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Fracture Resistance of Endodontically Treated Teeth: Three Walls versus Four Walls of Remaining Coronal Tooth Structure

Siriporn Arunpraditkul, DDS, MS,[1] Siranee Saengsanon, DDS,[2] & Wilasinee Pakviwat, DDS[2]

[1] Senior Lecturer, Department of Conservative Dentistry and Prosthodontics, Faculty of Dentistry, Srinakharinwirot University, Bangkok, Thailand
[2] Undergraduate Student, Faculty of Dentistry, Srinakharinwirot University, Bangkok, Thailand

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Correspondence
Siriporn Arunpraditkul, Department of Conservative Dentistry and Prosthodontics, Faculty of Dentistry, Srinakharinwirot University, Sukhumvit 23, Wattana, Bangkok, Thailand. E-mail: siriporr@hotmail.com

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Abstract

Purpose: The purpose of this study was to evaluate the fracture resistance of endodontically treated teeth between those with four walls and those with three walls of remaining coronal tooth structure and the effect of the site of the missing coronal wall.
Materials and Methods: Thirty-two endodontically treated second mandibular premolars were decoronated, leaving 3 mm above the cementoenamel junction (CEJ). A 0.5-mm-wide chamfer was prepared 1 mm above the CEJ. The teeth were randomly divided into four groups. Group 1 had four walls of coronal tooth structure, whereas groups 2, 3, and 4 had only three walls, missing the buccal, lingual, and mesial wall, respectively. The cast dowel and cores and crowns (Ni–Cr alloy) were cemented with zinc phosphate cement. A compressive load was applied 45° to the long axis, 2 mm below the buccal cusp, with an Instron machine until failure at a crosshead speed of 5 mm/min. Failure load (kg) and mode of failure were recorded. Data were analyzed with one-way ANOVA and Scheffé tests ($p < 0.05$).
Results: Group 1 had the highest fracture resistance (1190.3 ± 110.5 kg), significantly different from the other groups ($p < 0.05$) (group 2: 578.5 ± 197.4 kg; group 3: 786.6 ± 132.8 kg; group 4: 785.4 ± 289.9 kg). There were no significant differences among the test groups. The mode of failure in group 1 was a horizontal root fracture, whereas that of the other groups was either vertical or oblique fracture.
Conclusions: Teeth with four walls of remaining coronal dentine had significantly higher fracture resistance than teeth with only three walls. The site of the missing coronal wall did not affect the fracture resistance of endodontically treated teeth.

The preservation of tooth structure is an important factor in the successful restoration of endodontically treated teeth. Several authors have emphasized the maximum preservation of remaining sound tooth structure both around the dowel[1-3] and the coronal aspect.[4-5] The retaining coronal dentine provides an irregular contact surface between the tooth and cast core, resulting in increased retention of dowel and core,[5] reducing the stress transmission to the root,[6-8] increasing the dowel length, and resisting dowel and core rotation.[9] When the restored crown has 360° of sound coronal tooth structure, four walls of remaining coronal dentine, and extends as far as possible beyond the margin of the core, there will be a ferrule effect. There are four advantages of this effect: promoting hugging action, preventing the shattering of the root,[10] reducing the wedging effect of a tapered dowel, and resisting functional lever forces and the lateral forces exerted during dowel insertion.[11] The minimum effective ferrule should have 1.5 mm of coronal dentine above the crown margin.[12] If a ferrule is not obtained, the tooth is at risk of fracturing no matter what types of dowel and core are used.[13-14] Unfortunately, in most situations, the coronal tooth structure may be so damaged that an ideal ferrule cannot be made.

When there is insufficient ferrule effect, the clinician may consider either orthodontic extrusion or surgical crown lengthening. Both methods reduce the root length, leading to a compromised crown-to-root ratio, discomfort to the patient, and increased cost and treatment time. Moreover, crown lengthening with a surgical procedure may produce adverse esthetic results and weaken the tooth, because of a more apical finish line, which contributes to a decrease in the cross-section of the preparation.[15]

Patel and Gutteridge[16] showed that retained coronal dentine will not strengthen a tooth restored with a cast dowel and partial core. There was no statistically significant difference in the strength of a dowel with partial cores in teeth with retained lingual coronal dentine or buccal and lingual dentine when compared to teeth without coronal dentine. Teeth with retained buccal coronal dentine were significantly less fracture resistant than teeth without coronal dentine. On the other hand, Al-Wahadni and Gutteridge[17] demonstrated that retained coronal buccal dentine improved the fracture resistance of teeth restored with partial dowel and cores when compared to teeth without retained coronal dentine. Moreover, both in vitro studies were performed without a covering crown, which did not imitate the clinical condition of a crown with a ferrule. The benefit of a ferrule effect, four walls of remaining coronal dentine, was still suspected, and further investigation was recommended.

Therefore, the aim of this study was to evaluate the fracture resistance of endodontically treated teeth between those with four walls and those with three walls of remaining coronal tooth structure and the effect of the site of the missing coronal wall.

Materials and methods

Thirty-two human second mandibular premolars selected from a collection of extracted teeth were cleaned with 0.9% normal saline and stored in a 5% thymol solution at room temperature.[16-17] All selected teeth were examined under 220× magnification with phase contrast microscopy to ensure that they had no caries, no restorations, no endodontic treatment, and no cracks or fractures.

Buccolingual and mesiodistal width were measured by a digital caliper (Links, Harbin, China) at the labial midpoint of the cementoenamel junction (CEJ) level, and root length was measured from the apex to that level. All teeth were randomized into four groups of eight teeth. ANOVA was used to determine the significant difference among the groups ($p > 0.05$) (Table 1). All teeth were embedded 2 mm apical to the CEJ in autopolymerizing acrylic resin (Tokuso Curefast, Tokuyama Dent, Tokyo, Japan) contained in plastic tubes. Using a dental surveyor (Ney, Bloomfield, CT), the long axis of the embedded teeth was parallel to the tubes, perpendicular to the horizontal plane. The initial silicone index for each tooth was made with putty poly(vinyl siloxane) (Express, 3M ESPE, St. Paul, MN).

Root canal access was opened using round diamond burs (#016 Diatech Dental AG, Heerbrugg, Switzerland), and the root canal was instrumented with K-files (Mani, Tochigi-Ken, Japan) to ISO size 40 at 0.5 mm shorter than the apex and flared up to size 55 with the step-back technique. Sodium hypochlorite (5.25%) was used to irrigate the canal after each file. Canals were dried with paper points and were obturated with ISO No. 40 gutta percha cones and root canal sealer (CU root canal sealer, Bangkok, Thailand) using the lateral condensation technique. Dowel spaces were prepared with a hot instrument until the dowel length was 8.5 mm. Root canals were sealed with an interim filling material (Caviton, GC, Tokyo, Japan) and stored in 100% humidity at room temperature. A labiolingual and mesiodistal view radiograph of each tooth was made to verify that the root dentine around the dowel was not less than 1 mm.

Table 1 Tooth dimensions of each group (mm)

Group	Root length	Buccolingual width	Mesiodistal width
1	13.13 ± 0.37	7.16 ± 0.25	5.10 ± 0.30
2	12.92 ± 0.37	7.21 ± 0.22	5.29 ± 0.24
3	13.11 ± 0.41	7.31 ± 0.33	5.23 ± 0.22
4	12.79 ± 0.28	6.96 ± 0.31	5.16 ± 0.31
F-value	1.629	2.144	0.762
p-value	0.205	0.117	0.525

All teeth were decoronated using straight diamond burs (FG 314, Intensiv SA, Lugano, Switzerland), leaving 3 mm above the CEJ. A 0.5-mm-wide chamfer using a round end tapered diamond bur (FG D16, Intensiv SA) under water spray was prepared 1 mm above the CEJ. Teeth in group 1 (control group) were prepared as mentioned above. Buccal, lingual, and mesial walls were eliminated in groups 2, 3, and 4, respectively, until the heights of these walls were 1 mm above the CEJ (Fig 1).

Dowel and core patterns were fabricated with blue inlay wax (Kerr, Romulus, MI), and plastic burnout dowel (Swedish Dental Supplies, Åkarp, Sweden) using the initial silicone indices for each tooth to ensure uniform thickness of the full metal crowns. Each dowel and core pattern was invested and cast with NiCr alloy (Remanium CS, Dentaurum, Pforzheim, Germany). Small nodules on the castings were removed. The casting dowels were adjusted with a fit checker (Fit checker, GC) until dowels and cores were fully seated, and their fitness become passive. Radiographs of each tooth were made to verify complete seating. Cast dowel and cores were cemented with zinc phosphate cement (Hybond, Shofu, Kyoto, Japan) using a lentulo spiral (Mani, Tochigi, Japan). They were seated gently using pumping action to release the hydraulic back pressure[14] and held with finger pressure for 5 minutes. The excess cement was carefully trimmed using tapered diamond bur D16.

Wax patterns for the crowns were formed directly on teeth specimens using each initial silicone index. A 2 mm diameter of notch was placed on the buccal surface of each crown pattern, 2 mm from the buccal cusp. Wax patterns were invested and cast with Remarium CS Ni–Cr alloy by a skilled technician. Cast crowns were adjusted with fit checker until they were fully seated, and then they were cemented with zinc phosphate cement under finger pressure for 5 minutes. Specimens were stored in 100% humidity at room temperature for 24 hours before testing.

Specimens were mounted on an Instron universal testing machine (Instron 5566, London, UK). The compressive load was applied at a buccal notch, 45° to the long axis, with a rounded end steel rod with a crosshead speed of 5 mm/min until failure. This load angle imitated the clinically comparable angle of loading in a mandibular premolar when it is subjected to lateral force in eccentric jaw movement. Failure load or fracture resistance (in kg) was recorded from a force deflection curve, and mode of failure (loosening of dowel or fracture of tooth and/or dowel) was investigated under 220× magnification with phase contrast microscopy.

One-way ANOVA was used to compare the mean failure load for each group. Significant ANOVA results were also tested for multiple comparisons with the Scheffé test, with the statistical significance of $p < 0.05$.

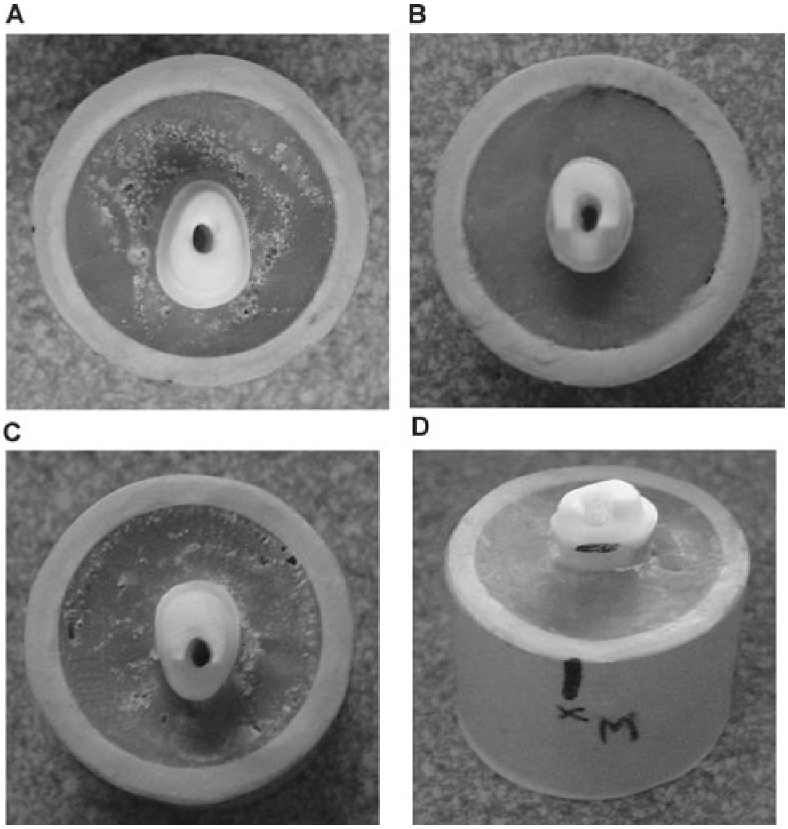

Figure 1 Groups of the prepared root canal-treated teeth. (A) Four walls of remaining coronal tooth structure. (B–D) Three walls of remaining coronal tooth structure with no buccal wall, lingual wall, and mesial wall, respectively

Results

The mean failure load is shown in Table 2, and the mode of failure is presented in Table 3. Multiple comparisons with the Scheffé test indicated that group 1 had the highest fracture resistance and a significant difference from the other groups. There was no significant difference between groups 2, 3, and 4. The mode of failure in group 1 was typically a horizontal root fracture at the middle of the root, whereas the majority of fractures in the other groups were vertical or oblique fractures extending from the dentin-core junction of the buccal surface down to the lingual surface.

Table 3 Mode of failure

Mode of failure	Group 1	Group 2	Group 3	Group 4
Horizontal cervical root fracture	–	1	–	–
Horizontal middle root fracture	6	–	1	–
Horizontal apical root fracture	2	–	1	–
Vertical root fracture	–	7	6	1
Horizontal and vertical root fracture	–	–	–	7

Discussion

Many publications have suggested that a ferrule enhances fracture resistance;[12,19,20] however, there are many clinical situations where it is not possible to construct an ideal ferrule. This investigation compared the fracture resistance of endodontically treated teeth with only three walls to those with four walls of remaining coronal tooth structure. The three walls of remaining coronal structure in this study represented the clinical situations with a less-than-ideal ferrule. This investigation imitated artificial crowns with a ferrule effect, whereas they were omitted in other studies.[16,17] The mean failure load of this study was greater than those of two previous studies. It is probable that the outcomes of the fracture resistance test would not be the result of the hugging action from a ferrule effect.

Table 2 Mean failure load (kg) and SD of the study groups

Group	Failure load
1 (control)	1190.3 ± 110.5*
2 (no B wall)	578.5 ± 197.4
3 (no Li wall)	786.6 ± 132.8
4 (no M wall)	785.4 ± 289.9

*Control is significantly different from other groups ($F = 13.562$, $p < 0.05$).

It was necessary to use only 32 second mandibular premolar teeth in this study due to difficulty in collecting intact human teeth. There was no statistically significant difference between their mean dimensions in each group. Second mandibular premolars were used in this study because they have a single root and are easier to collect than anterior teeth.

The dowel length of 8.5 mm in this study, which approximates the clinical crown length, was similar to that used by Patel and Gutteridge[16] and Al-Wahadni and Gutteridge.[17] The dowels and crowns were fabricated with Ni–Cr alloy because of its high modulus of elasticity, which transfers stress to the restoring systems resulting in a more damaging effect. The PFM crown was not used in this study due to the unexpected failure of porcelain. Zinc phosphate cement was considered an appropriate luting cement for dowels and crowns.[12,16,17] The load angle used imitated lateral force in eccentric jaw movement on the mandibular premolar. The lateral force contributes to greater damage to a tooth than the axial load. A variety of crosshead speeds have been used by other researchers, but this does not seem to be a critical factor.[17]

The results of this study demonstrated that the fracture resistance of a dowel-core-crown with ferrule and four walls of remaining coronal tooth structure was significantly greater than that with three walls of remaining coronal dentine. The result suggested that a ferrule can improve fracture resistance, because a ferrule can distribute the stress concentrations at the junction between the tooth and crown margin passing through the remaining coronal dentine above the crown margin.[21-25] Another possible explanation is that the strength of a tooth is directly related to the amount of tooth structure since stress distribution in root dentine became more favorable when coronal dentine was retained.[6-8] It can also provide an irregular joining between cast and tooth, contributing to an increased retention[5] and resistance to rotation of the dowel.[9] Therefore, coronal tooth structure should be preserved as much as possible.[11]

The mean failure load of teeth without a mesial wall was close to that of teeth without a lingual wall, and the mean failure loads of both groups were higher than those of teeth without a buccal wall. However, no statistical difference was detected among the groups with a less-than-ideal ferrule. It is possible that the direction of loading is a critical factor. This study used a static load from the buccal direction as simulating the clinical situation when mandibular premolars were subjected to lateral force. The teeth tended to bend lingually as with a fulcrum situated on the lingual surface. A buccal coronal wall may act as a critical factor to resist the displacement of the crown. Moreover, a natural tooth always contacts to the adjacent teeth. The proper proximal contacts facilitate friction in the neighboring teeth, resulting in a decrease of natural tooth movement. Stress generated on a natural tooth can also be distributed to the adjacent teeth via proximal contact.[26] Thus, fracture resistances of teeth without a buccal wall were the lowest among the tested groups, and teeth without a proximal wall tended to have the least effect on fracture strength.

This finding is similar to other in vitro studies that failure mode of all groups showed only catastrophic root fracture, which could not be retrieved as a result of restoring with cast dowel and core.[27,28] Most teeth with four walls of remaining coronal dentine demonstrated horizontal root fracture at the mid-root level, whereas teeth with only three walls of remaining coronal dentine presented vertical root fracture. This explanation may relate to the extension of a crown margin completely surrounding the cervical part of the tooth. The maximal amount of coronal tooth structure can diminish stress transmission to the root dentine. This may suggest that an ideal ferrule effect is likely to improve the fracture strength in restoring with dowel-core-crown.

There were some limitations in the design of this study. For more meaningful results, further studies should incorporate thermocycling and fatigue load instead of a static single load, and the specimens should adjoin the neighboring teeth. In addition, the preparation design of a lengthened crown to provide an ideal ferrule should be considered and compared.

Conclusions

Within the limitation of this in vitro study:

1. Teeth with four walls of remaining coronal dentine had a significantly higher fracture resistance than teeth with only three walls of remaining coronal dentine.
2. The site of the missing coronal wall did not affect the fracture resistance of endodontically treated teeth restored with dowel-core-crown.
3. All teeth restored with cast dowel and cores in this study showed catastrophic root fracture; however, teeth with four walls of remaining coronal dentine fractured horizontally at the mid-root level, whereas teeth with three walls of remaining coronal dentine mostly illustrated vertical or oblique root fracture.

References

1. Trabert KC, Caputo AA, Abou-Rass M: Tooth fracture a comparison of endodontic and restorative treatments. J Endod 1978;4:341-346
2. Caputo AA, Standlee JP: Pins and posts why, when and how? Dent Clin North Am 1976;20:299-331
3. Tjan AH, Whang SB: Resistance to root fracture of dowel channels with various thickness of buccal dentin walls. J Prosthet Dent 1985;53:496-500
4. Baraban DJ: Restoration of pulpless teeth. Dent Clin North Am 1967;11:633-653
5. Kafalias MC: Abutment preparation in crown and bridgework. Aust Dent J 1969;14:1-7
6. Henry PJ: Photoelastic analysis of post core restorations. Aust Dent J 1977;22:157-159
7. Hunter AJ, Flood AM: The restoration of endodontically treated teeth: Part 2. Posts. Aust Dent J 1989;34:5-12
8. Hunter AJ, Flood AM: The restoration of endodontically treated teeth: Part 3. Cores. Aust Dent J 1989;34:115-121
9. McKerracher PW: Rational restoration of endodontically treated teeth: 1. Principles, techniques and materials. Aust Dent J 1981;26:205-208
10. Rosen H: Operative procedures on mutilated endodontically treated teeth. J Prosthet Dent 1961;11:973-986
11. Sorensen JA, Engelman MJ: Ferrule design and fracture resistance of endodontically treated teeth. J Prosthet Dent 1990;63:529-536
12. Libman WJ, Nicholls JI: Load fatigue of teeth restored with cast post and cores and complete crowns. Int J Prosthodont 1995;8:155-161
13. Rosenstiel SF, Land MF, Fujimoto J: Restoration of the endodontically treated teeth. InRosenstiel SF, Land MF,

Fujimoto J (eds): Contemporary Fixed Prosthodontics (ed 2). St Louis, MO, Mosby, 1994, pp. 238-267
14. Chan DCN, Myers ML, Barrack GM, et al: Chipped, fractured, or endodontically treated teeth. InGoldstein RE (ed): Esthetics in Dentistry (ed 2). Hamilton, Ontario, Decker, 2002, pp. 525-598
15. Gegauff AG: Effect of crown lengthening and ferrule placement on static load failure of cemented cast post-cores and crowns. J Prosthet Dent 2000;84:169-179
16. Patel A, Gutteridge DL: An in vitro investigation of cast post and partial core design. J Prosthet Dent 1996;24:281-287
17. Al-Wahadni A, Gutteridge DL: An in vitro investigation into the effects of retained coronal dentine on the strength of a tooth restored with a cemented post and partial core restoration. Int Endodon J 2002;35:913-918
18. Cooney JP, Caputo AA, Trabert KC: Retention and stress distribution of tapered-end endodontic posts. J Prosthet Dent 1986;55:540-546
19. Rosen H, Patida-Rivera M: Iatrogenic fracture of roots reinforced with a cervical collar. Oper Dent 1986;11:46-50
20. Barkhordar RA, Radke R, Abbasi J: Effect of metal collars on resistance of endodontically treated teeth to root fracture. J Prosthet Dent 1989;61:676-678
21. Guzy GE, Nicholls JI: An in vitro comparison of intact endodontically treated teeth with and without endo-post reinforcement. J Prosthet Dent 1979;42:39-44
22. Assif D, Oren E, Marshak BL, Aviv I: Photoelastic analysis of stress transfer by endodontically treated teeth to the supporting structure using different restorative techniques. J Prosthet Dent 1989;61:535-543
23. Hemmings KW, King PA, Setchell DJ: Resistance to torsional forces of various post and core designs. J Prosthet Dent 1991;66:325-329
24. Yaman P, Thorsteinsson TS: Effect of core materials on stress distribution of posts. J Prosthet Dent 1992;68:416-420
25. Assif D, Bitenski A, Pilo R, et al: Effect of post design on resistance to fracture of endodontically treated teeth with complete crowns. J Prosthet Dent 1993;69:36-40
26. Guichet DL, Yoshinobu D, Caputo AA: Effect of splinting and interproximal contact tightness on load transfer by implant restorations. J Prosthet Dent 2002;87:528-535
27. Sorensen JA, Engelman MJ: Effect of post adaptation on fracture resistance of endodontically treated teeth. J Prosthet Dent 1990;64:419-424
28. Chan RW, Bryant RW: Post-core foundations for endodontically treated posterior teeth. J Prosthet Dent 1982;48:401-406