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Impact of Interproximal Groove Placement and Remaining Coronal Tooth Structure on the Fracture Resistance of Endodontically Treated Maxillary Anterior Teeth

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Abstract

Purpose: This in vitro study investigated the effect of grooves, remaining tooth structure, and their combination on tooth fracture resistance of endodontically treated anterior teeth with cast dowel and cores.
Materials and Methods: Sixty extracted maxillary anterior teeth of similar dimensions were endodontically treated and then randomly divided into three groups of 20 teeth each. The teeth in the first group were cut horizontally at the widest part of their anatomical crowns. Three hundred and sixty degree 1 and 2 mm axial walls for ferrule effect were provided for the teeth in the second and the third groups, respectively. Cast dowel and cores were fabricated for all teeth. Each group was then subdivided in two groups: one with no grooves and another with mesial and distal grooves. Hence, six groups were created as follows: (1) teeth with no remaining coronal tooth structure and no grooves (group A-control); (2) teeth with no remaining coronal tooth structure, with mesial and distal grooves (group B); (3) teeth with 1 mm remaining coronal tooth structure, with no grooves (group C); (4) teeth with 1 mm remaining coronal tooth structure, with mesial and distal grooves (group D); (5) teeth with 2 mm remaining coronal tooth structure and no grooves (group E); and (6) teeth with 2 mm remaining coronal tooth structure, with mesial and distal grooves (group F). Complete cast crowns were then fabricated for all teeth. A universal testing machine applied controlled loads to the teeth at a crosshead speed of 2.54 mm/min at an angle of 130° to the long axes of the teeth until failure occurred. The loads were applied 2 mm lower than the incisal edges of the specimens. Descriptive statistics, one-way ANOVA ($\alpha = 0.05$) and Tukey's honestly significant difference (HSD) tests were used to determine the effect of failure loads among the tested groups ($\alpha = 0.05$).
Results: The mean failure loads were (N): group A (control), 151.21 ± 38.18; group B, 221.53 ± 107.03; group C, 295.35 ± 81.92; group D, 270.20 ± 76.01; group E, 491.70 ± 180.36; group F, 432.67 ± 193.83. Group E presented the highest failure load and group A (control) the lowest.
Conclusion: The inclusion of interproximal grooves on the cast dowel and cores of endodontically treated anterior teeth with 1–2 mm of remaining coronal tooth structure does not significantly lower the failure threshold.

Endodontically treated anterior teeth do not require complete coverage restoration if they are not structurally compromised. Lovdahl and Nicholls[1] concluded that the intact endodontically treated central incisors were three times more resistant to fracture than teeth restored with dowels; however, tooth structure of endodontically treated teeth is frequently compromised due to existing extensive restorations, dental carries, access holes for endodontic treatment, canal instrumentation, and/or tooth preparation.[2] Consequently, a coronal build-up is often required for the retention of a complete coverage restoration needed for esthetical, biological, and functional reasons. Several methods have been suggested for the restoration of the lost tooth structure, including core build-ups with or without dowels and pins, and cast dowel and cores.[3-8] The main function of the dowel is to retain the core that substitutes the missing coronal portion of the tooth, and to provide both retention and resistance forms for an indirect restoration.

Although cast dowel and cores are widely used, they represent a risk factor for tooth survival. Dowel system employed,[9-15] dowel length,[16,17] dowel diameter,[18,19] passivity of fit and stress distribution,[20-27] corrosion products,[28,29] tooth position in the arch,[4,30] and patients' parafunctional habits are reasons, which, when combined, can ultimately cause a root fracture. Establishment of a ferrule effect has been suggested as a possible method to improve fracture resistance and decrease the incidence of dowel decementation.[31-35] Different heights of required tooth structure have been proposed for an efficient ferrule effect.[36,37] Recently acquired data indicate that an increased amount of coronal dentin of 2 mm or more significantly increases the fracture resistance of endodontically treated teeth.[38,39] It should be mentioned, however, that the remaining coronal tooth structure does not compose the ferrule effect. This is actually provided by a complete coverage restoration, which braces the remaining tooth structure of endodontically treated teeth.[40]

Other factors considered essential for long-term survival of complete coverage restorations include wall parallelism,[41,42] axial height, and surface area.[43] If these three factors cannot be acquired, other procedures, such as orthodontic extrusion or crown lengthening,[44] should be considered, with the prerequisite that they will not have adverse esthetic results or they will not unfavorably affect the periodontal parameters.

Secondary internal features such as boxes,[45,46] grooves,[47] and pinholes[48,49] can also be helpful in improving retention and resistance forms. The location of groove placement has to be carefully examined, because interproximal grooves provide maximum resistance to faciolingual forces,[50] whereas buccal or lingual grooves offer only partial resistance.[51] Besides location, other factors to be considered include length, depth, and parallelism between grooves.

Previous studies have examined the effect of grooves[52-54] on the retention and resistance forms for cast preparations or the ferrule effect and its impact on fracture resistance.[6,33,55]

The purpose of this study was to evaluate the effect of grooves, remaining tooth structure, and their combination on the fracture resistance of endodontically treated anterior teeth with cast dowel and cores.

Materials and methods

Sixty extracted maxillary anterior teeth of similar dimensions were obtained from the Oral and Maxillofacial Surgery Department of Tufts University, School of Dental Medicine, Boston, MA. Teeth were disinfected in 5.25% hypochlorite solution for 24 hours and were then stored in saline solution during all subsequent procedures. Pulp was removed, and a canal was shaped. Saline irrigation was used during instrumentation procedures. Canals were then dried with compressed air and absorbent paper points (Kerr Mfg. Co., Romulus, MI). Gutta-percha points (Hygenic Corp., Akron, OH) and pulp canal sealer (Kerr Mfg. Co.) applied to the master cone were used for the obturation of the root canals. The excess was removed with a heated instrument, and the teeth were returned to the saline solution. Dowel spaces for all teeth were made initially with a #4 Gates Glidden drill (Dentsply Maillefer, Montigny, France), and were finished with a #12 Metalor drill (Metaux Precieux, Neuchatel, Switzerland).

Table 1 Dimensions (mm) of teeth included in the study

Group	Length	Labiopalatal	Mesiodistal
1	23.95 ± 0.86	6.88 ± 0.25	6.33 ± 0.32
2	24.18 ± 0.76	6.83 ± 0.26	6.42 ± 0.39
3	24.27 ± 0.48	6.98 ± 0.12	6.29 ± 0.36
F-value	1.034	2.154	0.688
p-value	0.362	0.125	0.507

Labiopalatal and mesiodistal dimensions were measured at the level of the cervical margin.

No modification of the axial width of the specimens at the crown margin was attempted, because a previous study[33] demonstrated that it does not significantly increase the fracture resistance. The 60 teeth were randomly divided into three groups. After the randomized division, the teeth dimensions (length, labiopalatal, mesiodistal) were measured by a digital micrometer (Mitutoyo, Kawasaki, Japan) (Table 1). The teeth in the first group were cut horizontally at the widest part of their anatomical crowns, using a high-speed handpiece (625C Super Torque, KAVO GmbH, Biberach, Germany) with profound irrigation. A 360° 1-mm and and a 360° 2-mm axial wall for ferrule effect were provided for the teeth in the second and the third groups, respectively. The 1.5-mm shoulder margins were prepared at the widest part of the crowns, using an 856–018C (Brasseler USA, Savannah, GA) diamond bur. Under normal clinical procedures, the preparation would follow the cementoenamel junction; however, this was not performed, so that variations in shape and size of complete cast crowns to be fabricated in a later stage could be avoided. The tooth reduction was confirmed by means of an initial silicon index. All preparations were performed by the same operator.

Polymethyl-methacrylate autopolymerizing (PMMA) resin (GC Pattern Resin, GC Corp., Tokyo, Japan) was applied with a brush (Bendable Brush, 3M Dental Products, St. Paul, MN) on #12 burn-out plastic posts (Metalor, Metaux Precieux) and inserted in the root canals, which were previously lubricated with mineral oil (Alpha Chem, Kings Point, NY). The core part was waxed to its final configuration directly on the teeth, using ABS wax (Metalor, Metaux Precieux). The dowel part had a length of 10 mm for all teeth, while the core part had a height of 6 mm for the first group (no remaining coronal tooth structure), 5 mm for the second group (1 mm of remaining coronal tooth structure), and 4 mm for the third group (2 mm of remaining coronal tooth structure). The dimensions of the prepared dowel

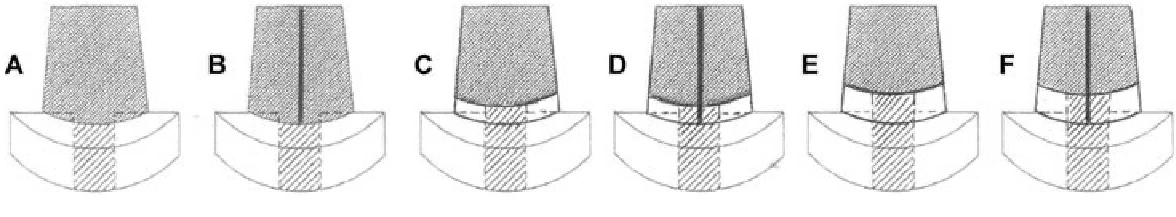

Figure 1 Six experimental tooth preparation designs. The shoulder margins were prepared at the widest parts of the clinical crowns, irrespective of CEJ location. In groups B, D, and F grooves were actually placed interproximally and not buccolingually as depicted in this illustration.

and cores were verified by a traveling micrometer microscope (Griffin Ltd., London, UK).

All dowel and core patterns were invested with gypsum investment (Novocast, Whip Mix Corp., Louisville, KY) and cast with type III gold (MiniGold, Williams, Amherst, NY). The cast dowel and cores were divested, placed in an ultrasonic cleaner, and inspected under a magnification of 10× (Olympus BH-2, Olympus Optical Co., Tokyo, Japan) for surface irregularities. Positive irregularities were removed with a No. 1/2 round bur (Brasseler). Castings were then air-abraded with 50-μm aluminum oxide particles under 2.8 kg/cm^2 pressure and steam cleaned. Root canals were irrigated with distilled water and then dried using an air syringe and absorbent paper points (Kerr Mfg. Co).

A resin-modified glass ionomer cement (Fuji CEM, GC Corp.) was employed for the cementation of all cast dowel and cores. Manufacturer's instructions were followed, and the cement was applied with a lentulo paste filler spiral (Dentsply Maillefer) into the canal and with a brush (Bendable Brush) on the cast dowel and core. The hydraulic pressure was released, and firm hand pressure was applied for a period of 10 minutes. All cement excess was removed with a curette. All cementations were performed by the same operator.

Each group was then subdivided into two groups: one with no grooves and another with mesial and distal grooves made with a #170 L (Brasseler) carbide bur. Hence, six groups were created as follows (Fig 1):

(1) Teeth with no remaining coronal tooth structure and no grooves (group A-control);
(2) Teeth with no remaining coronal tooth structure, with mesial and distal grooves (group B);
(3) Teeth with 1 mm remaining coronal tooth structure and no grooves (group C);
(4) Teeth with 1 mm remaining coronal tooth structure, with mesial and distal grooves (group D);
(5) Teeth with 2 mm remaining coronal tooth structure and no grooves (group E);
(6) Teeth with 2 mm remaining coronal tooth structure, with mesial and distal grooves (group F).

The prepared crown parts of all teeth were coated with a 20-μm thick layer of die spacer (Kerr Lab, Orange, CA). Die lubricant (Slick Lube, Kerr Lab) was applied and ABS-wax (Metalor) was used for direct waxing of complete cast crowns with a uniform thickness of 1.5 mm. The wax patterns were then invested with gypsum investment (Novocast,) and cast with type III gold (Mini Gold). The complete cast crowns were divested, placed in an ultrasonic cleaner, and then inspected under a magnification of 10× (Olympus BH-2) for surface irregularities. Positive internal irregularities were removed with a No.1/2 round bur (Brasseler). Castings were then air-abraded with 50-μm aluminum oxide particles under 2.8-kg/cm^2 pressure and steam cleaned. A resin-modified glass ionomer cement (Fuji CEM) was used for the cementation of all complete cast crowns. The cement was applied with a brush (Bendable Brush) on the intaglio surfaces of the crowns. Firm hand pressure was applied for a period of 10 minutes, and all cement excess was removed with a curette after the final setting of the luting agent. All cementations were performed by the same operator.

All specimens were embedded in autopolymeryzing PMMA transparent resin (Ortho resin, Caulk/Densply, Milford, DE). The top surface of the resin block was just 2 mm below the margin of the crown, to minimize the risk of root fracture. This design also simulated the clinical condition found in a healthy periodontium.[56]

A stainless steel rod with a rounded end mounted on a universal testing machine (Instron Corp., Canton, MA) applied controlled loads to the teeth at a crosshead speed of 2.54 mm/min. The loads were applied palatally, 2 mm lower than the incisal edges of the specimens. A custom-made device allowed the load to be exerted at an angle of 130° to the long axis of the tooth.[1,36,57] This angle of loading was chosen to simulate a contact angle between maxillary and mandibular anterior teeth found in a class I occlusal relationship.[58,59] Descriptive statistics, one-way analysis of variance (ANOVA) ($\alpha = 0.05$) and Tukey's honestly significant difference (HSD) tests were used to determine the effect of failure loads among the tested groups ($\alpha = 0.05$).

Results

The mean failure loads are listed in Table 2 and graphically represented in Figure 2. Group E presented the highest failure load and group A the lowest. Groups E and C, which included specimens with no grooves, presented higher failure loads than groups F and D. One-way ANOVA revealed statistically significant differences among the tested groups ($F = 10.42$, $p < 0.0001$) (Table 3). Tukey's HSD test revealed that groups A (control), B, D, and C did not present statistically significant differences ($p > 0.05$). Groups D, C, and F did not present significant differences either ($p > 0.05$). Group E presented

Table 2 Mean values (N) and standard deviations of each experimental condition (n = 10)

	Mean (± standard deviation)	Minimum	Maximum
Group A (control)	151.21 (±38.18)	106.80	240.30
Group B	221.53 (±107.03)	110.00	391.00
Group C	295.35 (±81.92)	213.60	433.00
Group D	270.20 (±76.01)	155.10	383.90
Group E	491.70 (±180.36)	237.30	845.10
Group F	432.67 (±193.83)	207.50	760.00

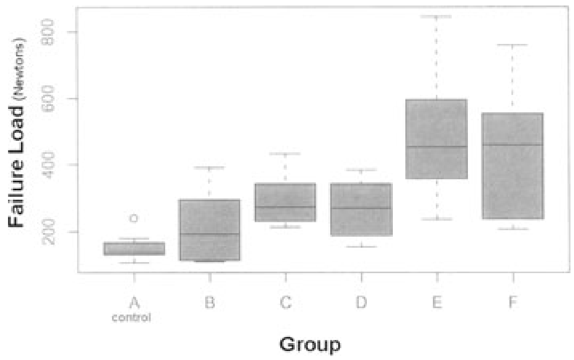

Figure 2 Box plots of failure loads of tested groups.

Table 3 Results of one-way ANOVA for different heights of remaining coronal tooth structure and incorporation of interproximal grooves ($\alpha = 0.05$)

Source	*df*	Sum of square	Mean square	F	*p*
Model	6	829,015.07	165,803.01	10.42	<0.0001
Error	54	85,957.84	15,917.92		
Corrected total	59	1,688,582.90			

statistically significant differences when compared to all groups ($p < 0.05$) with the exception of F ($p > 0.05$) (Table 4).

It should be noted that specimens in groups C, D, E, and F failed because of tooth fracture, while specimens in groups A (control) and B presented cement failure between the dentin and the cement. Groups A (control) and B also demonstrated oblique root fractures buccally (Table 5).

Table 4 Tukey's HSD test to compare the effect of different heights of remaining coronal tooth structure and incorporation of interproximal grooves on the failure threshold (N) ($\alpha = 0.05$) (n = 10)

Tukey grouping	Mean values	Group
I	491.70 (±180.36)	E
II I	432.67 (±193.83)	F
II III	295.35 (± 81.92)	C
II III	270.20 (± 76.01)	D
III	221.53 (±107.03)	B
III	151.21 (±38.18)	A (control)

Mean values with the same Roman numeral are not significantly different.

Table 5 Modes of failure

	Group A (control)	B	C	D	E	F
Cement failure	4	3	–	–	–	–
Tooth failure	6	7	10	10	10	10

Discussion

The current study demonstrated that endodontically treated teeth with 1 mm of remaining coronal tooth structure have a greater failure load than those with no tooth structure. Previous studies[14,33] have also reported that 1 mm of coronal tooth structure above the crown margin substantially increased the fracture resistance of endodontically treated teeth. Although these studies have demonstrated a statistically significant difference in failure loads between teeth with 1 mm and those with no remaining coronal tooth structure, the present study did not confirm this.

The results of this study also verified that a remaining tooth structure of 2 mm substantially increases failure loads when compared to teeth with no or with 1 mm of coronal tooth structure. The observed difference in failure loads between specimens with 2 mm and those with 1 mm of remaining tooth structure is statistically significant. Several papers have also suggested that the crown should extend 2 mm beyond the tooth-core junction to ensure a protective ferrule effect.[3,60] Other investigations based on a photoelastic stress analysis[61] and in vitro studies[36] have recommended that 1.5 mm of remaining tooth structure is needed to protect the tooth from wedging stresses that can cause a fracture.

An important finding of the current study is that the inclusion of interproximal grooves to endodontically treated anterior teeth with 1–2 mm of remaining coronal tooth structure decreases the failure loads. Nevertheless, this finding does not apply to teeth that have cast dowel and cores but those that lack coronal tooth structure. In that case, the failure load is greater for teeth that have proximal grooves. It should be mentioned, however, that the difference is not statistically significant. The inclusion of interproximal grooves as an effective means to improve retention and resistance form when there is a deficient axial height is well documented in the literature.[47,50,52–54] As previously discussed, existence of 1.5–2 mm of coronal tooth structure in endodontically treated teeth restored with dowel and cores seems to be essential to minimizing the risk of dowel dislodgement or root fracture; however, the present study demonstrated that the inclusion of interproximal grooves on teeth with 1–2 mm of coronal tooth structure decreases the failure load. Thus, it could be concluded that the interproximal grooves should be avoided when there is 1 mm or more coronal dentinal extension. In cases where the resistance properties of the preparation are questionable and the interproximal grooves should not be incorporated, the use of an adhesive resin luting agent may prove useful.[4] Nevertheless, it should be mentioned that the specimens of this study were prepared on the bench and the convergence of the axial walls was 8–10°,[62] which is less than usually found in the mouth. In that manner, it is probable that the inclusion of interproximal grooves was not as necessary as in actual patients.

The current study demonstrated that failure in endodontically treated teeth with a coronal tooth structure of 1 to 2 mm presents as a root fracture. On the other hand, in teeth with no coronal tooth structure, the failure is exhibited as decementation or root fracture. Although decementation of the crown or the cast dowel and core can be annoying to the patient, it is always a less frustrating complication than a root fracture, because the tooth and the restoration can usually be salvaged. The results of this study agree with the observations of Sorensen and Engelman[33] who reported that the mode of failure in teeth with remaining dentin will present as a tooth fracture, while on the other hand, teeth with no coronal dentinal extension will present cement failure, tooth fracture, or dowel fracture as modes of failure. Dowel fractures were not observed in the present study. Nevertheless, it should be noted that in Sorensen and Engelman's study a silver-palladium alloy was used while in the current study a type III gold alloy was employed. The luting agent used in the present study was resin-modified glass ionomer, which has a higher overall mean retention than other cements,[63] while in previous studies[14,33] a zinc phosphate cement was used.

A limitation of this in vitro study is that all restorations and bearing teeth were subjected to a static load. Thus, it presents only a partial indication as to what can actually occur in the mouth. Cyclic loading in a wet environment can probably be a better approximation to the clinical condition. A new study in that direction could therefore be helpful in drawing safer conclusions.

Conclusions

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

(1) The failure threshold of endodontically treated anterior teeth with 2 mm of remaining coronal tooth structure which have been restored with cast dowel and cores and crowns is significantly higher ($p < 0.05$) than those with 1 mm or no coronal dentinal extension.
(2) The incorporation of interproximal grooves on the cast dowel and cores of endodontically treated anterior teeth with 1–2 mm of remaining coronal tooth structure does not significantly lower ($p > 0.05$) the failure threshold.
(3) Endodontically treated teeth with 1–2 mm of remaining tooth structure fail because of tooth fracture, while those teeth with no coronal tooth structure fail either because of tooth fracture or cement failure.

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