Fatigue resistance of endodontically treated teeth restored with three dowel-and-core systems

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Statement of problem. The successful restoration of endodontically treated teeth is enhanced by a crown design employing the ferrule effect. However, it is unclear which dowel-and-core system most effectively supports successful treatment.

Purpose. The purpose of this study was to compare the load fatigue resistance of 3 dowel-and-core systems.

Material and methods. Fifteen endodontically treated maxillary central incisors were sectioned perpendicular to the long axis at a point 1.5 mm incisal to the cemento-enamel junction (CEJ). At the level of the CEJ, specimens were then prepared for crowns with 1-mm complete shoulder finish lines and 1.5 mm of axial wall height. The prepared teeth were divided into 3 groups (n=5) and restored with 1 of the following dowel-and-core combinations: Group CG, cast gold dowels and cores; Group TA, titanium alloy dowels (ParaPost XH) with composite cores; or Group FR, fiber-reinforced resin dowels (ParaPost FiberWhite) with composite cores. A dentin bonding agent (OptiBond Solo) was placed prior to the composite cores. Dowel-and-core castings and titanium alloy dowels were cemented with zinc phosphate cement. The fiber-reinforced dowels were cemented with a resin cement (ParaPost Cement). The crowns for all specimens were cast with an incisal notch for applying the fatigue load. The independent variable measured was the number of load fatigue cycles required to cause luting cement failure. The data were subjected to 1-way analysis of variance and the Student-Newman-Keuls test for 3 subsets (α=.05).

Results. The mean value ± standard deviation for the cycles to failure for each group was: Group CG: 11,897 ± 4080 load cycles, Group TA: 24,384 ± 8231 load cycles, and Group FR: 50,696 ± 7063 load cycles. Significant differences were found between all groups ($P<.05$).

Conclusions. Fiber-reinforced resin dowels and bonded composite cores under fatigue loading provided significantly stronger crown retention than cast gold dowels and cores and titanium alloy dowels with composite cores under fatigue loading. (J Prosthet Dent 2005;93:45-50.)

CLINICAL IMPLICATIONS

This in vitro study suggests that a stronger union between crowns and endodontically compromised teeth may be achieved by using resin-bonded fiber-reinforced dowels and composite cores, rather than conventional cast dowels and cores.

Endodontically treated teeth with inadequate remaining coronal tooth structure require foundation restorations to increase retention and resistance form for definitive restorations.[1-3] The cast gold alloy dowel and core has been regarded as the gold standard for foundation restorations.[4,5]

Many studies have investigated the fracture resistance of teeth restored with various dowel-and-core materials when a monotonic static load was applied.[6-13] The results from these studies conflict when comparing the fracture strengths of cast gold dowels and cores with prefabricated dowels and composite cores. The clinical significance of these results is questionable since a monostatic load does not represent the clinical situation where repetitive fatigue loading is characteristic.

The initial failure of crown cement associated with fatigue loading has been investigated.[14-18] Failure of crown cement has been determined to be the preliminary cause for failure when testing teeth restored with dowel-and-core foundations using dynamic repetitive

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fatigue loading. This test method duplicates the cyclic force of mastication, as opposed to an increasing monotonic load. Clinically, a fatigue type of failure will result in microleakage, which may lead to recurrent caries, loss of crown retention, and dowel fracture or tooth fracture. Consequently, testing for preliminary failure with fatigue loading is more clinically relevant than a monostatic fracture test.

Freeman et al[15] investigated the number of load cycles required to create crown cement failure with: (1) cast gold alloy dowels and cores; (2) prefabricated stainless-steel posts (ParaPost P-44-6B; Coltene/Whaldent, Cuyahoga Falls, Ohio) and dentin-bonded composite cores (Tenure/Core Paste; Den-Mat, Santa Maria, Calif); and (3) threaded, split-shaft (no. 2 Flexi-Post; Essential Dental Systems, Hackensack, NJ) and composite cores (Tenure/Core Paste). Freeman et al[15] found that the type of dowel system used did not significantly affect the number of cycles required for cement failure, and there was no difference in the degree of leakage between the different dowel systems tested.

A current search of the literature revealed no studies investigating the relationships between dynamic repetitive fatigue loading, preliminary crown cement failure, and different types of dowel-and-core systems. Therefore, the purpose of this investigation was to compare the number of load cycles required to cause crown cement failure with a conventional complete crown design and 3 different dowel-and-core systems. The systems selected were (1) a cast gold alloy dowel and core, (2) a prefabricated titanium alloy dowel and composite core, and (3) a glass fiber–reinforced resin dowel and composite core.

MATERIAL AND METHODS

Fifteen extracted human maxillary central incisors, free of cracks, fractures, or caries in the cervical and root areas, were used in this study. Teeth were kept hydrated at room temperature in distilled water prior to the study, and during tooth preparation each tooth was wrapped with a water-moistened gauze. Teeth were divided into 3 groups of 5 teeth. Before group selection, the buccolingual dimension of each tooth was measured using a digital caliper (series 500 Caliper; Mitutoyo America Corp, Aurora, Ill) accurate to 0.01 mm. Teeth were ranked, then sorted according to their buccolingual dimensions. The first, sixth, seventh, twelfth, and thirteenth teeth were placed in Group CG (mean buccolingual dimension 6.35 ± 0.21 mm), and the second, fifth, eighth, eleventh, and fourteenth teeth were placed in Group TA (mean 6.37 ± 0.20 mm). The remaining teeth were assigned to Group FR (mean 6.36 ± 0.21 mm). Figure 1 shows a diagrammatic representation of the 3 groups.

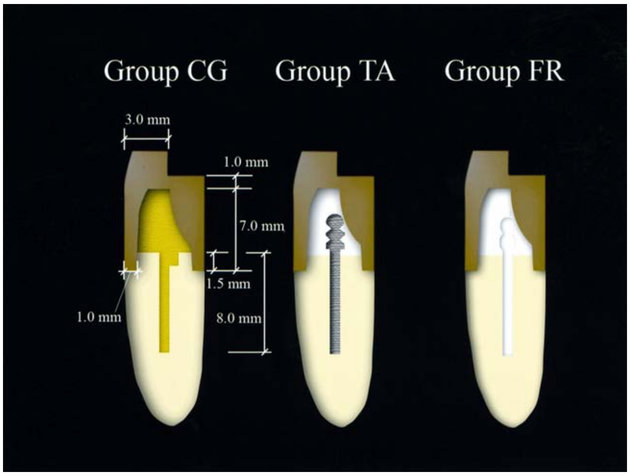

Fig. 1. Diagrammatic representation of study groups, *Group CG*: Cast gold alloy dowel and core; *Group TA*: prefabricated titanium alloy dowel and composite core; *Group FR*: glass fiber-reinforced dowel and composite core.

Each tooth was sectioned perpendicular to the long axis 1.5 mm coronal to the buccal CEJ, using a super coarse diamond instrument (KS1, 35005.31; Brasseler USA, Savannah, Ga) and copious irrigation. Then each root segment was mounted vertically in a copper cylinder with autopolymerizing resin (GC Pattern Resin; GC America, Alsip, Ill) to a level 4.5 mm from the sectioned tooth surface. Dowel spaces were prepared 8 mm deep using a 1.25-mm diameter twist drill (ParaPost; Coltene/Whaledent).

For the cast dowel-and-core specimens, Group CG, an antirotational notch measuring 1.0 mm vertically and 1.0 mm horizontally was placed on the lingual aspect of the dowel space preparations. A 1.25-mm–diameter plastic pattern (ParaPost XP; Coltene/Whaledent) was inserted into the prepared canal space, and a custom dowel-and-core pattern was fabricated (Fig. 1) using autopolymerizing resin (GC Pattern Resin; GC America). The root segments and resin patterns were then prepared to receive full shoulder complete crowns with a 1.5-mm ferrule feature included in the remaining coronal tooth structure. Preparations were made with a 1.0-mm–diameter diamond rotary cutting instrument (6847/016; Brasseler USA) creating 1.0-mm–wide shoulder finish lines with 1.5 mm of axial wall heights (Fig. 1). Dimensions were verified with the same digital caliper. The resin patterns were invested (Novocast; Whip Mix Corp, Louisville, Ky) and cast with a Type III gold alloy (Jelenko No. 7; Jelenko International, Armonk, NY). Castings were inspected under original magnification ×20 and adjusted to ensure a passive fit, then airborne-particle abraded using 25-μm aluminum oxide under 3 kg/cm^2 pressure. Zinc phosphate cement (Fleck's Cement; Mizzy Inc, Cherry Hill, NJ) was mixed according to manufacturer's instructions and used to

Table I. Experimental groups

Group	Group CG	Group TA	Group FR
Dowel-and-core materials	Cast gold dowel and core (Type 3 gold; Jelenko No. 7)	Titanium alloy dowel (ParaPost XH) Composite core (CoreRestore)	Fiber-reinforced resin dowel (ParaPost Fiber White) Composite core (CoreRestore)
Type of cement for dowel	Zinc phosphate (Fleck's)	Zinc phosphate (Fleck's)	Resin cement (ParaPost cement)

lute the dowel-and-core castings. The cement was delivered to the canal space with a lentulo spiral (Dentsply Maillefer, Tulsa, Okla), and castings were held in place under finger pressure until the cement set. Excess cement was removed with a sharp hand instrument.

For Group TA, each prefabricated titanium dowel was shortened to a 12.0-mm length by cutting the apical end with a high-speed carbide fissure bur (1958/012; Brasseler USA). This adjustment resulted in the dowels extending 4.0 mm above the coronal surface of the prepared teeth. Zinc phosphate cement was mixed with a cement spatula, applied to the dowel, and delivered to the canal space with a lentulo spiral. The dowels were gently seated to place and held with light pressure until the cement reached initial set (5 minutes).

In a similar manner for Group FR, each glass fiber dowel was reduced to a 12.0-mm length by cutting the apical end with the same high-speed carbide fissure bur, again resulting in a dowel extending 4.0 mm above the coronal surface of the prepared tooth. A standardized amount of autopolymerizing resin luting agent (ParaPost Cement; Coltene/Whaledent) was applied to the dowel according to the manufacturer's recommendations. Equal amounts of the accompanying conditioners A and B were mixed and applied to the canal walls, again according to the manufacturer's directions.

Composite cores (CoreRestore; Kerr Corp, Orange, Calif) extending 5.5 mm incisal to the sectioned tooth surfaces were fabricated for all Group TA and FR specimens in the following manner. First, coronal tooth surfaces were etched for 15 seconds with 37.5% phosphoric acid (Kerr Corp), then rinsed with tap water for 10 seconds. The excess water was removed using an air syringe for 5 seconds, leaving a moist surface. A bonding agent (OptiBond Solo Plus; Kerr Corp) was applied to the etched dentin surface and the 4.0 mm of exposed dowel using a light brushing motion for 15 seconds, then activated with an appropriate polymerization light source (Optilux 501; Kerr Corp) for 20 seconds. For each specimen, equal measures of core base and catalyst were thoroughly mixed with a plastic spatula, loaded into a syringe (Centrix CR EZ syringe; Centrix, Shelton, Conn) and carefully applied to the tooth surface to avoid air entrapment. Then the clear plastic core matrix was filled with core material and polymerized (Optilux 501; Kerr Corp) for 40 seconds on each of the 5 surfaces. The core and tooth was then prepared for a complete cast crown using a high-speed medium-grit diamond rotary cutting instrument (6847/016; Brasseler USA) and water spray. The crown design was the same as that used for Group CG (Fig. 1). Table I shows materials used in making the dowels and cores for the 3 groups of specimens.

Impressions were made of the tooth preparations for all 3 groups, using a vinyl polysiloxane impression material (Imprint II; 3M ESPE, St. Paul, Minn), cast with a Type IV dental stone (Fujirock; GC America), and allowed to set for 24 hours. One layer of die hardener (Stone Die and Plaster Hardener Resin; George Taub Products and Fusion, Jersey City, NJ) and 2 coats of die spacer (Tru Fit; George Taub Products and Fusion) were applied to the axial surfaces of each die 1 mm short of the finish lines. Wax copings (Pro-Art gray opaque sculpturing wax; Ivoclar Vivadent Inc, Amherst, NY) were fabricated for each stone die and transferred to the corresponding test specimens. The coping and specimen assembly was then positioned in a custom waxing device to produce a standardized notch in size, form, and location. The resulting wax copings were prepared with a notch 8.0 mm incisal to the finish line (Fig. 1) to standardize the position of the fatigue load device during testing. These notched wax copings were transferred back onto the appropriate stone dies, and a stylized wax crown was completed. Each crown was then invested (Novocast; Whip Mix Corp) and cast with a Type 3 gold alloy (Jelenko No. 7; Jelenko International) using a bent-arm centrifugal casting machine. After divesting, crowns were inspected under original magnification ×20 for fitting accuracy. After correct fit was established, intaglio crown surfaces were airborne-particle abraded with 25-μm aluminum oxide under 3.0 kg/cm^2 pressure.

The crowns were cemented with resin-modified glass-ionomer cement (Rely X; 3M ESPE) mixed according to manufacturer's directions. Each crown was held in place for 10 minutes under finger pressure. Following final set the excess cement was removed.

The strain gauges (EA-06-062AP 120; Vishay Micro-measurements Division, Vishay, Malvern, Pa) used for fatigue testing had an internal electrical resistance of 120 ohms (at 24°C) and a grid length of 1.6 mm. To accommodate the strain gauges the lingual surfaces of specimens were lightly ground with a diamond disk (6918 B; Brasseler USA), creating a flat, rough surface 2 mm apical and 2 mm incisal to the crown margin.

Table II. Load cycles to failure data

Specimen no.	Number of cycles to failure Cast dowel and core	ParaPost XH and composite core	ParaPost Fiber White and composite core
1	15,478	22,257	42,362
2	15,640	19,143	43,982
3	11,800	38,142	55,218
4	5672	25,020	53,818
5	10,894	17,360	58,102
Mean*	11,897	24,384	50,696
SD	4080	8231	7063

*All 3 mean values were significantly different ($P<.05$)

The flattened surfaces were then cleaned with alcohol, and a strain gauge was cemented with epoxy resin (DP-460; 3M Industrial Tape and Specialties Division, St. Paul, Minn) over each crown margin. Twenty-four hours after cementation, the gauges were completely covered with impression tray adhesive (3M ESPE) to ensure isolation from water during fatigue testing.

The fatigue loading device used in this study was described by Junge et al.[17] Fatigue testing was done at a frequency of 260 cycles per minute with specimens immersed in a room temperature water bath during testing. The load applied to each specimen was 6.0 kg at an angle of 135 degrees to the long axis of the tooth (Fig. 2). The strain gauges (Fig. 2), placed over the lingual crown margins, registered luting cement failure as described by Junge et al.[17]

Preliminary failure is defined as the propagation of a crack in or around the crown luting cement layer, which might result clinically in microleakage, caries, or lost crown retention. Once a crack develops in the cement layer, micromovement of the cast crown relative to the finish line will result. While not discernible to the unaided eye, this movement can be observed through the output of the strain gauge attached over the specimen's lingual marginal surface. Output from the strain gauges was recorded on a chart recorder (model LR 4110 Chart Recorder; Yokogawa Corporation of America, Newman, Ga).

The independent variable recorded was the number of load cycles required to induce preliminary failure of the crown luting cement. The data was subjected to a 1-way analysis of variance (ANOVA), and the Student-Newman-Keuls test was used to determine significant differences at α=.05.

RESULTS

Table II provides the number of load cycles recorded at the time of failure for each of the 15 specimens tested in the 3 groups. The means and standard deviations for cycles to failure for each group were: Group CG: 11,897 ± 4080 load cycles; Group TA: 24,384 ± 8231 load cycles; and Group FR: 50,696 ± 7063 load cycles. The 1-way ANOVA showed a significant difference among all 3 groups ($P<.05$), with the fiber-reinforced resin dowel specimens exhibiting the highest number of cycles prior to crown cement failure (Table III).

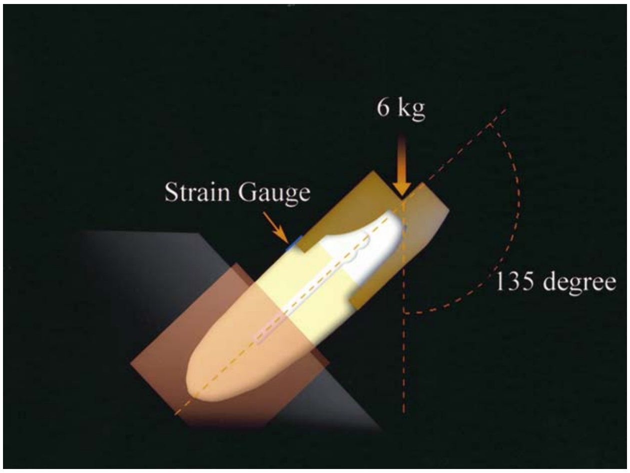

Fig. 2. Load value, load application angle, holding device, and strain gauge location.

DISCUSSION

It has been suggested that the bending stiffness of the dowel in an endodontically treated tooth compromised by lost tooth structure can be a reinforcing medium. The work of Sidoli et al[7] showed that the fracture strength of teeth with carbon fiber dowels was lower than that for teeth with metal dowels. However, in vivo loading is a dynamic and repetitive fatigue loading, and this type of loading was not used in the study by Sidoli et al.[7] Since the dowels used in the present study had the same cross-sectional areas and shapes, the bending stiffness of the dowels would be directly proportional to the modulus of elasticity of each material. The manufacturer of the 2 prefabricated dowels used in the present study stated the modulus of elasticity for glass fiber–reinforced resin dowels (ParaPost Fiber White) as 29.2 Gpa, and 112 Gpa for titanium alloy dowels (ParaPost XH). The gold alloy used in this study is purported to have a 90-GPa modulus of elasticity. Consequently, if the bending resistance of the dowel is a significant factor in tooth reinforcement, based on bending stiffness alone, one would expect the teeth with titanium alloy dowels to have survived a significantly higher number of fatigue cycles compared to those with the glass fiber dowels. This was not the case. The specimens with resin-reinforced glass fiber dowels survived roughly twice the number of cycles required to cause failure in specimens with titanium alloy dowels. This finding directs attention toward the different cements used in this study for luting the dowels. The titanium alloy dowels were

Table III. One-way ANOVA ($P<.05$)

Cycles	Sum of squares	*df*	Mean square	F	Sig.
Between groups	3922784096.533	2	1961392048.267	43.814	.000
Within groups	537193053.200	12	44766087.767		
Total	4459977149.733	14			

cemented with zinc phosphate cement, while the fiber-reinforced resin dowels were cemented with a resin luting agent. Thus the resin luting agent might be responsible for the higher number of cycles to luting agent failure.

At the rotational center of each specimen where the dowel is placed and under the applied load which bends the specimen, the direct tensile and compressive stress is minimal. However, the horizontal shear stress at this location is at a maximum.[19] The ability of the resin luting agent to resist the horizontal shear force seems to be far greater than that provided by zinc phosphate cement. Additionally, bonding is not achieved between the dowel and tooth structure with zinc phosphate cement. This increased resistance to shear stress provided by the resin luting agent may have resulted in reduced stress within the crown cement. From basic fatigue theory, a lower cement stress implies an increased number of cycles to failure of this cement.[19]

Group CG specimens failed at a mean value of 11,897 cycles, while Group TA specimens failed at a mean value of 24,384 cycles. Both dowels were metal, with little difference between their modulus of elasticity, but Group TA specimens failed at a significantly higher number of cycles. The difference might be explained by the work of Hsu et al,[18] who compared composite cores that were bonded to tooth structure with nonbonded composite cores. Results showed that bonding significantly increased the number of load cycles to failure. It is therefore conceivable that adhesive bonding may increase the number of load cycles to failure for the cast dowel-and-core foundations.

While no current clinical studies have evaluated the glass-reinforced resin dowel, the work of Fredriksson et al[12] demonstrated the effectiveness of a carbon fiber dowel. In this study, 236 patients with carbon fiber–reinforced resin dowels were evaluated over a period of 2 to 3 years. The author concluded that the carbon fiber dowel is a viable alternative to conventional dowel systems.

Although the results of this investigation have been derived from an in vitro study, it seems that a stronger union between a dowel and core and tooth structure is established using adhesive bonding techniques. This stronger union may significantly influence crown cement failure. The work of Junge et al[17] also suggested that a resin luting agent for bonding crowns increased the number of load cycles to cement failure. A 4-year clinical study by Ferrari et al[20] showed a success rate of 84% for cast dowel-and-core foundations versus a 95% success rate for a fiber-reinforced resin dowel and composite combination. The present study supports Ferrari's findings.

Although this in vitro method of testing is more clinically relevant than study methods employing a monotonic static load, limitations exist in the interpretation of these results from a clinical perspective. The specimens in this investigation were not subjected to thermal cycling, and the fatigue load was always applied in a uniform manner. These were variances from a clinical model. Also, dentin bonding was accomplished under ideal conditions that may not fully represent the clinical situation. Another limitation was a 24-hour delay before subjecting test specimens to fatigue loading. This time after cast crowns were cemented was necessary for the attachment of the strain gauges. Clinically, these cast restorations could have been loaded immediately after cementation.

CONCLUSIONS

Within the limitations of this in vitro study, the greatest resistance to preliminary crown cement failure was recorded for the group having fiber-reinforced resin dowels and composite cores, Group FR ($P<.05$). The least resistance to cement failure was shown by the group having cast gold alloy dowels and cores, Group CG. The Group TA, with titanium dowels and composite cores, demonstrated an intermediate level of resistance to crown cement failure.

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Noteworthy Abstracts of the Current Literature

Implant dentistry at the focus of liability lawsuits
Figgener L, Kleinheinz J. *Int J Oral Maxillofac Implants* 2004;19:382-6.

Purpose. In recent years, the growing readiness on the part of dental patients to take legal action has resulted in an increasing number of medical liability lawsuits. The aim of this retrospective analysis was to highlight aspects of these lawsuits of special significance, to subject them to both qualitative and quantitative analysis, and to show how conflicts can be avoided.
Materials and Methods. Forty relevant court decisions from the year 1984 onwards were found in online databases and through direct inquiries at the courts. These were supplemented by 21 reports prepared by experts at the University of Muenster, Department of Dental Medicine, commissioned by courts in connection with ongoing lawsuits. Analysis was initially based on formal aspects of the cases and reports. It was later supplemented by differentiated assignment of the questions addressed by the courts to the expert consultants. The principles underlying the judgments as to the liability arising from the terms of the contract were also assigned to the expert consultants in a differentiated manner.
Results. The results revealed marked differences in the frequency of liability-prone aspects of treatment. While the majority of judgments referred to the obligation to take due care during the preparatory and treatment phases, infringement of the obligations to provide information and to keep records played more than a minor role. Moreover, 90% of all cases represented combined charges covering various aspects, including those related to consequential failings.
Discussion and Conclusion. The detailed qualitative analysis of the grounds quoted and of the lines of reasoning can therefore be summed up in clearly defined recommendations aimed at helping the clinician avoid conflicts by observing the judicial requirements.—*Reprinted with permission of Quintessence Publishing.*