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Effect of Core Material and Restoration Design on Strength of Endodontically Treated Bovine Teeth: A Laboratory Study

Simon Hinckfuss, BDSc[1] & Peter R. Wilson, MDS, MS, FDSRCS Ed, DRDRCS Ed, PhD, PG Hlth Admn[2]

[1] Candidate for Doctor of Clinical Dentistry, School of Dental Science, University of Melbourne, Victoria, Australia
[2] Professor, School of Dentistry and Oral Health, La Trobe University, Bendigo, Victoria, Australia

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Correspondence
Prof. Peter Wilson, School of Dentistry and Oral Health, La Trobe University, PO Box 199, Bendigo, Victoria 3552, Australia.
E-mail: prwilson@latrobe.edu.au

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Abstract

Purpose: The purpose of this study was to evaluate the fracture resistance of bovine teeth restored with one-piece cast core/crowns and no ferrule, compared to teeth restored with amalgam cores and full coverage crowns, with and without a dentine ferrule.
Materials and Method: Thirty bovine incisors were selected and modified to ensure all teeth had axial dentine walls of similar size. The teeth were then randomly allocated to one of the three groups: control group restored with amalgam core and cast crown without ferrule; ferrule group restored with amalgam core and cast crown with a 2-mm dentine ferrule; one-piece group restored with one-piece cast core/crown without ferrule. Each tooth was loaded to the point of fracture.
Results: The mean load resisted by the control group, the ferrule group, and the one-piece group were 1092.5, 1843.5, and 1463.1 N, respectively. The mean load resisted by the ferrule group was significantly greater than the control group ($p < 0.001$) and the one-piece cast core/crown group ($p = 0.04$). The mean load resisted by the one-piece cast core/crown group was significantly greater than the control group ($p = 0.04$).
Conclusions: The maximum load resistance was significantly enhanced by a 2-mm ferrule compared with teeth with no ferrule and teeth restored with one-piece cast core/crowns. Teeth restored with one-piece cast core/crowns were significantly more resistant to loading than teeth restored with amalgam cores and crowns without a ferrule.

Endodontically treated molars should ideally be restored with durable restorations with cuspal coverage.[1] This is often achieved by either an amalgam or composite resin core initially, followed by a full coverage crown. An important feature of the restoration is that it will protect the tooth cusps from fracture and provide a coronal seal.

If there is minimal supragingival tooth structure, a decision must be made on whether to crown lengthen the tooth. A ferrule is considered beneficial when crowns are placed, as the load is resisted by the tooth and not just the core;[2-4] however, the creation of a ferrule may not be universally beneficial.[5] If a ferrule is not created, amalgam cores may not have sufficient tensile strength to resist occlusal forces.

The path of insertion of most molars means that it is possible to construct a one-piece cast core/crown without a post to restore endodontically treated molars. Neither laboratory nor clinical studies are available in the literature to support the use of one-piece cast core/crowns. Possible benefits of using a one-piece cast core/crown could be the following: increased tensile strength of the core portion, dimensional stability over time, similar coefficient of thermal expansion to dentine, assured retention of crown to core if clinical crown height is short, and clinical efficiency. A limitation is that the path of insertion of the crown must coincide with the core, and if a post is used, the crown, core, and post must all have the same path of insertion. This could require removal of additional tooth structure and/or shortening of the post.

Potential negative effects of creating a ferrule on molars are encroachment on the furcation, increasing the crown:root ratio, and removal of bone that may be needed later for implant placement. Crown lengthening only aids the creation of a ferrule when the remaining axial dentine thickness is adequate after the crown margin has been prepared. Gegauff's laboratory study[5] simulated the creation of a ferrule by crown lengthening and hence lengthening of the clinical crown and shortening of the root. It concluded that a ferrule might weaken premolar teeth. Most previous studies have ferrule specimens with more tooth structure than the control specimens, whereas the decision to create a ferrule often requires removal of additional tooth structure from a decoronated tooth.

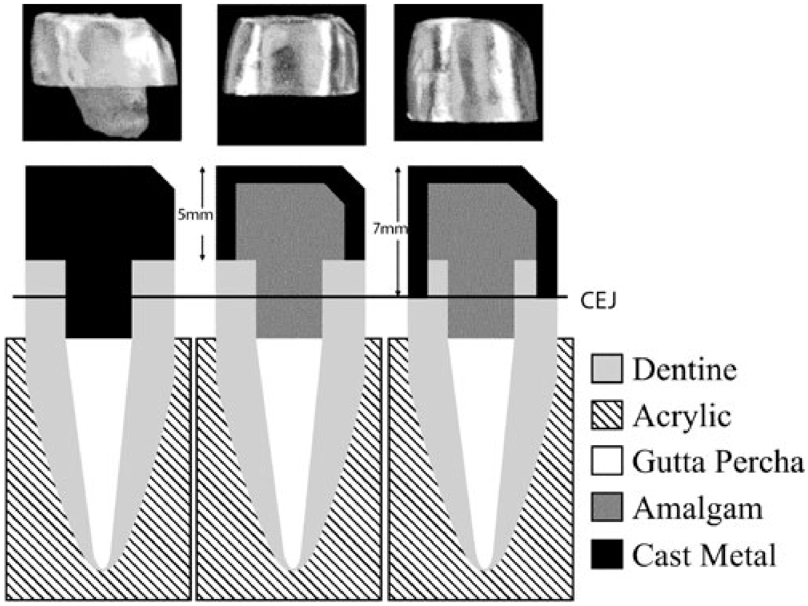

Figure 1 (l to r): One-piece cast crown (O), control (C), 2-mm ferrule (F).

Corono-radicular amalgam cores without posts have been shown to be adequate, so it is possible a cast core does not need a post either. Posts do not offer a benefit in molar teeth unless there is inadequate pulp chamber height to retain the core.[1,6–8]

Potential expansion of amalgam over time or as a result of thermal expansion has been theorized as a possible mechanism of root fracture.[9] There is no evidence to suggest that this is a clinical problem. Nevertheless, a cast core offers the advantage of dimensional stability within the pulp chamber eliminating this concern. During thermocycling, cast metal has a similar coefficient of expansion to dentine, whereas amalgam has a higher coefficient of thermal expansion.[10]

The purpose of this study is to compare the maximum static load that can be resisted by bovine teeth restored with one-piece cast core/crowns and no ferrule, with teeth restored with amalgam cores and full coverage crowns with and without a dentine ferrule. The three groups are represented diagrammatically (Fig 1).

Materials and methods

Maxillary incisors were extracted from recently killed cows. Soft tissue was removed from the external surface of all teeth using a scalpel blade prior to storage in 1% chloramine T solution. Thirty teeth were selected for the study.

All 30 teeth were mounted vertically in autopolymerizing acrylic resin (Vertex Dental BV, Zeist, The Netherlands) inside a 24-mm length of PVC pipe (20-mm diameter electrical conduit), with the buccal cemento-enamel junction (CEJ) 2 mm above the edge of the pipe. The teeth were decoronated horizontally 2 mm above the buccal CEJ using a diamond disc (Komet. Ref. No. 936104220 GEBR, Brasseler GmbH & Co, Lemgo, Germany). Pulp tissue was removed with barbed broaches. The pulp chambers of all teeth were then enlarged using a bullet-nosed diamond bur in a high-speed handpiece, with copious water irrigation, to standardize the axial wall thicknesses of all specimens at 2.4 mm on the buccal and 2 mm on the mesial, distal, and lingual. The pulp canals were then filled with gutta-percha leaving the "pulp floor" 4 mm apical to the buccal CEJ.

The teeth were then randomly allocated into three groups of ten. The control group (C) and the ferrule group (F) had amalgam cores packed (Permite, SDI, Melbourne, Australia) to create cores 4 mm high. Both of these groups had crown preparations with 1-mm wide shoulder margins prepared under copious water irrigation using a dental milling machine and long-shank tapered diamond bur with a 1-mm flat end (H 173016, Horico, Berlin, Germany). The taper of the bur was 5°, resulting in a total occlusal convergence (TOC) of 10°. The control group margin was at the same level as the core, whereas group F had a margin prepared 2 mm apical to the core–tooth junction (Fig 2).

Impressions of the teeth in all three groups were made with poly(vinyl siloxane) (Aquasil®, Dentsply, Milford, DE), and dies were then poured (GC Fuji Rock® EP, GC Europe, Leuven, Belgium). Four layers of die spacer (True-Fit, Geo. Taub, Jersey City, NJ) were applied to the dies. Full coverage crowns were

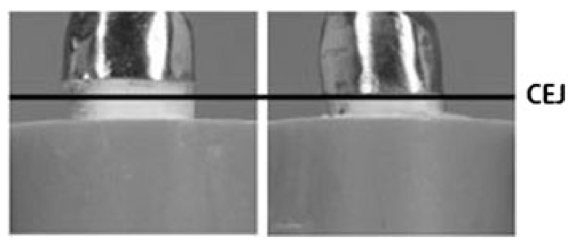

Figure 2 Specimens mounted in PVC tubes. Once cemented, the control (C) and one-piece casting (O) groups both had crown margins 4 mm above the PVC tubes edge. The ferrule group (F) had margins lowered 2 mm to the level of the CEJ (right).

waxed up on the dies for group C to a height 5 mm above the prepared cavosurface margin, and 7 mm above the margin for group F. One-piece cast core/crowns were waxed up for group O with a height 5 mm above the root face. A 45° bevel was placed on the lingual occluso-axial line angle. All three groups were cast using base metal alloy (Argeloy, SDI). Each casting was examined under 10× magnification for casting defects and to ensure passive seating on their respective teeth.

All restorations were cemented with encapsulated zinc phosphate cement (DeTrey® Zinc crown and Bridge Fixodont® Plus, Dentsply DeTrey GmbH, Konstanz, Germany) as per the manufacturer's instructions. A thin layer of cement was applied to the preparation and the margin of each crown using a brush. Finger pressure was maintained until the cement had set.

To hold the samples in a standardized position during testing, an acrylic block was built on a metal base with a hole in it to receive the specimens. The hole was made in the block at a 45° angle to allow application of a force at that angle. Fracture testing was conducted with a static load applied with a crosshead speed of 3 mm/min using an Instron Machine (Instron, Darmstadt, Germany).

The output from the machine was monitored with Labview software (National Instruments Corp., Austin, TX). Six specimens from group F did not fracture at the maximum force (2000 N) that could be applied with the Instron Machine. Those specimens were subsequently tested using an MTS machine (MTS System Corp., Eden Prairie, MN). The results were analyzed using a one-way ANOVA test and pairwise comparisons between groups, as well as a Kruskal-Wallis analysis.

Results

The mean load resisted by the control group was 1092.5 N (95% CI: 839.8, 1345.2). The mean load resisted for groups F and O were 1843.5 N (95% CI: 1590.8, 2096.2) and 1463.1 N (95% CI: 1210.4, 1715.8), respectively. The individual loads resisted are shown in Table 1 and represented as a dot plot in Figure 3.

A one-way ANOVA of the data found that overall the means for the groups were not the same ($p = 0.001$). The mean load resisted by group F was significantly greater than group C ($p < 0.001$) and group O ($p = 0.04$). The mean load resisted by group O was significantly greater than group C ($p = 0.04$).

Table 1 Maximum fracture force (N) for each group

Specimen	One-piece	Control (no ferrule)	Ferrule
1	1577.54	394.18	1454.04
2	1588.47	1436.55	2300.78
3	1839.84	1245.19	2000.00
4	1458.82	1252.27	2447.26
5	1152.37	1180.44	2462.89
6	1609.40	421.38	1226.11
7	1293.52	1517.86	2000.00
8	1371.48	1256.36	1317.42
9	1050.14	1152.37	1226.03
10	1689.81	1068.11	2000.00
Mean (N)	1463.14	1092.50	1843.45
95% CI	1210-1715	839-1345	1590-2096

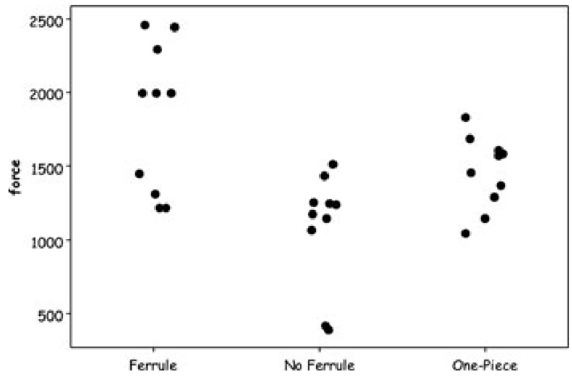

Figure 3 Maximum fracture force (N) for each sample in all groups.

There was some deviation from normality in the distribution of fracture forces in groups F and C. The ANOVA test assumes normality, so a nonparametric Kruskal-Wallis test was done to compare the medians. This test also found significant differences between the groups, confirming the results of the ANOVA.

The fracture mode was the same for all specimens in groups F and O, with the fracture occurring obliquely from the base of the pulp chamber and passing through to the buccal without cohesive fracture of the core material. The control group specimens varied, with some fracturing through the amalgam core as well as the root and others fracturing only the root (Fig 4).

There were two specimens in the control group that gave an indication the amalgam core may have been shearing as the load increased well prior to the root fracturing, as an audible crack occurred while this was happening. The fracture load for these specimens was recorded at the first audible fracture, and then the force was increased until separation of the restoration from the root occurred.

Discussion

Restoration of endodontically treated molars with amalgam cores and full coverage crowns is widely accepted as a reliable method. This is largely based on two retrospective clinical studies.[1,6] Most studies in this area are laboratory studies, which either examine cores alone or cores with crowns. Predominantly they examine anterior teeth with some studies examining posterior teeth, usually using premolars. As the width of axial dentine differs between tooth types, only studies using the same tooth type should be compared. Furthermore, studies examining the role of a ferrule can either have ferrule specimens with additional dentine relative to the control or specimens where the ferrule has been created by lowering the margin. Most studies have ferrule specimens with additional tooth structure, so the effect of crown lengthening endodontically treated molar teeth to create a ferrule has not been well studied.

The results of this laboratory study need to be interpreted within its limitations. The height of the crowns, dimension of the teeth, the type and direction of load, and mounting method could have influenced the outcome of this experiment. The specimens were mounted in PVC tubes with the buccal CEJ 2 mm above the acrylic. This approach has been followed by

Figure 4 Typical fracture patterns seen. Amalgam core and crown without ferrule (left), one-piece core/crown (center), amalgam core, and crown with ferrule (right).

numerous authors, who also mounted the teeth 2 mm below the CEJ simulating the natural average biologic width.[2,7,11,12]

A pulp chamber height of 4 mm was selected. The height of the pulp chamber primarily influences the retention of the core. The remaining pulp chamber height has been reported as 3 to 4 mm when the coronal portion of a mandibular molar is removed 1 to 2 mm coronal to the CEJ.[12,13] By selecting a 4-mm pulp chamber height, adequate retention is ensured for a core without using a post or extending the core into the canal orifices, and it simulates a molar that has been decoronated 2 mm supragingivally. It would be of interest to follow up this study on teeth with 2-mm pulp chamber heights (simulating a tooth decoronated equigingivally) and various crown heights.

The height of the crowns was 5 mm in groups O and C and 7 mm in group F due to the additional 2-mm apical extension to create the ferrule. Figure 5 shows how the clinical crown height could affect the type of force applied to the core for a given direction of loading.

The height used was consistent with similar studies. Hoag and Dwyer[11] and Kern et al[14] rebuilt the cores to 5 mm above the CEJ. Gelfand et al[15] built cores 6 mm above the CEJ. Kane et al[12] built cores 7.5 mm above the CEJ. Except for purely axial forces, taller crown heights alter the direction and magnitude of forces applied to the core for a given force, accentuating the lateral component.

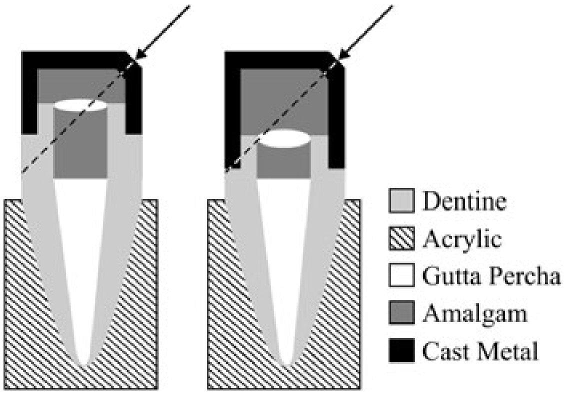

Figure 5 The force (arrow) applied toward a tooth with a shorter crown height (left) passes through the core applying a compressive and shearing force in the area of the white ellipse. If the clinical crown height is increased by crown lengthening (right), the same force will now create a tensile force in the area of the white ellipse.

Both groups with amalgam cores received crown preparations with 10° TOC. This was consistent with the 10° TOC used by Burke et al[16] and Kern et al.[14] Hormati and Denehy[17] prepared cores with a 7° TOC. None of the specimens showed cohesive failure of the cement between the crown and the tooth. If there is a situation where the expected TOC of an amalgam core prepared for a crown is too great, the one-piece cast core/crown is an alternative.

Bovine teeth were used rather than human molars due to the difficulty of collecting suitable human molars. The mechanical properties of bovine and human teeth are comparable,[18] and the dimensions of the specimens were similar to average human molars. Bovine incisors only have one canal, whereas human molars have multiple canals and usually have a pulp chamber floor. It is unclear whether this biased one design over another.

The cross-sectional area of the pulp chamber could have influenced the finding of a difference in the mode of fracture between groups C and O. A key difference between these groups was the possibility of the core fracturing in the control group. Amalgam cores require a larger bulk of material to resist tensile and shear forces compared with cast cores. The critical cross-sectional bulk of amalgam core material required was not investigated in this experiment, and it would be expected to vary depending on the direction of forces on an individual tooth. The dimensions of most human molar pulp chambers exceed those of the teeth used in this study. Two of the amalgam cores in the study fractured without the tooth also fracturing, which may not have occurred if the pulp chambers had been larger. Nevertheless, a cast core provides a theoretically superior resistance to cohesive fracture relative to an amalgam core.

A further limitation of this study may be the loading regimen. Fatigue testing has been proposed as having more clinical relevance, but this assumes that the fatigue limits of the restored teeth are below typical intraoral forces. Static load testing has been established as an appropriate method as a comparative test for core buildup restorations in posterior teeth,[16,19–21] which satisfied the aim of this experiment. It was decided that the time and resources required for fatigue testing would not add to the clinical significance of this experiment.

The initial audible cracking in two specimens in group C was speculated to be a sign that the amalgam cores were shearing while being simultaneously compressed. Gelfand et al[15] reported fractures at two loads, the first being at the point when an audible fracture could be heard and the second reported as visible separation of the segments occurred. The apparent failure of the amalgam cores in two specimens prior to the root fracturing gives an indication that they may be less resistant to the lateral component of the applied force compared with cast cores. The initial cracking noise occurred at 394 and 421 N in these two samples, which is less than typical maximum bite forces reported in vivo.[22,23] In situations where a ferrule is not present and significant lateral forces are expected, a cast core is unlikely to fracture.

The results support the creation of a ferrule in teeth with 2.4 mm of axial wall thickness. An important issue for ferrules could possibly be the axial wall thickness of the tooth. The different outcome between Gegauff's study,[5] which found a ferrule weakened premolar teeth, and the current study, which found a ferrule strengthened restored molar-sized teeth, may indicate that creation of a ferrule is of benefit in situations where there is adequate axial wall thickness. The axial wall thickness of specimens is rarely described and may well be relevant. If the axial wall thickness of a tooth is 2 mm, and a 1.5-mm crown margin is prepared with 2 mm of ferrule height, the ferrule will be 0.5 mm thick and 2 mm high, and hence offer little resistance to loading. The axial wall thickness of molar teeth has been reported to range between 2 and 3.3 mm at the CEJ, thus not all endodontically treated molars are suitable for 1.5-mm porcelain fused to metal margins, and thinner metal margins should be considered in some cases.

In situations where a decision is made not to create a ferrule, the results support the resistance to static load of one-piece cast core/crowns and showed them to be statistically significantly stronger than an amalgam core and cast crown without ferrule. The potential for the amalgam core to fracture at lower loads (around 400 N) as seen in two of the control specimens needs further investigation. It could indicate this design has a fatigue limit that is lower than the cast core and below typical in vivo forces. It would also be interesting to compare the resistance of one-piece cast core/crowns to horizontal loads. A proposed protocol for the use of one-piece cast core/crowns is:

(1) Thick axial dentine (remaining thickness after crown margin preparation is adequate): Creation of ferrule justified. Consider amalgam core and cast crown with ferrule. Minimal reduction using metal margins is recommended.
(2) Thin axial dentine (remaining thickness after crown margin preparation would be inadequate): Creation of ferrule not justified. Consider one-piece cast core/crown.
(3) The expected TOC of an amalgam core prepared for a crown is too great to provide retention and resistance for the crown. The one-piece cast core/crown is an alternative.
(4) In short teeth where the retention and resistance form of the crown preparation are poor, a one-piece cast core/crown ensures retention of the crown to the core.

Conclusion

Bovine teeth restored with amalgam cores and crowns were found to be strengthened when a 2-mm ferrule was created. When no ferrule was used, bovine teeth restored with one-piece cast core/crowns were significantly more resistant to fracture than amalgam cores with crowns. If a ferrule is not available and the clinical situation contraindicates crown lengthening, use of a one-piece cast core/crown can be considered. Future studies could examine the performance of one-piece cast core/crowns with ferrule, as well as the critical thickness of axial root dentine to make the ferrule effective.

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