Effect of Ferrule Thickness on Fracture Resistance of Endodontically Treated Incisors Restored with Fiber Post and Metal Crown

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Purpose: To assess the influence of ferrule thickness on the fracture resistance and failure mode of endodontically treated bovine incisors and to predict the long-term prognosis, as well as choose the most suitable clinical treatment, for teeth with different ferrule thicknesses.

Materials and Methods: A total of 50 endodontically treated bovine incisors were restored with quartz fiber posts and metal crowns and separated into five groups (n = 10 each): no ferrule (group A); 0.5-mm–thick ferrule (group B); 1.0-mm–thick ferrule (group C); 1.5-mm–thick ferrule (group D); and 2.0-mm–thick ferrule (group E). All specimens were subjected to a fatigue loading test (2.33 Hz, 50 N, 300,000 cycles). Survived specimens were loaded until fracture on a universal testing machine at an angle of 135 degrees and a crosshead speed of 0.5 mm/minute. Failure modes and fracture resistance were recorded. Data were analyzed using one-way ANOVA and least significant difference tests.

Results: A significant increase \( P < .05 \) was detected in fracture resistance with increase in ferrule thickness. Group D (1.5 mm) and group E (2.0 mm) showed significantly higher fracture resistance than the other three groups. All failures belonged to restorable fracture patterns.

Conclusion: Ferrule thickness contributed significantly to the fracture resistance of endodontically treated bovine incisors restored with quartz fiber posts and metal crowns. Teeth with ferrule thickness of ≥ 1.5 mm can achieve higher fracture resistance and have a better long-term prognosis.


Endodontically treated teeth (ETT) have a higher risk of fracture in comparison to vital teeth because of the lost tooth structure and increasing brittleness.1,2 Placement of a post-and-core buildup is recommended for the endodontically treated tooth with insufficient residual coronal structure.3 The significance of the ferrule effect has been suggested in many studies.4,5 A properly designed ferrule may decrease the stress concentration generated by masticatory function.6 Some studies have indicated that fracture resistance increased with an increase in ferrule height,7 and most studies recommend the retention of a 1.5- to 2-mm–height ferrule.8

There exists great possibility that the remaining walls of residual coronal structure are not complete. Thus, some studies have explored how fracture resistance varied with the number and site of the remaining walls in teeth with a partial crown ferrule.9,10 A positive correlation between the number of remaining coronal walls and the fracture strength was proven,11,12 and the importance for a complete ferrule surrounding the residual coronal tooth has been emphasized.13 Some studies showed that there was no correlation between the location of the residual coronal wall and
the fracture resistance of teeth with root canal treatment and post-and-core crown restoration, but some indicated that the location of residual dentin could influence fracture resistance.11,14

Nevertheless, the effect of ferrule thickness on fracture resistance has not been well studied. Tjan and Whang15 indicated that there were no significant differences in failure loads detected when the remaining dentin thickness varied. In their study, cast posts and cores were cemented on teeth, but crowns were not placed. Haralur et al16 studied the influence of the remaining dental wall thickness of mandibular premolars with a central defect and 6-mm residual coronal height and concluded that the remaining coronal wall thickness contributed significantly to fracture resistance. Kvanç et al17 suggested that reservation of 2 mm of ferrule thickness could strengthen fracture resistance better than 1 mm and 1.5 mm; however, no statistical differences were shown. More studies are needed to clarify the effect of ferrule thickness on the fracture resistance of ETT.

This in vitro study aimed to investigate how ferrule wall thickness affects the fracture resistance of ETT restored with quartz fiber posts and full metal crowns. The null hypothesis was that there would be no correlation between the ferrule thickness and fracture resistance of treated teeth.

MATERIALS AND METHODS

A total of 50 bovine incisors freshly separated from bovine mandibles were selected. The selected incisors had similar dimensions and shapes and were examined under ×10 magnification to identify the absence of cracks.15 After removing all the tissues and debris, the teeth were stored in 0.2% thymol solution at room temperature to control infection and prevent dehydration. All prepared teeth were randomly divided into five treatment groups of 10 teeth each. The crown portion of each incisor was sectioned perpendicularly to the longitudinal axis of the tooth using a diamond bur (DIATECH, Coltène) with copious irrigation. Specimens in group A were sectioned at 13 mm from the apex, and specimens in groups B, C, D, and E were sectioned at 15 mm above the apex to standardize the root canal lengths and imitate human root canals (Fig 1).16

During the root canal preparation, the working length was set at 1 mm above the apex. All canals were endodontically prepared to an International Standardization Organization (ISO) file size 40 (K-files, Dentsply Maillefer) using the step-back technique, rinsed alternately with saline and 0.2% sodium hypochlorite, obturated with gutta percha points (Gapadent) using the cold lateral condensation technique, and sealed with AH Plus sealer (Dentsply DeTrey). A radiograph was taken to ensure the quality of the root canal treatment.

The periodontal ligament surrounding each root was simulated using silicone-based impression material.18 Root surfaces were coated with foil (approximately 0.6 mm thick) 2 mm below the cervical limit of the root in the position where the crown portion had been sectioned from the root, leaving 2 mm of the coronal root surface exposed in the group with no ferrule and 4 mm in the groups with ferrule.19 Autopolymerizing acrylic resin was poured into the custom-made molds (20 mm in length, width, and height) used to embed all specimens along their longitudinal axis. The teeth were placed in a cool water bath during polymerization of the resin. During the rubbery stage of polymerization, the teeth were taken out from the polymerized resin blocks along their long axis, and spacer (foil) was wiped off from the surfaces of the root. Silicone-based impression material was filled into the obtained space. A standardized periodontal ligament simulated by silicone-based impression material was thus achieved.

After the specimens were embedded, each sample with ferrule was prepared to acquire a 0.5-mm–wide circumferential shoulder with a 4-degree convergence angle in the position of the cervical limit using a milling machine (Amann Girrbach). The post spaces in teeth with a ferrule were then enlarged 2 mm above the cervical limit of the roots using diamond burs (834-016-6.8-ML DIATECH Multilayer Diamond), leaving circumferential dentin approximately 0.5 mm thick in group B, 1.0 mm thick in group C, 1.5 mm thick in group D, and 2.0 mm thick in group E (Fig 2). The remaining ferrule thickness was measured using a caliper with an accuracy of 0.01 mm (Chengliang Tools) at eight sites: the labial, lingual, mesial, distal, mesiolabial, distolabial, mesiolingual, and distolingual. Group A had no ferrule.
Post spaces were initially obtained using heat-transferring instruments (SuperEndo-α2, B&L Biotech) and then prepared using Gates Glidden drills (no. 2 and 3, Dentsply Maillefer), leaving an apical sealing of 5 mm. Thus, the depth of prepared post spaces was 10 mm in teeth with ferrule and 8 mm in teeth without ferrule. Three percent sodium hypochlorite solution and 75% ethanol were used to irrigate, and paper points were used to dry the root canals. The quartz fiber posts (POPO, Shidelong) were cleaned with 75% ethanol and then inserted into the canal, luted with adhesive composite resin cement (CLEARFIL DC CORE/DC BOND, Kuraray) according to the manufacturer’s instructions, and seated under constant finger pressure until initial setting occurred. Excess luting resin was applied to cover the coronal part of the post. Adhesive composite resin (CLEARFIL DC CORE/DC BOND) was employed to build up the composite resin core according to the manufacturer’s instructions.

All composite cores were fabricated to the required dimensions using a copy-milling machine (Amann Girrbach) (Fig 3). The total preparation height was 4 mm coronal to the circumferential shoulder for roots with a ferrule and 6 mm for roots with no ferrule, and the convergence angle of the composite resin core was approximately 4 degrees. The palatal surface was prepared into a chamfer, and a 3-mm labial-palatal width was left at the most coronal tip of the core (Figs 4 and 5). After one coat of die spacer and one coat of separating agent, a standard wax pattern was created directly on the prepared core.

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one specimen. This pattern was prepared with 8-mm height and a circumferential thickness of 1 to 1.5 mm. The crown pattern was used to fabricate a mold for replica wax crown pattern production for all specimens. Nickel-chromium alloy (West China Hospital of Stomatology) was employed to invest and cast wax patterns. Cast metal crowns were completed and cemented to the prepared cores using resin-modified glass-ionomer (RelyX Luting Cement, 3M ESPE).

All specimens were immobilized in a universal testing machine (Instron 3365). A nominal fatigue load of 50 N at 2.33 Hz was applied for 300,000 loading cycles on the lingual surface 3 mm from the incisal edge at an angle of 135 degrees to the longitudinal axis of the tooth (Fig 6). Specimens were defined as failed when failures in metal crowns were detected under ×10 magnification. The specimens that survived the fatigue loading were continually tested to a gradual increasing force. Compressive force was applied at an angle of 135 degrees to the long axis of the tooth at a crosshead speed of 0.5 mm/minute until they were fractured. The maximum failure load was determined with a sudden decrease in the force vs time graph. Both failure mode and failure location were recorded.

SPSS version 18.0 software (IBM) was used to conduct statistical analyses. One-way analysis of variance (ANOVA) and least significant difference (LSD) analysis were employed to analyze the statistical data. The alpha (Type I) error level was set to .05 throughout the analysis.

RESULTS

None of the specimens fractured after 300,000 cycles of fatigue loading. All data of failure loads were analyzed using one-way ANOVA and LSD tests ($\alpha = .05$) after removing the maximum and minimum values in each group. Figure 7 summarizes the mean fracture resistance and standard deviation (SD) values for the five test groups. One-way ANOVA revealed a statistically significant difference ($P < .05$) among the groups. The fracture resistance increased with the increase in ferrule thickness. Group E, with a 2-mm–thick ferrule, showed the highest fracture resistance, whereas group A, without ferrule, showed the lowest fracture resistance. The LSD multiple comparison statistical tests indicated statistically significant differences ($P < .05$) between group A and all other treatment groups. The LSD test revealed no significant differences in fracture resistance between groups B and C ($P = .610$), but there were statistically significant differences between group B and groups D ($P = .014$) and E ($P = .006$). Differences in fracture resistance between group C and groups D and E were significant, with $P$ values of .047 and .017, respectively. Groups D and E showed no statistically significant differences in fracture resistance, with $P = .662$. 
There were four typical types of possible failure mode (Fig 8)16:

- Type 1: fracture in fiber post and resin core (restorable mode)
- Type 2: fracture in cervical third (restorable mode)
- Type 3: fracture in middle third (unrestorable mode)
- Type 4: fracture in apical third (unrestorable mode)

Each specimen was examined under ×10 magnification to determine failure mode. All the groups had complete restorable failure mode. Except for one specimen in group A that fractured in the tooth tissue as well as in the fiber post, all other specimens had Type 2 fracture mode.

DISCUSSION

The null hypothesis, that the fracture resistance of the treated teeth would not be influenced by the ferrule thickness, was rejected. The fracture resistance increased when the ferrule thickness increased. Sufficient ferrule thickness can guarantee more protection to ETT after post-and-core crown restoration.

Bovine incisors were used in this study instead of human incisors because they were easy to obtain in a better condition and showed less variability in size, anatomy, morphology, and dentin thickness of the canal. Bovine teeth are widely considered to present a mineral composition, morphology, microhardness, and ultrastructural architecture similar to that of human teeth.19 Therefore, bovine teeth provide a standard and reproducible material that allows evaluation of a clinical situation with different treatment modalities. Hence, they have been used frequently in recent in vitro studies.19–21

Fatigue loading test conducted on a universal testing machine was taken into consideration in this study to simulate clinical conditions and acquire significant results. The average daily chewing force for a young adult is about 50 N,22 and so a load of 50 N was chosen for the fatigue loading process.23,24 Moyers25 indicated that orientation of the biting force for anterior teeth was 45.5 degrees to the long axis of teeth, which gave a reference to the loading direction of 135/45 degrees to the long axis of the teeth for this study.

After 300,000 cycles of fatigue loading, none of the specimens failed. This is probably due to three main reasons: First, the total number of loading cycles was only 300,000. Wiskott26 demonstrated that 1,000,000 mastication movements could happen in 1 year if 3 meals a day, 15 minutes per meal, and 1 second per mastication movement were considered as parameters. The total number of fatigue loading cycles must be at least 300,000 to be equivalent to 1 year of chewing activity. Second, a 2-mm–height ferrule was chosen. Many studies4,5,8 have shown that a 2-mm–height ferrule could significantly increase the cycles of fatigue loading, and tooth preparation with a 2-mm–height ferrule is widely recommended; therefore, a 2-mm–height ferrule was chosen in this study. Third, prefabricated fiber posts were used. Some research27,28 has demonstrated that fiber posts have good long-term mechanical properties and increase the fracture resistance of root canal–treated teeth.

This study showed that the fracture resistance of the teeth increased significantly when the ferrule thickness increased. Aside from the ferrule thickness, many researchers also explored the effect of the remaining dentin wall thickness of roots on the fracture resistance of the teeth. Bhagat et al29 and Marchi et al30 both evaluated the remaining wall thicknesses around different post-and-core systems and suggested that wall thickness was a determinant factor of fracture resistance. Mireku31 calculated and recorded the average thickness of every sample root after fatigue loading and fracture resistance test and suggested that the dentin thickness of the roots that fractured was significantly less than those that did not. It is important to note that the effect of ferrule thickness on fracture resistance is extremely similar to the effect of ferrule height and remaining root wall thickness. This suggests that a positive correlation might exist between fracture resistance and the amount of retained dentin, which was consistent with the studies of Fernandes and Dessai,32 Ichim et al33 and Pereira et al.34

The failure modes of all the specimens were restorable. This result is consistent with the conclusions reported by other researchers,35,36 which is due to two aspects. First, the fiber post resembled dentin in elastic modulus, which enabled the fiber post and teeth to bend at the same time when they were subjected to occlusal forces, transmitting stress to the cervical third
of the roots. Second, the low elastic modulus of the fiber post led to low stress transmission to the root apex, playing a commendable role in apex protection.

In light of the results of this study, a preserving ferrule with a thickness of ≥ 1.5 mm will achieve a higher fracture resistance and better long-term clinical prognosis of the tooth. However, teeth sometimes do not have enough ferrule thickness, and in this situation, advance notification to patients at increased risk of fiber and tooth fracture during long-term use is needed. Also, chamfer preparation instead of shoulder preparation could be considered in order to preserve enough ferrule thickness and improve fracture resistance.

One of the limitations of this study was the lack of thermal cycling and short periods of chewing simulations. Thermal cycling and longer periods of fatigue loading, such as simulation of 5 to 10 years of clinical function, would have given a better clinical prediction of the restoration survival. Another limitation was that this study did not examine the interactive effects among the ferrule thickness, number, and sites of remaining root walls on the fracture resistance of the teeth. Further research is needed to explore the combined effects of these factors.

CONCLUSIONS

Within the limitations of this study, it can be concluded that ferrule thickness contributed significantly to the fracture resistance of endodontically treated bovine incisors restored with fiber posts and full-metal crowns. Presence of a ferrule significantly increased the fracture resistance of ETT. When the ferrule height was 2.0 mm, presence of 1.5- and 2.0-mm-thick ferrule was associated with significant increases in fracture resistance. Ferrules with a thickness of ≥ 1.5 mm should be reserved to enhance the clinical fracture resistance of ETT.

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REFERENCES


Patient-Reported Effect in Patients Receiving Implant or Tooth-Supported Fixed Prosthesis

The objective of this study was to compare the patient-reported effects of treatment with an implant-supported fixed prosthesis (ISFP) or a fixed dental prosthesis (FDP) in patients with a small number of teeth to replace. From a population of 155 patients receiving either an ISFP or FDP, 68 patients were matched in pairs based on gender, number of teeth replaced, zone of replacement, age, and number of remaining teeth. The patient-reported effect was prospectively obtained by measuring changes in the short-form Oral Health Impact Profile (OHIP-14) from before to 1 month after treatment. Effect size (ES), standardized response mean (SRM), and a minimal important difference of two units were applied to estimate the magnitude of the change. Both the ISFP and FDP groups showed significantly decreased OHIP-14 after treatment (P < .01). The change was not significantly different between the ISFP and FDP groups. The magnitude of the change for both treatments was moderate and slightly higher in the ISFP group (ES = 0.52 and SRM = 0.58) than in the FDP group (ES = 0.48 and SRM = 0.47). Applying the minimal important difference showed that 23 participants in the ISFP group and 21 in the FDP group had good effect. The patient-reported effect of treatment with an ISFP or FDP was similar, clinically meaningful, and of moderate magnitude in patients with a small number of teeth to replace.


Efficacy of Antibiotic Prophylaxis in Intraoral Bone Grafting Procedures: A Systematic Review and Meta-Analysis

The purpose of this systematic review was to investigate the efficacy of antibiotic prophylaxis (AP) in intraoral bone grafting procedures for the prevention of postoperative infection (POI). Electronic and manual searches were conducted to identify randomized controlled trials (RCTs). The primary outcome assessed was receptor site POI. Secondary outcomes assessed included donor site POI, wound dehiscence, pain, graft failure, need for re-grafting, adverse events, patient satisfaction, and quality of life. A random-effects meta-analysis was conducted to obtain risk ratios for dichotomous data. Four RCTs were selected: one examined AP vs placebo and concluded that there was an increased risk of POI without AP, and three examined comparative antibiotic regimens and found no statistically significant differences between them. A meta-analysis of the prophylactic regimens including data from the two RCTs that compared preoperative AP to perioperative AP indicated no statistically significant difference in POI outcomes (P = 0.94, risk ratio = 0.94). It was not possible to conduct further meta-analyses for POIs or for any secondary outcomes due to insufficient published data. The risk of bias assessment indicated an overall unclear risk of bias. On the basis of the present review, there is insufficient evidence to support or refute AP for the prevention of POIs in intraoral bone grafting procedures.


Artificial Intelligence in Dentistry: Current Applications and Future Perspectives

Artificial intelligence (AI) encompasses a broad spectrum of emerging technologies that continue to influence daily life. The evolution of AI makes the analysis of large data possible, which provides reliable information and improves the decision-making process. This article introduces the principles of AI and reviews its development and how it is currently being used. AI technology has influenced the health care field because of the need for accurate diagnosis and superior patient care. In order to understand the trends of AI in dentistry, an electronic search was carried out, and individual companies were approached to obtain the details of AI-based services. The current applications of AI in clinical dentistry were introduced and summarized. In the future, an AI-based comprehensive care system is expected to establish high-quality patient care and innovative research and development, facilitating advanced decision support tools. The authors believe that innovative interprofessional coordination among clinicians, researchers, and engineers will be the key to AI development in the field of dentistry. Despite the potential misinterpretations and the concern of patient privacy, AI will continue to connect with dentistry from a comprehensive perspective due to the need for precise treatment procedures and instant information exchange. Moreover, such developments will enable professionals to share health-related data and deliver insights that improve patient care to hospitals, providers, researchers, and patients.


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