Effect of Fatigue Testing on Core Integrity and Post Microleakage of Teeth Restored with Different Post Systems

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The purpose of this study was to evaluate a new nondestructive test system, which could test concurrently fatigue and microleakage. Fifty, single-rooted teeth were restored with one of the following posts systems and a composite core: titanium ParaPost cemented with zinc phosphate cement; CosmoPost; C-Post; Esthetic C-Post; and FibreKor post, all cemented with resin cement. Samples were embedded and placed in a positioning jig. They were impacted at 45 degrees to the long axis of the tooth with a force of 55 N at a frequency of 3 Hz for a total of 100,000 impacts. After 60,000 impacts, samples were thermocycled. Core integrity and post microleakage were evaluated periodically throughout the 100,000 impacts. Samples showed no detectable displacement of any of the cores, but the metallic group showed a statistically significant increase in microleakage (p < 0.05) at the conclusion of the study compared with the nonmetallic groups.

MATERIALS AND METHODS

Figure 1 shows the flow chart of the whole experiment protocol.

Sample Selection

Sixty, single-rooted, human teeth extracted for periodontal reasons were used in this study. These were examined under a stereoscopic microscope at ×10 magnification (Nikon AFX–IIA, Nikon Corp., Tokyo, Japan) to eliminate teeth displaying cervical caries, radicular cracks, or craze lines from the study. All teeth were stored in 0.2% sodium azide for a minimum of 1 week after
These were transferred from normal saline, blotted dry with 4-stone, IL), leaving a root of approximately 15 to 16 mm in length. Teeth were removed with a low-speed saw (Isomat Buehler, Evanston, IL), leaving a root of approximately 15 to 16 mm in length. Teeth were transferred to normal saline. The clinical crowns of 50 teeth were removed and placed under running deionized water for 20 min before being transferred to normal saline. The working length was determined by placing a #10 file into the root canal until it was visible at the apical foramen. One millimeter was then subtracted from that length. Canals were then prepared in a step-back manner to a master apical file size #45 using #2 to #4 Gates Glidden drills (Myco Industries/Union Broach Division, New York, NY) and Quantec rotary Ni-Ti files (SybronEndo, a division of Sybron Dental Specialties, Glendora, CA). Apical patency was established by inserting a #20 file through the apex at the end of instrumentation. Canals were irrigated with 10 ml of sodium hypochlorite (1%) during instrumentation, after which they were dried with paper points. Canals were then fitted with a #45 master gutta-percha cone (Hygenic Corp., Akron, OH) and accessory cones and AH 26 sealer (De Trey, KaVo Dental, Wallingford, CT). The cement was mixed and placed directly on posts and into the root canal using a lentulo spiral with a slow-speed handpiece. The post was then inserted into the canal and excess luting cement was removed with a #15 blade. Samples were allowed 5 min for chemical curing to occur. Samples from group 5 were cemented with a universal resin cement (Mission Dental Inc., Charleston, SC), without any etchant or conditioning of the canal. Powder was mixed with the liquid in the fixed ratio of one level scoop to four drops of the liquid. A cold, glass, mixing slab was used for this purpose and cement was inserted into the canal using a lentulo spiral. The post was also coated with the cement and then inserted into the canal. Excess cement was removed in a similar manner to the other groups. All samples were then stored for 24 h at 37°C and 100% humidity before core space preparation.

Control

Negative controls consisted of five intact teeth that did not have their crowns removed nor were restored with any of the posts. These were embedded in the same clear resin mold and were used to check the integrity of the fluid filtration system. Positive controls consisted of five teeth with conventional endodontic access and treatment, which were obturated without sealer. A post space was prepared in these controls and the access was left open. All samples served as their own control, because an initial fluid filtration reading was taken before each sample was connected to the impact-testing machine.

Post Space Preparation

Gutta-percha was removed from each canal to a depth of 11 mm with a #3 Gates Glidden drill. This left 4 to 5 mm of gutta-percha in the canal. Post space preparation was then finalized by sequentially using the #2 and #3 preshaping and finishing drills that came with the C-post system. This attempt at standardizing the post space preparation resulted in a post space that was 1.5 mm in diameter and 11-mm deep. Debris was removed from the canal by irrigating with deionized water.

Post Cementation

All posts were fitted to ensure that they went to the desired length. They were then cut with a low-speed saw to a length of 15 mm. For the groups that were cemented with resin cement, the following procedures were performed. Each canal was etched with 37% phosphoric acid for 15 s after which it was thoroughly rinsed with deionized water via a 27-gauge needle. Canals were then dried with coarse paper points. Equal amounts of Prime & Bond NT and Self Cure Activator (Dentsply Caulk, Milford, DE) were mixed and placed into the canal in two consecutive coats using a paper point and allowed to air dry. Excess was removed from the canal floor with a paper point.

All posts were wiped with an alcohol pad before cementation. A universal resin cement was used and mixed according to manufacturer’s instructions (Cement-It, Jeneric/Pentron Inc., Wallingford, CT). The cement was mixed and placed directly on posts and into the root canal using a lentulo spiral with a slow-speed handpiece. The post was then inserted into the canal and excess luting cement removed with a #15 blade. Samples were allowed 5 min for chemical curing to occur. Samples from group 5 were cemented with zinc phosphate cement (Mission Dental Inc., Charleston, SC), without any etchant or conditioning of the canal. Powder was mixed with the liquid in the fixed ratio of one level scoop to four drops of the liquid. A cold, glass, mixing slab was used for this purpose and cement was inserted into the canal using a lentulo spiral. The post was also coated with the cement and then inserted into the canal. Excess cement was removed in a similar manner to the other groups. All samples were then stored for 24 h at 37°C and 100% humidity before core fabrication.

Core Fabrication

Cores were built using a hybrid particulate, light-cured resin composite (Tetric Ceram, Ivoclar Vivadent, Amherst, NY). Samples were removed from storage and then blotted dry with gauze.

Group Assignments (n = 10)

Group 1: 1.4-mm C-Post (Bisco, Inc., Schaumburg, IL)
Group 2: 1.4-mm Esthetic C-Post (Bisco, Inc.)
Group 3: 1.25-mm Fibrekor Post (Jeneric/Pentron Inc., Wallingford, CT)
Group 4: 1.4-mm CosmoPost (Ivoclar Vivadent, Amherst, NY)
Group 5: 1.5-mm Titanium Para Post (Whaledent, Mahwah, NJ)

FIG 1. Flow chart of the whole experimental protocol. Microleakage was measured at the baseline before applying fatigue stresses and after 30K shear impacts, 60K shear impacts, thermocycling (60KTC), and at the conclusion of the experiment (100K shear impacts). FFT = fluid flow/filtration testing; TC = thermocycling.
Prepared surfaces were etched with 37% phosphoric acid for 15 s and then rinsed with running water for 20 s. Prime and Bond NT was applied to dentin using a brush applicator and then light cured for 20 s. A second coat was applied, which was left to air dry. Tetric Ceram was dispensed around the extended post, and a small plastic instrument was used to ensure proper adaptation of the material to the post and root. This was light-cured for 30 s in several 1- to 2-mm increments to produce a core of 4.5 to 5.0 mm in height and with an emergence profile consistent with that of the root.

**Sample Embedding for Impacting and Fluid Filtration Testing**

Samples were then placed in the middle of a cylindrical mold with a diameter of 22 mm. The center of this mold was designed with a small hole, which allowed the apex of the root to extend beyond it. Utility wax was placed over the apex to stabilize the sample as clear casting resin (Casting Craft, ETI, Fields Landing, CA) was poured around it. The casting resin was poured to a height just 2-mm apical to the core-root interface. This was then allowed to set for 3 h at 37°C and 100% humidity. Once set, the sample was removed from its plastic mold and the apical 3 mm that extended beyond the mold was cut off and any remaining gutta-percha removed (up to the apical extent of the post) with a GPX rotary file. This was performed to eliminate the confounding effect of leakage attributable to differences in the gutta-percha seal. A #56 bur was used to create a 2-mm, 45-degree inciso/lingual bevel on the core to serve as a platform to receive the impact from the chisel of the impact-testing machine (Fig. 2).

**Testing Procedures**

**Fluid Filtration System**

Samples were attached to a modification of the fluid filtration apparatus (Fig. 3) described by Derksen et al. (10). In this system, positive pressure was provided by a 180-cm column of water at 23°C representing 0.17 atm or 17.6 KPa. Before testing, the system...
was flushed to ensure that there were no leak or air bubbles trapped in the tubing. The coronal portion of each sample was connected to the tubing of the fluid filtration apparatus using manual pressure. This connection was secured using two tie wires, which provided a fluid-tight seal. An air bubble of approximately 3 mm in length was introduced into the system and its movement controlled by a microsyringe. The movement of air bubble per unit time was measured, and because the inner diameter of the micro tubing was known to be 1 mm, this was converted to microliters per 15 min. This information was used to calculate the volume of voids that exist along the root canal filling. Negative controls were connected to the system before any of the experimental groups. After the introduction of a bubble into the system, 10 min was required for the system to equilibrate. After this, the movement of the bubble that occurred for the next 15 min was recorded in millimeters. This was also performed for the positive controls. Each experimental sample was then connected to this system a total of five times. An initial reading was taken and then another after the sample had been impacted 30,000 times. This was then repeated after 60,000 impacts, after thermocycling, and after 100,000 impacts.

Impact Testing and Thermocycling

The new multifunctional testing machine, designed and developed by Dr. Reza Kazemi at the University of Connecticut School of Dental Medicine, was modified and used as a loading device in this study (Fig. 4). This impact machine was controlled by computer software, which allowed the number of impacts to be precisely determined. It also allowed the machine to shut off automatically if the core was displaced more than 2 mm. To simulate the conditions encountered in vivo, samples were placed in a positioning jig and subjected to repeated impacts of 55 N at a 45 degree angle to the long axis of the tooth at a frequency of 3 Hz. Before being impacted, all samples were connected to the fluid filtration system to obtain an initial reading. Samples were then subjected to several treatment events, each one followed by an evaluation using the fluid filtration system. First, they were impacted for 30,000 impacts (30K), then another 30,000 impacts (60K) followed by thermocycling (60KTC). Samples were cycled 1000 times between 5°C and 55°C. They were kept in each bath for 30 s and had a travel time of approximately 10 s. Finally, they were subjected to 40,000 impacts (100K) resulting in a total of 100,000 impacts. One hundred thousand impacts were estimated to represent about 6 months of chewing (13). All samples and controls were kept immersed in a water bath at room temperature during testing.

Core Displacement Measuring

A straight line was drawn parallel to the long axis of the tooth on both the mesial and distal aspect of each sample. This line extended from the middle of the core to the 2 mm of tooth structure that was coronal to the casting resin. Any displacement of the core during fatigue testing would result in the line becoming discontinuous. The degree of separation of the line would then be used as a measurement of core displacement.

Data Analysis

A mixed-model ANOVA was used to analyze the degree of post microleakage. The post type was the between-subject predictor
variable in the ANOVA. The within-subjects predictor variable was defined by treatment events as denoted by five discrete levels, each reflecting the number of cycles completed by a given tooth (baseline, 30K, 60K, 60KTC, 100K). If the mixed-model group by treatment event F-test proved significant, a protected post-hoc comparison procedure was utilized (Tukey’s B test) to make additional comparisons. To reduce the skewness of the fluid displacement data, it was square root transformed, thereby facilitating easier statistical analysis on the now symmetrical distribution. The confidence level used throughout the experiment was 95% ($p < 0.05$).

**Fig 5.** Microleakage of all groups. When the five groups were viewed as a whole, there was a statistically significant increase in microleakage after each treatment event ($p < 0.05$).

**Fig 6.** When the ceramic group (group 4) was compared to the fiber reinforced composite (FRC) groups (groups 1–3), no statistically significant difference was found between the means of these two different types of post systems at any of the treatment event testing ($p > 0.05$).
RESULTS

In the five positive controls, the movement of the air bubble was too fast to be measured. The amount of fluid movement observed in the negative controls was not found to be significant, hence neither of these controls was subjected to further statistical analysis. The randomization process used in assigning samples to different groups was effective, therefore, the data were not biased based on the distribution of samples within groups.

All samples completed the entire treatment protocol without any detectable root fractures, core fractures, or displacement. When the five experimental groups were viewed as a whole, there was a statistically significant increase in microleakage after each treatment event \( (p < 0.05) \) (Fig. 5).

When the ceramic group (group 4) was compared to the fiber reinforced groups (groups 1–3), no statistically significant difference was found between the means of these two groups during any of the treatment events \( (p > 0.05) \) (Fig. 6).

When the metallic group (group 5) and nonmetallic groups (groups 1–4) were compared over the first three treatment events, there was no significant change. After thermocycling, however, there was a statistically significant increase in the leakage of the nonmetallic groups compared to the metallic group \( (p < 0.05) \). Once samples were impacted once again between 60TC and 100K, there was a statistically significant difference between the groups with the metallic group leaking more \( (p < 0.05) \). (Fig. 7).

DISCUSSION

The results of this study indicate that the test design was successful in allowing simultaneous evaluation of the effects of fatigue on core stability and post microleakage within the same sample. Most studies that evaluate the load bearing properties of various posts relied on a destructive mode of testing (3, 4, 14). The utility of data generated by the application of one single force until the system fails is limited, because, in vivo, fatigue plays the predominant role in the failure of restorations. The data generated by this type of experimental design are unique, because other studies have only been able to generate data either on microleakage or core/post stability but not both on the same sample. This mode of evaluation seems more applicable to the kind of situation that occurs in vivo where the combination of fatigue and microleakage could lead to the failure of the restoration.

The use of cyclic loading with a force of 55 N resulted in no visible movement of the cores or failure of any of the samples. These findings are similar to that of Dietschi et al. (15) and Isidor et al. (16), who found no core failure even after 250,000 and 1,000,000 impacts, respectively. Although many other studies found visible failure of the post and core system, most of these relied upon the application of very large forces that are unlikely to be encountered in normal function (12). Another feature of the experimental design that might have contributed to no visible failure of any of the samples is the number of cycles used. We chose 100,000 impacts to represent a reasonable amount of mechanical stress that might correspond to approximately 6 months of normal function (13).

The mean leakage of all samples increased after each treatment event. Thermocycling resulted in a significant increase in the leakage of the nonmetallic groups compared with the metallic. This might be a result of the degradation of the polymer holding the fibers together and/or the fibers themselves being susceptible to the stress induced by thermal cycling. Drummond et al. (11) found that...
thermocycling had a more profound effect on carbon fiber posts compared with stainless steel. They, however, subjected samples to 6000 thermocycles compared with the 1000 cycles used in our study. Rosentritt et al. (17) examined post-retained composite cores that were repeatedly impacted and thermocycled and found that thermocycling had a pronounced negative effect on adhesion of the core and resin cement.

An important observation was that many of the samples displayed some degree of leakage before being stressed. This finding is similar to Fogel (18), who found that there was some leakage of even the negative controls. All connections were visibly inspected to rule out extraneous leakage. As a further negative control, the tubing was clamped off at the connection to the samples. No movement of the bubble was noted under these conditions. This testing of the system confirmed that the system’s several connectors were watertight and that any noted movement occurred within the samples. Explanations for this observation include the possibility that there might have been a hydration effect, but this does not seem plausible because all samples were kept at 100% humidity. Next, there is the possibility of entrapped air that could be compressed and result in the movement of the bubble. This was unlikely because the system was flushed before each sample was connected to ensure that it was free of all bubbles. A final explanation is that there were indeed some voids in the samples being tested.

The actual volume of fluid that was displaced in the samples was somewhat less than that reported by many other investigators. There are two reasons that might explain the lower values encountered in this study. First is the slight difference in the filtration system itself. Derksen et al. (10) used positive pressure, but this positive pressure was provided by nitrogen gas and was much greater than that used in this study. This nitrogen gas provided approximately 15 psi compared to 2.5 psi, which was used in our study. In a recent study, Pommel and Camps (19) evaluated the leakage that occurred with a 150-cm column compared with a 15-cm column and showed that more leakage occurs with the taller column. Second is the fact that in most of the microleakage studies, measurements were made of either a particular obturation technique or post without a core (10, 19). The presence of a core would reasonably be expected to retard the movement of fluid into the root canal system.

Including the effect of a core into the experimental design had several pros and cons. The core allowed us to simulate a worst-case scenario in which a core served as a definitive restoration for several months. It also provided a suitable surface for contact with the testing device. Conversely, a core added another level of complexity to the conclusions that could be drawn from the study. This made it impossible to accurately determine how much of the observed leakage was actually a result of fatigue on the post. It seems, however, that because all samples were restored with cores made of the same material and of similar dimensions that the observed differences could be attributed to the effects of the various posts and luting agents. In many studies utilizing fatigue testing, full coverage crowns were used (16, 20). Although using full coverage crowns in this study would have simulated clinical conditions more closely than cores alone, this would have added another level of complexity, which would further limit the conclusions that could be drawn from the study.

The results of this study suggest that dentists do have some flexibility in choosing a post system with which to restore an endodontically treated tooth. As a group, the nonmetallic posts that were cemented with resin cement all performed equally well, both in terms of load-bearing tests as well as microleakage. The titanium post cemented with zinc phosphate cement functioned well with regard to core/root integrity under mechanical testing but experienced significantly more microleakage than the other groups. Future directions for the use of this system include increasing the number of impacts to which samples are subjected to see whether the microleakage would continue to increase. The system might also be used to test full coverage crowns cemented over the post and cores to more closely simulate clinical conditions.

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References

5. Strindberg LZ. The dependence of the results of pulp therapy on certain factors. Acta Odontol Scand 1956;14 (Suppl);1–175.