In vitro fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations

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Statement of problem. The in vitro effectiveness of a uniform circumferential ferrule has been established in the literature; however, the effect of a nonuniform circumferential ferrule height on fracture resistance is unknown.

Purpose. This in vitro study investigated the resistance to static loading of endodontically treated teeth with uniform and nonuniform ferrule configurations.

Material and methods. Fifty extracted intact maxillary human central incisors were randomly assigned to 1 of 5 groups: CRN, no root canal treatment (RCT), restored with a crown; RCT/CRN, no dowel/core, restored with a crown; 2 FRL, 2-mm ferrule, cast dowel/core and crown; 0.5/2 FRL, nonuniform ferrule (2 mm buccal and lingual, 0.5 mm proximal), cast dowel/core and crown; and 0 FRL, no ferrule, cast dowel/core and crown. The teeth were prepared to standardized specifications and stored for 72 hours in 100% humidity prior to testing. Testing was conducted with a universal testing machine with the application of a static load, and the load (N) at failure was recorded. Statistical analysis was performed with a 1-way analysis of variance and the Tukey Honestly Significant Difference test (α=.05). The mode of fracture was noted by visual inspection for all specimens.

Results. There was strong evidence of group differences in mean fracture strength (P<.0001). Following adjustment for all pairwise group comparisons, it was found that the lack of a ferrule resulted in a significantly lower mean fracture strength (0 FRL: 264.93 ± 78.33 N) relative to all other groups. The presence of a nonuniform (0.5 to 2-mm vertical height) ferrule (0.5/2 FRL: 426.64 ± 88.33 N) resulted in a significant decrease (P=.0001) in mean fracture strength when compared with the uniform 2-mm vertical ferrule (2 FRL: 587.23 ± 110.25 N), the group without RCT (CRN: 583.67 ± 86.09 N), and the RCT-treated tooth with a crown alone (CRN/RCT: 571.04 ± 154.86 N). The predominant mode of failure was an oblique fracture extending from the lingual margin to the facial surface just below the insertion of the tooth into the acrylic resin.

Conclusion. The results demonstrated that central incisors restored with cast dowel/core and crowns with a 2-mm uniform ferrule were more fracture resistant compared to central incisors with nonuniform (0.5 to 2 mm) ferrule heights. Both the 2-mm ferrule and nonuniform ferrule groups were more fracture resistant than the group that lacked a ferrule. (J Prosthet Dent 2005;93:331-6.)

CLINICAL IMPLICATIONS

If possible, a uniform 2-mm circumferential ferrule should be provided for endodontically treated maxillary central incisors restored with a dowel and core and crown.

Dentists frequently restore teeth that have been endodontically treated. Unfortunately, these teeth have been shown to exhibit a significantly shorter service life when compared with vital teeth.[1-5] The failure of the majority of restored pulpless teeth was reported to be prosthetic rather than biological.[6] The generally accepted explanation for the increased failure rate is the substantially decreased structural integrity of the tooth because of the removal of tooth structure during endodontic access, dowel-space preparation, and cavity preparation.[7,8] Conversely, it has been shown that providing coronal coverage significantly increased the stiffness of the remaining tooth.[9] Several retrospective studies have reported that adequate coronal coverage following endodontic treatment resulted in a decrease in tooth loss.[10-12] Consequently, a large number of

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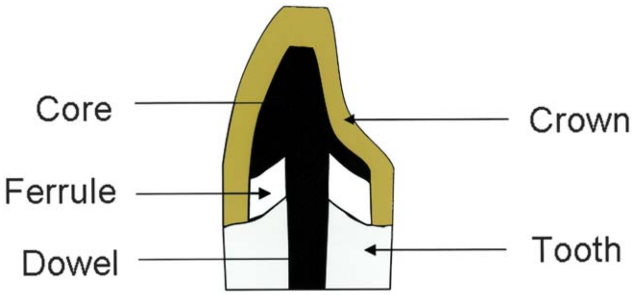

Fig. 1. Components of tooth restored with dowel and core and crown.

Fig. 2. Specimen mounted in acrylic block.

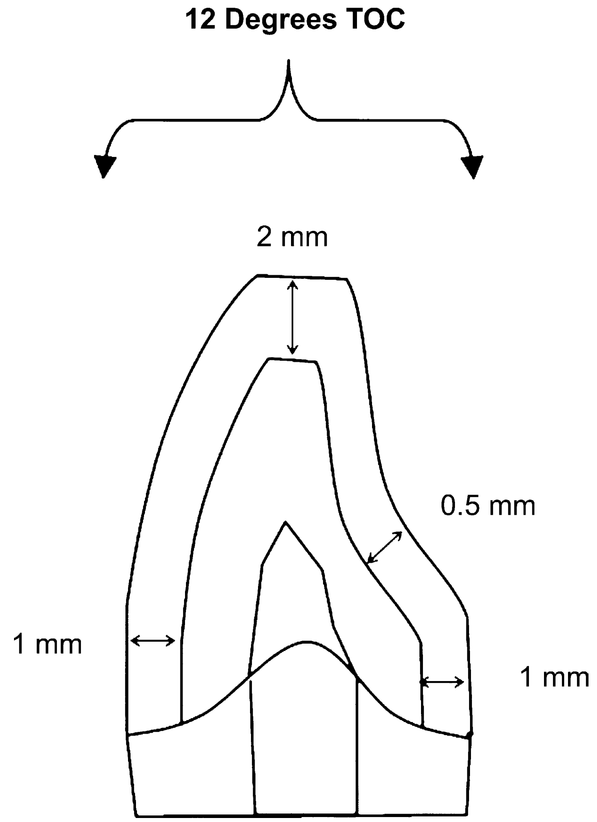

Fig. 3. Specifications of standardized tooth reduction. Total occlusal convergence (TOC).

endodontically treated teeth, particularly those that have undergone extensive tooth destruction, are restored with crowns to provide the required coronal coverage. In the instance of minimal remaining tooth structure, a foundation is required to retain the crown, often with the placement of a dowel to provide retention for the foundation restoration.

At one time, a dowel was thought to strengthen the remaining tooth and was referred to as an "intracoronal crutch" by Rosen.[13] Opinion has since changed, rejecting the notion that a tooth is strengthened by the incorporation of a dowel.[14] Despite potential detrimental effects, dowels are still indicated to retain a foundation. A key element of tooth preparation when using a dowel and core is the incorporation of a ferrule.[13] A ferrule is a metal band or ring used to fit the root or crown of a tooth (Fig. 1).[15] The effectiveness of the ferrule has been evaluated by a variety of methods, including fracture testing,[16-23] impact testing,[24] fatigue testing,[25,26] and photoelastic analysis.[27,28] The majority of studies regarding the effectiveness of a ferrule support the need for at least 1.5 mm of ferrule height.[29,30]

This recommendation requires that the ferrule encompass the entire circumference of the tooth. It is not understood how effective a ferrule of nonuniform height would be in preventing failure of a restored tooth. Methods of testing could include static loading to simulate a forceful clench,[31] as well as fatigue loading to simulate mastication and swallowing. If a nonuniform ferrule is as effective as a uniform ferrule, the clinical implications include the reduced need for interproximal crown lengthening or orthodontic extrusion. The purpose of this in vitro study was to investigate the fracture resistance of endodontically treated teeth with uniform and nonuniform ferrule configurations subjected to a static load.

MATERIAL AND METHODS

Fifty intact maxillary central incisor teeth were selected from the repository at the Dows Research Institute (University of Iowa, College of Dentistry). The coronal height was limited to 10 ± 1 mm, and root length was limited to 13 ± 1 mm. Teeth were chosen randomly by lot from a collection of 100 selected teeth and allocated into 1 of 5 groups: (1) teeth restored with crowns (CRN), (2) endodontically treated teeth restored with crowns (RCT/CRN), (3) endodontically treated teeth restored with cast dowels and cores and crowns incorporating a 2-mm ferrule (2 FRL), (4) endodontically treated teeth restored with cast dowels and cores and crowns incorporating a ferrule of nonuniform height (0.5/2 FRL), and (5) endodontically

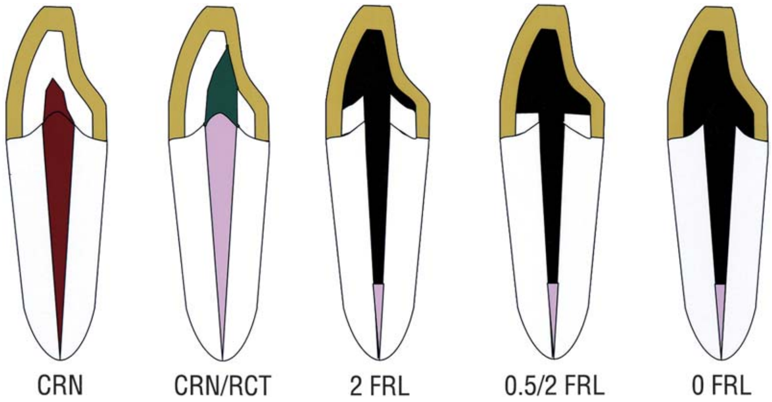

Fig. 4. Experimental groups: CRN, CRN/RCT, 2 FRL, 0.5/2 FRL, 0 FRL (left to right).

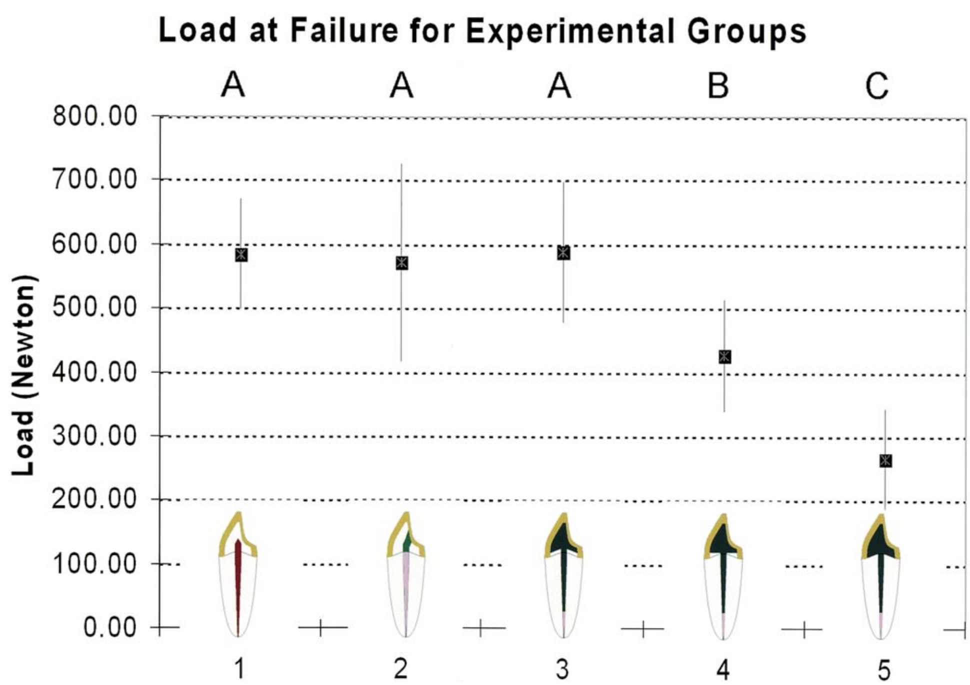

Fig. 5. Load at failure and Tukey groupings for experimental groups.

treated teeth restored with cast dowels and cores and crowns without a ferrule (0 FRL).

Teeth in RCT/CRN, 2 FRL, 0.5/2 FRL, and 0 FRL were subjected to a standard endodontic treatment by an operator who was unaware of the group allocations. Canal preparation was completed by using a crown-down technique with rotary nickel-titanium instrumentation (K3; Sybron Dental Specialties, Orange, Calif). Working length was set at 1 mm short of the apical foramen. Obturation was accomplished by cold lateral condensation with gutta percha (Dentsply Maillefer, Tulsa, Okla) and sealer (AH 26; Dentsply Maillefer). Teeth were inspected for cracks with ×3.5 magnification (Prism Loupes; Carl Zeiss Inc, Thornwood, NY) prior to mounting in acrylic resin

Table I. One-way ANOVA ($P<.0001$)

Source of variation	Sum of squares	*df*	Mean squares	F
Between	560203.85	4	140050.96	7.88
Error	550928.13	31	17771.88	

(Fast Tray; Bosworth Co, Skokie, Ill) blocks, with the long axis of each tooth parallel to the long axis of the block, and the mid-facial extent of the cementoenamel junction (CEJ) located 2 mm coronal to the acrylic resin (Fig. 2). Reduction guides were made from vinyl polysiloxane putty (ExaFlex Putty; GC America, Alsip, Ill) to record the external form of the tooth.

Tooth reduction for crown preparation was performed to standardized specifications as shown in

Fig. 6. Fractured specimen.

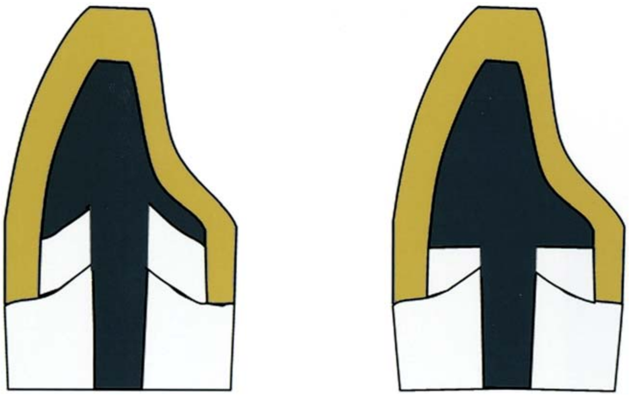

Fig. 7. Illustration of differences between 2-mm uniform ferrule (*left*) and nonuniform ferrule (*right*).

Figure 3. The crown margin was designed to follow the simulated contours of the free gingival tissue with the facial and lingual extents of the margin 1.5 mm more apical compared to the proximal margins. The margins were 1 mm wide with a rounded shoulder configuration. A diamond rotary cutting instrument (6847KR-016; Brasseler USA, Savannah, Ga) with a 12-degree total occlusal convergence angle was used for the margin preparation of each tooth, as well as 2 mm of incisal reduction and 1.5 mm of facial reduction. Lingual reduction of 0.5 mm was performed (6379-023; Brasseler USA). Teeth in 2 FRL were further reduced to leave a 2-mm uniform ferrule, teeth in (0.5/2 FRL) were reduced to create a ferrule of nonuniform height (2 mm mid-facial and mid-lingual and 0.5 mm proximal); and teeth in 0 FRL were reduced to eliminate the ferrule entirely (Fig. 4). The preparation convergence angle was standardized with the aid of a handpiece mounted on a dental surveyor (J.M. Ney Co, Bloomfield, Conn).

Dowel space preparation began with the removal of gutta percha using a heated Schilder's plugger (Hu-Friedy, Chicago Ill). Final gutta percha removal was performed with burs (#2 Gates-Glidden; Brasseler USA), taking care to preserve 4 mm of apical gutta percha. The apical region of the dowel space was prepared with a drill (size #3 post, ParaPost; Coltene Whaledent, Cuyahoga Falls, Ohio). Dowel-and-core patterns were made from autopolymerizing acrylic resin (GC Pattern Resin; GC America) and plastic dowel patterns (ParaDowel X; Coltene Whaledent) to replace the coronal dentin that had been removed. One pattern from each of the groups (to minimize batch variation) was invested in a phosphate bonded investment material (Fujivest; GC America) using a 1:1 special liquid-to-water ratio. Thirty minutes after the start of the mix, the investment was placed in a preheated burnout oven (Temp Master A; Jelrus, Hicksville, NY) at a temperature of 1100°C and left for 45 minutes. The patterns were cast in high noble gold alloy (Par 7; W. E. Mowrey, Minneapolis, Minn) with the aid of a centrifugal casting machine (Centrifico; Kerrlab, Orange, Calif). The dowels and cores were fitted to the respective teeth and subsequently cemented with a resin-modified glass ionomer cement (Fuji Cem; GC America).

Crown wax patterns were then made for the specimens with the aid of the reduction guide to recreate the original crown contour. A lingual ledge was added to create a standard loading point. One wax pattern from each group was invested and cast using the same protocol used with the dowels and cores. Crowns were cemented with a resin-modified glass ionomer cement (Fuji Cem) and stored for 3 days in an environment with 100% humidity.

Specimens were tested with a universal testing machine (Model 1445; Zwick USA, Atlanta, Ga) set to deliver an increasing load until failure. Failure was defined as a 25% drop in the applied load. The crosshead speed was 2.5 mm per minute, and the load was applied to the lingual ledge at a 45-degree angle to the long axis of the tooth. The specimens were tested in random order (samples were pooled, mixed, and chosen without visualization), and the operator of the machine was not informed of the group designation of the specimen being tested. The variable of interest was the load at failure measured in newtons. The statistical analyses used included 1-way analysis of variance (ANOVA) to detect the presence of group differences, and pairwise comparisons between groups with the Tukey adjustment for multiple comparisons using an overall Type I error (α=.05). A post hoc power analysis was also conducted. The mode of failure for each of the specimens was noted by visual inspection.

RESULTS

Figure 5 summarizes the findings of the investigation. Significant differences were detected by 1-way ANOVA (P<.0001) (Table I). The Tukey analysis separated the groups into 3 clusters: *A* (CRN, RCT/CRN, 2 FRL), which was more fracture resistant than *B* (0.5/2 FRL)($P<.05$), which was more fracture resistant then *C* (0 FRL)($P<.01$).

A post hoc power analysis was performed to assess power to detect mean differences among the 3 groups that were not distinguishable based on this study: the group with uniform 2-mm vertical ferrule, the group without RCT, and the group with RCT-treated tooth with a crown alone. In each instance in which 2 of these groups were compared, power to detect the modest observed difference was less than 10%, based on the sample sizes and a Type I error level of α=.05, even without adjustment for multiple comparisons. Similarly, considering the sample size that would be necessary to detect differences of this magnitude, the required per-group sample sizes would range from 690 to over 14,000. There was little power to detect differences as subtle as those observed among these 3 groups, and very large sample sizes would be required to have a reasonable probability of doing so. The mode of failure for 45 specimens was an oblique fracture extending from the lingual margin to the facial surface just below the tooth's insertion into the acrylic resin (Fig. 6). In the other 5 specimens, 1 from each group failed as a result of a root fracture extending from the apex of the dowel to the external surface.

DISCUSSION

The results of this investigation confirm the general consensus that a uniform 2-mm ferrule is superior to the lack of a ferrule in the prevention of tooth fracture under a static load.[30] The reported maximal occluding force for males exerted by a maxillary incisor tooth was 146 ± 44 N.[31] Allowing for 2 SDs of variation, teeth without a ferrule (265 ± 78 N) are at risk of fracture when subjected to maximal clenching force, whereas the teeth with a uniform 2-mm ferrule (587 ± 110 N) would resist forces from maximal clenching. This observation leads to the conclusion that there is substantial benefit in providing a ferrule whenever possible.

The results also indicated that a tooth with a nonuniform ferrule is more effective at resisting fracture than a tooth with no ferrule, but not as effective as a tooth with a uniform 2-mm ferrule. The nonuniform ferrule (427 ± 88 N) should also possess sufficient fracture resistance to survive the forces of maximal clenching. If a tooth initially does not have a ferrule, an attempt should be made to allow for at least 2 mm of facial and lingual ferrule.

The magnitude of the difference in failure load between the teeth with a uniform 2-mm ferrule and teeth with a nonuniform ferrule was surprising. This difference in failure load is attributed to the difference in remaining coronal tooth structure (Fig. 7). There are several mechanisms of action to be considered. The most likely explanation is that the greater amount of dentin allowed for redistribution and dissipation of a larger force. In addition, the extra dentin may have created a more stable foundation for the dowel and core, allowing a greater resistance to rotation. The core also formed a bevel over the tooth (Fig. 4) that may have acted as a modified or secondary ferrule. The increase resistance to fracture may also have been the result of a combination of these previously mentioned suggestions.

The clinical relevance between the uniform 2-mm ferrule and nonuniform ferrule is difficult to determine. While both groups could potentially survive a maximal clenching force applied by an average man, there is a large range of maximal occluding forces reported in the literature. Since the clinician cannot accurately determine the magnitude of oral forces generated for each patient, a maximal amount of ferrule probably should be developed whenever possible.

No statistically significant difference was detected between teeth with a uniform 2-mm ferrule and crowned teeth without a dowel and core. The authors provide 2 explanations for this lack of difference. Perhaps there was no actual difference between the groups, but this is surprising because of the significant differences in remaining tooth structure and method of restoration. Perhaps there was an insufficient sample size to detect a difference. As indicated by the post hoc power analyses, there was little power to detect differences this small, and very large sample sizes would be required to detect mean differences of this subtlety. Therefore, it cannot be concluded that a uniform 2-mm ferrule is as effective in preventing tooth fracture under a static loading as a tooth with completely intact natural tooth structure and restored with a complete crown. However, the actual differences in strengths between the 2 groups may not be clinically relevant.

The mode of failure of specimens was the same for all groups, with the predominant mode being an oblique fracture from the lingual margin to the facial tooth surface at the insertion into the acrylic resin. This result is also surprising because of the substantial structural differences among the groups. It is worth noting that this mode of failure does not represent failure as seen clinically.[32] A periodontal ligament was not simulated in this investigation. The teeth were held in place with rigid acrylic resin, which is more akin to an ankylosed tooth. This may explain the mode of failure.

There are several limitations to this study. Static loading represents a "worst case" scenario and does not directly replicate forces in the oral cavity with regard to both size of the load and nature of the load. Most pulpless teeth in vivo probably fail as a result of fatigue failure, so resistance to static loads is not the only issue of interest. The specimens were not thermal cycled, which has the effect of degradation of the luting agent and may possibly influence the outcome. Only maxillary central incisors were used; therefore, these results can only be applied to that group of teeth. The results are limited to teeth that were restored with cast dowels and cores rather than prefabricated dowels with direct cores. Also, only 1 loading point and angle were tested. Anterior teeth contact in a variety of positions, and angles were not tested in this study.

There are several avenues for further investigation. These include fatigue testing of specimens fabricated by using the same protocol. A comparison between the static load and fatigue load could also be conducted to investigate any correlation between the results obtained. This model could also be adapted to test teeth restored with prefabricated dowels and direct cores with the use of various ferrule dimensions and configurations. The effect of different dowel materials could also be tested along with different ferrule configurations, such as a 2-mm facial ferrule only. Expansion to include teeth other than maxillary central incisors is also possible.

CONCLUSIONS

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

1. The mean fracture strengths of endodontically treated maxillary central incisors restored with a crown without a dowel and endodontically treated maxillary central incisors restored with a cast dowel and core and crown with a uniform 2-mm ferrule were not significantly different.

2. Endodontically treated maxillary central incisors with a uniform 2-mm ferrule were more fracture resistant than those with a ferrule varying between 0.5 mm and 2 mm (P=.0001).

3. Endodontically treated maxillary central incisors with a ferrule length varying between 0.5 mm and 2 mm were more fracture resistant than those without a ferrule (P=.001).

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