In Vitro Evaluation of Five Core Materials

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Purpose: This in vitro study determined the fracture strength of five core materials supported by two different endodontic dowels. Diametral tensile strength and microhardness of the three resin composite core materials used in this study were also tested.

Material and Methods: The fracture strength study used one lanthanide-reinforced flowable resin composite (Ti-Core Auto E), one titanium- and lanthanide-reinforced composite (Ti-Core), one lanthanide-reinforced composite (Ti-Core Natural), and two metal-reinforced glass ionomer core materials (Ketac Silver and GC Miracle Mix). Two types of dowels were used: a multitiered, split-shank threaded dowel with a flange (#1 Flexi-Flange) and one without a flange design (#1 Flexi-Post). The specimens were divided into ten groups. Each tooth/dowel and core specimen was placed in a special jig at 45° and subjected to a load by a universal testing machine. The diametral tensile strength and the microhardness of the three resin composite core materials were measured by a universal testing machine and Barcol hardness tester, respectively. All test groups contained ten specimens.

Results: The fracture strength value of the resin composite core materials was significantly larger ($p < 0.0001$) than those for the metal-reinforced glass-ionomer core materials. Analysis of variance (ANOVA) also showed that the Flexi-Flange dowel interacted with Ti-Core and Ti-Core Auto E to significantly ($p < 0.0013$) increase the fracture strength relative to the Flexi-Post. One-way ANOVA revealed that there were no significant differences between them in terms of diametral tensile strength. The Barcol hardness values of the composite core materials were statistically different ($p < 0.0001$), with the Ti-Core the highest, followed by Ti-Core Natural, then Ti-Core Auto E.

Conclusions: Resin composite core material performed better than glass ionomer material in this in vitro study. The flowable composite core material performed about the same in terms of fracture strength and diametral tensile strength compared with nonflowable composites. Combined with certain core materials, the flange design increased the fracture strength of the tooth/dowel and core combination.

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MATERIALS USED FOR CORE restoration after endodontic treatment include amalgam,[1-3] glass ionomer,[4,5] hybrid glass ionomer,[6,7] resin composites, and cast metal alloys. Silver amalgam has been widely used as a dental restorative material for more than 150 years. The major disadvantages of this material are the long setting time and low initial tensile/compressive strength.[1-3,8] In addition, the interpretation and implementation of environmental laws have recently impacted the use of amalgam.[9] Glass ionomer cements have some advantages such as a low thermal expansion coefficient and fluoride release.[3,10,11] Their disadvantages include deterioration at low pH, lack of strength, and sensitivity to moisture;[4,5,12] however, they are still routinely used as core materials.[13] Hybrid glass ionomers can weakly bond to dentin, but they have low strength and high water absorption.[4,5] Resin composites set faster than dental amalgam, have higher mechanical strength compared with glass ionomers, and are easier to manipulate,[8,14,15] but their fracture toughness is lower than

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amalgam.[16] Flowable composites have been recently introduced by various companies to make composite fluid injectable,[17-20] but there are concerns that the mechanical properties might be compromised for flowability.[19]

Fillers such as barium glass, zirconia-silica, micas, glass powders, alumino silicates, titanium, and rare earth metal (a group of elements) salts can enhance the mechanical strength of Bis-GMA-based dental resin.[21-25] Generally, to make composite more flowable, the amount of inorganic filler in the cement often needs to be reduced.[19] This suggests that flowable materials might be mechanically weaker than their more filled counterparts.

The purpose of this study was to compare the fractural load threshold of four types of core materials (dual-cure lanthanide-reinforced flowable composite, autopolymerizing titanium- and lanthanide-reinforced composite, autopolymerizing lanthanide-reinforced composite, and autopolymerizing metal-reinforced glass ionomer) supported by either a mulitiered, threaded split-shank dowel with flange design or without flange design. The diametral tensile strength and the microhardness of the composites were also measured.

Figure 1. Left: multitiered, split-shank threaded dowel (No. 1 Flexi-Post). Right: multitiered, split-shank threaded dowel with flange design (No. 1 Flexi-Flange).

Materials and Methods

Fracture Strength Test

The following core materials were used: one flowable lanthanide-reinforced composite (Ti-Core Auto E, Essential Dental Systems, South Hackensack, NJ), one titanium- and lanthanide-reinforced composite (Ti-Core, Essential Dental Systems), one lanthanide-reinforced composite (Ti-Core Natural, Essential Dental Systems), and two metal-reinforced glass ionomers (Ketac-Silver GIC, 3M ESPE, Seefeld, Germany and GC Miracle Mix GIC, GC Corp, Tokyo, Japan).

Materials used in specimen preparation were divided into ten groups of ten specimens each. A total of 100 recently extracted single-rooted human incisors and premolars were used. All samples were prepared by a single operator. The dowels used in this study were either a multitiered, split-shank threaded dowel (#1 Flexi-Post, Essential Dental Systems) or a multitiered, split-shank threaded dowel with flange design (#1 Flexi-Flange, Essential Dental Systems) as shown in Figure 1. The dowel space was prepared according to manufacturer's instructions. The dowels were luted into the prepared teeth using composite luting cement (Flexi-Flow, Essential Dental Systems). The luting cement was mixed and applied according to the manufacturer's instructions; no bonding agent was used during the dowel luting process.

For the composite core materials, a multi-step bonding agent (All-Bond 2, Bisco Inc., Schaumburg, IL) was used to bond the core material to each tooth. Fabrication of all cores was performed by placing a copper band matrix (#1 hard, Moyco Industries Inc., Philadelphia, PA) around each tooth. Core materials were mixed according to their manufacturer's instructions and placed into the supporting matrices. The polymerization of flowable composite (other composites are autopolymerizing) was photoinitiated with an Optilux 400 curing light (Demetron Research Corp, Danbury, CT) for 40 seconds. After removing the copper matrix, each core preparation was standardized to a height of 4.5 mm, which is the height of the dowel extruding out of the tooth surface if the dowel space was prepared correctly, according to instructions. Preparations were made freehand to an 8-10° convergence angle to simulate clinical practice. The width for each preparation varied according to the tooth diameter and was brought to the outside shoulder for each tooth. The prepared tooth specimens were then directly mounted in acrylic resin blocks (Acratray, Henry Schein Inc., Melville, NY). No overcasting or crown was placed on the core, in order to provide a worst-case scenario for the core supported by the dowel in the tooth. The specimens were aged in distilled water at room temperature for 2 weeks before testing. This represents a worst case scenario where the temporary crown leaks between dental office visits. The worst-case scenario was used because it eliminates the variable of crown preparation and fabrication and concentrates on the core strength and dowel combination. Each specimen was held in place for testing in a special jig with its long axis inclined facially, at an angle of 45° and subjected to a load on a universal testing machine (810 MTS, Material Test System Corp, Minneapolis, MN) at a crosshead speed of 0.63 cm/min until failure occurred. Figures 2 and 3 depict the specimen before and after fracture.

Diametral Tensile Strength Test

The diametral tensile strengths of the three composite core materials used in this study were also measured. Materials were divided into three groups of ten specimens each. All core materials were prepared according to their manufacturer's directions, and specimens were made according to ADA Specification number 27 (resin-based filling materials).[26] The polymerization of flowable composite was photoinitiated with an Optilux 400 curing light for 40 seconds on each side. Each cylinder specimen was allowed to polymerize for 1 hour and then aged in distilled water for 2 weeks. A force was applied with a universal testing machine (810 MTS) at a crosshead speed of 0.635 cm/min until the specimens were crushed. The diametric tensile strength was calculated from the following equation:

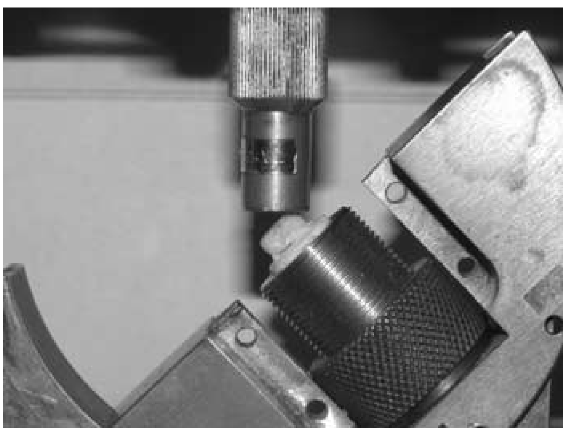

Figure 2. Example of specimen placed in a special jig on a universal testing machine before fracture.

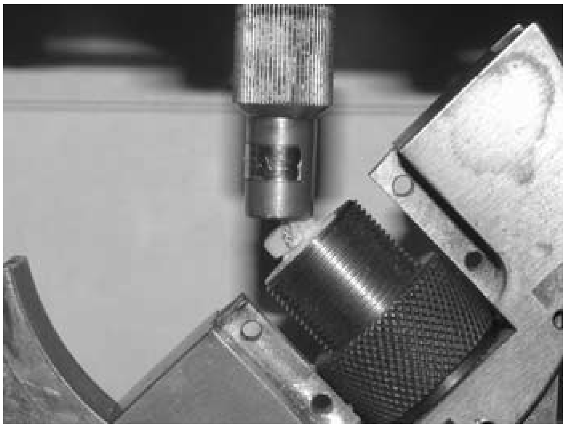

Figure 3. Example of specimen placed in a special jig on a universal testing machine after fracture.

$$\text{Diametral tensile strength} = \frac{2 \cdot p}{\pi \cdot d \cdot l}$$

where p is the force at fracture (load), d is the diameter of specimen, and l is the length of specimen.

Microhardness

The microhardness of the three composite core materials used in this study was also measured. Materials were divided into three groups of ten specimens each. All core materials were prepared according to their manufacturer's directions. To produce specimens with a smooth, void-free surface, a 1-mm-thick, 20-mm-diameter steel mold was placed on a glass slab, and excess test material was then placed into the mold. Another glass slab was then placed on top of the mold, and hand pressure was applied to extrude excess material. A 15 pound weight was then placed on top of the glass slab for 10 minutes. All specimens were aged in distilled water for 2 weeks before measurement.

Hardness measurements were performed using a Barcol hardness tester (Model # GYZJ 934-1, Barber-Colman Co., Loves Park, IL) that conformed to American Society for Testing and Materials Standard D-2583. The instrument was calibrated before each test, using a disc (Barber-Colman Test Disc, Barber-Colman Co.) with a known hardness between 87 and 89. Five readings were taken on both sides of the test specimen and then averaged to obtain the Barcol value for the individual specimen. In order to avoid inaccurate readings, the hardness indenter was positioned so all test points were at least 1.5 mm away from any other tested spot.

Statistical Analysis

Two-way analysis of variance (ANOVA) was used to test the effects of core material and post type on fracture resistance. One-way ANOVAs were performed on the diameteral tensile strength and microhardness data. A significant ANOVA result was followed by the Student-Neuman-Keuls multiple comparisons test. If $p < 0.05$, the results were considered statistically significant.

Results

The metal reinforced glass-ionomer cores partially dissolved while the specimens were placed in distilled water. During the fracture strength test, only core fracture was observed as the mode of failure; no post or tooth structure failure was observed. Figure 4 shows the mean fracture strength of the different dowel and core material combinations. The fracture strength of the resin-based core materials was at least 1.9 times that of the glass-ionomer-based core materials with the same post design. ANOVA testing showed that the difference was statistically significant ($p < 0.0001$). The Ti-Core Auto E had about the same or even higher mean fracture strength compared to Ti-Core with the same dowel design. In the cases of Ti-Core Auto E and Ti-Core, the Flexi-Flange had a statistically significant ($p < 0.0013$) interaction with the core to increase the fracture strength.

The measured diametral tensile strengths (MPa) of Ti-Core, Ti-Core Natural, and Ti-Core Auto E were 36 ± 5, 31 ± 3, and 35 ± 4, respectively. One-way ANOVA analysis revealed that there was no significant difference between groups in terms of diametral tensile strength.

The measured Barcol hardness values of Ti-Core, Ti-Core Natural, and Ti-Core Auto E were 77 ± 1, 75 ± 1, and 69 ± 1, respectively. One-way ANOVA analysis revealed that the difference of the hardness value between these three composites was significant ($p < 0.0001$).

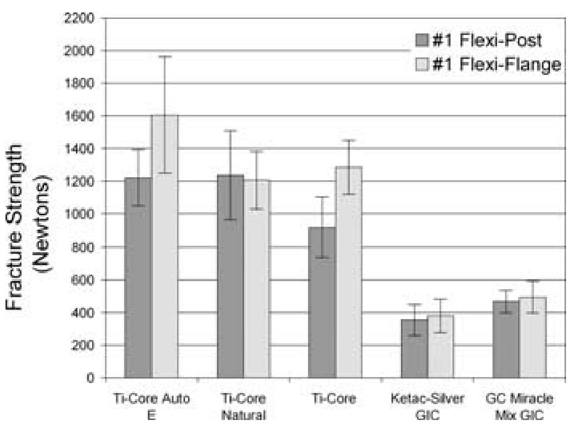

Figure 4. Fracture strength of five core materials combined with one of the two multitiered, split-shank threaded dowels.

Discussion

The dual-cure flowable composite Ti-Core Auto E has the same species of filler and resin as its predecessor, autopolymerizing lanthanide-reinforced composite Ti-Core Natural, but the filler content by weight of Ti-Core Auto E is 58% while Ti-Core Natural is 75%. The filler content by weight of titanium- and lanthanide-reinforced composite Ti-Core is also 75%. Although fillers usually enhance the mechanical strength of Bis-GMA-based dental resin,[21-25] the diametral tensile strength of the less-filled flowable composite was not different from the more-filled composites'. The flowable composite had about the same, or in some cases statistically higher, mean fracture strength compared with the other two more-filled composites. Both of these findings were unexpected considering the filler content difference. One possible explanation was that the reduction of the filler content leads to better integration between filler and resin. When less filler is used, the size of the aggregated filler particle domain should decrease, and the domains should be more separated. Therefore, cracks should propagate less easily.

The fracture strengths of Flexi-Flange/Flexi-Post dowels with core materials like Ti-Core, Ketac-Silver, and GC Miracle reported in this study were in agreement with previously reported data.[27] It was previously reported that Tytin silver amalgam had similar fractural strength compared with Ti-Core with Flexi-Flange/Flexi-Post dowels.[27] The ranking of the microhardness values of the composites was expected. The titanium- and lanthanide-reinforced composite was the highest, followed by the lanthanide-reinforced composite without titanium reinforcement. The less-filled, lanthanide-reinforced flowable composite was the lowest.

Recent literature suggested that use of dowels less rigid than metal dowels, such as fiber dowels, can reduce the clinical risk of root fracture.[28,29] Although the dowels used in this fracture strength study were made of stainless steel, no root fracture was observed even after the core was displaced from its corresponding dowel head. This suggested that root fracture was not a concern even under the largest possible fracture load before core failure with metal dowels. This finding is consistent with both a finite element study, which found that higher elastic moduli dowels like Flexi-Post lowered the stresses throughout the tooth,[30] and photoelastic stress/finite element studies that claim that the multi-tiered Flexi-Post/Flexi-Flange dowel and core systems directed stresses in a symmetrical pattern.[31,32]

It is difficult to explain why only in the cases of Ti-Core and Ti-Core Auto E the Flexi-Flange had a statistically significant interaction with the core to increase the fracture strength. Factors like mechanical properties of the core, filler type, and content of the core measurement errors have to be considered. Another possibility is that the flange, when seated in its preparation, makes the head of the post more resistant to bending. If the head of the post bends less, it puts less stress on the overlying core material. It is worth pointing out that the mean Young's modulus of Ti-Core Natural (22 GPa) was statistically higher than Ti-Core (19 GPa), so the Ti-Core was more flexible than Ti-Core Natural.[33] Nevertheless, it was demonstrated that the flange design helped to increase the fracture resistance of the core in some cases.

It has been reported that the diametral tensile strength of the two metal-reinforced glass ionomer-based core materials (Ketac-Silver GIC and GC Miracle Mix GIC) were 12.51 ± 2.22 and 9.71 ± 3.10 MPa, respectively.[25] These values were higher than the values for conventional glass ionomers,[34] yet less than half of the values for the resin composite core materials used in this study. As expected, the fracture strengths of the glass ionomer-based core materials Ketac-Silver GIC and GC Miracle Mix GIC were statistically lower than those of the resin-based core materials used in this study by at least 49% for the same dowel design. This result was consistent with previous studies.[8,27]

It was reported that Ketac-Silver GIC underwent a slow setting contraction (tested in silicone oil) between 30 minutes and 56 days as high as 9.66%, while composite core material, such as Ti-Core, contracted less than 0.4%.[35] In water, the GIC absorbed a large amount of water due to its hydrogel nature.[35] Thus, in order to simulate the worst-case clinical condition, the specimens used in this experiment were immersed in water for 2 weeks before testing. The observed partial dissolution of the metal-reinforced glass ionomer during the aging period suggested that, clinically, a portion of the core fabricated by those materials might be ingested by patients. Though the use of glass ionomers as core material is still common,[13] they have been considered to be too weak for use as core material.[36]

Conclusions

Within the limitations of this study, the following conclusions can be drawn:

1. The mean fracture strength of flowable composite Ti-Core Auto E was similar to nonflowable composite core materials such as Ti-Core and Ti-Core Natural, with the same dowel design.
2. The composite cores had statistically higher mean fracture strengths than the glass-ionomer core materials with the same dowel design.
3. Statistically higher fracture strengths were recorded for Ti-Core Auto E and Ti-Core materials with the Flexi-Flange dowel compared with Ti-Core Auto E and Ti-Core combined with Flexi-Post, a dowel without a flange design.
4. The diametral tensile strengths of the composite core materials were statistically similar, while the statistical ranking of microhardness was Ti-Core > Ti-Core Natural >Ti-Core Auto E.

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