In Vitro Comparison of the Fracture Resistance and Failure Mode of Fiber, Ceramic, and Conventional Post Systems at Various Stages of Restoration

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Purpose: This in vitro study evaluated 6 post systems over 4 simulated clinical stages of tooth restoration to (1) determine quantitatively the fracture resistance strength at each stage when a static loading force is applied to cause failure; (2) determine the failure mode for each post system at each simulated clinical stage; and (3) determine the feasibility of removing failed post systems.

Materials and Methods: Ten post systems made with various materials and designs were tested at the following 4 stages of simulated clinical treatment: stage #1: posts only, loaded using a 3-point loading model to failure, to determine transverse strengths and failure modes for each post system; stage #2: posts alone, bonded into teeth; stage #3: posts bonded into teeth with core build up; stage #4: post and core build up and full veneer restoration. For stages #2 through #4, the coronal portion of 60 mandibular premolars was amputated at the cemento-enamel junction, the canals were treated endodontically, and the specimens were mounted in acrylic blocks. A testing force was applied to the posts at 90° to the long axis of the tooth, 4 mm from the cemento-enamel junction. The O'Brien test for constant variance was performed over the treatment groups. For nonconstant variance, the Welsh analysis of variance was used to test for equalities of treatment means. The Tukey Kramer procedure determined which treatment procedures differed.

Results: The failure thresholds for each post system were significantly different at each stage of testing, but the order of test results by post type remained generally consistent from one stage to the next. ParaPosts (Coltene, Whaledent Int, New York, NY) and core build up resulted in significantly higher failure thresholds through all 4 stages of testing. This post system also consistently displayed a high number of unfavorable tooth fractures. FibreKor post and cores (Jeneric Pentron Inc, Wallingford, CT) resulted in significantly lower failure threshold values in stages #2 through #4. This post system displayed no tooth fractures in stages #2 and #3 and a similar number of unfavorable tooth fractures in stage #4 when compared with the other systems. C-Post (Bisco Dental Products, Schaumburg, IL), CosmoPost (Ivoclar Vivadent North America Inc, Amherst, NY), and AestheticPost (Bisco Dental Products) grouped in descending order through stages #2 to #4. These systems displayed intermediate fracture resistance strengths, as well as a moderate number of unfavorable tooth fractures. CosmoPost exhibited a significant number of brittle post fractures with fragments left in the root canal at all stages. The fracture resistance of the cast metal post varied from stage to stage. No teeth fractured at stage #2. At stage #3, 9 of 10 teeth fractured nonfavorably, and all teeth fractured nonfavorably in stage #4.

Conclusions: The fiber posts evaluated provided an advantage over a conventional post that showed a higher number of irretrievable post and unrestorable root fractures. At the stage of final restoration insertion, there was no difference in force to failure for all but the FibreKor material, which continued to be weaker than all other tested materials. The fiber posts were readily retrievable after failure, whereas the remaining post systems tested were nonretrievable.


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POST MATERIALS and designs have been evaluated extensively to determine which are the most retentive and the least stressful to surrounding dentin. Threaded posts are consistently shown to be the most retentive followed by parallel-sided posts.1-3 Parallel-sided posts with serrations are more retentive than parallel-sided nonserrated posts or tapered posts.1-4

Post and core failures from root fractures have been reported in the range of 3% to 10%5,6 of all tooth build-up failures. Tapered threaded screw posts produce the greatest dentinal stress surrounding the post.7 Threaded posts cause high internal stresses during loading.8 Increasing post length increases the resistance of a root to fracture, and increasing post diameter decreases the resistance of a root to fracture.9 In a retrospective study, Sorensen and Martinoff10 determined that the highest success occurred with paralleled-sided, serrated posts, whereas tapered cast posts and cores showed a higher failure rate. This study showed that the use of tapered cast post and cores resulted in more nonrestorable failures.

Dallari and Rovatti11 have proposed several attributes of an ideal intraradicular restorative system. They suggest that this system should have biomechanical characteristics similar to natural tooth tissues. The integration of adhesive techniques into post and core procedures has altered post designs and has resulted in the use of new materials. Thus, there should be the potential to obtain a bonded tooth-post-core-crown "monobloc" type of restoration, instead of an assemblage of heterogeneous materials. The esthetic properties of materials used for preprosthetic foundations are an important concern for clinicians, especially with the increased use of full ceramic crowns in the anterior region. Light conducting, fiber, and all-ceramic posts12,13 are available for restorations in these more esthetically demanding areas. These materials have similar transparency to natural dentin and thus permit optimal esthetics in all-ceramic restorations. Additionally, post systems based on polymer/ceramic materials have been introduced, producing, according to manufacturers' claims, a post with high esthetic potential.14 These posts have a universal tooth color and are highly translucent. Elimination of dark metal substructures enhances esthetics by preventing the possibility of the metallic color showing through the labial plate of the root and the overlying attached gingiva.

Another consideration being addressed through contemporary technology focuses on the concept that a post with a modulus of elasticity significantly greater than that of dentin might create stresses at the tooth/cement/post interface, with the possibility of post separation and failure. In addition, the transmission of occlusal and lateral forces through a metallic core and post can concentrate stresses resulting in the possibility of unfavorable fracture of the root.15 The modulus of elasticity of dentin is approximately 14.2 GPa.16 According to the manufacturers of the materials included in this study, the fiber posts have moduli that are approximately 1 to 2 times as great. This similarity in elasticity may allow post flexion to mimic tooth flexion. In contrast, the parapost and cast parapost modulus of elasticity is 8 to 9 times that of dentin, whereas the modulus for the ceramic post is approximately 15 times that of dentin. If the post is bonded to dentin, this may reduce the concentration of stresses in the remaining root and more equally distribute forces over the entire bonded interface.17

With the evolution of the dentin bonding technology18-20 and the increased bonding strengths of the latest generation dentin bonding agents, it may be possible to obtain an integrated tooth-post-core bonded restoration, instead of an assemblage of heterogenous materials (ie, post [metal], cement [zinc phosphate], core [metal, amalgam, or composite resin]). The bonded interface between the root canal dentin and compatible restorative materials may result in an internally bonded restoration. Depending on the post material being used and its physical properties, the post and core can absorb occlusal and functional stresses that are applied to the bonded post/crown complex and redirect them along the long axis of the remaining root. If failures occur, they might result in teeth that are less severely damaged and ultimately could be restorable.

The purposes of this study were to evaluate 6 post systems over 4 clinical stages of tooth restora-
tion to: (1) determine quantitatively the fracture resistance strengths at each stage, when a static loading force is applied to cause failure; (2) determine the failure mode for each post system at each simulated clinical stage; and (3) determine the feasibility of removing failed post systems.

Materials and Methods

Post Systems

Six post systems were chosen for evaluation (Table 1). Post systems were chosen to represent conventional systems (Para Post XH [Coltene, Whaledent International, New York, NY]; Cast Metal Post Para Post XH plastic pattern [Coltene, Whaledent International], fiber systems (C-Post [Bisco Dental Products, Schaumburg, IL]; AestheticPost [Bisco Dental Products], FibreKor Composite Post [Jeneric/Pentron Inc, Wallingford, CT]), and a ceramic system (CosmoPost; Ivoclar Vivadent North America Inc, Amherst, NY).

Different stages of simulated clinical treatment were tested.

In stage #1, the posts were tested to determine flexural strength. Ten post samples from each manufacturer were sectioned into 10-mm lengths and placed individually into a holder to stabilize the posts. A universal test machine (Instron Corp, Wilmington, DE), at a crosshead speed of 0.05 inches per minute, impacted the midpoint of the post samples at right angles, yielding a 3-point flexure bend test (Fig 1A) to determine the flexure strength of the posts. Each post was loaded (measured in newtons) until plastic deformation or failure occurred.

In stage #2 of this study, 10 freshly extracted mandibular premolars with straight roots were randomly selected and assigned to each of the 6 test systems: the AestheticPost (AP), CosmoPost (CP), C-Post (CR), FibreKor Post (FK), Cast Metal ParaPost XH (GP), and Para Post XH (PP) post systems. The clinical crowns were removed at the cemento-enamel junction (CEJ) on an Isomet Low Speed Saw (Buehler, Ltd, Lake Bluff, IL), perpendicular to the long axis of the root. The root occlusal surfaces were polished with 600-grit fine grade sandpaper and the root mounted in an acrylic resin block (Fastray; Caulk/Dentsply, Milford, DE). Three millimeters of root structure extended beyond the block (Fig 1B). Clinically acceptable serial instrumentation of the root canals was performed with K-type files (Kerr Corp, Romulus, MI). The minimal apical size was a No. 40 file, and step back flaring was accomplished with No. 2 and No. 3 Gates Glidden bars (Moyno Industries, York, PA). A 5.25% NaOCl, aqueous solution (Chlorox; Chlorox Inc, Oakland, CA) was repeatedly used for irrigation during canal instrumentation. The root canals were obturated with Gutta Percha (Coltene/Whaledent, Mahwah, NJ) and Roth’s Root Canal Cement (Roth International, Chicago, IL). The post spaces of all groups of 10 teeth were prepared to a depth of 8 mm with Gates Glidden bars and the preapron drills provided with the post system according to the manufacturers’ instructions. The posts were bonded following the manufacturers’ instructions using the resin cement recommended by the manufacturers. The bonding agents were brushed onto the posts and into the canals to ensure full wetting, and the posts were covered with luting cement and immediately inserted into the canals. Any excess material was cleaned from the flat tooth surface, leaving a smooth prepared surface. Samples were stored in a humidor for 24 hours, then placed in water at 37°C for 7 days. After this time, each sample was statically loaded in the universal test machine, at a crosshead speed of 0.05 inches per minute with the load applied at a 90 degree angle to the long axis of the endodontic post and tooth. The force was applied at a point 4 mm from the CEJ (Fig 1B) until failure in the form of post or root fracture occurred. Force until failure was recorded in newtons.

The third stage of testing followed the same specimen preparation and testing technique used in stage #2, with the exception of core preparation. In stage #3, posts were left to extend from the root canal and root surface. Core composite resin material recommended by each post manufacturer was mixed, dispensed into a standardized omnivac matrix shell, placed over the post, and bonded to the root occlusal surface/post unit (Fig 1C). The specimens were then placed under light (Caulk/Dentsply), and/or allowed to auto-cure depending on manufacturer recommendations. Dentin bonding agents and core build-up materials recommended by the manufacturer were used to optimize the conditions for each combination of materials. The composite cores were machined to a height of 5 mm and with a convergence angle of 6 degrees using a flat end tapered bur (Premier Two Striper #703.10; Premier, Morristown, PA). The cast metal cores were fabricated directly to the plastic Para Post patterns using acrylic resin (Duralay Reliance Dental Mfg Co, Worth, IL) and cast in Pd-Au alloy (Ultima Gold; Ney International, Bloomfield, CT). Specimens were polished to the established external tooth surface finish line. The acrylic blocks and teeth were placed in a specialized holder, and the cores were machined to a height of 5 mm and with a convergence angle of 6 degrees using a flat end tapered bur. Each post and core sample was placed in the universal test machine and loaded as described in stage #2 (Fig 1C). The force was applied on the core material at a point 4 mm from the CEJ until failure, defined as core fracture, core debonding, post fracture, or root fracture, occurred.

In stage #4, the specimens were prepared as previously described. Cores were fabricated as described for stage #3. The entire circumference of each tooth and core was machined to a shoulder preparation of 1 mm in
<table>
<thead>
<tr>
<th>Post Systems (Manufacturer)</th>
<th>Post Material</th>
<th>Dentin Bonding</th>
<th>Luting Agent</th>
<th>Core Material</th>
<th>Core Material Manufacturer</th>
<th>Post Diameter</th>
<th>Manufacturer's Post Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>AesthetiPost (AP)* (Bisco Dental Products, Schaumburg, IL)</td>
<td>Carbon/quartz fiber epoxy composite</td>
<td>All Bond II</td>
<td>Bis Core</td>
<td>Bis Core</td>
<td>Bisco Dental Products, Schaumburg, IL</td>
<td>1.8 mm</td>
<td>2</td>
</tr>
<tr>
<td>C-Post (CR) (Bisco Dental Products)</td>
<td>Carbon fiber epoxy composite</td>
<td>All Bond II</td>
<td>Bis Core</td>
<td>Bis Core</td>
<td>Bisco Dental Products</td>
<td>1.8 mm</td>
<td>2</td>
</tr>
<tr>
<td>FibreKor Post (FK) (Jeneric Pentron, Wallingford, CT)</td>
<td>Glass fiber composite</td>
<td>Bond One</td>
<td>Cement It</td>
<td>Build It</td>
<td>Jeneric Pentron, Wallingford, CT</td>
<td>1.5 mm</td>
<td>3</td>
</tr>
<tr>
<td>CosmoPost (CP) (Ivoclar Vivadent North America, New York, NY)</td>
<td>Zirconium oxide</td>
<td>Syntac</td>
<td>Variolink II</td>
<td>Coradent</td>
<td>Ivoclar Vivadent North America, New York, NY</td>
<td>1.7 mm</td>
<td>2</td>
</tr>
<tr>
<td>Cast Metal ParaPost XH (GP) (Coltene, Whaledent Int, New York, NY)</td>
<td>Palladium gold alloy</td>
<td>ED Primer</td>
<td>Panavia 21</td>
<td>Palladium gold alloy</td>
<td>J Morita USA, Tustin, CA</td>
<td>1.75 mm</td>
<td>7</td>
</tr>
<tr>
<td>Para Post XH (PP) (Coltene, Whaledent Int)</td>
<td>Titanium</td>
<td>ED Primer</td>
<td>Panavia 21</td>
<td>Ti Core</td>
<td>Essential Dental Systems, Hackensack, NJ</td>
<td>1.75 mm</td>
<td>7</td>
</tr>
</tbody>
</table>

*Letters in brackets are abbreviations used throughout the remainder of this paper.
width and depth into tooth structure perpendicular to the long axis of the root with a flat end tapered bur (Fig 1D). The core was prepared to a height of 4 mm with a convergence angle of 6 degrees. Each specimen received a custom cast crown made in conventional fashion using Pd-Au alloy (Ultima Gold), which was luted onto the tooth/core with a resin/glass ionomer cement (Vitremer; 3M, Minneapolis, MN). The teeth were stored in a humidor for 24 hours, then stored in water at 37°C for 7 days. Each post, core, and crown sample was placed in the universal test machine, and statically loaded as in stages #2 and #3. The force was applied on the crown at a point 4 mm from the CEJ (Fig 1D) until failure, in the form of crown debonding, post fracture, core fracture, or root fracture, occurred.\textsuperscript{21} The location of failure in stages #2, #3, and #4 was recorded.\textsuperscript{21} When the teeth exhibited vertical or oblique fractures extending into or below the surrounding acrylic resin block, the fracture was considered to be unfavorable and nonrestorable. Fractures of the tooth above the acrylic resin block were considered restorable and more favorable.
The ability to reaccess the root canal space with intact surrounding tooth structure was also evaluated as to the restorability of the tooth. An attempt at removal of the fractured post fragments was made to evaluate the degree of difficulty required for retreatment of a failed post system. Where possible, a quantitative measure of time for post removal was obtained. For removal of the fiber based systems, AP, CR, and FK, the Carbon Fiber Post Removal Kit (Bisco Dental Products) was used, with the technique outlined by Sakkal.\textsuperscript{23} For the remaining systems, an ultrasonic scaler (Titan Scaler; Scar Dental, Valley Forge, PA) was applied to the sides of the post extending from the tooth surface for 10 minutes, in an attempt to loosen and remove the post. When this failed, the post was sectioned at the tooth post interface, and a flat end tapered diamond was used in an attempt to grind through the post fragment.

The sequential staging permitted the analysis of each post system at 4 phases of simulated treatment. Using a simple comparison of stage \#2 to stage \#3 fracture resistance values, and stage \#2 to stage \#4 fracture resistance values, it was possible to establish a Strength Increase Ratio (SIR), to compare the sequential strength increases from one stage to the next.

To determine statistical significance, the O'Brien test\textsuperscript{24} for constant variance over the treatment stages was performed. When this test indicated nonconstant variances, the Welch analysis of variance (ANOVA)\textsuperscript{25} was used to test for equalities of treatment means. When this test indicated treatment differences, the Tukey Kramer\textsuperscript{26} procedure was used to determine which procedures differed. The computations were performed by JMP IN, Version 3.2 for Windows (SAS Institute Inc, Cary, NC). Whenever the associated $p$ value was less than .05, statistical significance was claimed. Computations were performed using Stat Xact Version 4.0.1 (CYTEL Software Corp, Cambridge, MA).

## Results

Mean fracture resistance strengths with standard errors of the means, and the change in clinical performance for each post system at each clinical stage of testing are listed in Table 2. Post retrievability after testing is shown in Table 3. Significant differences in fracture resistance between post systems were determined with the Tukey Kramer intervals calculated at the $p < .05$ significance level and illustrated in Table 4. Observations on the retrievability, fracture patterns, and esthetic considerations for the 6 post systems are provided in Table 5. Figure 2 shows the failure of posts and effects on tooth samples at stages \#2 to \#4.

The between-post difference in fracture resistance was statistically significant (Welch ANOVA test, $p < .0001$) in stage \#1. The PP samples displayed significantly greater resistance to failure than the other post systems; GP and CP grouped together in the mid strength range and a third weaker grouping of posts AP, FK, and CR were also significantly different (Table 4).

There were distinct differences in failure patterns for the posts in this experimental stage. PP and GP exhibited a bending mode of failure with a gradual plastic deformation. AP, CR, and FK post systems also bent, but with a distinct “green stick” type fracturing of the individual posts as a result of fiber composition of the post. Failure of the CP occurred with an abrupt brittle fracture.

The between-post difference in fracture resistance and failure modes was statistically significant.

### Table 2. Means and Standard Errors of Means of Failure Loads During Fracture Resistance Testing for Each Post System and for Each Simulated Clinical Stage

<table>
<thead>
<tr>
<th>System</th>
<th>Stage #1 Posts Only (N)</th>
<th>Stage #2 Tooth-post (N)</th>
<th>Stage #3 Tooth-post-core (N)</th>
<th>Strength Increase Ratio Stages #2-3</th>
<th>Stage #4 Tooth-crown (N)</th>
<th>Strength Increase Ratio Stages #2-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>212.1 (5.1)*</td>
<td>91.5 (6.1)</td>
<td>176.1 (22.7)</td>
<td>1.92</td>
<td>225.4 (16.8)</td>
<td>2.46</td>
</tr>
<tr>
<td>CR</td>
<td>184.8 (3.9)</td>
<td>114.7 (3.4)</td>
<td>183.3 (18.4)</td>
<td>1.59</td>
<td>262.8 (22.8)</td>
<td>2.29</td>
</tr>
<tr>
<td>FK</td>
<td>206.1 (4.3)</td>
<td>50.3 (1.3)</td>
<td>108.6 (6.3)</td>
<td>2.16</td>
<td>180.5 (14.6)</td>
<td>3.57</td>
</tr>
<tr>
<td>CP</td>
<td>301.3 (18.7)</td>
<td>101.5 (3.7)</td>
<td>179.7 (10.6)</td>
<td>1.77</td>
<td>238.8 (20.4)</td>
<td>2.35</td>
</tr>
<tr>
<td>GP</td>
<td>345.9 (3.9)</td>
<td>70.5 (3.2)</td>
<td>194.8 (11.5)</td>
<td>2.61</td>
<td>207.3 (13.5)</td>
<td>2.95</td>
</tr>
<tr>
<td>PP</td>
<td>1089.3 (54.5)</td>
<td>223.9 (8.6)</td>
<td>204.1 (10.6)</td>
<td>.91</td>
<td>204.7 (16.4)</td>
<td>1.27</td>
</tr>
</tbody>
</table>

Note. Strength increase ratio was used to determine the performance contribution of the dental materials to the strength of the restoration for each clinical stage.

*Mean of 10 specimens with SEM in parentheses.
Table 3. A Measure of the Ability to Retrieve Posts After Testing Procedures, With Instrumentation Used

<table>
<thead>
<tr>
<th>System</th>
<th>Number of Posts</th>
<th>Instrumentation Used</th>
<th>Premier Flat End Taper Diamond</th>
<th>Mean Removal Time (mins)</th>
<th>Problems Encountered</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>9</td>
<td>Yes</td>
<td></td>
<td>1:17</td>
<td>Sparking, post not removable</td>
</tr>
<tr>
<td>CR</td>
<td>9</td>
<td>Yes</td>
<td></td>
<td>1:21</td>
<td>Heat generated, post not removable</td>
</tr>
<tr>
<td>FK</td>
<td>10</td>
<td>Yes</td>
<td></td>
<td>1:25</td>
<td>Post not removable</td>
</tr>
<tr>
<td>GP</td>
<td>10</td>
<td>No success</td>
<td></td>
<td></td>
<td>Heat generated, post not removable</td>
</tr>
<tr>
<td>PP</td>
<td>3</td>
<td>No success</td>
<td></td>
<td></td>
<td>Post not removable</td>
</tr>
</tbody>
</table>

in stage #2 (Welch ANOVA test, $p < .0001$; Freeman-Halton's Extension of the Fisher exact test, $p < .0002$).

The order of the failure modes by post type for this experimental stage was similar to stage #1, but the loads required decreased considerably when compared with the transverse strengths of the previous stage (Table 2). PP again exhibited the greatest resistance to failure (Table 4) and had the greatest detrimental effect on the supporting teeth. Loading forces on 7 of 10 teeth resulted in vertical root fractures, separation of the buccal half of the root on the compression side, extension into the surrounding acrylic block, and the resulting unfavorable fractures (Fig 2).

There was no significant difference in the failure load for CR and CP, and CP and AP, but there was a significant difference between CR and AP (Table 4). Both CR and AP resulted in 1 unfavorable tooth fracture (Fig 2).

A third grouping occurred in this experimental stage. GP and FK exhibited significantly lower resistance to permanent deformation (Table 4). No tooth fractures were observed for these post systems (Fig 2).

Quantitative measure of post removal could be obtained for the 3 fiber-based post systems only. Mean extraction times are listed in Table 3. An ultrasonic scaler was used to attempt to remove the 3 ParaPosts that were present in nonfractured teeth, but 10 minutes of ultrasonic vibration failed to loosen the posts. After sectioning the posts at the CEJ, attempts at grinding through the length of the post with the flat-ended tapered diamond to regain access to the root canal space were unsuccessful. These attempts were terminated after 30 minutes or after the use of 5 new diamond burs. Similar attempts were made with the cast metal posts (GP) and ceramic (CP) posts, but these efforts also resulted in failure to remove the posts.

The between-post difference in fracture resistance was statistically significant (Welch ANOVA test, $p = .0001$) for posts in stage #3. Failure of each post and core sample was recorded when the

Table 4. Tukey Kramer Groupings (TKG)

<table>
<thead>
<tr>
<th>Stage #1</th>
<th>Transverse Posts Strength</th>
<th>Post Failure Resistance in Teeth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Means (N) TKG</td>
<td>Means (N) TKG</td>
</tr>
<tr>
<td>PP-1089.3</td>
<td>PP-223.9</td>
<td>PP-108.5</td>
</tr>
<tr>
<td>GP-345.8</td>
<td>CR-114.7</td>
<td>CR-184.7</td>
</tr>
<tr>
<td>CP-301.3</td>
<td>GP-101.5</td>
<td>CP-179.7</td>
</tr>
<tr>
<td>AP-212.1</td>
<td>AP-91.5</td>
<td>AP-176.1</td>
</tr>
<tr>
<td>FK-206.0</td>
<td>GP-70.5</td>
<td>FK-108.5</td>
</tr>
<tr>
<td>CR-184.8</td>
<td>FK-50.3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stage #2</th>
<th>Stage #3</th>
<th>Stage #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Failure Resistance in Teeth</td>
<td>Posts &amp; Cores Failure Resistance in Teeth</td>
<td>Posts &amp; Cores &amp; Crowns Failure Resistance</td>
</tr>
<tr>
<td>Means (N) TKG</td>
<td>Means (N) TKG</td>
<td>Means (N) TKG</td>
</tr>
<tr>
<td>PP-204.0</td>
<td>CR-262.8</td>
<td>PP-284.7</td>
</tr>
<tr>
<td>GP-184.7</td>
<td>CR-183.3</td>
<td>CP-238.8</td>
</tr>
<tr>
<td>CP-179.7</td>
<td>AP-225.4</td>
<td>GP-207.3</td>
</tr>
<tr>
<td>AP-176.1</td>
<td>GP-207.3</td>
<td>FK-180.0</td>
</tr>
<tr>
<td>FK-108.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. The lines connect groups that are not significantly different.
margin interface between the core and the tooth opened. This failure for some post systems was gradual, whereas for others there was a sudden release, often with the subsequent fracture of the root.

Fracture resistance for FK posts and cores proved to be the weakest and was significantly different than the other post and core systems (Table 4). Release of the core in these samples was a gradual separation at the tooth/core interface with no damage occurring to any roots.

The remaining post and core systems showed statistical equivalence (Table 4). Failure loads for the PP samples were lower at this stage when compared with the PP results of stages #1 and #2. The fracture resistances of AP, CP, CR, FK, and GP post and core samples all increased.

In stage #4, failure was noted when the margin of the cast crown restoration opened, indicating failure of the luting agent to seal the tooth margin/ tooth interface. In most instances, this coincided with the sudden release of the crown from the tooth and subsequent fracture. The order of system failures for stage #4 was the same as that for stage #2. The between-post difference in fracture resistance was statistically significant (Welch ANOVA test, p = .0062).

Three main comparison groupings of post systems occurred for this experimental stage (Table 4). PP, CR, CP, and AP exhibited fracture resistance forces that were not significantly different. The PP samples again required the highest loads to cause failure. GP and FK were significantly lower than the remaining systems. A second grouping included the CR, CP, AP, and GP that were not significantly different. The last grouping included CP, AP, GP, and FK. Fracture resistance for restored teeth of the FK specimens was the weakest of all the systems and was significantly different.

Discussion

Four of the 6 systems studied in this investigation represent recent developments in post and core restoration of endodontically treated teeth. The experimental design of this study permitted the evaluation of these systems as forces were applied to teeth through sequential simulated clinical stages of tooth rehabilitation until a final comparison was made with fully restored teeth.

The 90 degree angle of incidence between the compressive head of the universal test machine and
Figure 2. Failure of posts and effects on tooth samples at stages #2 to #4. ☐ tooth fractures S2; ☐ post fractures S2; ☐ tooth fractures S3; ☐ post fracture S3; ■ tooth fracture S4; □ post fracture S4.

the long axis of the tooth specimen was chosen to simulate a traumatic blow that a maxillary anterior tooth might encounter in an accident. It also represented the worst case scenario of force application to a restoration. This permitted the precise measurement of loads required to cause failure of the post and/or dentin bond. The force required to cause failure of the dentin bond may not be adequate to cause tooth fracture, but would be sufficient to allow microleakage to occur beneath the restoration and eventual failure.

At stage #2, the applied load created force on the post, adjacent tooth, and surrounding root structure. The recorded force until failure identifies the weakest of these factors. Likewise, at stage #3, the load measured the effect of the post strength, dentin bond strength, tooth and root strength, and the effect of the core on these factors.

As described by Assif et al., complete crown coverage with a 2-mm ferrule on sound tooth structure changes the distribution of forces to the root and post and core complex. At stage #4 of this study, a 1-mm ferrule was created to measure the effect of the post strength when minimal tooth structure is present to support the crown and post and core complex. The forces required to cause failure through the first 3 simulated clinical stages were different for each system, but differences were not evident at the final stage. This finding supports the observation made by Assif et al., in that the ferrule and coping were the only differences and yet the results showed no significant differences.

The high number of catastrophic failures evident for the PP and GP systems are not often seen clinically. Because of the testing methodology, the forces required to cause failure in this study are less than reported previously. Restored teeth with adequate axial tooth structure remaining and loaded axially may require much greater forces to cause failure. The data in this study suggests that any of the post systems tested may work equally well clinically when restored with full coronal coverage and with at least 1 mm of axial tooth structure, but each system has some inherent deficiencies.

PP system, with its very high transverse strengths at stage #1, provided no significant strengthening effect by stages #3 and #4. FK was significantly weaker at stages #2 and #3 than most of the other post systems, but at stage #4, the force to failure was not significantly different than 3 of the other post systems (Table 4).

With use of the SIR, to compare the sequential strength increases from one stage to the next, the post system that showed the greatest increase in fracture resistance from stage #2 to stage #3 was the cast metal post and core system. The homogeneous nature of this post and core may have contributed to the increase in fracture resistance strength by a factor of 2.61. The FK system, which was the weakest system in fracture resistance testing, benefited the most from full coronal coverage with a SIR of 3.57 from stage #2 to stage #4 (Table 2). This most likely indicates the degree of influence the final restoration plays in an inherently weaker post system. In the PP system, which had the stiffest posts and the highest resistance to fracture values when the post alone was
tested, the final restoration added proportionately less to the failure resistance. There was a slight increase in SIR from stage #2 to stage #4 with a factor increase of 1.27.

**Conclusions**

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

1. The fiber posts evaluated, C-Post and Aestheti-Post, provide an advancement over conventional posts, in which the conventional posts are known to cause tissue and root discoloration and were shown in this study to create a higher number of irretrievable post and unrestorable root fractures.

2. At the stage of final restoration insertion, there was no difference in force to failure for all but the FibreKor material, which continued to be weaker than all other tested materials.

3. The fiber posts were readily retrievable after failure, whereas the remaining systems tested were nonretrievable.

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**References**

