Effect of core stiffness on the in vitro fracture of crowned, endodontically treated teeth

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Statement of problem. Dentin and core materials that substitute for missing dentin are dissimilar materials. A core material with a lower elastic modulus may deform more under applied stress and therefore result in reduced stress concentration at the core/dentin junction.

Purpose. This in vitro study examined the effect of core stiffness on the fracture resistance and failure characteristics of a crowned, endodontically treated tooth under simulated occlusal load.

Material and methods. Forty extracted human mandibular premolars were divided equally into 4 groups and prepared for posts and cast crowns as follows: group 1 = cast post and core, cast crown; group 2 = preformed metal post, composite core, and cast crown; group 3 = preformed metal post, amalgam core, and cast crown; and group 4 (control) = preformed metal post, no core, and cast crown. All prepared teeth had 2 mm of sound dentin on which the cemented crown rested. A continuous load (kg) was applied to the buccal cusp at a 30-degree angle to the long axis of each tooth at a crosshead speed of 2 mm/min until failure. Collected data were subjected to 1-way analysis of variance with the Welch modification to compare groups (P<.05).

Results. Failure loads for the 4 test groups were as follows: 98.1 ± 34.6 kg (group 1), 94.4 ± 41.8 kg (group 2), 105.5 ± 18.6 kg (group 3), and 101.1 ± 55.3 kg (group 4). No significant difference in failure load values was found among the 4 groups. The primary mode of failure (80%) in all groups was an oblique radicular fracture, either apical to the post or at the post level. Horizontal fracture of the root and post was found in groups 1, 2, and 3 (20%). Loosening of the crown, post, and core was found only in group 2 (20%).

Conclusion. Within the limitations of this study, core stiffness did not affect the failure resistance of teeth restored with posts and cores and complete-coverage cast metal crowns. The dominant pattern of failure was unrepairable root fracture. Only the composite core exhibited repairable fractures. (J Prosthet Dent 2002;88: 302-6.)

CLINICAL IMPLICATIONS
The results of this in vitro study suggest that when an endodontically treated tooth is restored with a crown (with margins on healthy root substance 2 mm apical to the core material), composite, amalgam, and cast posts and cores are equally appropriate core materials.

Post-and-core foundation restorations provide retention for crowns on endodontically treated teeth. Materials with high yield limits and high strength are desirable to reduce the risk of distortion or fracture. The situation is much less obvious when stiffness is considered. The stiffness of a core material is related to its modulus of elasticity (Young’s modulus) and its geometry. Core materials include composite, amalgam, glass ionomer, and cast alloy. The elastic moduli of some commonly used core materials are as follows: 16.6 GPa (composite), 27.6 GPa (amalgam), and 99.3 GPa (Type 4 gold alloy).2

Research completed in partial fulfillment of a DMD degree (E.L.).
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A low-modulus material allows greater bending under load. When strain exceeds the yield point, the material is irreversibly deformed, with some strain persisting even after the load has been removed. The modulus of resilience is the quantity of energy that the material can absorb and still retain elasticity. When a structure comprised of dissimilar materials (such as core material and dentin) is stressed, the material with the higher modulus deforms less. This difference causes more stress concentration at the walls and line angles of tooth/restorative interfaces before the material is permanently deformed.3 Wear, flow, or even fracture of core materials under masticatory loads are more desirable than tooth fracture. The effect of different post-and-core foundations or corono-radicular build-ups on the resistance to fracture of endodontically treated teeth with complete-coverage crowns has been evaluated.4 8 In one study, ParaPost (Whaledent Inc, New York, N.Y.) and composite build-
ups exhibited higher mean failure loads than pin/amalgam or glass-ionomer/amalgam corono-radicular build-ups. Kovarik et al compared 3 core materials with prefabricated stainless steel posts by cyclically loading crowned teeth for 1 million cycles or until fracture occurred. Amalgam cores had the lowest failure rate, followed by composite cores. All teeth restored with crowns over glass-ionomer build-ups failed. In a separate investigation, less force was required to cause the failure of cast gold posts and cores, but most teeth showed evidence of root fracture. Amalgam or composite cores, used in combination with a cemented steel post, failed at a higher mean load. These specimens primarily exhibited core fracture; post dislodgment and root fracture were less frequent. The better performance of amalgam and composite specimens was attributed to greater post rigidity and to superior adaptation of the amalgam and composite compared to the cement interface of the cast core. Similarly, Moll et al found that a pin-retained composite core was stronger than a cast post and core when both were covered by complete cast crowns. However, Sidoli et al reported that well-established cast gold alloy post-and-core combinations exhibited higher stress values at failure than composite post-and-core systems.

Endodontically treated teeth with natural crowns demonstrated greater strength than pin-retained amalgam cores and cast gold dowel cores in a study by Lovdahl and Nicholls. Pin-retained amalgam cores were significantly stronger than cast gold dowel cores. It has been reported that cast posts and cores have a tendency to cause tooth splitting, whereas composite cores on metal posts are more predisposed to core failure. However, the disadvantage of this study and similar ones is that loads were applied directly to the core materials or on uncrowned teeth. The force distribution to roots is altered once a crown terminating on sound dentin is placed; the type of post system and core material do not appear to be significant. The purpose of this in vitro study was to examine the effect of core stiffness on the fracture resistance and failure characteristics of a crowned, endodontically treated tooth under simulated occlusal load.

Table 1. Core materials used

<table>
<thead>
<tr>
<th>Brand name</th>
<th>Lot number</th>
<th>Manufacturer</th>
<th>Elastic modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite</td>
<td>Prosthodont</td>
<td>8159 PN1DE</td>
<td>Lee Pharmaceuticals, Los Angeles, Calif.</td>
</tr>
<tr>
<td>Amalgam</td>
<td>Spherodon M</td>
<td>32000 4030</td>
<td>Silmet, Or Yehuda, Israel</td>
</tr>
<tr>
<td>Alloy</td>
<td>Pallorag 33</td>
<td>L0500000 12901</td>
<td>Cendres and Metaux Sa, Biel Bienne, Switzerland</td>
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</tbody>
</table>

*Information obtained from Craig. Information obtained from manufacturer.

MATERIAL AND METHODS

Forty extracted, single-rooted mandibular premolars free of caries, fractures, and cervical wear were selected and stored in saline solution. The anatomic crowns were similar in dimension, measuring 7.75 \pm 1.75 mm buccolingually and 6.5 \pm 1 mm mesiodistally. The root canals were instrumented to a No. 70 K file (Kerr, Romulus, Mich.) and obturated with gutta-percha (Maillefer, Ballaigues, Switzerland) and endodontic sealer (AH-26; De Trey AG, Zurich, Switzerland). Teeth were randomly divided into 4 groups of 10.

In 3 groups, a water-cooled, high-speed diamond bur (C2; Strauss Co, Ra'anana, Israel) was used to remove the anatomic crown perpendicular to the long axis of the tooth, 2 mm coronal to the cemento-enamel junction (CEJ). Gutta-percha was removed to a depth of 8 mm from the entrance to the canal with a heated plugger, and the canal was prepared to receive a stainless steel post 0.9 mm in diameter (ParaPost; Whaledent Inc). Three types of post cores were fabricated (Table I).

In group 1, cast post-and-core specimens were fabricated in a Type 3 base-metal alloy (Pallorag 33; Cendres and Metaux Sa, Biel Bienne, Switzerland) with the use of a direct technique, a plastic burn-out casting post (Whaledent Inc), and resin buildup (Duralay; Reliance Dental Mfg, Worth, Ill.). Post cores were luted with zinc-phosphate cement (Harvard Dental; Richter and Hoffman, Berlin, Germany), which was mixed and applied according to the manufacturer's instructions. In group 2 the 0.9-mm-diameter stainless steel post was cemented into the canal with zinc-phosphate cement, which was mixed and applied according to the manufacturer's instructions. A copper band was adapted to each tooth and filled with autopolymerizing composite (Prosthodont; Lee Pharmaceuticals, Los Angeles, Calif.). In group 3, the stainless steel post was cemented as described above. A spherical type of amalgam (Spherodon M; Silmet, Or Yehuda, Israel) was used to fabricate a core with a copper band serving as the matrix.

Group 4 served as the control. Natural crowns were not removed from the teeth. A stainless steel post was cemented with zinc-phosphate cement into the canal through the access cavity. The preparations were etched with 37% phosphoric acid for 15 seconds, rinsed for 15
seconds, and dried for 2 seconds. Adhesive resin (Scotchbond Multi Purpose; 3M Dental Products, St. Paul, Minn.) was applied, and the preparations were packed incrementally with visible light-polymerizing composite (Visio-fil; ESPE, Seefeld, Germany). Each 2-mm increment was polymerized for 20 seconds (Demetron 401; Demetron Research Corp, Danbury, Conn.).

After 30 minutes, all specimens were immersed in 37°C water for 72 hours. The copper bands of groups 2 and 3 were removed after 24 hours, and the specimens were reimmersed in water for an additional 48 hours.

All teeth were prepared for complete cast crowns with a chamfer finishing line at the CEJ; a high-speed, water-cooled diamond bur was used (C1; Straus Co). Crown preparations were 5 mm high with a 0.4-mm chamfer finish line 2 mm apical to the core/tooth junction. The angle of convergence was 16 degrees. Vinyl polysiloxane (Exaflex; GC, Tokyo, Japan) impressions were made with copper bands and poured in die stone (Silky Rock; Whip Mix, Louisville, Ky.). Three coats of die spacer (Tru-fit; George Taub, Jersey City, N.J.) were applied to within 1 mm of the finish line. Full veneer cast crowns (Pallorag3;) were fabricated and cemented with zinc-phosphate cement (Harvard Dental). The crowns were seated with the use of finger pressure for 1 minute and then placed under a 2.4-kg load for 15 minutes.

Each tooth was embedded in cylindrical-shaped acrylic resin (Fastray; Harry J. Bosworth Co, Skokie, Ill.) up to 2 mm apical to the CEJ, with the long axis of the tooth parallel to that of the cylinder wall. Specimens were mounted in a jig that allowed loading of the buccal cusp in the axio-occlusal line at a 30-degree angle to the long axis of the tooth. Continuous compressive force was applied by a universal testing machine (1026; Instron Corp, Canton, Mass.) at a crosshead speed of 2 mm/min until failure occurred. All specimens were evaluated under ×5 magnification by one examiner. The failure load and mode were recorded. One-way analysis of variance with the Welch modification (to account for differences in variance among groups) was used to compare groups (P<.05).

RESULTS

Mean failure loads, standard deviations, and the median of the 4 experimental groups are presented in Table II. One-way analysis of variance revealed no significant differences in failure load among the 4 groups (P=.8613), indicating that core stiffness was not a factor in resistance to fracture. The resistance to fracture of group 4 teeth did not significantly differ from teeth restored with various post-and-core systems and a crown. The amalgam core treatment was slightly more resistant to fracture than the composite core, but the difference was not significant.

Teeth failed in 5 different patterns (Table III). Horizontal fracture of the root and post, passing through the center of the post, was found in group 2 (30%), group 3 (20%), and group 1 (10%) but not in group 4. Oblique fracture apical to the post was found in group 3 (60%), group 4 (70%), group 2 (30%), and group 1 (10%). Oblique fracture of the root at the level of the post, without fracture of the post, was seen in group 1 (40%), group 4 (30%), and groups 2 and 3 (10% each). Fracture at the root apex occurred mainly in group 1 (40%), with reduced frequency in groups 2 and 3 (10% each). Loosening of the crown, post, and core occurred only in group 2 (20%) without root fracture or with a minimal hairline fracture in the area near the crown margin.

DISCUSSION

It is important to distinguish stiffness, a measure of the load needed to induce a given deformation in the material, from strength, which usually refers to the resistance of the material to failure by fracture or excessive deformation. Stiffness is related to Young’s modulus (E) and specimen geometry. Natural dentin and the core materials that substitute for dentin are dissimilar materials. Occlusal loads applied to a lower-modulus core material tend to deform the core and may reduce stress concentration at the core/dentin junction.8

The effect of core type on the ability of endodontically treated teeth to withstand stresses (with direct application of forces on the core material with no crown in place) has been reported, but the results are inconsistent. In a study by Lovdahl and Nicholls,9 core materials with lower moduli (amalgam and composite) exhibited

### Table II. Mean failure loads (kg), standard deviations, and median values for various test groups (n = 10 per group)

<table>
<thead>
<tr>
<th>Failure mode</th>
<th>Group 1: Cast core (%)</th>
<th>Group 2: Composite core (%)</th>
<th>Group 3: Amalgam core (%)</th>
<th>Group 4: Control (%)</th>
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<tr>
<td>1</td>
<td>10</td>
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<td>5</td>
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1. Horizontal fracture of the root and post, passing through the center of the post; 2, oblique fracture of the root apical to the post; 3, oblique fracture of the root at the post level; 4, fracture of the root apex; 5, loosening of the crown, post, and core.

### Table III. Percentage of failure modes in each group

<table>
<thead>
<tr>
<th>Failure mode</th>
<th>Group 1: Cast core (%)</th>
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higher mean failure loads than higher-modulus materials (cast alloys). The opposite was true in 2 other investigations. In contrast, the same 3 studies reported a consistent mode of failure. The low-modulus materials (composite and amalgam) failed through core fracture, whereas cast post and cores failed through root fracture. This finding has little clinical application, because posts and cores usually are covered with crowns that embrace the tooth and terminate on sound dentin substance. Placement of a complete crown changes the distribution pattern of the externally applied load to the tooth so that stresses concentrate around the margins. Several authors reported that when cast crowns were fitted to endodontically treated teeth with margins on healthy tooth tissue, differences in mean failure loads were nonsignificant in spite of varied core materials or post configurations. Similar results were obtained with 3-dimensional finite element analysis. Others investigators, however, have reported differences when a variety of core materials and dowel designs were used for foundation restorations under complete cast crowns.

Chan and Bryant demonstrated that ParaPost and composite or amalgam build-ups failed at a higher mean load than cast post and cores. Perez Moll et al reported that a pin/composite base was at least 4 times stronger than a cast post-and-core base. These results and others cannot be compared with this study because different experimental designs were used. In studies that varied both post/pin and core materials in the experimental groups, core stiffness was not the only variable. In this study metal posts of similar dimensions differed but both post/pin and core materials in the experimental groups, core stiffness was not the only variable. In this study metal posts of similar dimensions differed but post/pin and core materials in the experimental groups, core stiffness was not the only variable.

Control specimens contained only a stainless steel post and dentin core. Interestingly, the control group did not differ significantly from the other groups. It is difficult to draw a definite conclusion, however, given that the coefficient of variation associated with the control group was the highest (54%). This variation may be attributed to differences in tooth dimensions that, although similar, were not identical to the variation in dentin substrate.

The primary mode of failure (80%) in all groups was an oblique radicular fracture, either apical to the post or at the post level. The experimental design dictated the mode of failure as a class I lever arm. When loading force was applied to the buccal cusp at the axio-occlusal line angle, tensile forces accumulated on the buccal root surface until fracture occurred. This failure pattern is similar to that reported by Kahn et al and Assif et al. Reversible tooth failure (loosening of the crown, post, and core) was found only in the composite core group.

The test conditions of this in vitro study differed from intraoral conditions; it is therefore difficult to extrapolate the results directly to the clinical situation. The elasticity of the periodontal ligament was not duplicated, the ferule height was constant, and the applied load was continuous to failure. Nondestructive methods or fatigue testing may be more appropriate methods for analysis of the relative importance of core stiffness. Clinical evidence indicates that most fractures in endodontic restorations occur after several years. Generally, such failures are unrelated to an episode of acute overload, but result from fatigue failure. Further research on this subject is needed.

CONCLUSIONS

Within the limitations of this study, stiffness of the core material did not affect the fracture resistance or failure mode of teeth restored with cast crowns with margins 2 mm apical to the core. The dominant pattern of failure was unrepairable root fractures. Only the composite cores exhibited repairable fractures.

REFERENCES

Materials design of ceramic-based layer structures for crowns.

Purpose. All-ceramic crowns primarily fail due to radial cracking. This study examined the hypothesis that critical loads for such radial cracking vary as the square of ceramic layer thickness diminishes to less than 1 mm.

Material and methods. Four materials were obtained (Mark II, Vita Zahnfabrik, a porcelain ceramic; In-Ceram, Vita Zahnfabrik, an alumina ceramic; Prozyr, Norton, a zirconia ceramic; and Dicor, Dentsply, a glass-ceramic) in the form of plates. The specimens were ground flat and polished, with thickness ranging from 100 μm to 6 mm. Each ceramic specimen was then bonded to 12.7-mm thick, clear polycarbonate supports using an epoxy adhesive. Single cycle Hertzian tests were then accomplished on the bonded specimens with an Instron universal testing machine at a crosshead speed of 0.15 mm/min in air. An optical zoom microscope and video tape recorder were used to monitor radial cracking of the specimens in situ. Contact loads from the testing machine output were recorded on the tape. Regression analyses were performed on the gathered data, and correlation coefficients were determined.

Results. Prozyr (zirconia) exhibited an increase in the resistance to radial cracking relative to In-Ceram (alumina). Additionally, In-Ceram (alumina) demonstrated an increase in the resistance to radial cracking relative to Mark II (porcelain).

Conclusion. Data analysis from this study provided a validation of the hypothesis that critical loads for radial cracking are indeed dependent on the square of the ceramic layer thickness. Further, a reliable physical basis was provided for rating the clinical performance of the ceramic materials studied. 31 References.—DL Dixon