Original Article

Effect of central cavity depth and ferrule on the mechanical retention of endo-crowns

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Abstract
Introduction: This study evaluated the effect of central cavitation depth and the presence of ferrule on the mechanical retention of zirconia endo-crowns.
Methods: A mandibular molar was selected and scanned after different preparations. The preparation designs were grouped as follows: Group 1 (Control): Full coverage complete crown, group 2 (EF4): endo-crown with 4 mm central cavity depth and ferrule, group 3 (E4): butt joint endo-crown with 4 mm central cavity depth, group 4 (E2): butt joint endo-crown with 2 mm central cavity depth, and group 5 (EF2): endo-crown with 2 mm central cavity depth and ferrule. Then zirconia copings were made using computer-aided design (CAD) and computer-aided manufacturing (CAM) and cemented by glass ionomer. After thermocycling, the specimens were subjected to a tensile test along the axis and at an angle of 30°.
Results: All restorations in E2 were deboned during thermocycling. There was no significant difference between the other groups in pulling-out forces. Pulling-out forces under the axial test were 75.7 N, 84.7 N, 98.7 N, and 80.9 N, and under the lateral force were 21.2 N, 27.5 N, 35.4 N, and 28.5 N, for the control, E4, EF4, and EF2 groups, respectively. The difference in pulling-out forces was not significant between the control, E4, EF4, and EF2 groups (P=0.46).
Conclusion: The presence of ferrule increased mechanical retention to some extent. It appears that peripheral reduction in the aims of gaining a ferrule may increase mechanical retention in teeth with shallow cavity depths. *(J Dent Mater Tech 2023;12(1): 35-42)*

Keywords: *Central cavitation depths, endo-crown, ferrule, mechanical retention, zirconia*

Introduction
Rehabilitation of endodontically treated teeth is still challenging (1). Fabrication of post and core followed by crown full coverage is commonly suggested for teeth that lost two or more coronal walls (2). However, this type of restoration requires several appointments, and access to the root canals would be difficult or impossible in the case of future endodontic retreatment (3). Moreover, post-fabrication is not applicable in teeth with short or curved roots (4,5). In addition, this treatment plan would not provide sufficient crown resistance without a ferrule and in cases with short occlusal height (5,6).

The monoblock design of the endo-crown was introduced as a conservative alternative for restoring severely damaged teeth to maximize dental structure preservation. This restoration consists of a ceramic piece (4) comprising a coronal structure and a central retainer, which uses the pulp chamber for mechanical retention rather than the root canals (4, 7).

According to the available literature, endo-crowns may perform similarly or even better than conventional intra-radicular posts, inlays/onlays, and direct composite resin restorations (8). Clinical studies have reported a success rate of 94-100% for endo-crowns (8-10). The long-term success of endo-crowns is affected by the appropriate case selection, adhesion to the dental substrate, and material selection, as well as the tooth preparation design (9).

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Endo-crowns are now a reliable option for molar restoration; although, there is disagreement among researchers regarding the endo-crown survival rate in premolars (9). Sedrez-Porto et al. exhibited no significant difference in the survival rates of molars restored with endo-crowns or conventional post-core crowns (8). A retrospective study revealed that over a 10-year long period, only 2% of reported endo-crown failures were due to debonding (11).

In addition to the mechanical retention from the pulp chamber cavity, endo-crowns attain retention by chemical bonding to the dental substrate. Therefore, the endo-crowns are fabricated with materials that can be chemically adhered to the tooth (4, 6) such as indirect composite resins, lithium disilicate, and zirconia ceramics (12, 13); among them, zirconia has the highest strength (14). With the introduction of numerous techniques, including acid etching and abrasion by diamond chip tools (1), zirconia can now be considered a bondable material to the tooth structure (15-18), benefitting from a combination of mechanical and chemical retention (19). Evaluating the mechanical retention of different designs of endo-crowns and comparing them with conventional crowns is an interesting subject for all-ceramic materials, especially zirconia.

In endo-crowns, the depth of the central cavity is determined by the pulp chamber anatomy and the remaining coronal tissues. It can influence the marginal adaptation of the restoration, stress distribution, and fracture resistance of the tooth (20-22). The presence of any finish-line preparation in the cervical margin of the endo-crown can be regarded as the ferrule. It has been demonstrated that the presence of a ferrule improves fracture resistance of dental structures (23-25), and it leads to more favorable stress distribution to the roots as compared to a cast post and core (1, 26). Although in endo-crown preparation, a butt joint finishing line is prepared for maximum bonding above the cement-enamel junction (CEJ) (4), in some studies, other forms of preparations such as chamfer or shoulder finish-line have been used (27-32).

The present study aimed to evaluate the effect of central cavity depth and the presence of ferrule on the mechanical retention of endo-crowns.

Ferrule presence promoted more satisfactory stress distribution to the roots.

Materials and Methods

One sound mandibular molar was selected and extracted due to periodontal involvement, and the tooth was scanned by a cone-beam computed tomography (CBCT) device (PLANMECA Promax 3DMax-Helsinky Finland) after each preparation (Fig 1). For each preparation design, ten specimens were printed (DLP/PLANMECA Creo-Helsinki Finland) using a dental resin model and cured by ultraviolet (UV) light.

Preparation designs

The preparation designs were grouped as follows:

Group 1 (C; control): A conventional full crown preparation was designed in this group. The axial wall was prepared with a convergence of 10º and a 120º-sloped shoulder finish line using a diamond dental bur. When the preparation was completed, the coronal height was 5 mm from the finish line at the CEJ. Then it was scanned, and ten specimens were made, as mentioned above (Fig 1-A).

To prepare other groups, the axial walls were shortened to 2 mm above the CEJ. The access cavity was then prepared, and the root canals were cleaned and obturated by gutta-percha and a resin-based sealer. After that, the next four groups with different endo-crown designs were prepared as follows:

Group 2 (EF4; the endo-crown group with 4 mm central cavity depth and ferrule): The pulp chamber floor was flattened with glass ionomer luting (GC Fuji I) till the vertical height of the chamber reached 4 mm. Then it was scanned, and ten specimens were printed (Fig 1B).

Group 3 (E4; the butt joint endo-crown group with 4 mm central cavity depth): The finish-line of EF4 preparation was modified to the butt joint finish-line by glass ionomer mixed with amalgam powder (1 mm width, 4 mm height). Then it was scanned, and ten 3D-printed specimens were made (Fig 1C).

Group 4 (E2; the butt joint endo-crown group with 2 mm central cavity depth): Glass ionomer was added to the chamber floor of E4 preparation to reduce the vertical height of the chamber to 2 mm (Fig 1D).

Group 5 (EF2; the endo-crown group with 2 mm central cavity depth and ferrule): The combination of glass and amalgam powder that was added to create the butt joint margin was eliminated from the E2 preparation design. Then, the tooth was scanned, and ten 3D-printed specimens were prepared (Fig 1E).

Table 1 shows a short description of groups and their specifications.

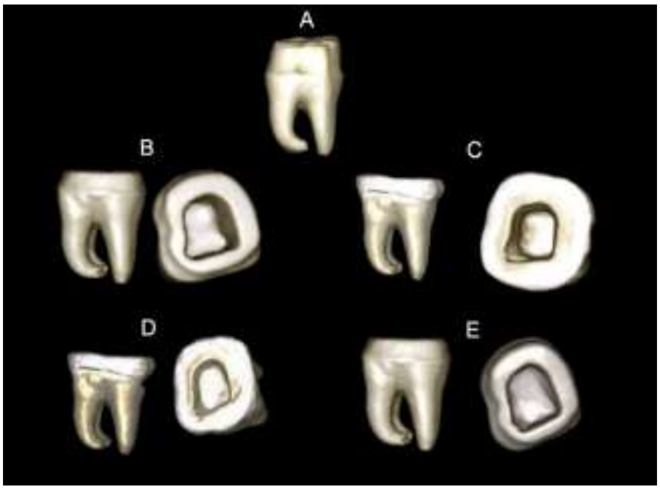

Figure 1. Representative images of scanned specimens after different preparations. A. Full crown preparation, B. The endo-crown group with 4 mm central cavity depth and ferrule (EF4), C. The butt joint endo-crown group with 4 mm central cavity depth (E4), D. The butt joint endo-crown group with 2 mm central cavity depth (E2), E. The endo-crown group with 2 mm central cavity depth and ferrule (EF2).

Fabrication of restorations

The printed specimens were scanned with a Laboratory Scanner (Smart Optic-Activity885). Zirconia copings (Dental Direkt, Germany) were designed by Exocat software and milled with a milling machine (VHF-S2, Germany/CAM5-S2 impression). All the copings had the same external height and an extension of $3\times3\times3\ mm^3$ for tensile tests (Fig 2).

Tensile bonding test

The root section of specimens was mounted in self-cure acrylic resin using a cylindrical mold. The copings were cemented with glass ionomer luting cement (GC Fuji TM, Japan/LOT: 1705181) under a force of 300 g. Five thousand thermal cycles between 5º and 55℃ were performed. Finally, a tensile load was applied along the vertical axis at a 1 mm/min speed using a universal testing machine (STM-20, Santam, Iran; Fig 3).

Table 1. The group specifications

Group	*Description*	*Number*
C	5 mm height-axial wall with a convergence of 10º and 120º sloped shoulder finish-line	10
EF4	Endo-crown with 4 mm central cavity depth and ferrule	10
E4	Butt joint endo-crown with 4 mm central cavity depth	10
E2	Butt joint endo-crown with 2 mm central cavity depth	10
EF2	Endo-crown with 2 mm central cavity depth and ferrule	10

Figure 2. Printed resin specimens and zirconia copings for each group

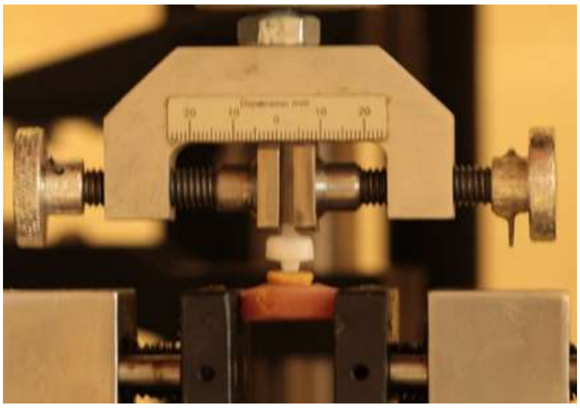

Figure 3. Tensile test along the vertical axis of the specimens

The mode of failure was determined using a stereomicroscope at 40X magnification. The failure mode was scored as follows:

A: The failure occurred entirely at the cement-zirconia coping interface, and all cement remained on the dental resin model.

B: Some parts of the cement are on the dental resin model, and the rest are on the zirconia coping.

C: The failure occurred entirely at the cement-resin model interface, and the cement remained on the zirconia coping.

The specimens and copings were cleaned after the cement was removed from the surfaces. Copings were re-cemented and aged as previously mentioned. The specimens were then subjected to 30º angular tensile testing.

A jig was designed with SolidWorks software (Fig 4) and printed using a 3D MBOT printer to perform the angular test. The jig was a three-dimensional trapezoid with a 30° angled face. To accommodate the coping extensions, a cubic hollow (3×3×3 mm) was created at the middle of the angled face and perpendicular to its surface. The jig was duplicated to 50 pcs using self-cure acrylic resin and was attached to the specimens using a rapid-cure cyanoacrylate adhesive (SanaBond, Alan Sanat, Iran). When the jig was vertically attached to the device, the specimens had an angular 30° longitudinal axis. Finally, the tensile load was applied at the speed of 1 mm/min until the restorations were detached (Fig 5).

Results

Restorations were detached in all 10 specimens of the E2 group after the thermocycling. Therefore, no analysis was performed for this group. Table 2 shows the mean and standard deviation of pulling-out forces for the remaining 40 specimens.

The Two-way ANOVA showed that different designs of specimen preparation had no significant effect on either axial or lateral pulling-out forces (P=0.46; Table 2).

Figure 4. The designed jig for angular tensile force

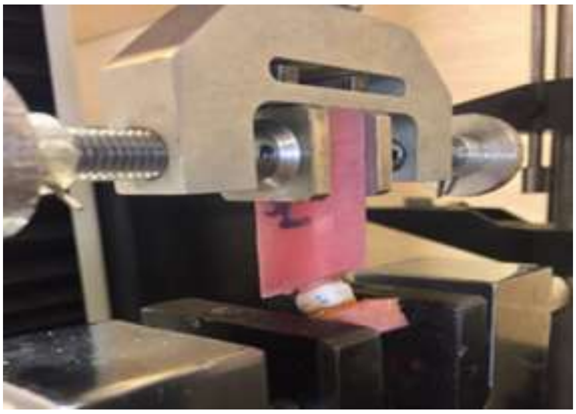

Figure 5. Angular tensile test

However, the effect of the loading angle was significant (P<0.001; Table 2). The interaction between the two variables (Preparation design × loading angle) was not significant (P=0.9; Table 2).

Figure 6 presents representative samples of different failure modes in the study groups. All specimens detached from cement joints, except for one specimen in the EF4 group, which was fractured through the dental resin model above the CEJ.

The Chi-square test showed that the distribution of cement failure location was significantly different among the groups in the axial tensile test [P=0.02], but there was no significant difference in failure mode among the groups when applying the angular pulling-out force [P=0.06].

Table 2. The mean and standard deviation (SD) of axial (0°) and lateral (30°) pulling-out forces in the study groups

Group	Axial force	Lateral force
	Mean (SD)	Mean (SD)
Control	75.7 (26.5)	21.2 (9.0)
E4	84.7 (29.4)	27.5 (21.1)
EF2	80.9 (27.6)	28.5 (11.5)
EF4	98.7 (23.2)	35.4 (9.0)
Effect of preparation design	P=0.46	
Effect of loading angle	P<0.001	
Interaction	P=0.9	

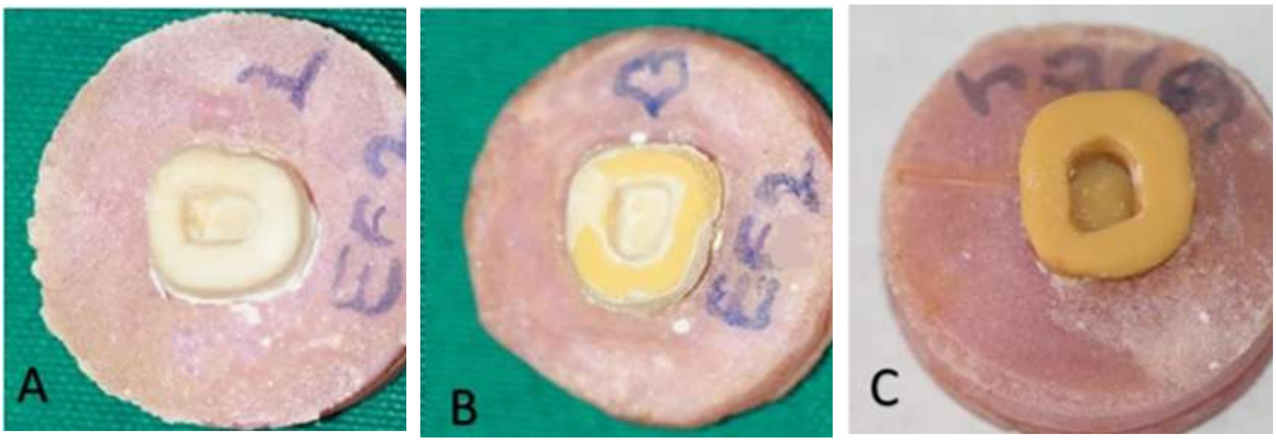

Figure 6. Representation of different types of cement failure

Discussion

The present study examined the mechanical retention of different endo-crown designs. There are controversial studies on the effect of the depth of the central cavity and the presence of ferrule on endo-crown retention (7, 20-22, 28, 29, 31-37). Some studies have shown that different depths of the central cavity affect the marginal and internal gaps of endo-crown restorations, such that the internal and marginal gaps increase in deeper central cavities (20, 21). However, in other studies, changes in central cavity depth did not affect the marginal gap and marginal internal consistency (35, 36, 38).

In the present study, the mechanical retention was enhanced to some extent by increasing the central cavity depth regardless of the finish-line design. This can be explained by the increased surface area, which decreases the stress magnitude. However, the difference between groups was small and not statistically significant. On the other hand, the effect of loading angle on bond strength was significant, so the values of pulling-out forces were significantly lower in the lateral tensile test than that in the axial tensile test.

In the current study, debonding occurred at lower forces in the full crown preparation design as compared to most endo-crown groups. Although the difference was not significant, the lower debonding force can be due to the greater distance of the axial walls from the point of the applied force (center of the tooth) in the full crown design compared to the endo-crown preparation designs. It means that the pulling force produced much more moment in axial walls in the full crown design; consequently, the failure was observed at lower forces.

In this study, mechanical retention improved by increasing the central cavity depth. Moreover, a comparison of displacement force between E4 and EF2 groups showed that adding ferrule may have a compensating effect when the central cavity is shallow. As all specimens in the E2 group failed during thermocycling, it can be assumed that these specimens had a significantly lower force value than that of the EF2 group, in which the ferrule was added to the same cavity depth. These findings reveal that ferrule can increase mechanical retention, especially when the central cavity is shallow. This increased retention can be attributed to the increased surface area, and the creation of four outer and inner axial walls that oppose each other, thus affecting the stress distribution (39).

It has been observed that the presence of ferrule decreases the probability of catastrophic failures. Einhorn et al. (28) reported that non-ferrule endo-crown preparation showed the least failure load and fracture resistance. On the other hand, catastrophic failures were lower in endo-crowns with a 1 mm ferrule (28, 40). In our study, except for one specimen in the EF4 group that fractured through the dental resin model above the CEJ, all other specimens just detached from the cement joint. The location of cement failure may imply how deep debonding stresses distribute along with the tooth structure. By increasing the depth of the central cavity and adding the ferrule effect, the failure progresses deeper into the cement and cement-tooth model interface.

The outcomes of this study showed significant differences in failure mode among the groups when axial forces were applied, whereas pulling-out force with a lateral angle did not affect the pattern of debonding. This may indicate that the preparation design was effective on stress distribution in axial pulling-out forces. During the application of lateral pulling-out force, the stress distribution was not significantly affected by the preparation design.

Conclusion

Regarding the conditions and limitations of this study, it can be concluded that:

1. Mechanical retention of endo-crowns improves slightly with increasing the central cavity depth. However, the risk of catastrophic failure should be studied in the future.

2. Adding ferrule increases mechanical retention of endo-crowns with shallow central cavities and may be suggested in teeth with insufficient crown length.

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Conflict of Interest

No potential conflict of interest was reported by the authors regarding the publication of the present study.

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