UNIFORMED SERVICES UNIVERSITY OF THE HEALTH SCIENCES
AIR FORCE POSTGRADUATE DENTAL SCHOOL
301 Fisher Street, Room 1F505
Keesler Air Force Base, Mississippi 39534
www.usuhs.mil

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Signature

Dr. Elizabeth M. Litman

Printed Name

AEGD 24 Month Residency Program
Air Force Postgraduate Dental School
Uniformed Services University of the Health Sciences

CAD/CAM Preparation Design Effects on Endodontically Treated Molars

Capt (Dr.) Elizabeth M. Litman, USAF, DC

APPROVED:

[redacted]

Colonel (Ret) Howard W. Roberts (Chairman)
Former Director, Keesler AFB Postgraduate Dental Research

[redacted]

Lt Col John A. Brewster
Director, Keesler AFB Postgraduate Dental Research

[redacted]

Colonel Michael N. Wajdowicz
AEGD 24 Month Residency Director

21 June 2018

Date

APP[redacted]OVED:

[redacted]

Colonel Jay D. Graver
Dean, Air Force Postgraduate Dental School

CAD/CAM Preparation Design Effects on Endodontically Treated Molars

Elizabeth M. Litman

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Abstract:

Objective: To evaluate the static load fracture resistance of endodontically treated molars restored with lithium dislicate full coverage restorations using either the Endocrown technique or crowns based on preparations comprised of composite cores with various dentin axial wall heights.

Materials and Methods: 48 recently extracted human molars were endodontically accessed, pulp chamber debrided and canals instrumented by a board-certified endodontist. Teeth were randomly assigned in four groups and embedded in acrylic. Groups were then randomly placed into four restoration schemes: Endocrown; and three composite core restored preparation designs consisting of two millimeters dentin axial wall height (AWH), one millimeter AWH, and a group containing minimal AWH. Resin composite cores restorations were placed according to assigned group with all manufacturer instructions followed. After 24 hours storage, specimens were prepared according to planned dentin AWH scheme. Endocrown preparation designs, consisted of a 2mm deep chamber retention. Preparation heights and surface area was measured using a digital microscope (Hirox).

To simulate clinical conditions, an acrylic scanning jig was fabricated with an opening in the first molar position. Each specimen was inserted into the scanning jig and digitally captured with using a CAD/CAM device. Designed lithium disilicate crowns were milled, crystallized, intaglio surfaces prepared according to manufacturer instructions and cemented with a self-adhesive resin luting agent after preparations were cleansed with a pumice/water slurry and were stored in distilled water under dark conditions.

After 24 hours, specimens were placed onto a universal testing machine at a 45-degree angle to the long axis and loaded to failure at a rate of 0.5 mm/min. Peak Force (Newtons) recorded with mean data analyzed with Kruskal-Wallis/Dunn’s post hoc at a 95 percent level of confidence (α=0.05)

Results: The composite core group with a preparation at two millimeters of ferrule effect demonstrated the highest failure load. The failure load of the remaining groups showed decreased fracture resistance from 1mm, to 0mm to the endocrowns, respectively. Failure mode analysis revealed that greater amount of remaining tooth structure also showed an increased trend toward mixed cohesive failure, while a reduction of remaining tooth as well as the endocrown groups tended toward adhesive failure. Very few restorations in any group displayed catastrophic failure.

Conclusions: Under the conditions of this study, lithium disilicate crowns based on preparations comprised of composite core foundations with various dentin AWH overall displayed greater failure load resistance than endocrown restorations with a 2mm pulp chamber extension. The results showed decreased resistance to fracture as the remaining tooth structure was reduced with the endocrowns showing the least resistance to failure. However, greater ferrule effect showed high tendency toward mixed failure vs. adhesive failure of the endocrowns.

Introduction

The restoration of endodontically treated teeth remains a difficult challenge for even the most seasoned operative dentist. Research has shown that increased fracture tends to follow reduced remaining tooth structure[1], and after possible necessary removal of caries, restoration and completion of endodontic access, it can be postulated that a tooth might be structurally compromised. Several procedures may be utilized, including direct restorative techniques, prefabricated or cast posts and cores, and indirect restorative procedures. Preparation parameters have been proposed by Fages and Bennasar[2] emphasizing the need to marry the ideal biomechanics with optimal material properties. However, comparisons between endocrown restorations compared to a traditional placement of a core and crown are still needed to determine the optimal time to choose the appropriate restorative treatment.

The concept of placing the core and crown as one unit was first described by Pissis[3] in 1995, which was described at that time as the "monoblock" technique that includes both the core and crown as one functional unit. Since that time, the earlier term described by Pissis has evolved into the "endocrown" technique has gained some clinical evidence as a possible alternative for the restoration of endodontically treated teeth with severe structural compromise. [2,4,5] Dejak and Młotkowski [A] using an in silico finite element analysis reported that under simulated masticatory function the endocrown had lower dentin stress concentration than compared to traditional post and core methods. Accordingly, the endocrown has been evaluated with recent longer-duration studies relating positive clinical outcomes. [B,C] A recent systematic review suggested that endocrowns may perform similar to and/or better than conventional treatments involving intraradicular posts, direct composite resin, or inlay/onlay restorations. [D] However, those authors cautioned the need for further studies as the systematic review conclusions were based only on 3 clinical trials and 5 in vitro studies. [D] CAD/CAM advocates promote the endocrown method as providing improved ceramic adhesive bonding compared to that with amalgam or resin cores, stating that the endocrown preparation provides more dentin surface available for adhesive bonding. Some further anecdotally infer that the adhesive bond to amalgam and/or resin cores is not as effective as that to dentin, [E] 46 while providing expedient coronal sealing that is crucial for the success endodontic treatment. [F,G,H] 47-50

In addition, steady improvements in clinical outcomes of CAD/CAM technology have made it possible to produce clinically satisfactory outcomes in a shorter time due to the expediency chair-side ceramic manufacture, as well as same-day delivery of the restoration. Eliminating the otherwise necessary lab aspect, production of accurate margins, and the fabrication of acceptable esthetics with CAD/CAM technology has allowed the clinician to reclaim a lot of the restoration design aspect to producing indirect restorations. Proponents of the endocrown technique have postulated that the loss of coronal dentin for necessary bonding will be re-accomplished from the dentinal walls in the depth of the chamber[5]. This has been successfully demonstrated clinically in clinical case studies[5] as well as in vitro studies[6, 7]. The purpose of this study was to evaluate in vitro whether adhesion of the endocrown to the chamber provides adequate resistance to failure load a as compared to lithium disilicate crowns based on more traditional preparations consisting of a composite core with various dentin axial wall heights. The null hypothesis is that there would be no failure load resistance between the groups.

Materials and Methods: Human carious free maxillary third molars were used in this study following protocol approved by the 81rst Medical Group Institutional Review Board. Forty-eight recently-extracted teeth were collected from local oral and maxillofacial surgery clinics that had been removed for routine clinical indications. The teeth were imbedded in self-curing denture base resin blocks resin (Impak Self-Cure, CMP Industries, Albany, NY, USA). A board certified endodontist then preformed endodontic access, of which access size was determined by the ability for the endodontist to adequately instrument all located canals. The pulpal remnants were removed with canals instrumented to remove remaining root canal soft tissue. The teeth were then randomly assigned into 4 groups (n = 12); Endocrown, preparations containing 2 mm dentin AWH, 1 mm dentin AWH, as well as a group containing no dentin AWH (known hereafter as the 0 mm dentin AWH group). The coronal tooth structure was then sectioned perpendicular to the tooth long axis at approximately 4 mm above the cemento-enamel junction (CEJ) with a slow speed diamond saw (**Model #**, Buehler, Lake Forest, IL, USA) Sectioned specimens were then restored to full contour using (WHAT CORE MATERIAL) and a self-etch, two-step adhesive (Clearfil DC, Kurary, Houston, TX, USA) and then stored in 0.2M phosphate buffered saline (PBS). All manufacturer recommendations were followed an required visible light polymerization was accomplished using a Polywave® visible light curing unit (Bluephase G2, Ivoclar-Vivadent, Amherst, NY, USA) whose irradiance (~ 1000 mW/cm^2) was frequently assessed using a radiometer (Bluephase Meter II, Ivoclar-Vivadent). After 24 hours, core material group wase prepared following CAD/CAM guidelines for all-ceramic IPS E.max CAD crowns using a fixed-lathe arrangement Endocrown specimens were restored with composite **(WHAT COMPOSITE, WHICH ADEHSIVE)** placed on the chamber floor with an amount sufficient and finished to establish a parallel surface 2 mm apical to the occlusal table. Preparation parameters were verified with dentin surface area measured using a digital measuring microscope (KH-8700, Hirox Hackensack, NJ, USA).

A standardized jig to represent a clinical scanning scenario was fabricated that specimens were inserted into and then digitally captured using the OmniCam CAD/CAM system (Cerec AC, Cerec MC XL, Dentsply-Sirona, software version 4.4.4.72301).

Figure 1: Scanned tooth preparation example

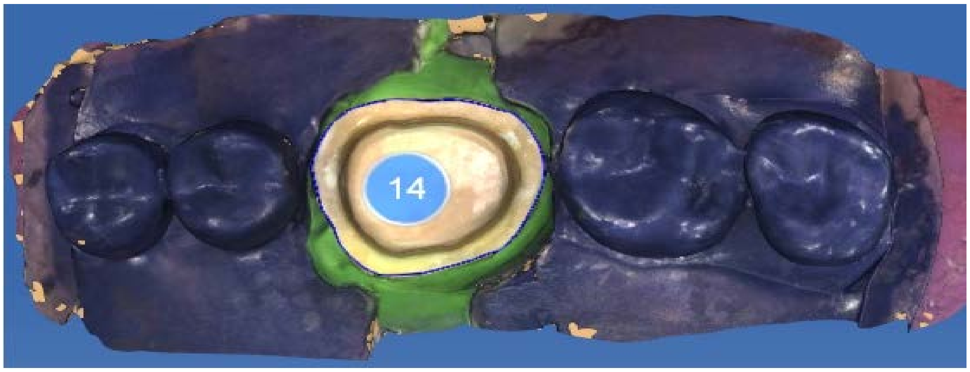
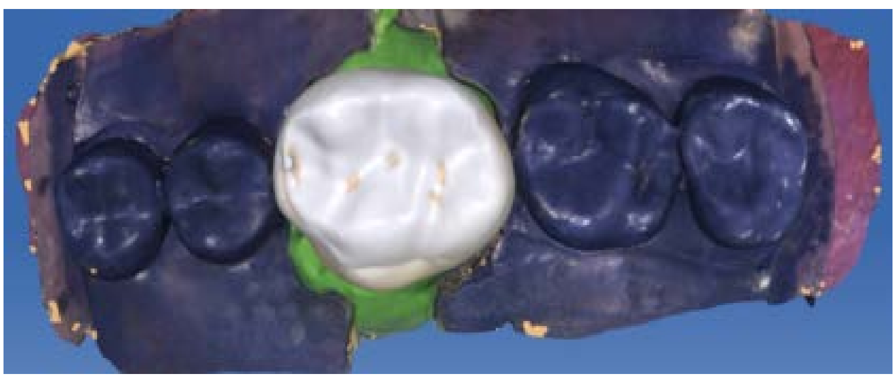
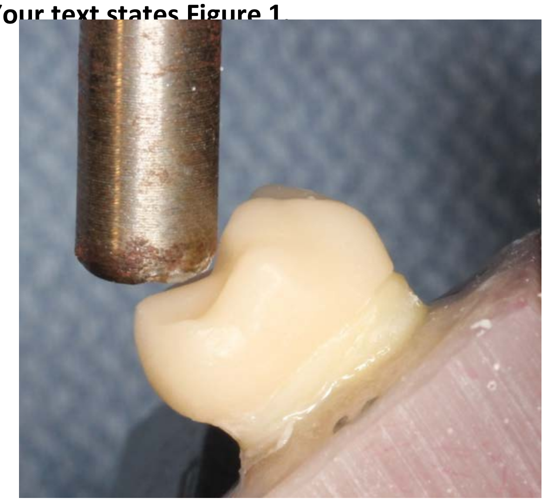


Figure 2: Proposed lithium disilicate crown



The crowns were milled from lithium disilicate material (IPS E.max CAD HT A2 Ivoclar-Vivadent) with fit verification ascertained. The crowns were then crystallized **(HOW—USING WHAT)**, steam cleaned & dried. The intaglio surfaces were treated with 5% HF acid etch (IPS Ceramic Etching Gel, Ivoclar Vivadent) for 20s and rinsed, and dried using oil-free compressed air. The etched ceramic surfaces were then treated with silane (Monobond Plus, Ivoclar-Vivadent) for 60 seconds and then air-dried. In preparation for cementation preparation tooth surfaces were cleansed with a pumice and water slurry mix on a slow sped handpiece with a prophy cup (Extended Straight Attachment DPA, Preventech), (Midwest Shorty, Dentsply International, York, PA, USA) and were then rinsed, dried. The restorations were delivered luted using a self-adhesive resin cement (RelyX Unicem, 3M ESPE, St. Paul, MN, USA) with digital pressure with visual confirmation of marginal seating. Excess cement was immediately removed with a microbrush (Microbrush International, Grafton, WI and then each surface was light cured for 20 seconds. All materials were used following manufacturer recommendations. Throughout the experiment, all specimens were stored in phosphate buffered solution under dark conditions when not undergoing treatments. After 24 hours, the specimens were placed into a universal testing machine (Alliance RT-5, MTS Corporation, Eden Prairie, MN, USA) in a vise at a 45° angle to the long axis of the tooth (Figure 1). The mesial lingual cusps were loaded with a three-millimeter diameter hardened, stainless steel piston with a 0.5-meter radius of curvatureat a rate of 0.5 millimeter per minute until failure with the failure load recorded in Newtons. Specimens were examined to determine if failure mode was cohesive for the lithium disilicate ceramic, adhesive failure between the ceramic and the tooth structure, tooth material fracture, or mixed. Failure analysis was accomplished both visually with at 20X magnification (KH-8700, Hirox Hackensack, NJ, USA) and with 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, Kontich, Belgium) with resultant recombined images visualized CTan and CTVox software (Bruker microCT, Kontich, Belgium).

Figure 3: Orientation of fracture test specimens
Your text states Figure 1



Mean failure load data was first subjected to the Shapiro-Wilk Test and Bartlett's Test which identified both an abnormal data distribution as well as variance imhomogeneity between the groups. The data was then subjected to the Kruskal-Wallis test and Dunn's post hoc test. Statistical analysis was accomplished using a computer based software program (SPSS 20, IBM SPSS, Chicago, IL, USA) using a 95 percent level of confidence ($\alpha = 0.05$).

Results

The mean tooth preparation parameters are presented in Table 1.

Table 1: Mean Preparation Parameters

	Mean Dentin Surface Area (mm2)	Mean Composite Surface Area (mm2)	Mean Total Wall Height (mm)	Mean Ferrule Wall Height (mm)	Mean Total Occlusal Convergence (degrees)
2mm Dentin AWH Composite Core	84.4 (9.2)	53.5 (7.7)	3.1 (0.08)	2.05 (0.05)	10.5 (0.5)
1mm Dentin AWH Composite Core	68.5 (7.0)	64.5 (8.8)	3.1 (0.04)	1.06 (0.04)	10.5 (0.5)
0mm Dentin AWH Composite Core	38.6 (5.0)	82.3 (6.3)	3.0 (0.05)	*	10.1 (0.4)
Endocrown 2mm Chamber Extension	98.7(12.4)	*	*	*	*

n = 12; * annotates not applicable; AWH = Axial Wall Height;

The authors maintain that preparation standardization was met with reasonable success as mean dentin surface area covariance was within the range of 10 to 13 percent while the composite resin core surface area ranged from seven to 13 percent.

The mean failure load (standard deviation) results are presented in Table 2.

Table 2: Mean Failure Loads (N)

	Failure Load (N)
Composite core 2mm ferrule group	1554.0 (CD)
Composite core 1mm ferrule group	940.0 (CD)
Composite core 0mm ferrule group	657.6 (BC)
Endocrown	354.6 (AB)

n = 12; Groups identified with same capital letter are similar within each column (Ryan-Einot-Gabriel-Welsch Range, p=0.05)

The 2mm and 1mm dentin AWH and groups demonstrated significantly greater failure load compared to the 0mm AWH and the Endocrown restorations.

The results of the failure mode analysis is shown in Table 3.

Table 3: Failure Mode Analysis

	Adhesive Failure	Core Fracture	Ceramic Fracture	Root Fracture	Restorable Fracture	Non-Restorable Fracture
Composite Core 2mm Ferrule	5	4	3	0	12	0
Composite Core 1mm Ferrule	10	0	1	1	11	1
Composite Core 0mm Ferrule	10	2	0	0	12	0
Endocrown	9	??????	0	1	11	1

n = 12

Catastrophic failure = fracture is non-restorable due to fracture of the preparation, restoration

Root fracture = fracture that involves the root and not the restoration and/or is apical to restoration

The 2mm dentin AWH group displayed different displaying adhesive, tooth and combined fractures. The remaining groups largely displayed adhesive fractures with the overall result showing a predominance of restorable fractures.

Discussion

Providing a definitive restoration that provides a coronal seal and cuspal-coverage protection after endodontic therapy is imperative. The lack of proper restoration will not only allow bacterial recontamination of the root canal [F,G] and endangers the survival of the root-filled tooth. [H,I] Aquilino *et al* [8] reported that lack of coronal restoration lead to significantly higher tooth loss in posterior endodontically treated teeth., In addition, literature from Ray and Trope[7] established that more adverse clinical outcomes were observed with inadequate coronal restorations in spite of inadequate root canal obturation. A recent meta-analysis from Gillen *et al* [10] identified that adequate coronal restoration was a crucial factor in the survival of endodontically treated teeth.

Multiple methods s have been advocated for the restoration of endodontically treated teeth, to include direct amalgam or resin composite cores/full coverage restorations, either direct or indirect post and core systems, as well as the placement of a full coverage crown. Although direct cuspal coverage amalgam restorations have demonstrated successful clinical outcomes[7], but the most frequent restoration currently placed for endodontically treated teeth is a full coverage crown. Furthermore, a more recent systematic review of coronal restoration outcomes from Afrashtehfar *et al* [12] suggested in the situations of reduced surviving tooth structure, full-coverage crowns demonstrated the most promising clinical success, whereas full coverage resin composites exhibited more unfavorable clinical outcome, regardless of remaining dentinal structure.

The advent of CAD/CAM technology allows more expedient processing of full-coverage restorations as compared to conventional laboratory techniques. Use of CAD/CAM adhesive technology has the potential to facilitate the restoration of endodontically treated teeth, of which some CAD/CAM clinicians advocate the endocrown technique. The endocrown technique has the advantage of to expediently produce both a core and a crown as a single until, eliminating technique sensitive post and core procedures as well as alleviating potentional bacterial reinfection of the root canal due to an inadequate provisional restoration. A growing preponderance of both in vitro and recent in vivo reports have demonstrated some mixed results regarding the value of the endocrown as a restorative modality. Bellaflame *et al* [13] reported 10 year in vivo evidence of a 98 percent clinical success rate. Furthermore, when endocrowns have been compared to various ferrule effect levels, it has been demonstrated that the outcomes of the endocrowns fared as well, if not better, than conventional core and crown placement. , However, Bindl *et al* suggested that appropriate clinical conditions should exist, such as adequate dentin surface for bonding, greater height to width ratio, and adequate pulp chamber dimensions are necessary factors to ensure success. This seems to suggest that certain clinical situations, such as premolars or molars without adequate chamber depth, display poorer outcomes than larger molars. A more recent systematic review and meta-analysis from Sedrez-Porto *et al* indicated that endocrowns have shown promising clinical and laboratory outcomes historically. However, it should be noted that those authors cautioned of their results and stressed the need for further studies as the systematic review conclusions were based only on 3 clinical trials and 5 in vitro studies.

This study was designed to evaluate lithium disilicate endocrown failure resistance   as compared to lithium disilicate crowns supported by preparations consisting of conventional composite core restorations containing various denitn axial wall heights. In particular, the study was designed to evaluate if the increase of dentin surface area afforded by the endocrown method would provide equivalent adhesion as compared to traditional crown preparation designs.

To assist in standardization, all specimens were prepared by a single researcher with the handpiece inserted in a fixed lathe device. The authors feel that standardization efforts were met with some success, as all surface area measurements contained 13 percent or less covariance.

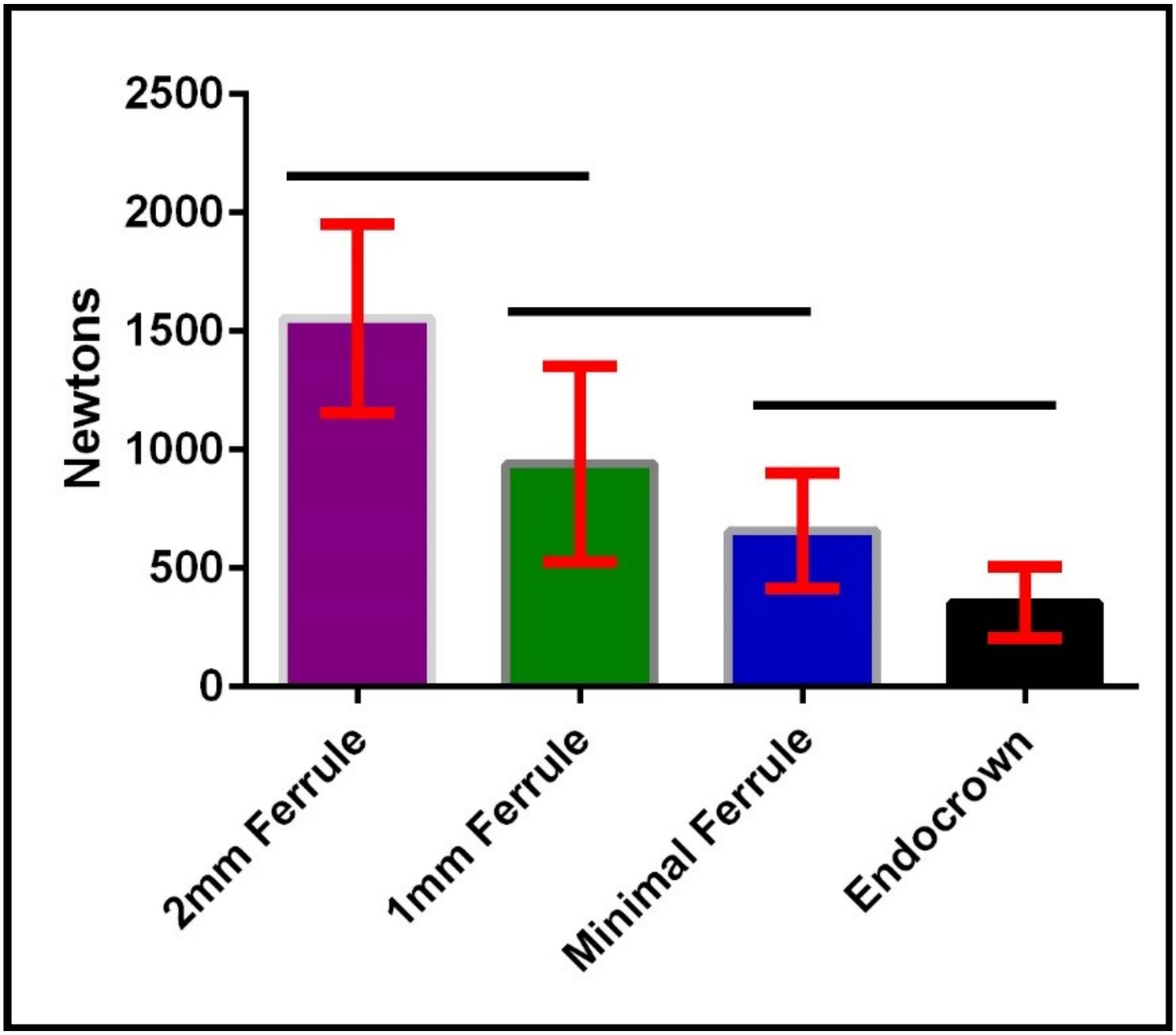
	Mean Dentin Surface Area (mm2)	Mean Composite Surface Area (mm2)	Mean Total Wall Height (mm)	Mean Ferrule Wall Height (mm)	Mean Total Occlusal Convergence (degrees)
2mm Ferrule Composite Core	84.4 (9.2)	53.5 (7.7)	3.1 (0.08)	2.05 (0.05)	10.5 (0.5)
1mm Ferrule Composite Core	68.5 (7.0)	64.5 (8.8)	3.1 (0.04)	1.06 (0.04)	10.5 (0.5)
0mm Ferrule Composite Core	38.6 (5.0)	82.3 (6.3)	3.0 (0.05)	*	10.1 (0.4)
Endocrown 2mm Chamber Extension	98.7(12.4)	*	*	*	*

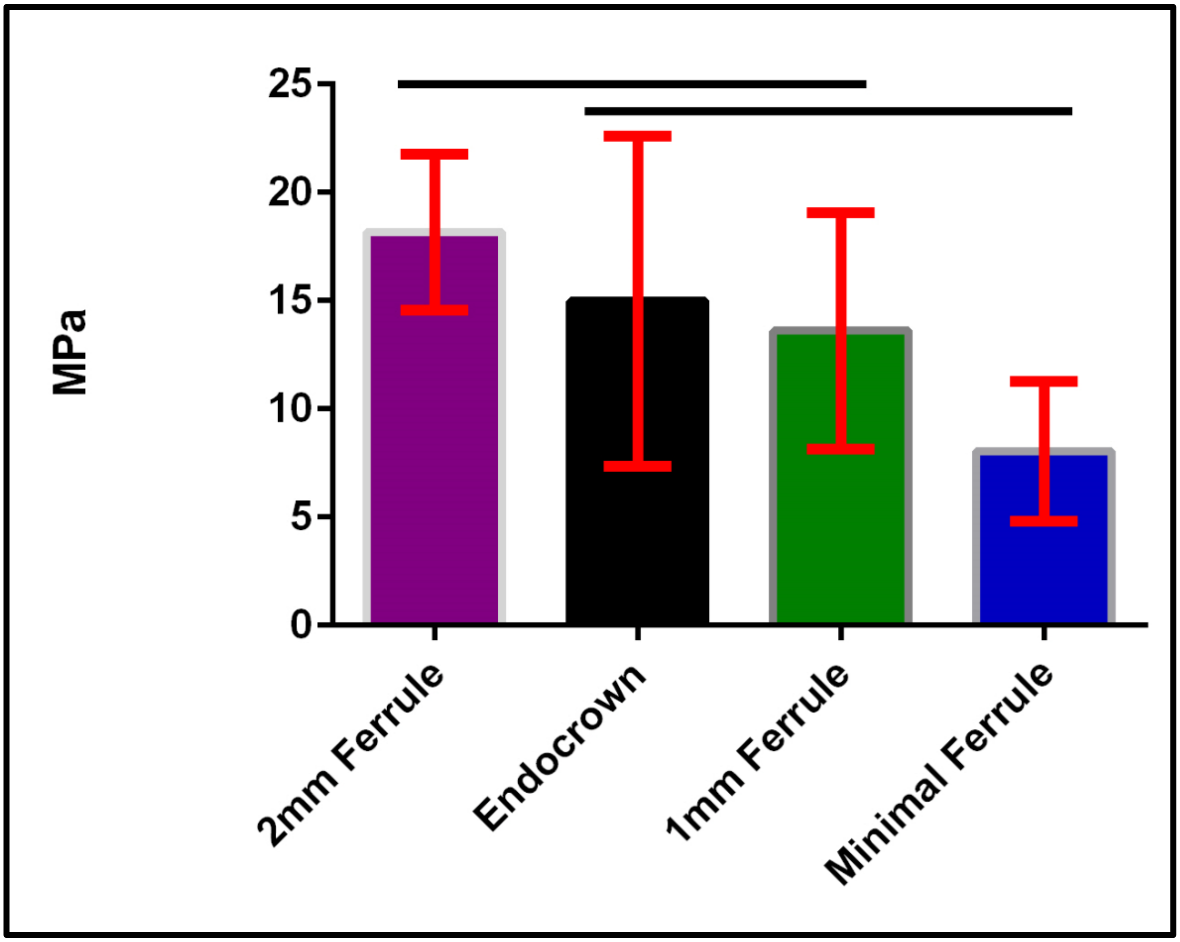
The endocrown group demonstrated 16% more surface area than the 2mm dentin AWH group, 31% more more than the 1mm dentin AWH group, and over 60% greater surface area than the 0mm dentin AWH group. Despite the additional surface area, the endocrown group did not demonstrate equivalent failure resistance as the two and one dentiun AWH groups.

. The failure modes of the endocrown, zero, and one millimeter dentin AWH groups essentially demonstrated adhesive failures. Only the 2mm dentin AWH group demonstrated multiple failure modes, to include cohesive ceramic and fracture of the resin core. Reduction of the dentin AWH did not seemingly provide adequate preparation resistance form that adhesion could not compensate for. It has been proposed by Bindl[12] that clinical results showing root fractures in endocrown restorations in premolars are partially due to the lever action of the core material putting pressure against the already compromised root surfaces. However, this concern was not demonstrated in the present study. It is perhaps the poorer quality of the dentin within the chamber that allowed the restoration to simply debond before adequate force necessary to fracture the root could be produced.

Under the conditions of this study, resistance to failure there was a decreased resistance to fracture that was seen with decreased ferrule effect, with the endocrowns performing the worst. The use of bonded core materials still provides a predictable and clinically superior outcome when adequate remaining tooth structure is present, but with reduced remaining structure, the placement of endocrowns in molar teeth is an acceptable alternative method to placing conventional core materials with a resultant full coverage crown. The failure load graphical results is depicted in Figure 4.

Figure 4: Mean Failure Load (N)




MPa
25
20
15
10
5
0
2mm Ferrule
Endocrown
1mm Ferrule
Minimal Ferrule

In order to standardize the specimens for the study, all teeth were prepared with a 2mm extension into the chamber. However, in a clinical situation, one could extrapolate that a clinician may be able to gain significantly greater dentinal chamber surface area should they have a tooth with a longer pulpal chamber. These results seem to be possible despite the reduced mineral content and reduced bonding ability of the dentin closest to the pulp. This seems to indicate that if a clinician is selective in their choices for the clinical application of the endocrown to include only situations where a larger tooth of at least average molar dimensions will be included, clinical success can still be achieved. The overall failure mode results under the conditions this appear to suggest that both composite core based preparations and endocrowns predominately produced restorable failures. This finding may correlate to the finite element analysis reported by Helal *et al* that indicated an overall favorable endocrown failure mode. .

. <u>Under the conditions of this study, the null hypothesis was rejected.</u>

LIMITATIONS OF THIS STUDY INCLUDE: no fatigue testing, fill in the blanks.

The results suggest that if sufficient interarch space exists, a lithium disilicate crown based on a preparation containing at least 2 and or 1 mm of dentin AWH can be a viable alternative to the endocrown method. The next planned research concerning endocrowns should involve cyclic fatigue testing of similar materials as well as differing depths of endocrown core preparations to better analyze the forces generated in function and whether there can be an ideal, established protocol for endocrown preparations.

Conclusions:

Under the conditions of this study, endodontically treated teeth restored with lithium disilicate crowns based on preparations containing two and one millimeters of dentin axial wall height and composite core restorations displayed significantly greater failure resistance than endocrown restorations. However, all preparations demonstrated predominately restorable failure modes. These results suggest that a traditional crown preparation and restoration may provide a viable alternative to endocrown restorations when sufficient interarch space exists.

Any opinions contained in this work are of the authors only and do not constitute the official opinion of the United States Air Force, the Department of Defense, the Uniformed Services University of the Health Sciences, or the United States Government.

The use of any materials and techniques contained in this work does not imply endorsement.

Bibliography:

1) Caron GA, Murchison DF, Cohen RB, Broome JC (1996) Resistance to fracture of teeth with various preparations for amalgam. Journal of Dentistry 24(6): 407-410.
2) Fages M, Bennasar B (2013) The Endocrown: A Different Type of All-Ceramic Reconstruction for Molars. J Can Dent Assoc 79: d140
3) Pissis P (1995) Fabrication of a metal-free ceramic restoration utilizing the monobloc technique. Practical Periodontics and Aesthetic Dentistry 7(5): 83-94.
4) Bindl A, & Mormann WH (1999) Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years: preliminary results. Journal of Adhesive Dentistry 1(3) 255-265.
5) Biacchi GR, Mello B, Bastings RZ (2013) The endocrown: an alternative approach for restoring extensively damage molars. J Esthet Restor Dent 25:383-391.
6) Burcu K-E, Serkan S, Ege K, Dilek H-Y, Egemen, Yasemin Y (2018) Fracture strengths of endocrown restorations fabricated with different preparation depths and CAD/CAM materials. Dental Materials Journal 37(2): 256-265.
7) Rocca GT, Daher R, Saratti CM, Sedlacek R, Suchy T, Feilzer AJ, Krejci I (2018) Restoration of severely damaged endodontically treated premolars: the influence of the endo-core length on marginal integrity and fatigue resistance of lithium disilicate CAD-CAM ceramic endocrowns. Journal of Dentistry (2018) 68: 41-50.
8) Aquilino SA, Caplan DJ (2002) Relationship between crown placement and the survival of endodontically treated teeth. J Prosthet Dent 87(3):256-63.

9) Ray HA, Trope M (1995) Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration. International Endodontic Journal 28(1): 12-18.

10) Gillen BM, Looney SW, Gu LS, Loushine BA, Wellen RN, Loushine RJ, Pashley DH, Tay FR (2011) Impact of the quality of coronal restoration versus the quality of root canal fillings on success of root canal treatment: a systemic review and meta-analysis. J. Endod 37(7): 895–902.

11) Robbins JW & Summitt JB (1988) Longevity of complex amalgam restorations. Operative Dentistry 13(2) 54-57.

12) Afrashtehfar KI (2017) Failure rate of single-unit restorations on posterior vital teeth: A systematic review. J Prosthet Dent. 117(3):345-353.

13) Bellaflame MM, Sabine GO, Louwette MM, Grenade CF, AVanheusden AJ, Mainjot AK(2017) No post-no-core approach to restore severely damaged posterior teeth: An up to 10-year retrospective study of documented endocrown cases. J of Dent 63: 1-7.

14) Bindl A, Richter B, & Mormann WH (2005) Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry. International Journal of Prosthodontics 18(3) 219-224.

15) Sedrez-Porto JA, Oliveira da Rose WL, Fernandes da Silva A, Munchow EA, Pereira-Cenci T (2016) Endocrown restorations: A systematic review and meta-analysis. J Dent. 52:8-14.

16) Magne P, Carvalho AO, Bruzi G, Anderson RE, Maia HP, Giannini M (2014) Influence of no-ferrule and no-post buildup on the fatigue resistance of endodontically treated molars restored with nonceramic CAD/CAM crowns. Oper Dent 39:595-602.

17) Helal MA, Wang Z (2017) Biomechanical assessment of restored mandibular molar by endocrown in comparison to a glass fiber post-retained conventional crown: 3D finite elemental analysis. Journal of Prosthodontics 00: 1-9.

18) Ibrahim AMBR, Richards LC, Berekally TL (2016) Effect of remaining tooth structure on the fracture resistance of endodontically-treated maxillary premolars: An in vitro study. J Prosthet Dent 115(3): 290-95.

19) Aurélio IL, Fraga S, Rippe MP, Valandro LF (2015) Are posts necessary for the restoration of root filled teeth with limited tissue loss? A structured review of laboratory and clinical studies. Intern Endo Journal 49(9): 827-835.

20) Waltimo A, Kononen M. A novel bite force recorder and maximal isometric bite force values for healthy-young adults. Scandinavian Journal of Dental Research 1993;101:171-5.

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

22) **B**. Belleflamme MM, Geerts SO, Louwette MM, Grenade CF, Vanheusden AJ, Mainjot AK. No post-no core approach to restore severely damaged posterior teeth: An up to 10-year retrospective study of documented endocrown cases. J Dent 2017;63:1-7.

23) **C.** Fages M, Raynal J, Tramini P, Cuisinier FJG, Durand JC. Chairside Computer Aided Design/Computer Aided Manufacturer all-ceramic crown and endocrown restorations: A 7-year survival rate study. Int J Prosthodont 2017;30:556-560.

D. Sedrez-Porto JA, Rosa WL, da Silva AF, Münchow EA, Pereira-Cenci T. Endocrown restorations: A systematic review and meta-analysis. J Dent 2016;52:8-14.

E. Hewlett S, Wadenya RO, Mante FK. Bond strength of luting cements to core foundation materials. Compend Cont Educ Dent 2010;31:140-146.

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

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

H. Pratt I, Aminoshariae A, Montagnese TA, Williams KA, Khalighinejad N, Mickel A. Eight-year retrospective study of the critical time lapse between root canal completion and crown placement: Its influence on the survival of endodontically treated teeth. Int Endod J 2016;42:1598-1603.

I. Ye K, Bhagavatula P, Stover S, Eichmiller F, Hashimoto L, MacDonald S, Barkley III G. Survival rates of teeth with primary endodontic treatment after core/post placement. J Endod 2018;44:220-225.