired). Catastrophic fractures were observed in the titanium and zirconia groups.

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