Preparation Ferrule Design Effect on EndoCrown Fracture Resistance

Michael L. Einhorn

Preparation Ferrule Design Effect on EndoCrown Fracture Resistance

Major Michael L. Einhorn

APPROVED:

Colonel Howard W. Roberts (Chairman)

For Nicholas B DuVall

Major Nicholas B. DuVall

Colonel Michael N. Wajdowicz

24 May 2016

Date

APPROVED:

Col Drew W. Fallis
Dean, Air Force Postgraduate Dental School

Acknowledgements:

Special thanks to Col Howard Roberts, Maj Nicholas DuVall, Maj Sara Cushen.

23 May 2016

The author hereby certifies that the use of any copyrighted material in the thesis manuscript entitled:

Preparation Ferrule Design Effect on EndoCrown Fracture Resistance

is appropriately acknowledged and beyond brief excerpts, is with the permission of the copyright owner.

Michael L Eubanks

Signature

Michael L. Eubanks

Printed Name

USAF Postgraduate Dental School
Keesler AFB, MS
Uniformed Services University

Abstract:

Objective: To evaluate the effect of ferrule with retention of adhesively-bonded mandibular molar CAD/CAM Endocrowns.

Methods: Recently-extracted mandibular third molars were randomly divided into 3 groups (n=12) with the coronal tooth structure removed perpendicular to the root long axis approximately 2mm above the CEJ with a water-cooled, slow-speed diamond saw. The pulp chamber was exposed using a diamond bur in a high speed handpiece. Pulpal remnants were removed and canals instrumented using endodontic hand instruments. The chamber floor was restored using a resin core material with a two-step, self-etch adhesive and photopolymerized with a visible light curing unit to create a 2mm endocrown preparation pulp chamber extension. One and two millimeter ferrule height groups were prepared using a diamond bur in a high speed handpiece following CAD/CAM guidelines. Completed preparation surface area was determined using a digital measuring microscope. Scanned preparations (CEREC) were restored with lithium disilicate restorations with a self-adhesive resin luting agent. All manufacturer recommendations were followed. Specimens were stored at 37C/98% humidity and tested to failure after 24 hours at a 45-degree angle to the tooth long axis using a universal testing machine. Failure load was converted in MPa using the available bonding surface area with mean data analyzed using Kruskal-Wallis/Dunn (p=0.05).

Results: Calculated failures stress found no difference in failure resistance among the three groups. However, failure load results identified that the endocrown preparations had significantly lower failure load resistance. Failure mode analysis identified that all preparations demonstrated a high number of catastrophic failures.

Conclusions: Under the conditions of this study, the addition of ferrule preparation features afforded no advantage when failure stress is concerned. All preparations, regardless of features, demonstrated a high number of catastrophic failure.

Table of Contents:

List of Tables: viii

List of Figures: ix

Introduction: 1

Materials and Methods: 2

Results: 9

Discussion: 10

Conclusions: 19

Literature Sources ..... Error! Bookmark not defined.

List of Tables:

Table 1, Resultant mean failure load and stress 9

Table 2, Resultant failure modes 10

Table 3, Mean Endocrown Preparation Parameters 12

List of Figures:

Figure 1, Prepared acrylic embedded specimens 3

Figure 2, Occlusal Table and Margin Surface Area Determination 4

Figure 3, CAD/CAM Standardized Scanning Templates 5

Figure 4, CAD/CAM Standardized Scanning Template with Specimen 5

Figure 5, CAD/CAM Restoration Designs for 0mm, 1mm, and 2mm Ferrule Preparations 6

Figure 6, Cemented Standardized e.max Restoration 7

Figure 7, Specimen Testing Orientation 8

Figure 8, Ferrule Wall Occlusal Convergence 11

Figure 9. Mean Failure Stress Results (MPa) 13

Figure 10. Mean Failure Load Results (N) 13

Figure 11. 3D Tiled Image Zero Millimeter Ferrule Failure 14

Figure 12. MicroCT Image of 1mm Ferrule – Catastrophic Failure 15

Figure 13. MicroCT Image of 1mm Ferrule – Catastrophic Failure 15

Figure 14. MicroCT Image 2mm Ferrule – Catastrophic Failure 16

Figure 15. Cross Section of endocrowns with decreased crown adaption 17

Figure 16. Preparation with deficient tooth structure for ferrule 18

Introduction:

Posterior teeth following endodontic therapy require adequate full coverage restorations to minimize risk of fracture, coronal seal to prevent bacterial contamination, and restore function. [1-4] Endodontically-treated teeth may be restored using various methods, including direct and indirect restorations, with indirect full-coverage methods being preferred by many clinicians. [5] Post and core procedures may be required in the situation of severe loss of coronal hard tissue, but may decrease tooth fracture resistance due to additional dentin removal while also increasing root perforation risk.[6,7] With advancements in computer aided design/computer assisted manufacturing (CAD/CAM) proponents claim that adhesive technology may provide clinicians with additional treatment options that may be more efficient and conservative for the restoration of endodontically-treated teeth.[8]

The endocrown is an indirect treatment option technique that is gaining clinical popularity for the restoration of endodontically treated posterior teeth. The endocrown is described as a full-coverage restoration with a circumferential butt-joint margin and a central retentive feature that extends into the pulp chamber space. [9] Several studies suggest a two millimeter central retentive feature to afford the optimal retention and resistance features. [7,10] Other endocrown preparation parameters have been recommended to include:

1. Cuspal Reduction of 2-3mm;
2. 90 degree butt margins;
3. Smooth internal transitions;
4. Six degree occlusal cervical internal taper of the pulpal chamber;
5. Flat pulpal floor with sealed radicular spaces; and
6. Supragingival enamel margins when possible. [11,12]

The increased fracture resistance imparted by the incorporation of ferrule features into preparations has been well described. [10,13,14] The addition of minimal ferrule of 0.5 millimeters has been suggested to significantly increase fatigue cycles to failure in teeth restored with all ceramic, full-coverage restorations supported by a resin core and fiber posts. [14] Also, the effect of ferrule has been demonstrated add significant fracture resistance than the presence of a post. [15] The addition of ferrule features to the endocrown preparation has not been previously investigated. The purpose of this study was to determine the effect on endocrown restoration failure strength with various ferrule features added to the endocrown preparation. The null hypothesis was that there would be no difference in failure strength between traditional endocrown restorations and endocrown restorations with a prepared ferrule.

Materials and Methods:

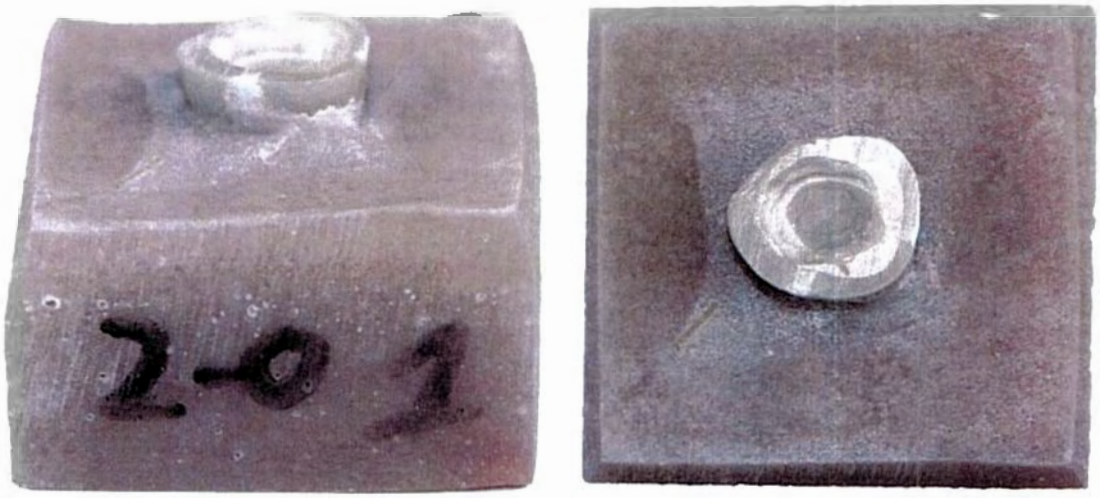
Human mandibular third molar teeth were used in this study, which had been removed as per routine clinical indications were collected from local oral and maxillofacial surgery clinics under the local Institutional Review Board (IRB) protocol approval.

Thirty six, recently-extracted mandibular third molars of approximate equal size were sectioned with a slow-speed diamond saw (Buehler, Lake Forest , IL USA) at the facial-lingual height of contour perpendicular to the long axis. All preparations were completed by one researcher to standardize preparations as much as possible with a locally established preparation feature covariance threshold established at 25 percent above which specimens were discarded. Access into the pulp chamber were accomplished using a high-speed handpiece (EA-51LT, Adec, Newburg, OR, USA) and a diamond bur (6847.33.016, Brassler USA, Savannah, GA, USA) using copious water spray. Pulpal remnants were removed with barbed broaches and gross instrumentation with hand files (Miltex, York, PA, USA). Canal orifices were further

prepared using Gates-Glidden rotary instruments (DENTSPLY-Maillefer, Tulsa, OK) to further simulate endodontic preparation of the pulp chamber and canals.

The specimens were embedded into auto-polymerizing denture base resin (Impak Self Cure, CMP Industries, Albany, NY, USA) with the coronal features prepared following endocrown preparation guidelines as previously described. (Figure 1)

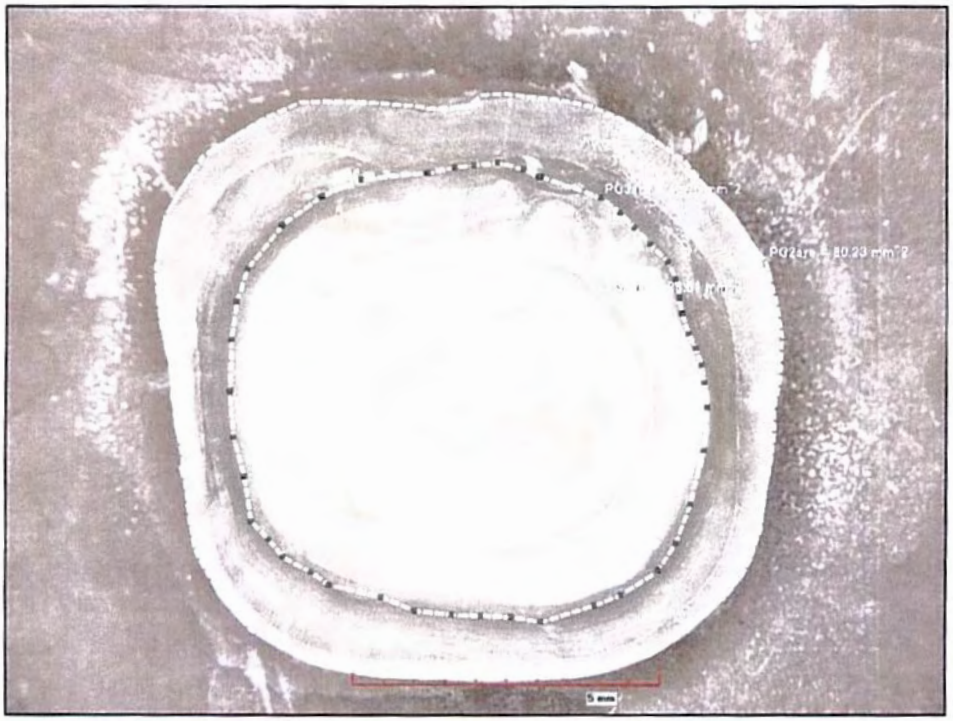
Figure 1, Prepared acrylic embedded specimens



Pulp chamber restoration was accomplished using a two-step, self-etch adhesive (Clearfil SE, Kuraray America, Houston, TX, USA) and a dual cure core material (Gradia Core, GC America, Alsip, IL, USA) to achieve a two millimeter pulp chamber depth whose floor was parallel to the endocrown occlusal table. All visible light polymerization was provided by a light-emitting-diode-based visible light curing (VLC) unit (Bluephase G2, Ivoclar-Vivadent, Amherst, NY, USA) whose irradiance were verified using a laboratory-grade laser power meter (10A-V1, Ophir-Spiricon, North Logan, UT, USA).

The completed endocrown preparations were then randomly subdivided into three groups (n = 12). Two of the groups received ferrule preparation features to the external coronal surface consisting of one and two millimeters placed circumferentially apical to the endocrown occlusal table. The third group did not receive additional preparation features. All specimens had preparation features confirmed and surface area measured using a digital recording microscope (KH- 7700, Hirox USA, Hackensack, NJ, USA). (Figure 2)

Figure 2, Occlusal Table and Margin Surface Area Determination



Two identical standardized templates were fabricated using acyclic. The template represented teeth #28 through #31 with one template having tooth #30 removed . (Figure 3) All specimens were scanned and restored using thestandardized template (Figure 4) to simulate clinical conditions using a chairside CAD/CAM unit (Cerec AC/Cerec MC XL, Dentsply Sirona, Charlotte, NC, USA; Software version 4.2.4.72301) with the full-coverage restorations milled

using a lithium disilicate glass-ceramic restorations (IPS e.max CAD, Ivoclar-Vivadent). (Figure 5)

Figure 3, CAD/CAM Standardized Scanning Templates

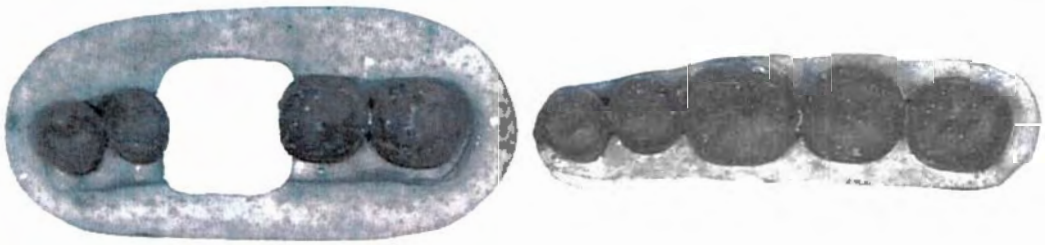
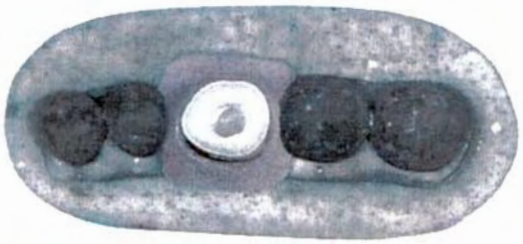
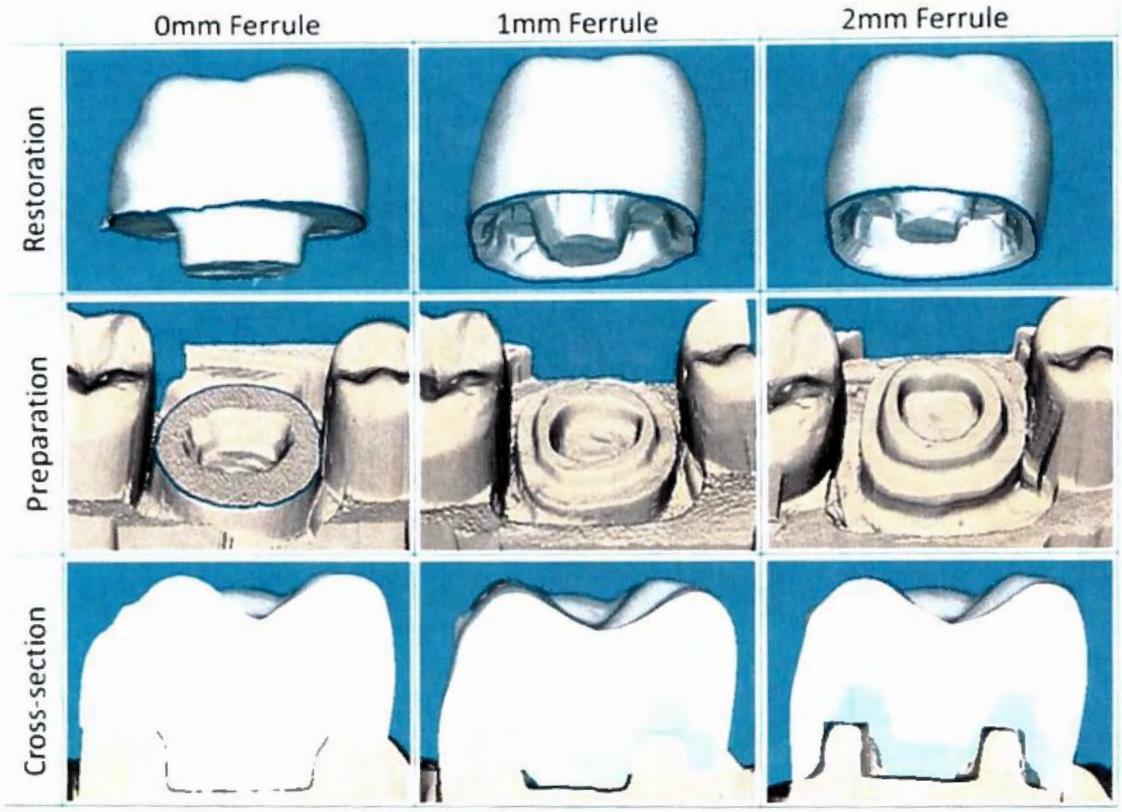


Figure 4, CAD/CAM Standardized Scanning Template with Specimen



All restorations were designed with identical occlusal table anatomy as well as axial wall height so as not to incorporate different lever action vectors into the testing design.

Figure 5, CAD/CAM Restoration Designs for 0mm, 1mm, and 2mm Ferrule Preparations



Two coats of spray glaze (IPS e.max CAD Crystall/Glaze spray, Ivoclar-Vivadent) were applied with crystallization firing accomplished following manufacturer recommendations in a dental laboratory ceramic furnace (Programat P700, Ivoclar-Vivadent). Proper seating was verified using a disclosing media (Occlude, Pascal International, Bellevue, WA, USA) followed by thorough steam cleaning and drying with oil free compressed air. Restoration intaglio surfaces were etched for 20 seconds using 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) followed by thorough rinse with water for 15 seconds and dried with oil free compressed air. A thin coat of silane agent (Monobond Plus, Ivoclar Vivadent) was applied with a microbrush to the etched intaglio surface for two, 60-second intervals with the excess dispersed with compressed air. The tooth surfaces were prepared for cementation using pumice slurry on a prophylaxis cup (Extended Straight Attachment DPA, Preventech, Indian

Trail, NC, USA) using a slow-speed handpiece (Midwest Shorty, Dentsply International, York, PA, USA) attachment followed by water rinse and air drying. Restorations were cemented with a self-adhesive resin cement (Rely-X Unicem, 3M ESPE, St. Paul, MN, USA) with firm digital pressure with a one-second tack cure applied to all surfaces using a VLC unit (Bluephase G2, Ivoclar Vivadent) after which excess cement was removed. All surfaces then received a final exposure to a VLC unit (Bluephase G2, Ivoclar Vivadent) for 20 seconds after which the specimens were stored in distilled water under dark conditions at 37 ± 1 °C and 98 ± 1% humidity. (Figure 6)

Figure 6, Cemented Standardized e.max Restoration

Twenty-four hours after cementation each specimen were placed into a fixture on a universal testing machine (RT-5, MTS Corporation, Eden Prairie, MN, USA) with the long axis of the tooth oriented at a 45 degree angle to the testing device. (Figure 7)

Figure 7, Specimen Testing Orientation

The facial cusps were loaded with a three-millimeter diameter hardened, stainless steel piston with a 0.5-meter radius of curvature as described by Kelly *et al.* [16] Specimens were loaded at a rate of 0.5 millimeter per minute until failure with the failure load recorded in Newtons. Failure load was also converted to failure stress using the measured surface area available for adhesion. Specimens were examined for failure mode to determine if the failure was cohesive for the ceramic restorative material, adhesive failure between the ceramic and the tooth structure, tooth material fracture, or mixed failure. Analysis was accomplished both visually at 20X magnification (Hirox-4400, Hirox USA) as well as microradiographic tomography (microCT) (Skyscan 1172, Bruker microCT/Micro Photonics, Allentown, PA, USA). Fractured samples were scanned over 180 degrees at 9.8-micron resolution with a 0.4 degree step size with aluminum filtration. Resultant individual images were recombined with software (nRecon,

Bruker microCT) with resultant recombined images visualized using CTan and CTVox software (Bruker microCT).

Analysis of the mean data with the Shaprio-Wilk Test and Bartlett's Test identified irregularities within both the data distribution and variance. Therefore, the mean data was analyzed with Kruskal-Wallis with Dunn's *post hoc* test when required. A 95 percent level of confidence ($p = 0.05$) was used with all analysis.

Results:

Table 1, Resultant Mean Failure Load and Stress

Mean Failure Loads (N) and Stress (MPa)

Endocrown Ferrule (mm)	Failure Load (N)	Failure Stress (MPa)
0	638.5 (238.5) A	6.13 (1.7) A
1	1101.0 (487.0) B	7.85 (3.3) A
2	956.3 (294.5) B	6.32 (1.8) A

n = 12; Groups identified with same capital letter are similar within each column (Dunn's p = 0.05)

When considering failure load, the endocrown restorations containing one and two millimeters of ferrule demonstrated greater failure load resistance than the endocrowns without ferrule. However, under conditions of calculated failure stress, there was no significant difference between any of the groups.

Table 2. Failure Mode Results

Endocrown Ferrule	Failure Mode				
	Adhesive Debonding	Restorable Fracture	Catastrophic Fracture	Cohesive Root Fracture	Ceramic Cohesive Failure
0 mm	0	2	10	0	0
1 mm	2	1	8	0	1
2 mm	0	0	12	0	0

n = 12

Catastrophic failure = Non-restorable fracture that involves the restoration and restoration preparation.
Cohesive Root Fracture = Fracture that does not involve restoration/preparation complex at a level apical to the preparation.
Restorable Fracture = Fracture either separate or combined of restoration and tooth deemed restorable

All of the groups demonstrated a high number of catastrophic failures. The endocrown group with two millimeters ferrule displayed universal catastrophic failure with the endocrown demonstrating slightly less. The endocrown group with one millimeter of ferrule demonstrated the least amount of non-restorable failures as well as a small amount of adhesive failures.

Discussion:

The importance of full-coverage restorations following endodontic therapy is well known. Tang and colleagues [2] reported the failure to replace interim restorations expediently with permanent restorations after endodontic treatment resulted in greater than 65 percent tooth loss over three years. Equally important is the provision of a coronal seal over the completed endodontic treatment, as microbial re-contamination of the root canal system has been shown with *in vitro* testing to occur between 24 and 30 days after exposure of the gutta percha material to oral fluids. [3,4] The placement of intracanal posts is often required to augment retention and resistance features for the core material in situations of advanced loss of coronal tooth structure. [17-19] Notwithstanding, such use of intracoronal posts is not without its hazards. The use of posts has been suggested to increase incidence of failure in the instance of post and tooth material modulus mismatch, excess dentin removal, and failure to provide adequate

ferrule. [2,21,22] Furthermore, posts may not be a viable option when confronted with certain canal morphology such as dilacerated or calcified canals. [23]

CAD/CAM proponents describe the endocrown as an effective and expedient means for the restoration of endodontically treated teeth [9,12,24,25] especially of situations where insufficient ferrule is present. [12] Additionally, *in vitro* finite element analysis studies suggest the endocrown method produces less internal stress forces than full coverage restorations supported by post and cores, [26,27] but other studies suggest that endocrowns should be limited to molars. [27,28] The purpose of this study was to determine the effect of ferrule on molar endocrown restoration failure strength and failure mode analysis. The endocrown restoration was fabricated using a lithium disilicate restorative material (e.max CAD, Ivoclar Vivadent) which was bonded using a self-adhesive resin cement (Unicem, 3M ESPE). Specimens were prepared as uniformly as possible where the surface area available for bonding (Figure 2) and ferrule wall occlusal convergence (Figure 8) was determined using a digital measuring microscope (Hirox 4400, Hirox USA). The mean specimen parameters are listed in Table 3.

Figure 8, Ferrule Wall Occlusal Convergence

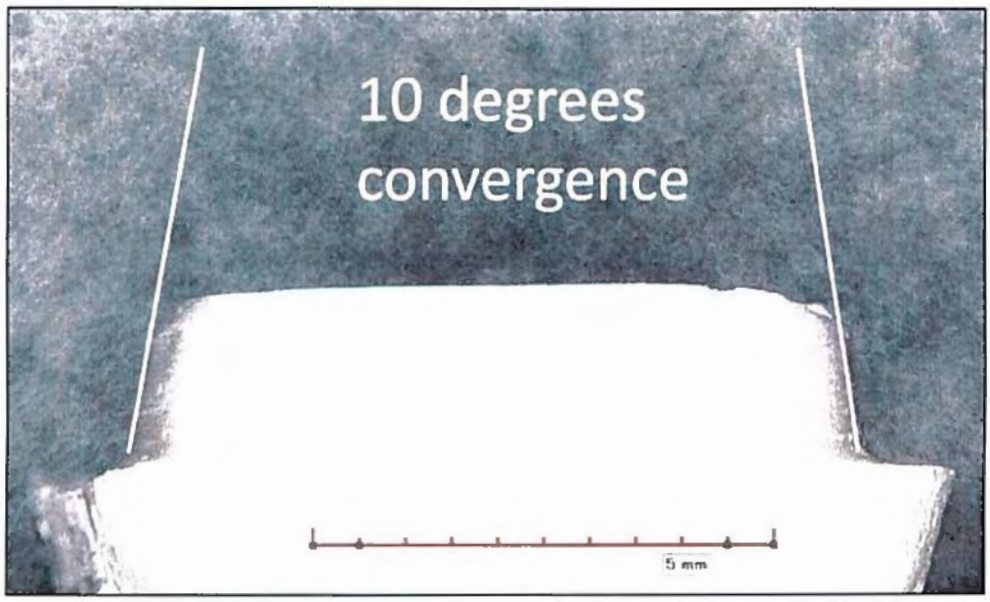


Table 3, Mean Endocrown Preparation Parameters

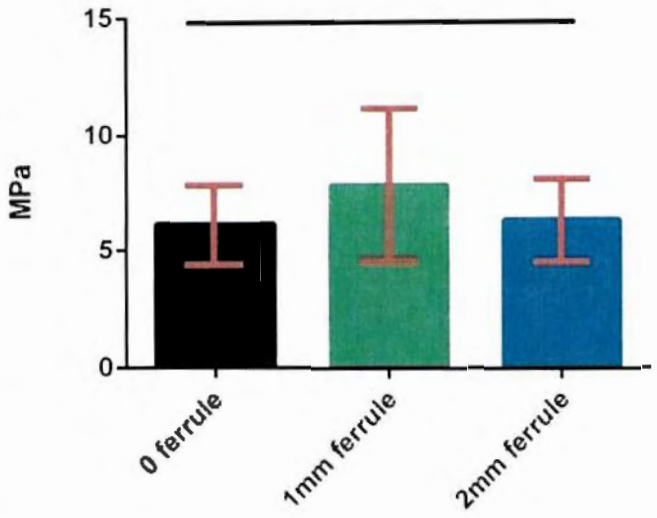
Group (Ferrule)	Mean dentin surface area (mm^2)	Mean ferrule wall height (mm)	Ferrule wall mean total occlusal convergence (degrees)
0mm	102.3 (16.1)		
1mm	139.1 (10.6)	1.07 (0.01)	10.4 (0.5)
2mm	150.1 (10.2)	2.04 (0.05)	10.3 (0.6)

n = 12

The resin-restored chamber floor was also included in the surface area available for bonding. As stated earlier, one researcher prepared all of the specimens before restoration, which was also completed by a single, different researcher. Preparation standardization was achieved with some success as the mean measured surface area covariance of the ferrule group preparations was approximately seven percent, while the total occlusal convergence covariance for the same groups was approximately five percent. The endocrown preparation surface area was more variable with a 15 percent covariance, but still below the established covariance 25 percent threshold. Preparation surface area available for bonding increased 36 percent from the standard endocrown to the one millimeter ferrule group while the surface area between the standard endocrown restoration and the two millimeter ferrule endocrown restoration group increased 47 percent. However, there was only an eight percent increase in surface area between the one and two millimeter ferrule group.

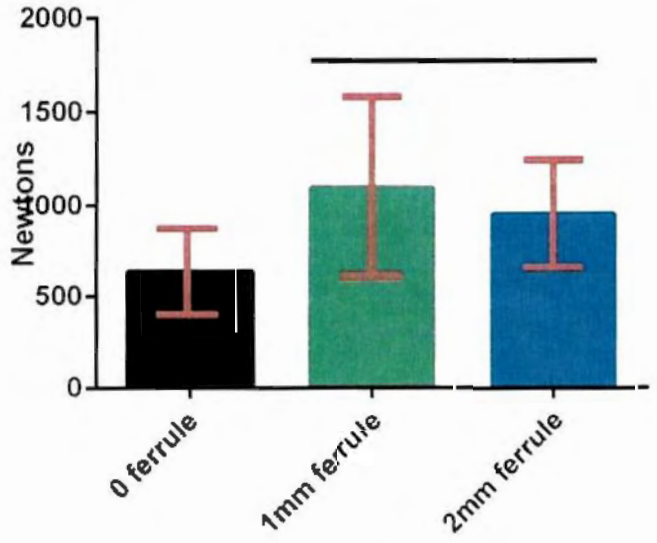
Under the conditions of this study the calculated failure stress (MPa) found no significant difference noted between the preparation groups ($p = 0.427$). However, analysis using failure load (N) demonstrated a difference between the groups ($p = 0.016$), with *post hoc* testing identified that the ferrule groups were similar with each other ($p = 0.857$) but was significantly greater than the endocrown group ($p = 0.0212$) as depicted in Figure 9 and 10.

Figure 9. Mean Failure Stress Results (MPa)



n = 12; Items connected by same bar are significantly similar (Kruskal-Wallis, p = 0.42)

Figure 10. Mean Failure Load Results (N)



n = 12; Items connected by same bar are significantly similar (Kruskal-Wallis/Dunn's, p = 0.021)

Therefore, the null hypothesis was rejected under the consideration of failure load, but was accepted when the failure stress data was observed. It is interesting to note that although the available surface for adhesion increased over 47 percent from the standard endocrown to the endocrown with a two millimeter ferrule, no difference in failure stress was noted. However, failure load results identified the ferrule groups failed at significantly greater loads than the standard endocrown restoration.

The most clinically relevant findings of this study may be noted when the failure analysis results are considered. MicroCT analysis proved to be a valuable tool in assessing the failure modes, as some specimens with visually judged repairable damage (Figure 11) was found to contain irreparable fractures that, depending on location, may or may not be visible on a standard periapical film (Figure 12, Figure 13).

Figure 11. 3D Tiled Image Zero Millimeter Ferrule Failure

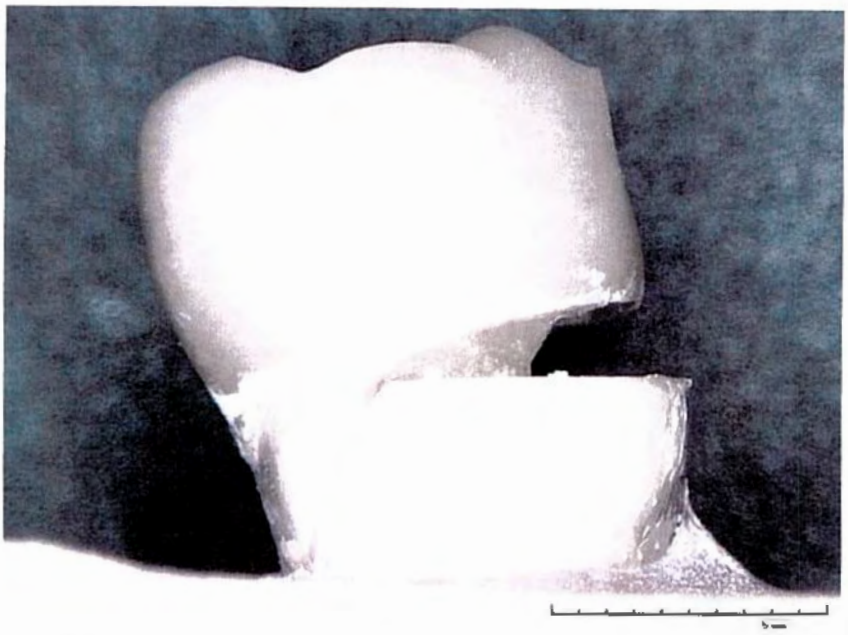


Figure 12. MicroCT Image of 1mm Ferrule – Catastrophic Failure

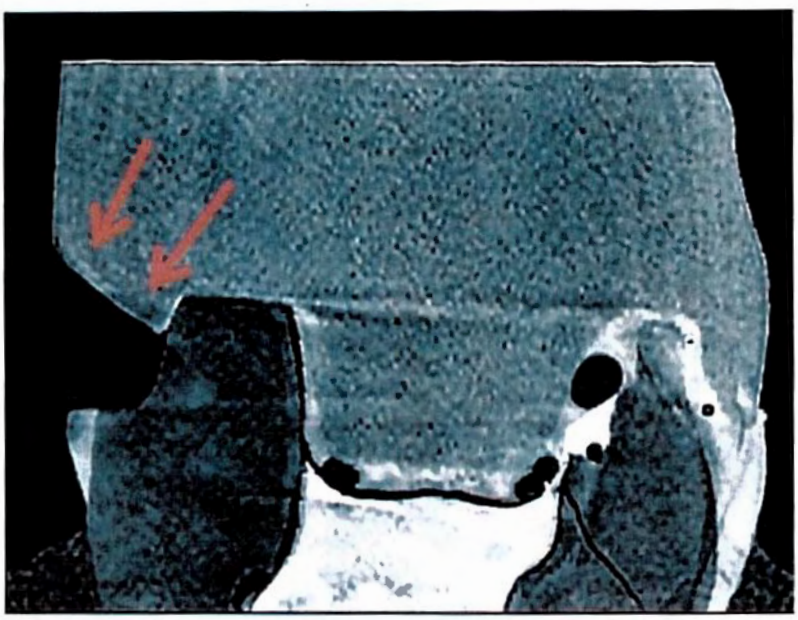


Figure 13. MicroCT Image of 1mm Ferrule – Catastrophic Failure

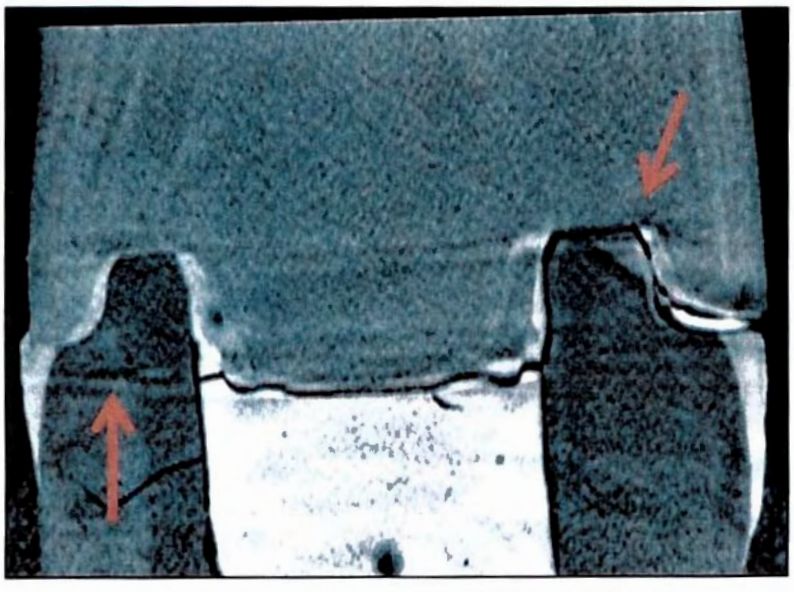
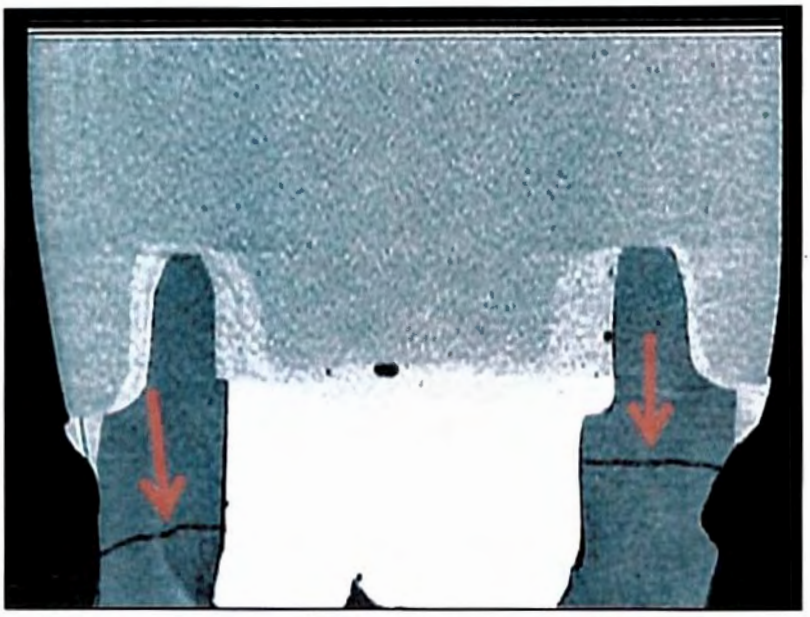


Figure 14. MicroCT Image 2mm Ferrule – Catastrophic Failure



All of the endocrown preparations containing two millimeters of ferrule failed catastrophically, (Figure 14) followed by 10 of the 12 standard endocrown preparations. The one millimeter endocrown ferrule group had the least number of catastrophic failures, albeit with 66 percent of the specimens exhibiting non-restorable fractures. Thus, under laboratory testing the endocrowns, regardless of ferrule preparation features, demonstrated a high percentage of catastrophic failures.

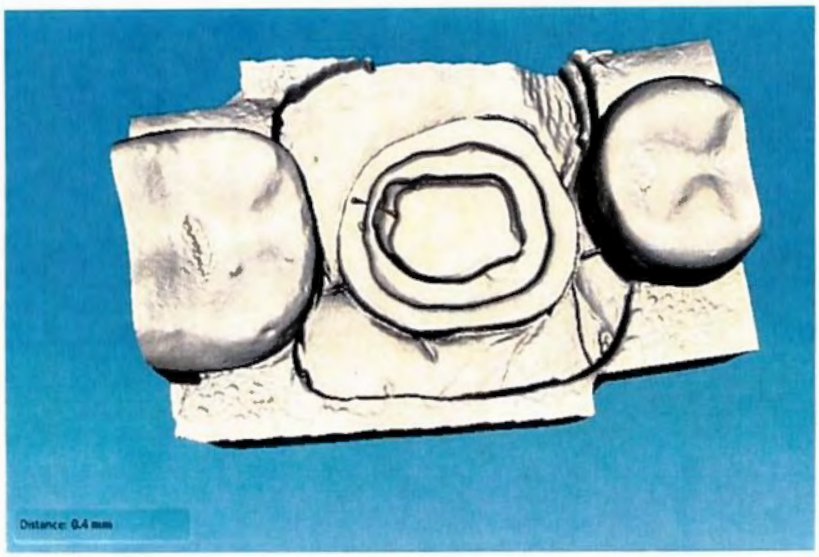
The results of this study should be considered with the failure load results are in excess of that reported for normal human function and the ferrule containing endocrown preparations approach those suggested for accidental biting and/or trauma. [29-36] Although the force was applied to the functional cusp, the static applied load can be in variance with normal oral function. The measured human maximum bite force varies with different reported studies. For instance, one study reported the average bite force for males was approximately 285 N and 254 N for females, [35] while another study reported 654 and 464 N for the same two gender groups, respectively. [36] Notwithstanding , the next research objective is to repeat the conditions of this

study under fatigue forces with non-destructive microCT assessment of internal changes that may lead to failure.

A preparation parameter that was observed that may affect restoration performance was the milling limitations in reproducing the intaglio surface of the crown. Accordingly, it was observed that the more complex the preparation, the more complex the restoration design and therefore resulted in decrease crown adaptation with 1mm and 2mm designs with larger cement space (Figure 15). Another preparation parameter was the sometimes tooth structure limitation realized by a ferrule addition in the cervical area. This resulted in some ferrule areas with limited ferrule wall thickness (Figure 16).

Figure 15. Cross Section of endocrowns with decreased crown adaption

Figure 16. Preparation with deficient tooth structure for ferrule



This study also sought to determine if the failure stress calculation would perhaps provide normalization of the failure load results, which could be skewed due to tooth size discrepancies. The failure stress determination did appear to normalize the failure load data under the conditions of this study. However, more definitive research and analysis is required before more recommendations can be proffered.

When considering the traditional endocrown preparations, the results of this study are similar to that reported by Biacchi and Basting [25] who reported a median endocrown failure of approximately 674 N. That study also reported a high number of non-restorable fractures similar to that found in the present study. However, the present study's results are less than that reported by Magne et al [7] who reported endocrown failure loads of 2606 N as well as that reported by El-Damanhoury et al [37] whose lithium disilicate material demonstrated a mean fracture load of 1368 N. Furthermore, Gresnight and colleagues [38] also reported failure values above that found with the present study. However, those reports differ somewhat from the present study with the application of different force vectors.

Conclusions:

Under the conditions of this study, calculated failure stress based on available surface area for adhesive bonding found no difference in failure between standard endocrown preparations and endocrown preparations containing either one or two millimeters of ferrule. In contrast, failure load results found the ferrule-containing endocrown preparations demonstrated significantly greater failure loads than standard endocrown restorations. Regardless of the presence of a ferrule, this study found endocrown restorations suffered a high proportion of catastrophic failures but at loads greater than reported normal masticatory function. Based on these results, fatigue studies should be investigated.

Bibliography

1. Robbins JW (1990) Guidelines for the restoration of endodontically treated teeth. J Am Dent Assoc 1990;120:558-566.

2. Tang W, Wu Y, Smales RJ. Identifying and reducing risks for potential fractures in endodontically treated teeth. J Endod 2010;36:609–617.

3. Torabinejad M, Ung B, Kettering JD. In vitro bacterial penetration of coronally unsealed endodontically treated teeth. J Endod 1990;16:566-569.

4. Khayat A, Lee SJ, Torabinejad M. Human saliva penetration of coronally unsealed obturated root canals. J Endod 1993;19:458-461.

5. Salhrabi R, Rotstein I. Endodontic treatment outcomes in a large patient population in the USA: an epidemiological study. J Endod 2004;30:846-850.

6. Schwartz RS, Robbins JW. Post placement and restoration of endodontically treated teeth: a literature review. J Endod 2004;30:289-301.

7. Magne P, Carvalho AO, Bruzi G, Anderson RE, Maia HP, Giannini M. Influence of no-ferrule and no-Post buildup design on the fatigue resistance of endodontically treated molars restored with resin nanoceramic CAD/CAM crowns. Oper Dent 2014;39:595-602.

8. Ramı´rez-Sebastia` A, Bortolotto T, Roig M, Krejci I. Composite vs Ceramic Computer-aided Design/Computer-assisted Manufacturing Crowns in Endodontically Treated Teeth: Analysis of Marginal Adaptation. Oper Dent 2013;38:663-673.

9. Pissis P. Fabrication of a metal-free ceramic restoration utilizing the monobloc technique. Practical Periodontics and Aesthetic Dentistry 1995;7:83-94.

10. Forberger N, Göhring TN. Influence of the type of post and core on in vitro marginal continuity, fracture resistance, and fracture mode of lithia disilicate-based all-ceramic crowns. J Prosthet Dent 2008;100:264-73.

11. Moore P. Cerec Doctors publications, Dentsply Sirona, Charlotte, NC, 2013.

12. Lander E, & Dietschi D. Endocrowns: a clinical report. Quintessence Int 2008;39:99-106.

13. Pereira JR, de Ornelas F, Conti PCR, do Valle AL. Effect of a crown ferrule on the fracture resistance of endodontically treated teeth restored with prefabricated posts. J Prosthet Dent 2006;95:50-54.

14. Ma PS, Nicholls JI, Junge T, Phillips KM. Load fatigue of teeth with different ferrule lengths, restored with fiber posts, composite resin cores, and all-ceramic crowns. J Prosthet Dent 2009;102:229-234.

15. Lima AF, Spazzin AO, Galafassi D, Correr-Sobrinho L, Carlini-Junior B. Influence of ferrule preparation with or without glass fiber post on fracture resistance of endodontically treated teeth. J Appl Oral Sci 2010;18:360-363.

16. Kelly RJ, Rungruanganunt P, Hunter B, Vailati F. Development of a clinically validated bulk failure test for ceramic crowns. J Prosthet Dent 2010;104:228-238.

17. Baba NZ, Golden G, Goodacre CJ. Nonmetallic Prefabricated Dowels: A Review of Compositions, Properties, Laboratory, and Clinical Test Results. J Prosthodont 2009;18:527-536.

18. Balkenhol M, Wöstmann B, Rein C, Ferger P. Survival time of cast post and cores: A 10-year retrospective study. J Dent 2007;35:50-58.

19. Fokkinga WA, Kreulen CM, Bronkhorst EM, Creugers NHJ. Up to 17-year controlled clinical study on post-and-cores and covering crowns. J Dent 2007;35:778-786.

20. Zhu Z, Dong XY, He S, Pan X, Tang L. Effect of post placement on the restoration of endodontically treated teeth: A systematic review. Int J Prosthodont 2015;28:475-483.

21. Ona M, Wakabayashi N, Yamazaki T, Takaichi A, Igarashi Y. The influence of elastic modulus mismatch between tooth and post and core restorations on root fracture. Int Endod J 2013;46:47-52.

22. Assif D, Bitenski A, Pilo R, Oren E. Effect of post design on the resistance to fracture of endodontically treated teeth with complete crowns. J Prosthet Dent 1993;69:36-40.

23. Biacchi GR, Mello B, Bastings RZ. The Endocrown: An Alternative Approach for Restoring Extensively Damaged Molars. J Esthet Restor Dent 2013;25:383–391.

24. Bindl A, Mormann WH. Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years: preliminary results. J Adh Dent 1999;1:255-265.

25. Biacchi GR, Basting RT. Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. Oper Dent 2012;37:130-136.

26. Lin CL, Chang YH, Chang CY, Pai CA, Huang SF. Finite element analyses to estimate failure risks in the ceramic endocrown and classical crown for endodontically treated maxillary premolars. Eur J Oral Sci 2010;118:87-93.

27. Dejak B, Młotkowski A. 3D-Finite element analysis of molars restored with endocrowns and posts during masticatory simulation. Dent Mater 2013;29:e309–e317

28. Bindl A, Richter B, Mormann WH. Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry. Int J Prosth 2005;18:219-224.

29. Chen C, Trindade FZ, de Jager N, Kleverlaan C, Feilzer AJ. The fracture resistance of a CAD/CAM Resin Nano Ceramic (RNC) and a CAD ceramic at different thicknesses. Dent Mater 2014;30:954-962.

30. Sinn DP, DeAssis EA, Throckmorton GS. Mandibular excursions and maximum bite forces in patients with temporomandibular joint disorders. J Oral Maxil Surg 1996;54:671-9.

31. Vaneijden T. 3-Dimensional analyses of human bite-force magnitude and moment. Arch Oral Biol 1991;36:535-9.

32. Pruim GJ, Dejongh HJ, Tenbosch D. Forces acting on the mandible during bilateral static bite at different bite force levels. J Biomech 1980;13:755 3.

33. Gibbs CH, Mahan PE, Mauderli A, Lundeen HC, Walsh EK. Limits of human bite strength. J Prosth Dent 1986;56:226-9.

34. Waltimo A, Kononen M. A novel bite force recorder and maximal isometric bite force values for healthy-young adults. Scand J Dent Res 1993;101:171-5.

35. Pizolato RA, Gavião MB, Berretin-Felix G, Sampaio AC, Trindade Junior AS, Maximal bite force in young adults with temporomandibular disorders and bruxism. Braz Oral Res. 2007;21:278-83.

36. Takaki P, Vieira M, Bommarito S. Maximum bite force analysis in different age groups. Int Arch Otorhinolaryngol. 2014 Jul;18(3):272-6.

37. El-Damanhoury HM, Haj-Ali RN, Platt JA. Microleakage of Endocrowns Utilizing Three CAD-CAM Blocks. Oper Dent 2015;40:201-210.

Preparation Ferrule Design Effect on EndoCrown Fracture Resistance

Michael L. Einhorn

Preparation Ferrule Design Effect on EndoCrown Fracture Resistance

Major Michael L. Einhorn

APPROVED:

Colonel Howard W. Roberts (Chairman)

For Nicholas B DuVall

Major Nicholas B. DuVall

Colonel Michael N. Wajdowicz

24 May 2016

Date

APPROVED:

Col Drew W. Fallis
Dean, Air Force Postgraduate Dental School

Acknowledgements:

Special thanks to Col Howard Roberts, Maj Nicholas DuVall, Maj Sara Cushen.

23 May 2016

The author hereby certifies that the use of any copyrighted material in the thesis manuscript entitled:

Preparation Ferrule Design Effect on EndoCrown Fracture Resistance

is appropriately acknowledged and beyond brief excerpts, is with the permission of the copyright owner.

Michael L Eubanks

Signature

Michael L. Eubanks

Printed Name

USAF Postgraduate Dental School
Keesler AFB, MS
Uniformed Services University

Abstract:

Objective: To evaluate the effect of ferrule with retention of adhesively-bonded mandibular molar CAD/CAM Endocrowns.

Methods: Recently-extracted mandibular third molars were randomly divided into 3 groups (n=12) with the coronal tooth structure removed perpendicular to the root long axis approximately 2mm above the CEJ with a water-cooled, slow-speed diamond saw. The pulp chamber was exposed using a diamond bur in a high speed handpiece. Pulpal remnants were removed and canals instrumented using endodontic hand instruments. The chamber floor was restored using a resin core material with a two-step, self-etch adhesive and photopolymerized with a visible light curing unit to create a 2mm endocrown preparation pulp chamber extension. One and two millimeter ferrule height groups were prepared using a diamond bur in a high speed handpiece following CAD/CAM guidelines. Completed preparation surface area was determined using a digital measuring microscope. Scanned preparations (CEREC) were restored with lithium disilicate restorations with a self-adhesive resin luting agent. All manufacturer recommendations were followed. Specimens were stored at 37C/98% humidity and tested to failure after 24 hours at a 45-degree angle to the tooth long axis using a universal testing machine. Failure load was converted in MPa using the available bonding surface area with mean data analyzed using Kruskal-Wallis/Dunn (p=0.05).

Results: Calculated failures stress found no difference in failure resistance among the three groups. However, failure load results identified that the endocrown preparations had significantly lower failure load resistance. Failure mode analysis identified that all preparations demonstrated a high number of catastrophic failures.

Conclusions: Under the conditions of this study, the addition of ferrule preparation features afforded no advantage when failure stress is concerned. All preparations, regardless of features, demonstrated a high number of catastrophic failure.

Table of Contents:

List of Tables: viii

List of Figures: ix

Introduction: 1

Materials and Methods: 2

Results: 9

Discussion: 10

Conclusions: 19

Literature Sources ..... **Error! Bookmark not defined.**

List of Tables:

Table 1, Resultant mean failure load and stress 9

Table 2, Resultant failure modes 10

Table 3, Mean Endocrown Preparation Parameters 12

List of Figures:

Figure 1, Prepared acrylic embedded specimens 3

Figure 2, Occlusal Table and Margin Surface Area Determination 4

Figure 3, CAD/CAM Standardized Scanning Templates 5

Figure 4, CAD/CAM Standardized Scanning Template with Specimen 5

Figure 5, CAD/CAM Restoration Designs for 0mm, 1mm, and 2mm Ferrule Preparations 6

Figure 6, Cemented Standardized e.max Restoration 7

Figure 7, Specimen Testing Orientation 8

Figure 8, Ferrule Wall Occlusal Convergence 11

Figure 9. Mean Failure Stress Results (MPa) 13

Figure 10. Mean Failure Load Results (N) 13

Figure 11. 3D Tiled Image Zero Millimeter Ferrule Failure 14

Figure 12. MicroCT Image of 1mm Ferrule – Catastrophic Failure 15

Figure 13. MicroCT Image of 1mm Ferrule – Catastrophic Failure 15

Figure 14. MicroCT Image 2mm Ferrule – Catastrophic Failure 16

Figure 15. Cross Section of endocrowns with decreased crown adaption 17

Figure 16. Preparation with deficient tooth structure for ferrule 18

Introduction:

Posterior teeth following endodontic therapy require adequate full coverage restorations to minimize risk of fracture, coronal seal to prevent bacterial contamination, and restore function. [1-4] Endodontically-treated teeth may be restored using various methods, including direct and indirect restorations, with indirect full-coverage methods being preferred by many clinicians. [5] Post and core procedures may be required in the situation of severe loss of coronal hard tissue, but may decrease tooth fracture resistance due to additional dentin removal while also increasing root perforation risk.[6,7] With advancements in computer aided design/computer assisted manufacturing (CAD/CAM) proponents claim that adhesive technology may provide clinicians with additional treatment options that may be more efficient and conservative for the restoration of endodontically-treated teeth.[8]

The endocrown is an indirect treatment option technique that is gaining clinical popularity for the restoration of endodontically treated posterior teeth. The endocrown is described as a full-coverage restoration with a circumferential butt-joint margin and a central retentive feature that extends into the pulp chamber space. [9] Several studies suggest a two millimeter central retentive feature to afford the optimal retention and resistance features. [7,10] Other endocrown preparation parameters have been recommended to include:

1. Cuspal Reduction of 2-3mm;
2. 90 degree butt margins;
3. Smooth internal transitions;
4. Six degree occlusal cervical internal taper of the pulpal chamber;
5. Flat pulpal floor with sealed radicular spaces; and
6. Supragingival enamel margins when possible. [11,12]

The increased fracture resistance imparted by the incorporation of ferrule features into preparations has been well described. [10,13,14] The addition of minimal ferrule of 0.5 millimeters has been suggested to significantly increase fatigue cycles to failure in teeth restored with all ceramic, full-coverage restorations supported by a resin core and fiber posts. [14] Also, the effect of ferrule has been demonstrated add significant fracture resistance than the presence of a post. [15] The addition of ferrule features to the endocrown preparation has not been previously investigated. The purpose of this study was to determine the effect on endocrown restoration failure strength with various ferrule features added to the endocrown preparation. The null hypothesis was that there would be no difference in failure strength between traditional endocrown restorations and endocrown restorations with a prepared ferrule.

Materials and Methods:

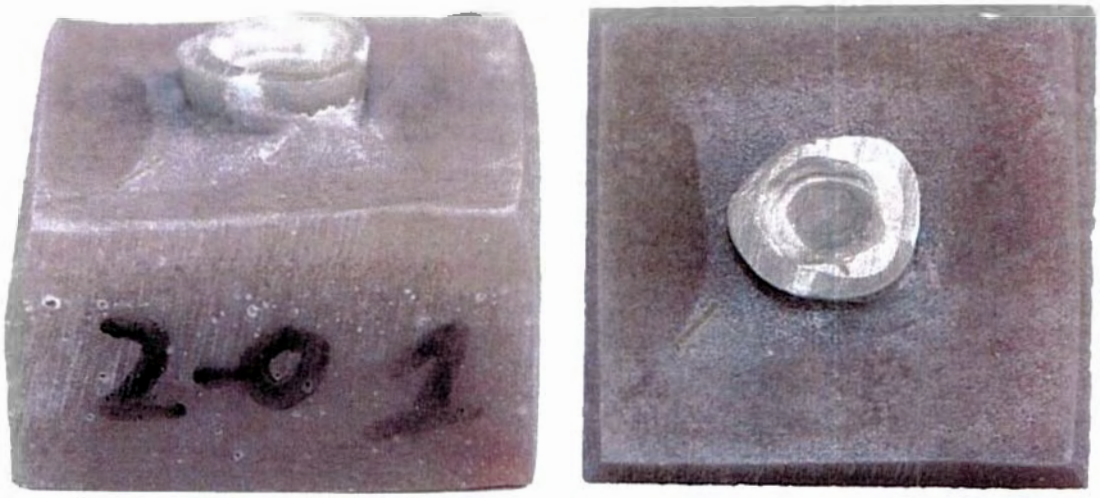
Human mandibular third molar teeth were used in this study, which had been removed as per routine clinical indications were collected from local oral and maxillofacial surgery clinics under the local Institutional Review Board (IRB) protocol approval.

Thirty six, recently-extracted mandibular third molars of approximate equal size were sectioned with a slow-speed diamond saw (Buehler, Lake Forest , IL USA) at the facial-lingual height of contour perpendicular to the long axis. All preparations were completed by one researcher to standardize preparations as much as possible with a locally established preparation feature covariance threshold established at 25 percent above which specimens were discarded. Access into the pulp chamber were accomplished using a high-speed handpiece (EA-51LT, Adec, Newburg, OR, USA) and a diamond bur (6847.33.016, Brassler USA, Savannah, GA, USA) using copious water spray. Pulpal remnants were removed with barbed broaches and gross instrumentation with hand files (Miltex, York, PA, USA). Canal orifices were further

prepared using Gates-Glidden rotary instruments (DENTSPLY-Maillefer, Tulsa, OK) to further simulate endodontic preparation of the pulp chamber and canals.

The specimens were embedded into auto-polymerizing denture base resin (Impak Self Cure, CMP Industries, Albany, NY, USA) with the coronal features prepared following endocrown preparation guidelines as previously described. (Figure 1)

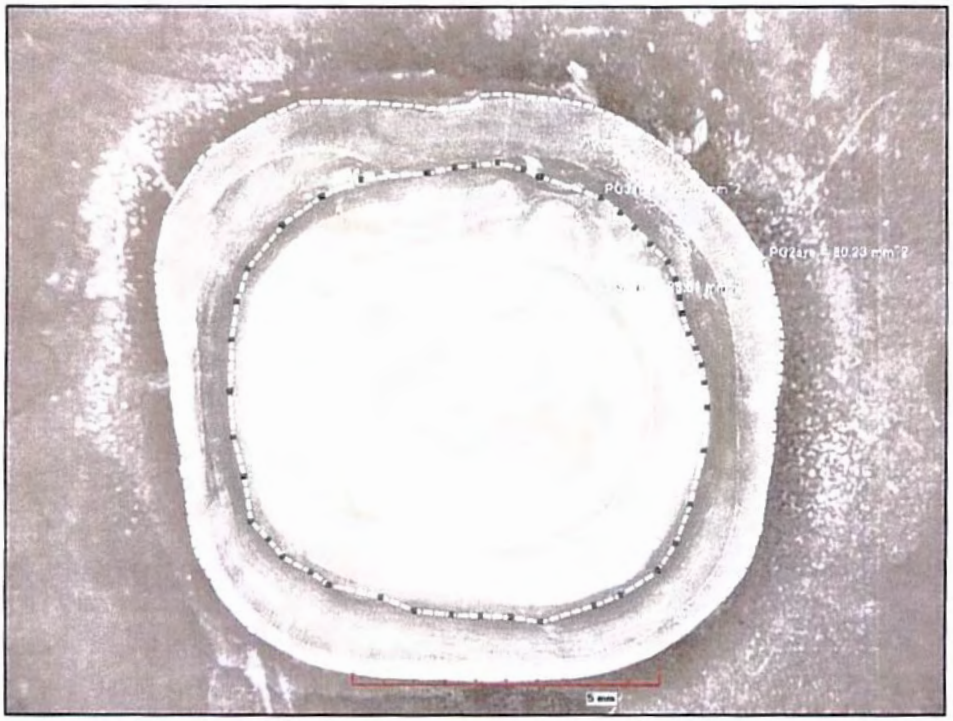
Figure 1, Prepared acrylic embedded specimens



Pulp chamber restoration was accomplished using a two-step, self-etch adhesive (Clearfil SE, Kuraray America, Houston, TX, USA) and a dual cure core material (Gradia Core, GC America, Alsip, IL, USA) to achieve a two millimeter pulp chamber depth whose floor was parallel to the endocrown occlusal table. All visible light polymerization was provided by a light-emitting-diode-based visible light curing (VLC) unit (Bluephase G2, Ivoclar-Vivadent, Amherst, NY, USA) whose irradiance were verified using a laboratory-grade laser power meter (10A-V1, Ophir-Spiricon, North Logan, UT, USA).

The completed endocrown preparations were then randomly subdivided into three groups (n = 12). Two of the groups received ferrule preparation features to the external coronal surface consisting of one and two millimeters placed circumferentially apical to the endocrown occlusal table. The third group did not receive additional preparation features. All specimens had preparation features confirmed and surface area measured using a digital recording microscope (KH- 7700, Hirox USA, Hackensack, NJ, USA). (Figure 2)

Figure 2, Occlusal Table and Margin Surface Area Determination



Two identical standardized templates were fabricated using acyclic. The template represented teeth #28 through #31 with one template having tooth #30 removed . (Figure 3) All specimens were scanned and restored using thestandardized template (Figure 4) to simulate clinical conditions using a chairside CAD/CAM unit (Cerec AC/Cerec MC XL, Dentsply Sirona, Charlotte, NC, USA; Software version 4.2.4.72301) with the full-coverage restorations milled

using a lithium disilicate glass-ceramic restorations (IPS e.max CAD, Ivoclar-Vivadent). (Figure 5)

Figure 3, CAD/CAM Standardized Scanning Templates

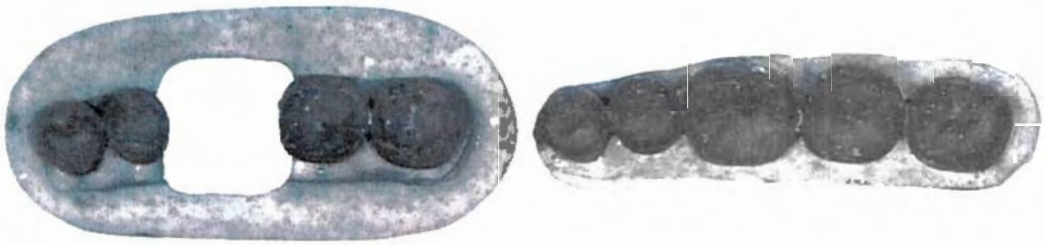
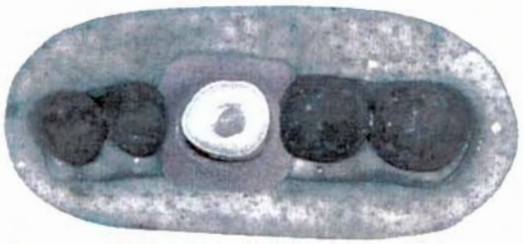
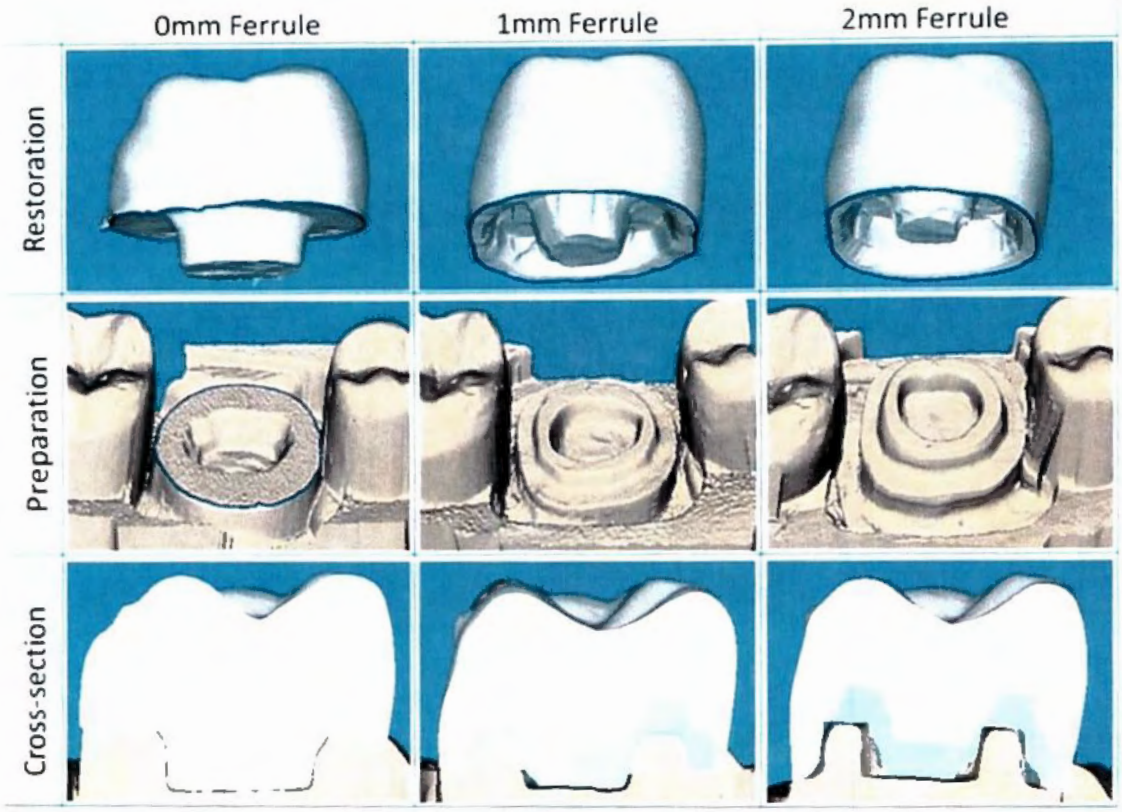


Figure 4, CAD/CAM Standardized Scanning Template with Specimen



All restorations were designed with identical occlusal table anatomy as well as axial wall height so as not to incorporate different lever action vectors into the testing design.

Figure 5, CAD/CAM Restoration Designs for 0mm, 1mm, and 2mm Ferrule Preparations



Two coats of spray glaze (IPS e.max CAD Crystall/Glaze spray, Ivoclar-Vivadent) were applied with crystallization firing accomplished following manufacturer recommendations in a dental laboratory ceramic furnace (Programat P700, Ivoclar-Vivadent). Proper seating was verified using a disclosing media (Occlude, Pascal International, Bellevue, WA, USA) followed by thorough steam cleaning and drying with oil free compressed air. Restoration intaglio surfaces were etched for 20 seconds using 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) followed by thorough rinse with water for 15 seconds and dried with oil free compressed air. A thin coat of silane agent (Monobond Plus, Ivoclar Vivadent) was applied with a microbrush to the etched intaglio surface for two, 60-second intervals with the excess dispersed with compressed air. The tooth surfaces were prepared for cementation using pumice slurry on a prophylaxis cup (Extended Straight Attachment DPA, Preventech, Indian

Trail, NC, USA) using a slow-speed handpiece (Midwest Shorty, Dentsply International, York, PA, USA) attachment followed by water rinse and air drying. Restorations were cemented with a self-adhesive resin cement (Rely-X Unicem, 3M ESPE, St. Paul, MN, USA) with firm digital pressure with a one-second tack cure applied to all surfaces using a VLC unit (Bluephase G2, Ivoclar Vivadent) after which excess cement was removed. All surfaces then received a final exposure to a VLC unit (Bluephase G2, Ivoclar Vivadent) for 20 seconds after which the specimens were stored in distilled water under dark conditions at 37 ± 1 °C and 98 ± 1% humidity. (Figure 6)

Figure 6, Cemented Standardized e.max Restoration

Twenty-four hours after cementation each specimen were placed into a fixture on a universal testing machine (RT-5, MTS Corporation, Eden Prairie, MN, USA) with the long axis of the tooth oriented at a 45 degree angle to the testing device. (Figure 7)

Figure 7, Specimen Testing Orientation

The facial cusps were loaded with a three-millimeter diameter hardened, stainless steel piston with a 0.5-meter radius of curvature as described by Kelly *et al.* [16] Specimens were loaded at a rate of 0.5 millimeter per minute until failure with the failure load recorded in Newtons. Failure load was also converted to failure stress using the measured surface area available for adhesion. Specimens were examined for failure mode to determine if the failure was cohesive for the ceramic restorative material, adhesive failure between the ceramic and the tooth structure, tooth material fracture, or mixed failure. Analysis was accomplished both visually at 20X magnification (Hirox-4400, Hirox USA) as well as microradiographic tomography (microCT) (Skyscan 1172, Bruker microCT/Micro Photonics, Allentown, PA, USA). Fractured samples were scanned over 180 degrees at 9.8-micron resolution with a 0.4 degree step size with aluminum filtration. Resultant individual images were recombined with software (nRecon,

Bruker microCT) with resultant recombined images visualized using CTan and CTVox software (Bruker microCT).

Analysis of the mean data with the Shaprio-Wilk Test and Bartlett's Test identified irregularities within both the data distribution and variance. Therefore, the mean data was analyzed with Kruskal-Wallis with Dunn's *post hoc* test when required. A 95 percent level of confidence ($p = 0.05$) was used with all analysis.

Results:

Table 1, Resultant Mean Failure Load and Stress

Mean Failure Loads (N) and Stress (MPa)

Endocrown Ferrule (mm)	Failure Load (N)	Failure Stress (MPa)
0	638.5 (238.5) A	6.13 (1.7) A
1	1101.0 (487.0) B	7.85 (3.3) A
2	956.3 (294.5) B	6.32 (1.8) A

n = 12; Groups identified with same capital letter are similar within each column (Dunn's p = 0.05)

When considering failure load, the endocrown restorations containing one and two millimeters of ferrule demonstrated greater failure load resistance than the endocrowns without ferrule. However, under conditions of calculated failure stress, there was no significant difference between any of the groups.

Table 2. Failure Mode Results

Endocrown Ferrule	Failure Mode				
	Adhesive Debonding	Restorable Fracture	Catastrophic Fracture	Cohesive Root Fracture	Ceramic Cohesive Failure
0 mm	0	2	10	0	0
1 mm	2	1	8	0	1
2 mm	0	0	12	0	0

n = 12

Catastrophic failure = Non-restorable fracture that involves the restoration and restoration preparation.
Cohesive Root Fracture = Fracture that does not involve restoration/preparation complex at a level apical to the preparation.
Restorable Fracture = Fracture either separate or combined of restoration and tooth deemed restorable

All of the groups demonstrated a high number of catastrophic failures. The endocrown group with two millimeters ferrule displayed universal catastrophic failure with the endocrown demonstrating slightly less. The endocrown group with one millimeter of ferrule demonstrated the least amount of non-restorable failures as well as a small amount of adhesive failures.

Discussion:

The importance of full-coverage restorations following endodontic therapy is well known. Tang and colleagues [2] reported the failure to replace interim restorations expediently with permanent restorations after endodontic treatment resulted in greater than 65 percent tooth loss over three years. Equally important is the provision of a coronal seal over the completed endodontic treatment, as microbial re-contamination of the root canal system has been shown with *in vitro* testing to occur between 24 and 30 days after exposure of the gutta percha material to oral fluids. [3,4] The placement of intracanal posts is often required to augment retention and resistance features for the core material in situations of advanced loss of coronal tooth structure. [17-19] Notwithstanding, such use of intracoronal posts is not without its hazards. The use of posts has been suggested to increase incidence of failure in the instance of post and tooth material modulus mismatch, excess dentin removal, and failure to provide adequate

ferrule. [2,21,22] Furthermore, posts may not be a viable option when confronted with certain canal morphology such as dilacerated or calcified canals. [23]

CAD/CAM proponents describe the endocrown as an effective and expedient means for the restoration of endodontically treated teeth [9,12,24,25] especially of situations where insufficient ferrule is present. [12] Additionally, *in vitro* finite element analysis studies suggest the endocrown method produces less internal stress forces than full coverage restorations supported by post and cores, [26,27] but other studies suggest that endocrowns should be limited to molars. [27,28] The purpose of this study was to determine the effect of ferrule on molar endocrown restoration failure strength and failure mode analysis. The endocrown restoration was fabricated using a lithium disilicate restorative material (e.max CAD, Ivoclar Vivadent) which was bonded using a self-adhesive resin cement (Unicem, 3M ESPE). Specimens were prepared as uniformly as possible where the surface area available for bonding (Figure 2) and ferrule wall occlusal convergence (Figure 8) was determined using a digital measuring microscope (Hirox 4400, Hirox USA). The mean specimen parameters are listed in Table 3.

Figure 8, Ferrule Wall Occlusal Convergence

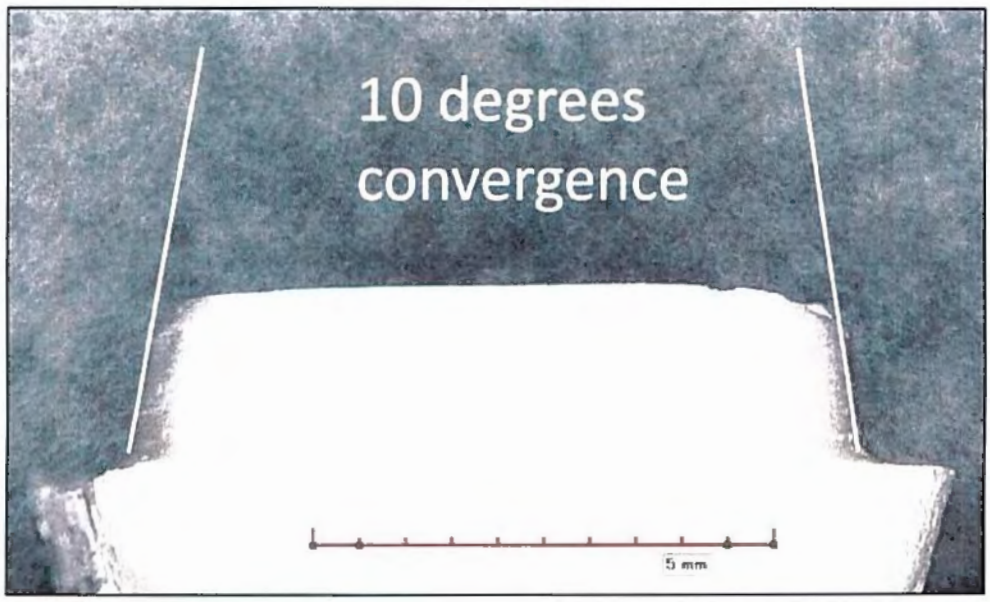


Table 3, Mean Endocrown Preparation Parameters

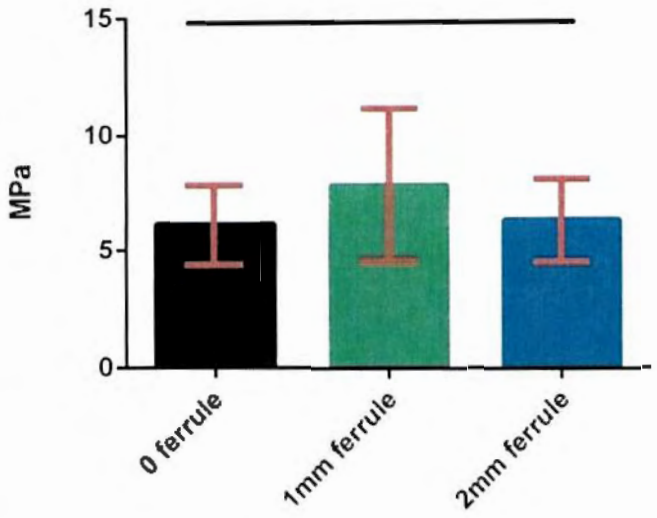
Group (Ferrule)	Mean dentin surface area (mm^2)	Mean ferrule wall height (mm)	Ferrule wall mean total occlusal convergence (degrees)
0mm	102.3 (16.1)		
1mm	139.1 (10.6)	1.07 (0.01)	10.4 (0.5)
2mm	150.1 (10.2)	2.04 (0.05)	10.3 (0.6)

n = 12

The resin-restored chamber floor was also included in the surface area available for bonding. As stated earlier, one researcher prepared all of the specimens before restoration, which was also completed by a single, different researcher. Preparation standardization was achieved with some success as the mean measured surface area covariance of the ferrule group preparations was approximately seven percent, while the total occlusal convergence covariance for the same groups was approximately five percent. The endocrown preparation surface area was more variable with a 15 percent covariance, but still below the established covariance 25 percent threshold. Preparation surface area available for bonding increased 36 percent from the standard endocrown to the one millimeter ferrule group while the surface area between the standard endocrown restoration and the two millimeter ferrule endocrown restoration group increased 47 percent. However, there was only an eight percent increase in surface area between the one and two millimeter ferrule group.

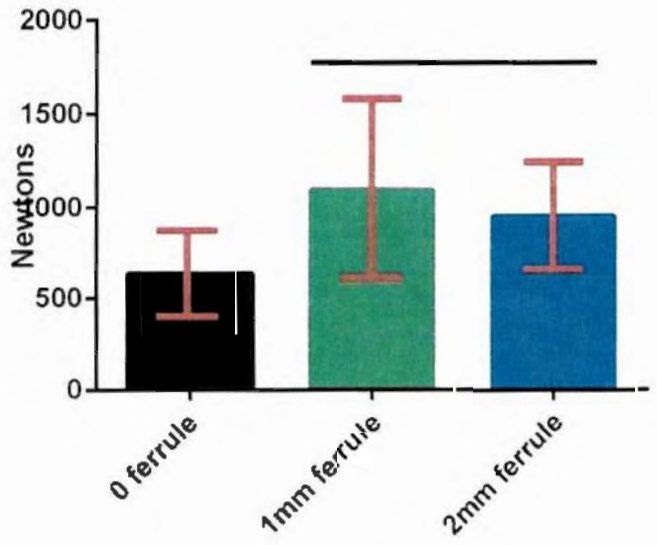
Under the conditions of this study the calculated failure stress (MPa) found no significant difference noted between the preparation groups ($p = 0.427$). However, analysis using failure load (N) demonstrated a difference between the groups ($p = 0.016$), with *post hoc* testing identified that the ferrule groups were similar with each other ($p = 0.857$) but was significantly greater than the endocrown group ($p = 0.0212$) as depicted in Figure 9 and 10.

Figure 9. Mean Failure Stress Results (MPa)



n = 12; Items connected by same bar are significantly similar (Kruskal-Wallis, p = 0.42)

Figure 10. Mean Failure Load Results (N)



n = 12; Items connected by same bar are significantly similar (Kruskal-Wallis/Dunn's, p = 0.021)

Therefore, the null hypothesis was rejected under the consideration of failure load, but was accepted when the failure stress data was observed. It is interesting to note that although the available surface for adhesion increased over 47 percent from the standard endocrown to the endocrown with a two millimeter ferrule, no difference in failure stress was noted. However, failure load results identified the ferrule groups failed at significantly greater loads than the standard endocrown restoration.

The most clinically relevant findings of this study may be noted when the failure analysis results are considered. MicroCT analysis proved to be a valuable tool in assessing the failure modes, as some specimens with visually judged repairable damage (Figure 11) was found to contain irreparable fractures that, depending on location, may or may not be visible on a standard periapical film (Figure 12, Figure 13).

Figure 11. 3D Tiled Image Zero Millimeter Ferrule Failure

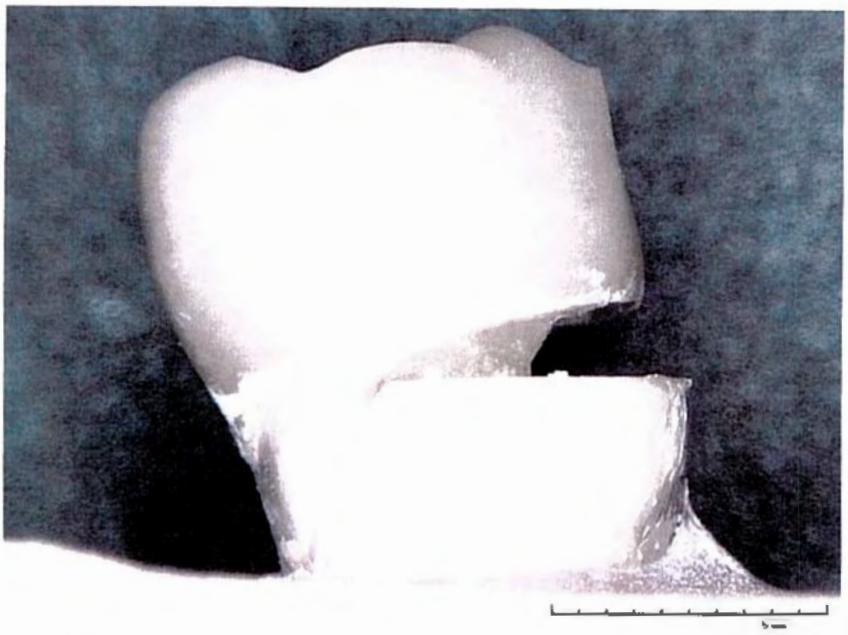


Figure 12. MicroCT Image of 1mm Ferrule – Catastrophic Failure

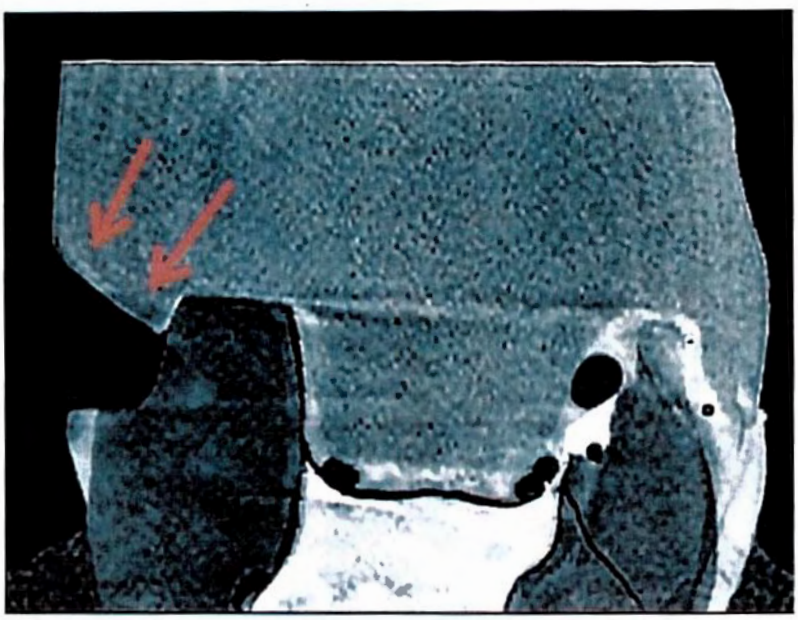


Figure 13. MicroCT Image of 1mm Ferrule – Catastrophic Failure

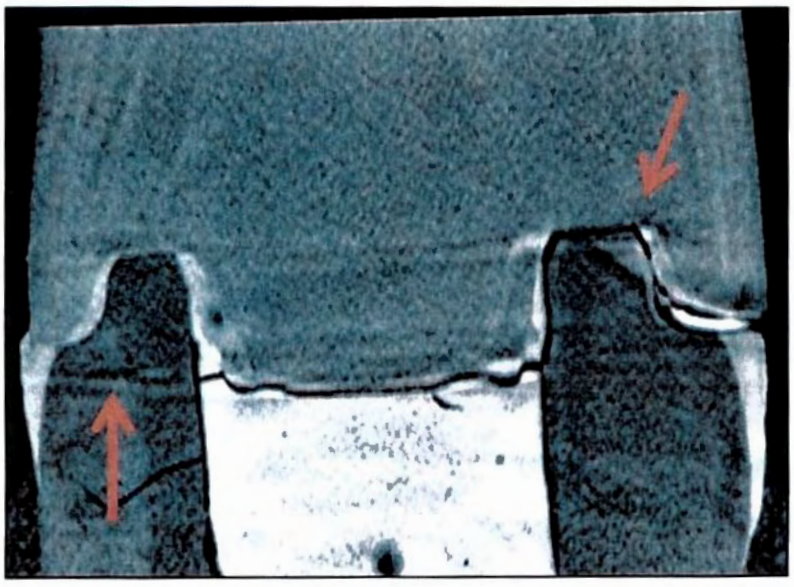
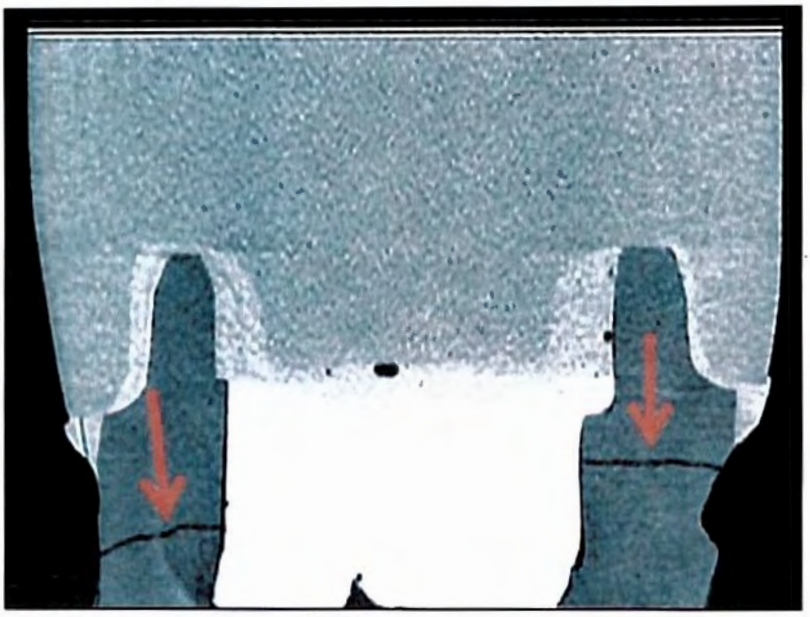


Figure 14. MicroCT Image 2mm Ferrule – Catastrophic Failure



All of the endocrown preparations containing two millimeters of ferrule failed catastrophically, (Figure 14) followed by 10 of the 12 standard endocrown preparations. The one millimeter endocrown ferrule group had the least number of catastrophic failures, albeit with 66 percent of the specimens exhibiting non-restorable fractures. Thus, under laboratory testing the endocrowns, regardless of ferrule preparation features, demonstrated a high percentage of catastrophic failures.

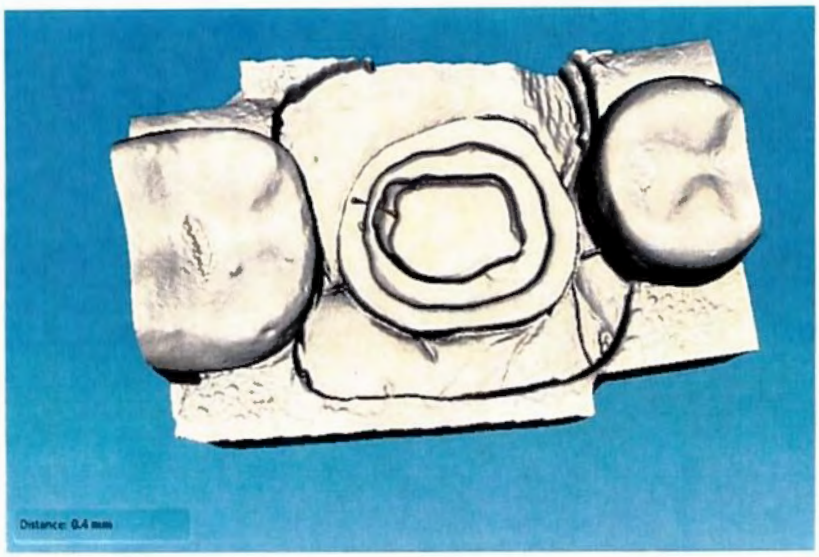
The results of this study should be considered with the failure load results are in excess of that reported for normal human function and the ferrule containing endocrown preparations approach those suggested for accidental biting and/or trauma. [29-36] Although the force was applied to the functional cusp, the static applied load can be in variance with normal oral function. The measured human maximum bite force varies with different reported studies. For instance, one study reported the average bite force for males was approximately 285 N and 254 N for females, [35] while another study reported 654 and 464 N for the same two gender groups, respectively. [36] Notwithstanding , the next research objective is to repeat the conditions of this

study under fatigue forces with non-destructive microCT assessment of internal changes that may lead to failure.

A preparation parameter that was observed that may affect restoration performance was the milling limitations in reproducing the intaglio surface of the crown. Accordingly, it was observed that the more complex the preparation, the more complex the restoration design and therefore resulted in decrease crown adaptation with 1mm and 2mm designs with larger cement space (Figure 15). Another preparation parameter was the sometimes tooth structure limitation realized by a ferrule addition in the cervical area. This resulted in some ferrule areas with limited ferrule wall thickness (Figure 16).

Figure 15. Cross Section of endocrowns with decreased crown adaption

Figure 16. Preparation with deficient tooth structure for ferrule



This study also sought to determine if the failure stress calculation would perhaps provide normalization of the failure load results, which could be skewed due to tooth size discrepancies. The failure stress determination did appear to normalize the failure load data under the conditions of this study. However, more definitive research and analysis is required before more recommendations can be proffered.

When considering the traditional endocrown preparations, the results of this study are similar to that reported by Biacchi and Basting [25] who reported a median endocrown failure of approximately 674 N. That study also reported a high number of non-restorable fractures similar to that found in the present study. However, the present study's results are less than that reported by Magne et al [7] who reported endocrown failure loads of 2606 N as well as that reported by El-Damanhoury et al [37] whose lithium disilicate material demonstrated a mean fracture load of 1368 N. Furthermore, Gresnight and colleagues [38] also reported failure values above that found with the present study. However, those reports differ somewhat from the present study with the application of different force vectors.

Conclusions:

Under the conditions of this study, calculated failure stress based on available surface area for adhesive bonding found no difference in failure between standard endocrown preparations and endocrown preparations containing either one or two millimeters of ferrule. In contrast, failure load results found the ferrule-containing endocrown preparations demonstrated significantly greater failure loads than standard endocrown restorations. Regardless of the presence of a ferrule, this study found endocrown restorations suffered a high proportion of catastrophic failures but at loads greater than reported normal masticatory function. Based on these results, fatigue studies should be investigated.

Bibliography

1. Robbins JW (1990) Guidelines for the restoration of endodontically treated teeth. J Am Dent Assoc 1990;120:558-566.

2. Tang W, Wu Y, Smales RJ. Identifying and reducing risks for potential fractures in endodontically treated teeth. J Endod 2010;36:609–617.

3. Torabinejad M, Ung B, Kettering JD. In vitro bacterial penetration of coronally unsealed endodontically treated teeth. J Endod 1990;16:566-569.

4. Khayat A, Lee SJ, Torabinejad M. Human saliva penetration of coronally unsealed obturated root canals. J Endod 1993;19:458-461.

5. Salhrabi R, Rotstein I. Endodontic treatment outcomes in a large patient population in the USA: an epidemiological study. J Endod 2004;30:846-850.

6. Schwartz RS, Robbins JW. Post placement and restoration of endodontically treated teeth: a literature review. J Endod 2004;30:289-301.

7. Magne P, Carvalho AO, Bruzi G, Anderson RE, Maia HP, Giannini M. Influence of no-ferrule and no-Post buildup design on the fatigue resistance of endodontically treated molars restored with resin nanoceramic CAD/CAM crowns. Oper Dent 2014;39:595-602.

8. Ramı´rez-Sebastia` A, Bortolotto T, Roig M, Krejci I. Composite vs Ceramic Computer-aided Design/Computer-assisted Manufacturing Crowns in Endodontically Treated Teeth: Analysis of Marginal Adaptation. Oper Dent 2013;38:663-673.

9. Pissis P. Fabrication of a metal-free ceramic restoration utilizing the monobloc technique. Practical Periodontics and Aesthetic Dentistry 1995;7:83-94.

10. Forberger N, Göhring TN. Influence of the type of post and core on in vitro marginal continuity, fracture resistance, and fracture mode of lithia disilicate-based all-ceramic crowns. J Prosthet Dent 2008;100:264-73.

11. Moore P. Cerec Doctors publications, Dentsply Sirona, Charlotte, NC, 2013.

12. Lander E, & Dietschi D. Endocrowns: a clinical report. Quintessence Int 2008;39:99-106.

13. Pereira JR, de Ornelas F, Conti PCR, do Valle AL. Effect of a crown ferrule on the fracture resistance of endodontically treated teeth restored with prefabricated posts. J Prosthet Dent 2006;95:50-54.

14. Ma PS, Nicholls JI, Junge T, Phillips KM. Load fatigue of teeth with different ferrule lengths, restored with fiber posts, composite resin cores, and all-ceramic crowns. J Prosthet Dent 2009;102:229-234.

15. Lima AF, Spazzin AO, Galafassi D, Correr-Sobrinho L, Carlini-Junior B. Influence of ferrule preparation with or without glass fiber post on fracture resistance of endodontically treated teeth. J Appl Oral Sci 2010;18:360-363.

16. Kelly RJ, Rungruanganunt P, Hunter B, Vailati F. Development of a clinically validated bulk failure test for ceramic crowns. J Prosthet Dent 2010;104:228-238.

17. Baba NZ, Golden G, Goodacre CJ. Nonmetallic Prefabricated Dowels: A Review of Compositions, Properties, Laboratory, and Clinical Test Results. J Prosthodont 2009;18:527-536.

18. Balkenhol M, Wöstmann B, Rein C, Ferger P. Survival time of cast post and cores: A 10-year retrospective study. J Dent 2007;35:50-58.

19. Fokkinga WA, Kreulen CM, Bronkhorst EM, Creugers NHJ. Up to 17-year controlled clinical study on post-and-cores and covering crowns. J Dent 2007;35:778-786.

20. Zhu Z, Dong XY, He S, Pan X, Tang L. Effect of post placement on the restoration of endodontically treated teeth: A systematic review. Int J Prosthodont 2015;28:475-483.

21. Ona M, Wakabayashi N, Yamazaki T, Takaichi A, Igarashi Y. The influence of elastic modulus mismatch between tooth and post and core restorations on root fracture. Int Endod J 2013;46:47-52.

22. Assif D, Bitenski A, Pilo R, Oren E. Effect of post design on the resistance to fracture of endodontically treated teeth with complete crowns. J Prosthet Dent 1993;69:36-40.

23. Biacchi GR, Mello B, Bastings RZ. The Endocrown: An Alternative Approach for Restoring Extensively Damaged Molars. J Esthet Restor Dent 2013;25:383–391.

24. Bindl A, Mormann WH. Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years: preliminary results. J Adh Dent 1999;1:255-265.

25. Biacchi GR, Basting RT. Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. Oper Dent 2012;37:130-136.

26. Lin CL, Chang YH, Chang CY, Pai CA, Huang SF. Finite element analyses to estimate failure risks in the ceramic endocrown and classical crown for endodontically treated maxillary premolars. Eur J Oral Sci 2010;118:87-93.

27. Dejak B, Młotkowski A. 3D-Finite element analysis of molars restored with endocrowns and posts during masticatory simulation. Dent Mater 2013;29:e309–e317

28. Bindl A, Richter B, Mormann WH. Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry. Int J Prosth 2005;18:219-224.

29. Chen C, Trindade FZ, de Jager N, Kleverlaan C, Feilzer AJ. The fracture resistance of a CAD/CAM Resin Nano Ceramic (RNC) and a CAD ceramic at different thicknesses. Dent Mater 2014;30:954-962.

30. Sinn DP, DeAssis EA, Throckmorton GS. Mandibular excursions and maximum bite forces in patients with temporomandibular joint disorders. J Oral Maxil Surg 1996;54:671-9.

31. Vaneijden T. 3-Dimensional analyses of human bite-force magnitude and moment. Arch Oral Biol 1991;36:535-9.

32. Pruim GJ, Dejongh HJ, Tenbosch D. Forces acting on the mandible during bilateral static bite at different bite force levels. J Biomech 1980;13:755 3.

33. Gibbs CH, Mahan PE, Mauderli A, Lundeen HC, Walsh EK. Limits of human bite strength. J Prosth Dent 1986;56:226-9.

34. Waltimo A, Kononen M. A novel bite force recorder and maximal isometric bite force values for healthy-young adults. Scand J Dent Res 1993;101:171-5.

35. Pizolato RA, Gavião MB, Berretin-Felix G, Sampaio AC, Trindade Junior AS, Maximal bite force in young adults with temporomandibular disorders and bruxism. Braz Oral Res. 2007;21:278-83.

36. Takaki P, Vieira M, Bommarito S. Maximum bite force analysis in different age groups. Int Arch Otorhinolaryngol. 2014 Jul;18(3):272-6.

37. El-Damanhoury HM, Haj-Ali RN, Platt JA. Microleakage of Endocrowns Utilizing Three CAD-CAM Blocks. Oper Dent 2015;40:201-210.

Preparation Ferrule Design Effect on EndoCrown Fracture Resistance

Michael L. Einhorn

Preparation Ferrule Design Effect on EndoCrown Fracture Resistance

Major Michael L. Einhorn

APPROVED:

Colonel Howard W. Roberts (Chairman)

For Nicholas B DuVall

Major Nicholas B. DuVall

Colonel Michael N. Wajdowicz

24 May 2016

Date

APPROVED:

Col Drew W. Fallis
Dean, Air Force Postgraduate Dental School

Acknowledgements:

Special thanks to Col Howard Roberts, Maj Nicholas DuVall, Maj Sara Cushen.

23 May 2016

The author hereby certifies that the use of any copyrighted material in the thesis manuscript entitled:

Preparation Ferrule Design Effect on EndoCrown Fracture Resistance

is appropriately acknowledged and beyond brief excerpts, is with the permission of the copyright owner.

Michael L Eubanks

Signature

Michael L. Eubanks

Printed Name

USAF Postgraduate Dental School
Keesler AFB, MS
Uniformed Services University

Abstract:

Objective: To evaluate the effect of ferrule with retention of adhesively-bonded mandibular molar CAD/CAM Endocrowns.

Methods: Recently-extracted mandibular third molars were randomly divided into 3 groups (n=12) with the coronal tooth structure removed perpendicular to the root long axis approximately 2mm above the CEJ with a water-cooled, slow-speed diamond saw. The pulp chamber was exposed using a diamond bur in a high speed handpiece. Pulpal remnants were removed and canals instrumented using endodontic hand instruments. The chamber floor was restored using a resin core material with a two-step, self-etch adhesive and photopolymerized with a visible light curing unit to create a 2mm endocrown preparation pulp chamber extension. One and two millimeter ferrule height groups were prepared using a diamond bur in a high speed handpiece following CAD/CAM guidelines. Completed preparation surface area was determined using a digital measuring microscope. Scanned preparations (CEREC) were restored with lithium disilicate restorations with a self-adhesive resin luting agent. All manufacturer recommendations were followed. Specimens were stored at 37C/98% humidity and tested to failure after 24 hours at a 45-degree angle to the tooth long axis using a universal testing machine. Failure load was converted in MPa using the available bonding surface area with mean data analyzed using Kruskal-Wallis/Dunn (p=0.05).

Results: Calculated failures stress found no difference in failure resistance among the three groups. However, failure load results identified that the endocrown preparations had significantly lower failure load resistance. Failure mode analysis identified that all preparations demonstrated a high number of catastrophic failures.

Conclusions: Under the conditions of this study, the addition of ferrule preparation features afforded no advantage when failure stress is concerned. All preparations, regardless of features, demonstrated a high number of catastrophic failure.

Table of Contents:

List of Tables: viii

List of Figures: ix

Introduction: 1

Materials and Methods: 2

Results: 9

Discussion: 10

Conclusions: 19

Literature Sources ..... **Error! Bookmark not defined.**

List of Tables:

Table 1, Resultant mean failure load and stress 9

Table 2, Resultant failure modes 10

Table 3, Mean Endocrown Preparation Parameters 12

List of Figures:

Figure 1, Prepared acrylic embedded specimens 3

Figure 2, Occlusal Table and Margin Surface Area Determination 4

Figure 3, CAD/CAM Standardized Scanning Templates 5

Figure 4, CAD/CAM Standardized Scanning Template with Specimen 5

Figure 5, CAD/CAM Restoration Designs for 0mm, 1mm, and 2mm Ferrule Preparations 6

Figure 6, Cemented Standardized e.max Restoration 7

Figure 7, Specimen Testing Orientation 8

Figure 8, Ferrule Wall Occlusal Convergence 11

Figure 9. Mean Failure Stress Results (MPa) 13

Figure 10. Mean Failure Load Results (N) 13

Figure 11. 3D Tiled Image Zero Millimeter Ferrule Failure 14

Figure 12. MicroCT Image of 1mm Ferrule – Catastrophic Failure 15

Figure 13. MicroCT Image of 1mm Ferrule – Catastrophic Failure 15

Figure 14. MicroCT Image 2mm Ferrule – Catastrophic Failure 16

Figure 15. Cross Section of endocrowns with decreased crown adaption 17

Figure 16. Preparation with deficient tooth structure for ferrule 18

Introduction:

Posterior teeth following endodontic therapy require adequate full coverage restorations to minimize risk of fracture, coronal seal to prevent bacterial contamination, and restore function. [1-4] Endodontically-treated teeth may be restored using various methods, including direct and indirect restorations, with indirect full-coverage methods being preferred by many clinicians. [5] Post and core procedures may be required in the situation of severe loss of coronal hard tissue, but may decrease tooth fracture resistance due to additional dentin removal while also increasing root perforation risk.[6,7] With advancements in computer aided design/computer assisted manufacturing (CAD/CAM) proponents claim that adhesive technology may provide clinicians with additional treatment options that may be more efficient and conservative for the restoration of endodontically-treated teeth.[8]

The endocrown is an indirect treatment option technique that is gaining clinical popularity for the restoration of endodontically treated posterior teeth. The endocrown is described as a full-coverage restoration with a circumferential butt-joint margin and a central retentive feature that extends into the pulp chamber space. [9] Several studies suggest a two millimeter central retentive feature to afford the optimal retention and resistance features. [7,10] Other endocrown preparation parameters have been recommended to include:

1. Cuspal Reduction of 2-3mm;
2. 90 degree butt margins;
3. Smooth internal transitions;
4. Six degree occlusal cervical internal taper of the pulpal chamber;
5. Flat pulpal floor with sealed radicular spaces; and
6. Supragingival enamel margins when possible. [11,12]

The increased fracture resistance imparted by the incorporation of ferrule features into preparations has been well described. [10,13,14] The addition of minimal ferrule of 0.5 millimeters has been suggested to significantly increase fatigue cycles to failure in teeth restored with all ceramic, full-coverage restorations supported by a resin core and fiber posts. [14] Also, the effect of ferrule has been demonstrated add significant fracture resistance than the presence of a post. [15] The addition of ferrule features to the endocrown preparation has not been previously investigated. The purpose of this study was to determine the effect on endocrown restoration failure strength with various ferrule features added to the endocrown preparation. The null hypothesis was that there would be no difference in failure strength between traditional endocrown restorations and endocrown restorations with a prepared ferrule.

Materials and Methods:

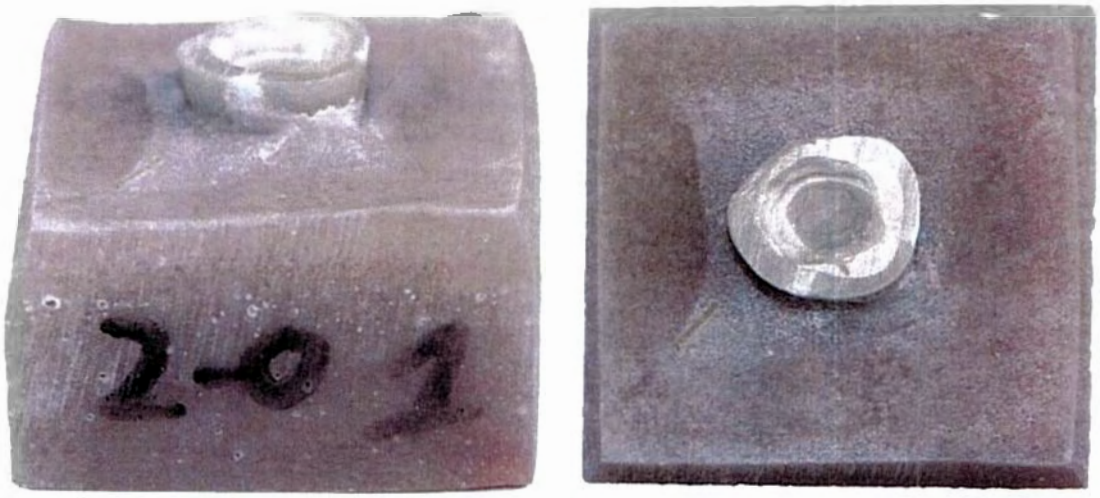
Human mandibular third molar teeth were used in this study, which had been removed as per routine clinical indications were collected from local oral and maxillofacial surgery clinics under the local Institutional Review Board (IRB) protocol approval.

Thirty six, recently-extracted mandibular third molars of approximate equal size were sectioned with a slow-speed diamond saw (Buehler, Lake Forest , IL USA) at the facial-lingual height of contour perpendicular to the long axis. All preparations were completed by one researcher to standardize preparations as much as possible with a locally established preparation feature covariance threshold established at 25 percent above which specimens were discarded. Access into the pulp chamber were accomplished using a high-speed handpiece (EA-51LT, Adec, Newburg, OR, USA) and a diamond bur (6847.33.016, Brassler USA, Savannah, GA, USA) using copious water spray. Pulpal remnants were removed with barbed broaches and gross instrumentation with hand files (Miltex, York, PA, USA). Canal orifices were further

prepared using Gates-Glidden rotary instruments (DENTSPLY-Maillefer, Tulsa, OK) to further simulate endodontic preparation of the pulp chamber and canals.

The specimens were embedded into auto-polymerizing denture base resin (Impak Self Cure, CMP Industries, Albany, NY, USA) with the coronal features prepared following endocrown preparation guidelines as previously described. (Figure 1)

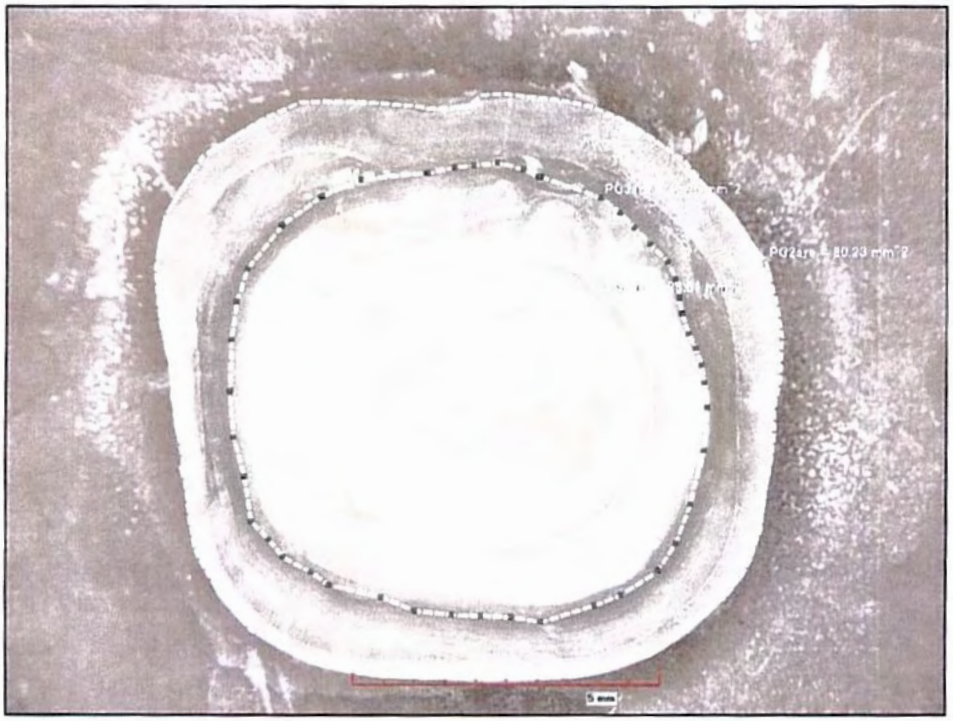
Figure 1, Prepared acrylic embedded specimens



Pulp chamber restoration was accomplished using a two-step, self-etch adhesive (Clearfil SE, Kuraray America, Houston, TX, USA) and a dual cure core material (Gradia Core, GC America, Alsip, IL, USA) to achieve a two millimeter pulp chamber depth whose floor was parallel to the endocrown occlusal table. All visible light polymerization was provided by a light-emitting-diode-based visible light curing (VLC) unit (Bluephase G2, Ivoclar-Vivadent, Amherst, NY, USA) whose irradiance were verified using a laboratory-grade laser power meter (10A-V1, Ophir-Spiricon, North Logan, UT, USA).

The completed endocrown preparations were then randomly subdivided into three groups (n = 12). Two of the groups received ferrule preparation features to the external coronal surface consisting of one and two millimeters placed circumferentially apical to the endocrown occlusal table. The third group did not receive additional preparation features. All specimens had preparation features confirmed and surface area measured using a digital recording microscope (KH- 7700, Hirox USA, Hackensack, NJ, USA). (Figure 2)

Figure 2, Occlusal Table and Margin Surface Area Determination



Two identical standardized templates were fabricated using acyclic. The template represented teeth #28 through #31 with one template having tooth #30 removed . (Figure 3) All specimens were scanned and restored using thestandardized template (Figure 4) to simulate clinical conditions using a chairside CAD/CAM unit (Cerec AC/Cerec MC XL, Dentsply Sirona, Charlotte, NC, USA; Software version 4.2.4.72301) with the full-coverage restorations milled

using a lithium disilicate glass-ceramic restorations (IPS e.max CAD, Ivoclar-Vivadent). (Figure 5)

Figure 3, CAD/CAM Standardized Scanning Templates

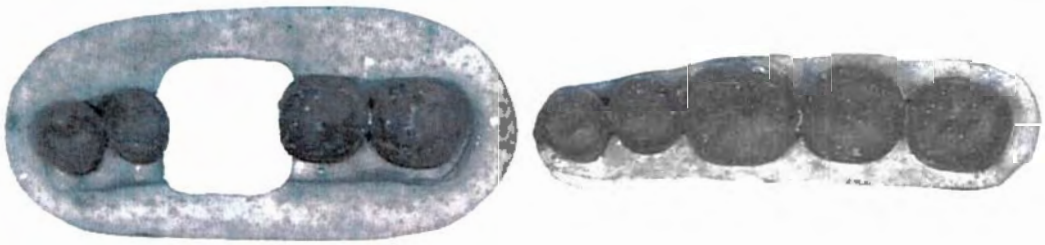
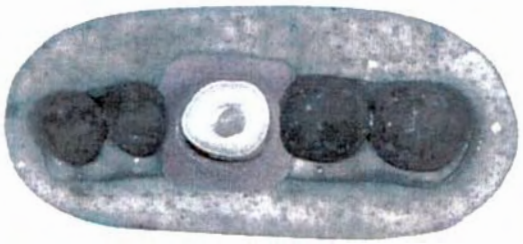
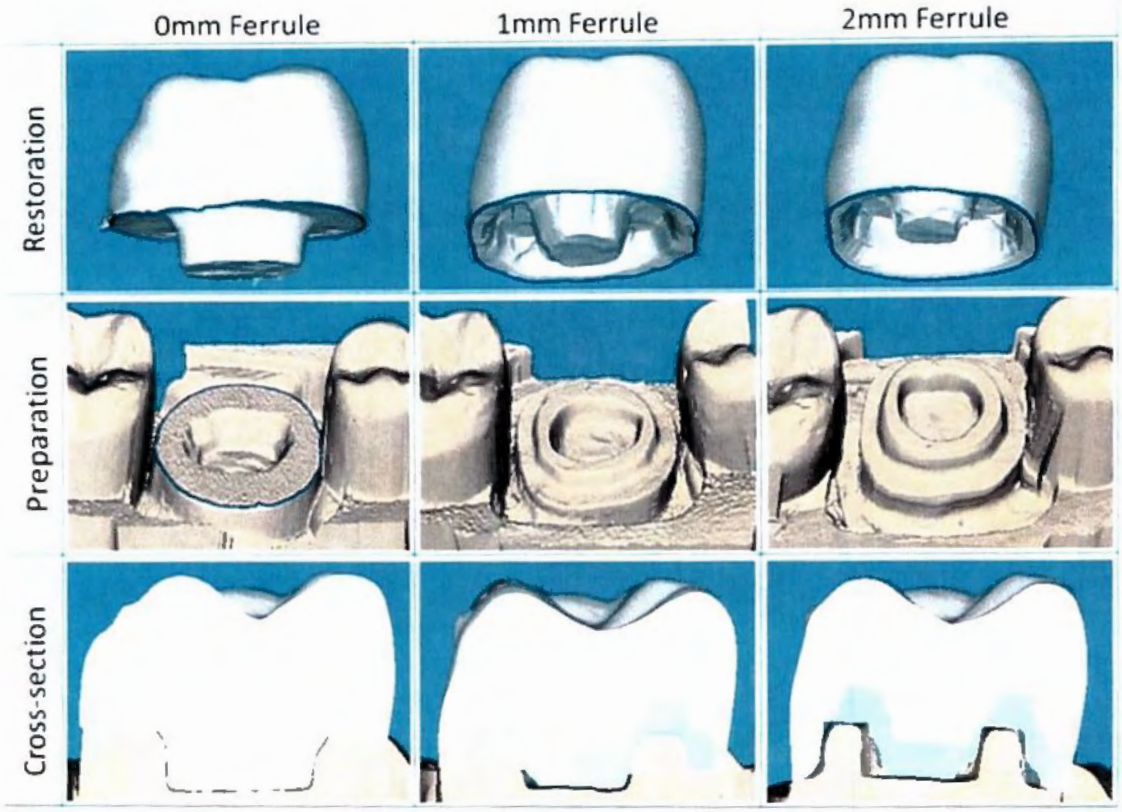


Figure 4, CAD/CAM Standardized Scanning Template with Specimen



All restorations were designed with identical occlusal table anatomy as well as axial wall height so as not to incorporate different lever action vectors into the testing design.

Figure 5, CAD/CAM Restoration Designs for 0mm, 1mm, and 2mm Ferrule Preparations



Two coats of spray glaze (IPS e.max CAD Crystall/Glaze spray, Ivoclar-Vivadent) were applied with crystallization firing accomplished following manufacturer recommendations in a dental laboratory ceramic furnace (Programat P700, Ivoclar-Vivadent). Proper seating was verified using a disclosing media (Occlude, Pascal International, Bellevue, WA, USA) followed by thorough steam cleaning and drying with oil free compressed air. Restoration intaglio surfaces were etched for 20 seconds using 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) followed by thorough rinse with water for 15 seconds and dried with oil free compressed air. A thin coat of silane agent (Monobond Plus, Ivoclar Vivadent) was applied with a microbrush to the etched intaglio surface for two, 60-second intervals with the excess dispersed with compressed air. The tooth surfaces were prepared for cementation using pumice slurry on a prophylaxis cup (Extended Straight Attachment DPA, Preventech, Indian

Trail, NC, USA) using a slow-speed handpiece (Midwest Shorty, Dentsply International, York, PA, USA) attachment followed by water rinse and air drying. Restorations were cemented with a self-adhesive resin cement (Rely-X Unicem, 3M ESPE, St. Paul, MN, USA) with firm digital pressure with a one-second tack cure applied to all surfaces using a VLC unit (Bluephase G2, Ivoclar Vivadent) after which excess cement was removed. All surfaces then received a final exposure to a VLC unit (Bluephase G2, Ivoclar Vivadent) for 20 seconds after which the specimens were stored in distilled water under dark conditions at 37 ± 1 °C and 98 ± 1% humidity. (Figure 6)

Figure 6, Cemented Standardized e.max Restoration

Twenty-four hours after cementation each specimen were placed into a fixture on a universal testing machine (RT-5, MTS Corporation, Eden Prairie, MN, USA) with the long axis of the tooth oriented at a 45 degree angle to the testing device. (Figure 7)

Figure 7, Specimen Testing Orientation

The facial cusps were loaded with a three-millimeter diameter hardened, stainless steel piston with a 0.5-meter radius of curvature as described by Kelly *et al.* [16] Specimens were loaded at a rate of 0.5 millimeter per minute until failure with the failure load recorded in Newtons. Failure load was also converted to failure stress using the measured surface area available for adhesion. Specimens were examined for failure mode to determine if the failure was cohesive for the ceramic restorative material, adhesive failure between the ceramic and the tooth structure, tooth material fracture, or mixed failure. Analysis was accomplished both visually at 20X magnification (Hirox-4400, Hirox USA) as well as microradiographic tomography (microCT) (Skyscan 1172, Bruker microCT/Micro Photonics, Allentown, PA, USA). Fractured samples were scanned over 180 degrees at 9.8-micron resolution with a 0.4 degree step size with aluminum filtration. Resultant individual images were recombined with software (nRecon,

Bruker microCT) with resultant recombined images visualized using CTan and CTVox software (Bruker microCT).

Analysis of the mean data with the Shaprio-Wilk Test and Bartlett's Test identified irregularities within both the data distribution and variance. Therefore, the mean data was analyzed with Kruskal-Wallis with Dunn's *post hoc* test when required. A 95 percent level of confidence ($p = 0.05$) was used with all analysis.

Results:

Table 1, Resultant Mean Failure Load and Stress

Mean Failure Loads (N) and Stress (MPa)

Endocrown Ferrule (mm)	Failure Load (N)	Failure Stress (MPa)
0	638.5 (238.5) A	6.13 (1.7) A
1	1101.0 (487.0) B	7.85 (3.3) A
2	956.3 (294.5) B	6.32 (1.8) A

n = 12; Groups identified with same capital letter are similar within each column (Dunn's p = 0.05)

When considering failure load, the endocrown restorations containing one and two millimeters of ferrule demonstrated greater failure load resistance than the endocrowns without ferrule. However, under conditions of calculated failure stress, there was no significant difference between any of the groups.

Table 2. Failure Mode Results

Endocrown Ferrule	Failure Mode				
	Adhesive Debonding	Restorable Fracture	Catastrophic Fracture	Cohesive Root Fracture	Ceramic Cohesive Failure
0 mm	0	2	10	0	0
1 mm	2	1	8	0	1
2 mm	0	0	12	0	0

n = 12

Catastrophic failure = Non-restorable fracture that involves the restoration and restoration preparation.
Cohesive Root Fracture = Fracture that does not involve restoration/preparation complex at a level apical to the preparation.
Restorable Fracture = Fracture either separate or combined of restoration and tooth deemed restorable

All of the groups demonstrated a high number of catastrophic failures. The endocrown group with two millimeters ferrule displayed universal catastrophic failure with the endocrown demonstrating slightly less. The endocrown group with one millimeter of ferrule demonstrated the least amount of non-restorable failures as well as a small amount of adhesive failures.

Discussion:

The importance of full-coverage restorations following endodontic therapy is well known. Tang and colleagues [2] reported the failure to replace interim restorations expediently with permanent restorations after endodontic treatment resulted in greater than 65 percent tooth loss over three years. Equally important is the provision of a coronal seal over the completed endodontic treatment, as microbial re-contamination of the root canal system has been shown with *in vitro* testing to occur between 24 and 30 days after exposure of the gutta percha material to oral fluids. [3,4] The placement of intracanal posts is often required to augment retention and resistance features for the core material in situations of advanced loss of coronal tooth structure. [17-19] Notwithstanding, such use of intracoronal posts is not without its hazards. The use of posts has been suggested to increase incidence of failure in the instance of post and tooth material modulus mismatch, excess dentin removal, and failure to provide adequate

ferrule. [2,21,22] Furthermore, posts may not be a viable option when confronted with certain canal morphology such as dilacerated or calcified canals. [23]

CAD/CAM proponents describe the endocrown as an effective and expedient means for the restoration of endodontically treated teeth [9,12,24,25] especially of situations where insufficient ferrule is present. [12] Additionally, *in vitro* finite element analysis studies suggest the endocrown method produces less internal stress forces than full coverage restorations supported by post and cores, [26,27] but other studies suggest that endocrowns should be limited to molars. [27,28] The purpose of this study was to determine the effect of ferrule on molar endocrown restoration failure strength and failure mode analysis. The endocrown restoration was fabricated using a lithium disilicate restorative material (e.max CAD, Ivoclar Vivadent) which was bonded using a self-adhesive resin cement (Unicem, 3M ESPE). Specimens were prepared as uniformly as possible where the surface area available for bonding (Figure 2) and ferrule wall occlusal convergence (Figure 8) was determined using a digital measuring microscope (Hirox 4400, Hirox USA). The mean specimen parameters are listed in Table 3.

Figure 8, Ferrule Wall Occlusal Convergence

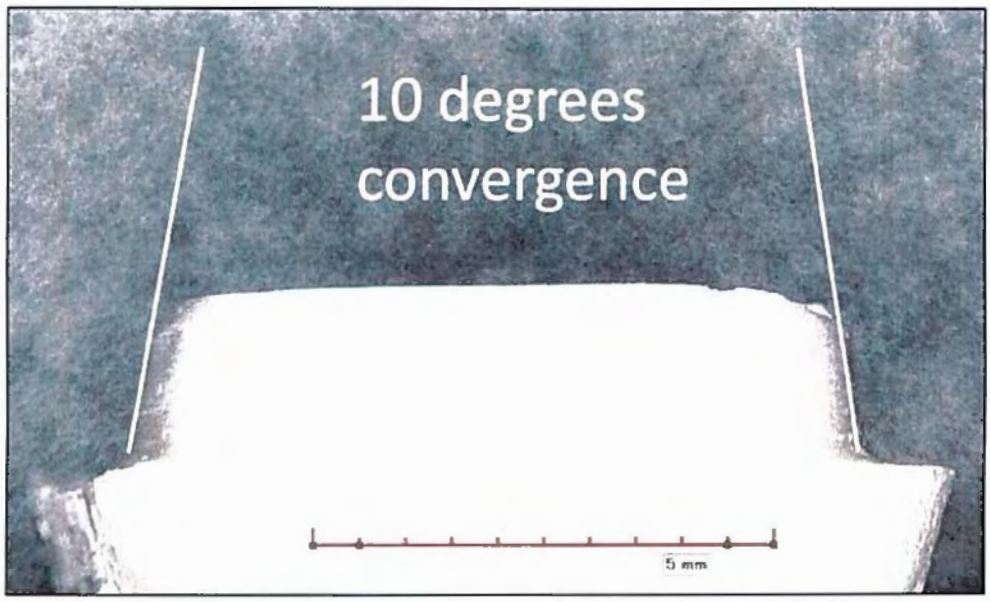


Table 3, Mean Endocrown Preparation Parameters

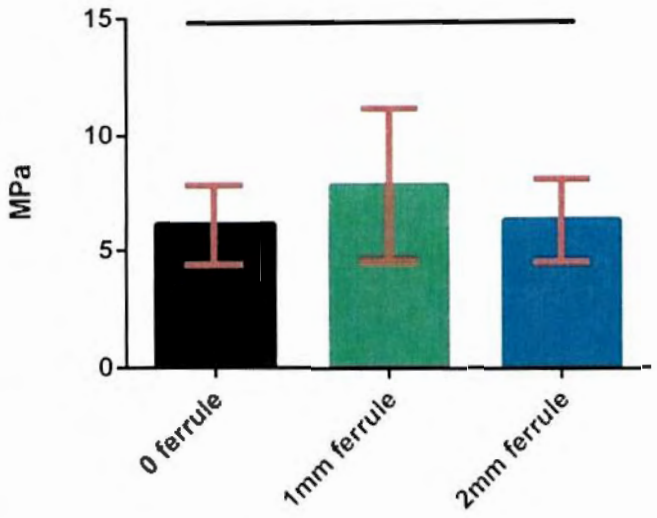
Group (Ferrule)	Mean dentin surface area (mm^2)	Mean ferrule wall height (mm)	Ferrule wall mean total occlusal convergence (degrees)
0mm	102.3 (16.1)		
1mm	139.1 (10.6)	1.07 (0.01)	10.4 (0.5)
2mm	150.1 (10.2)	2.04 (0.05)	10.3 (0.6)

n = 12

The resin-restored chamber floor was also included in the surface area available for bonding. As stated earlier, one researcher prepared all of the specimens before restoration, which was also completed by a single, different researcher. Preparation standardization was achieved with some success as the mean measured surface area covariance of the ferrule group preparations was approximately seven percent, while the total occlusal convergence covariance for the same groups was approximately five percent. The endocrown preparation surface area was more variable with a 15 percent covariance, but still below the established covariance 25 percent threshold. Preparation surface area available for bonding increased 36 percent from the standard endocrown to the one millimeter ferrule group while the surface area between the standard endocrown restoration and the two millimeter ferrule endocrown restoration group increased 47 percent. However, there was only an eight percent increase in surface area between the one and two millimeter ferrule group.

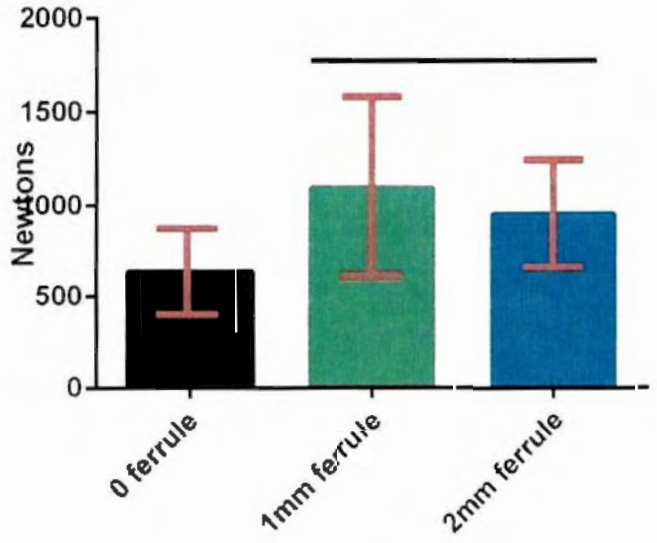
Under the conditions of this study the calculated failure stress (MPa) found no significant difference noted between the preparation groups ($p = 0.427$). However, analysis using failure load (N) demonstrated a difference between the groups ($p = 0.016$), with *post hoc* testing identified that the ferrule groups were similar with each other ($p = 0.857$) but was significantly greater than the endocrown group ($p = 0.0212$) as depicted in Figure 9 and 10.

Figure 9. Mean Failure Stress Results (MPa)



n = 12; Items connected by same bar are significantly similar (Kruskal-Wallis, p = 0.42)

Figure 10. Mean Failure Load Results (N)



n = 12; Items connected by same bar are significantly similar (Kruskal-Wallis/Dunn's, p = 0.021)

Therefore, the null hypothesis was rejected under the consideration of failure load, but was accepted when the failure stress data was observed. It is interesting to note that although the available surface for adhesion increased over 47 percent from the standard endocrown to the endocrown with a two millimeter ferrule, no difference in failure stress was noted. However, failure load results identified the ferrule groups failed at significantly greater loads than the standard endocrown restoration.

The most clinically relevant findings of this study may be noted when the failure analysis results are considered. MicroCT analysis proved to be a valuable tool in assessing the failure modes, as some specimens with visually judged repairable damage (Figure 11) was found to contain irreparable fractures that, depending on location, may or may not be visible on a standard periapical film (Figure 12, Figure 13).

Figure 11. 3D Tiled Image Zero Millimeter Ferrule Failure

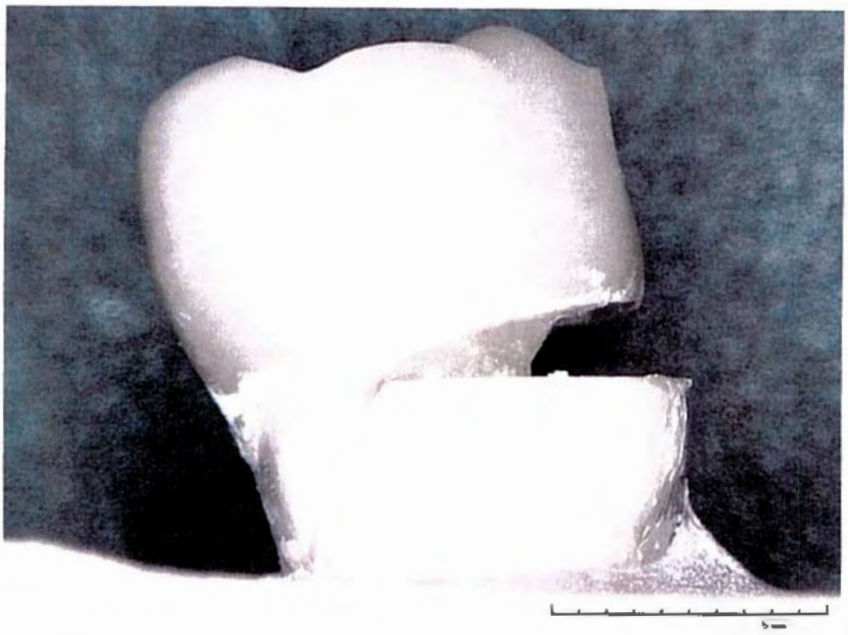


Figure 12. MicroCT Image of 1mm Ferrule – Catastrophic Failure

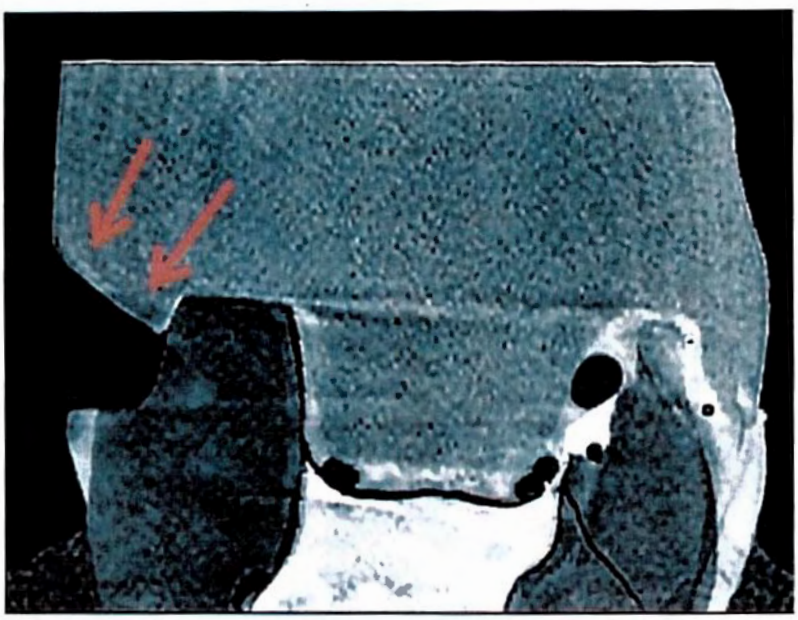


Figure 13. MicroCT Image of 1mm Ferrule – Catastrophic Failure

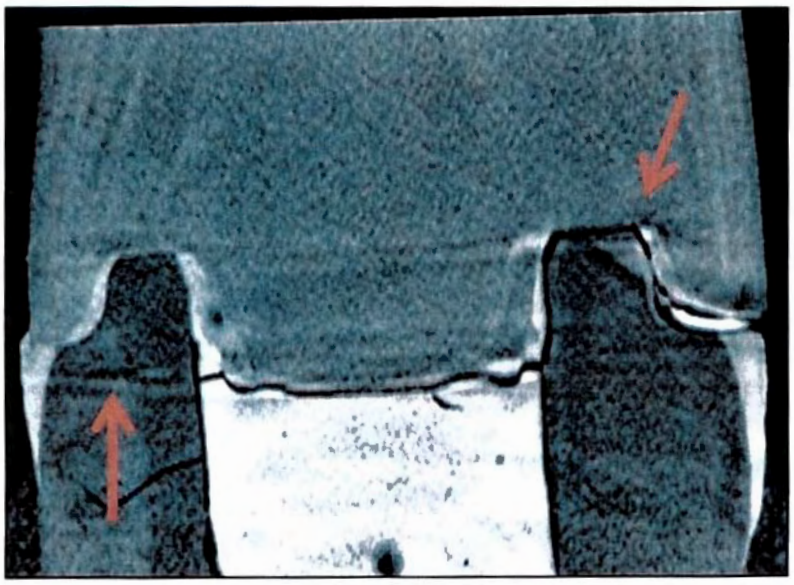
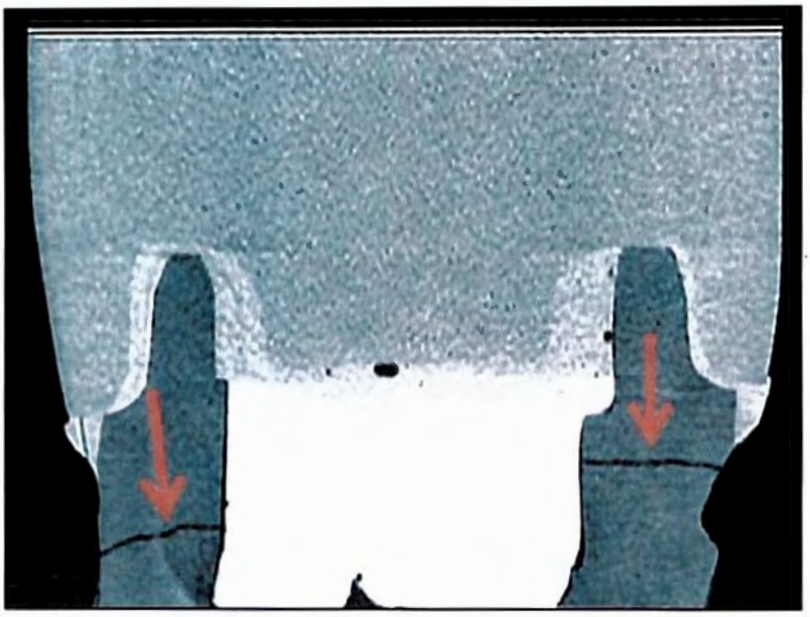


Figure 14. MicroCT Image 2mm Ferrule – Catastrophic Failure



All of the endocrown preparations containing two millimeters of ferrule failed catastrophically, (Figure 14) followed by 10 of the 12 standard endocrown preparations. The one millimeter endocrown ferrule group had the least number of catastrophic failures, albeit with 66 percent of the specimens exhibiting non-restorable fractures. Thus, under laboratory testing the endocrowns, regardless of ferrule preparation features, demonstrated a high percentage of catastrophic failures.

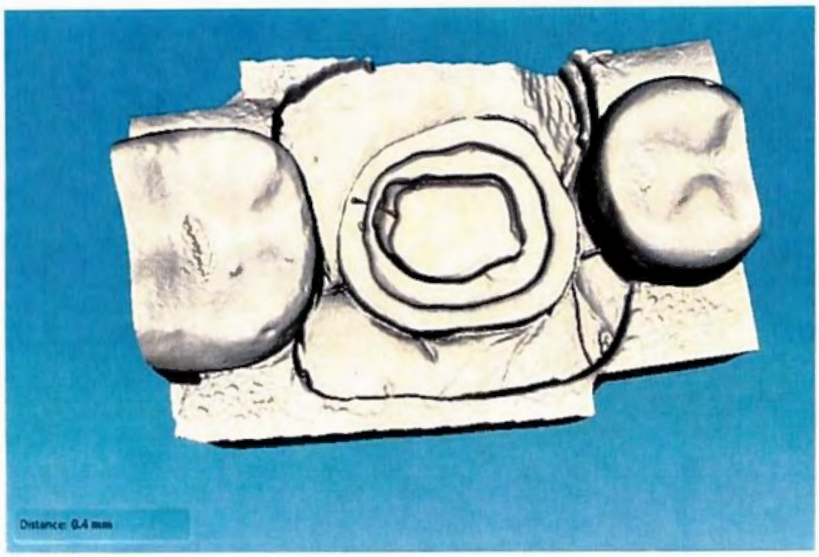
The results of this study should be considered with the failure load results are in excess of that reported for normal human function and the ferrule containing endocrown preparations approach those suggested for accidental biting and/or trauma. [29-36] Although the force was applied to the functional cusp, the static applied load can be in variance with normal oral function. The measured human maximum bite force varies with different reported studies. For instance, one study reported the average bite force for males was approximately 285 N and 254 N for females, [35] while another study reported 654 and 464 N for the same two gender groups, respectively. [36] Notwithstanding , the next research objective is to repeat the conditions of this

study under fatigue forces with non-destructive microCT assessment of internal changes that may lead to failure.

A preparation parameter that was observed that may affect restoration performance was the milling limitations in reproducing the intaglio surface of the crown. Accordingly, it was observed that the more complex the preparation, the more complex the restoration design and therefore resulted in decrease crown adaptation with 1mm and 2mm designs with larger cement space (Figure 15). Another preparation parameter was the sometimes tooth structure limitation realized by a ferrule addition in the cervical area. This resulted in some ferrule areas with limited ferrule wall thickness (Figure 16).

Figure 15. Cross Section of endocrowns with decreased crown adaption

Figure 16. Preparation with deficient tooth structure for ferrule



This study also sought to determine if the failure stress calculation would perhaps provide normalization of the failure load results, which could be skewed due to tooth size discrepancies. The failure stress determination did appear to normalize the failure load data under the conditions of this study. However, more definitive research and analysis is required before more recommendations can be proffered.

When considering the traditional endocrown preparations, the results of this study are similar to that reported by Biacchi and Basting [25] who reported a median endocrown failure of approximately 674 N. That study also reported a high number of non-restorable fractures similar to that found in the present study. However, the present study's results are less than that reported by Magne et al [7] who reported endocrown failure loads of 2606 N as well as that reported by El-Damanhoury et al [37] whose lithium disilicate material demonstrated a mean fracture load of 1368 N. Furthermore, Gresnight and colleagues [38] also reported failure values above that found with the present study. However, those reports differ somewhat from the present study with the application of different force vectors.

Conclusions:

Under the conditions of this study, calculated failure stress based on available surface area for adhesive bonding found no difference in failure between standard endocrown preparations and endocrown preparations containing either one or two millimeters of ferrule. In contrast, failure load results found the ferrule-containing endocrown preparations demonstrated significantly greater failure loads than standard endocrown restorations. Regardless of the presence of a ferrule, this study found endocrown restorations suffered a high proportion of catastrophic failures but at loads greater than reported normal masticatory function. Based on these results, fatigue studies should be investigated.

Bibliography

1. Robbins JW (1990) Guidelines for the restoration of endodontically treated teeth. J Am Dent Assoc 1990;120:558-566.

2. Tang W, Wu Y, Smales RJ. Identifying and reducing risks for potential fractures in endodontically treated teeth. J Endod 2010;36:609–617.

3. Torabinejad M, Ung B, Kettering JD. In vitro bacterial penetration of coronally unsealed endodontically treated teeth. J Endod 1990;16:566-569.

4. Khayat A, Lee SJ, Torabinejad M. Human saliva penetration of coronally unsealed obturated root canals. J Endod 1993;19:458-461.

5. Salhrabi R, Rotstein I. Endodontic treatment outcomes in a large patient population in the USA: an epidemiological study. J Endod 2004;30:846-850.

6. Schwartz RS, Robbins JW. Post placement and restoration of endodontically treated teeth: a literature review. J Endod 2004;30:289-301.

7. Magne P, Carvalho AO, Bruzi G, Anderson RE, Maia HP, Giannini M. Influence of no-ferrule and no-Post buildup design on the fatigue resistance of endodontically treated molars restored with resin nanoceramic CAD/CAM crowns. Oper Dent 2014;39:595-602.

8. Ramı´rez-Sebastia` A, Bortolotto T, Roig M, Krejci I. Composite vs Ceramic Computer-aided Design/Computer-assisted Manufacturing Crowns in Endodontically Treated Teeth: Analysis of Marginal Adaptation. Oper Dent 2013;38:663-673.

9. Pissis P. Fabrication of a metal-free ceramic restoration utilizing the monobloc technique. Practical Periodontics and Aesthetic Dentistry 1995;7:83-94.

10. Forberger N, Göhring TN. Influence of the type of post and core on in vitro marginal continuity, fracture resistance, and fracture mode of lithia disilicate-based all-ceramic crowns. J Prosthet Dent 2008;100:264-73.

11. Moore P. Cerec Doctors publications, Dentsply Sirona, Charlotte, NC, 2013.

12. Lander E, & Dietschi D. Endocrowns: a clinical report. Quintessence Int 2008;39:99-106.

13. Pereira JR, de Ornelas F, Conti PCR, do Valle AL. Effect of a crown ferrule on the fracture resistance of endodontically treated teeth restored with prefabricated posts. J Prosthet Dent 2006;95:50-54.

14. Ma PS, Nicholls JI, Junge T, Phillips KM. Load fatigue of teeth with different ferrule lengths, restored with fiber posts, composite resin cores, and all-ceramic crowns. J Prosthet Dent 2009;102:229-234.

15. Lima AF, Spazzin AO, Galafassi D, Correr-Sobrinho L, Carlini-Junior B. Influence of ferrule preparation with or without glass fiber post on fracture resistance of endodontically treated teeth. J Appl Oral Sci 2010;18:360-363.

16. Kelly RJ, Rungruanganunt P, Hunter B, Vailati F. Development of a clinically validated bulk failure test for ceramic crowns. J Prosthet Dent 2010;104:228-238.

17. Baba NZ, Golden G, Goodacre CJ. Nonmetallic Prefabricated Dowels: A Review of Compositions, Properties, Laboratory, and Clinical Test Results. J Prosthodont 2009;18:527-536.

18. Balkenhol M, Wöstmann B, Rein C, Ferger P. Survival time of cast post and cores: A 10-year retrospective study. J Dent 2007;35:50-58.

19. Fokkinga WA, Kreulen CM, Bronkhorst EM, Creugers NHJ. Up to 17-year controlled clinical study on post-and-cores and covering crowns. J Dent 2007;35:778-786.

20. Zhu Z, Dong XY, He S, Pan X, Tang L. Effect of post placement on the restoration of endodontically treated teeth: A systematic review. Int J Prosthodont 2015;28:475-483.

21. Ona M, Wakabayashi N, Yamazaki T, Takaichi A, Igarashi Y. The influence of elastic modulus mismatch between tooth and post and core restorations on root fracture. Int Endod J 2013;46:47-52.

22. Assif D, Bitenski A, Pilo R, Oren E. Effect of post design on the resistance to fracture of endodontically treated teeth with complete crowns. J Prosthet Dent 1993;69:36-40.

23. Biacchi GR, Mello B, Bastings RZ. The Endocrown: An Alternative Approach for Restoring Extensively Damaged Molars. J Esthet Restor Dent 2013;25:383–391.

24. Bindl A, Mormann WH. Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years: preliminary results. J Adh Dent 1999;1:255-265.

25. Biacchi GR, Basting RT. Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. Oper Dent 2012;37:130-136.

26. Lin CL, Chang YH, Chang CY, Pai CA, Huang SF. Finite element analyses to estimate failure risks in the ceramic endocrown and classical crown for endodontically treated maxillary premolars. Eur J Oral Sci 2010;118:87-93.

27. Dejak B, Młotkowski A. 3D-Finite element analysis of molars restored with endocrowns and posts during masticatory simulation. Dent Mater 2013;29:e309–e317

28. Bindl A, Richter B, Mormann WH. Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry. Int J Prosth 2005;18:219-224.

29. Chen C, Trindade FZ, de Jager N, Kleverlaan C, Feilzer AJ. The fracture resistance of a CAD/CAM Resin Nano Ceramic (RNC) and a CAD ceramic at different thicknesses. Dent Mater 2014;30:954-962.

30. Sinn DP, DeAssis EA, Throckmorton GS. Mandibular excursions and maximum bite forces in patients with temporomandibular joint disorders. J Oral Maxil Surg 1996;54:671-9.

31. Vaneijden T. 3-Dimensional analyses of human bite-force magnitude and moment. Arch Oral Biol 1991;36:535-9.

32. Pruim GJ, Dejongh HJ, Tenbosch D. Forces acting on the mandible during bilateral static bite at different bite force levels. J Biomech 1980;13:755 3.

33. Gibbs CH, Mahan PE, Mauderli A, Lundeen HC, Walsh EK. Limits of human bite strength. J Prosth Dent 1986;56:226-9.

34. Waltimo A, Kononen M. A novel bite force recorder and maximal isometric bite force values for healthy-young adults. Scand J Dent Res 1993;101:171-5.

35. Pizolato RA, Gavião MB, Berretin-Felix G, Sampaio AC, Trindade Junior AS, Maximal bite force in young adults with temporomandibular disorders and bruxism. Braz Oral Res. 2007;21:278-83.

36. Takaki P, Vieira M, Bommarito S. Maximum bite force analysis in different age groups. Int Arch Otorhinolaryngol. 2014 Jul;18(3):272-6.

37. El-Damanhoury HM, Haj-Ali RN, Platt JA. Microleakage of Endocrowns Utilizing Three CAD-CAM Blocks. Oper Dent 2015;40:201-210.