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Effect of Endocrown Pulp Chamber Extension Depth on Molar Fracture Resistance

A Hayes • N Duvall • M Wajdowicz • H Roberts

Clinical Relevance

Endocrown pulp chamber extension depth should not be greater than 2 mm.

SUMMARY

Purpose: The purpose of this study was to evaluate the effect of endocrown pulp chamber extension on mandibular molar fracture resistance.

Methods and Materials: A total of 36 recently extracted mandibular third molars of approximate equal size were sectioned at the facial lingual height of contour followed by endodontic access into the pulp chamber. The specimens were then randomly divided into three groups (n=12) and pulpal and root canal contents removed. Pulp chamber floors were established at 2, 3, and 4 mm from the occlusal table using a three-step etch-and-rinse adhesive and a flowable resin composite. The prepared specimens were then embedded in autopolymerizing denture base resin with surface area available for adhesive bonding determined using a digital recording microscope. Specimens were restored using a standardized template with a chairside computer-aided design/computer-aided manufacturing unit with the endocrown milled from a lithium disilicate glass–ceramic material. Restoration parameters of occlusal table anatomy and thickness were standardized with the only parameter difference being the pulp chamber extension depth. The endocrown restorations were luted with a self-adhesive resin luting agent and tested to failure after 24 hours on a universal testing machine, with force applied to the facial cusps at a 45° angle to the long axis of the tooth. The failure load was converted into stress for each specimen using the available surface area for bonding. Mean failure load and stress among the three groups was first subjected to the Shapiro-Wilk and Bartlett tests and then analyzed with an analysis of variance with the Tukey post hoc test at a 95% confidence level (p=0.05).

Results: The 2- and 4-mm chamber extension groups demonstrated the highest fracture resistance stress, with the 3-mm group similar to the 2-mm group. The 3- and 4-mm chamber

Aaron J Hayes, DDS, deputy director AEGD-1, 633 Dental Squadron, Joint Base Langley-Eustis, VA, USA

Nicholas DuVall, DDS, MS, deputy director, AEGD-2, Air Force Postgraduate Dental School, Keesler Air Force Base, Biloxi, MS, USA

Michael Wajdowicz, DMD, director, AEGD-2, Air Force Postgraduate Dental School, Keesler Air Force Base, Biloxi, MS, USA

*Howard Roberts, DMD, MS, director, Graduate Dental Research AEGD-2, Air Force Postgraduate Dental School, Keesler Air Force Base, Biloxi, MS, USA

*Corresponding author: 606 Fisher St, Keesler AFB, MS 39534; e-mail: howard.roberts@us.af.mil

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extension group specimens demonstrated nearly universal catastrophic tooth fracture, whereas half the 2-mm chamber extension group displayed nonrestorable root fractures.

Conclusions: Under the conditions of this study, mandibular molars restored with the endocrown technique with 2- and 4-mm pulp chamber extensions displayed greater tooth fracture resistance force as well as stress. All groups demonstrated a high number of catastrophic fractures, but these results may not be clinically significant because the fracture force results are higher than normal reported values of masticatory function.

INTRODUCTION

Restoration of endodontically treated teeth remains a challenge because they represent a stark biomechanical difference compared with their vital counterparts, representing a multifactorial dissimilarity that includes changes in tissue composition and dentin microstructure and macrostructure as well as the evident loss of tooth structure.[1] Many different compensatory treatment strategies have been proposed, including intracoronal post systems, directly placed complex restorations, and adhesive considerations.[1] Full-coverage indirect crown restorations are usually the preferred method of most practitioners and have been reported to display an increased survival rate compared with directly placed restorations.[2,3] Amalgam and resin composite cores have traditionally served as crown foundation materials, with recent reports that resin cores present either equivocal[4] or increased longevity compared with cast metal cores.[5] When adequate sound-dentin-supported enamel is present, intracoronal bonded resin composite restorations have been suggested to demonstrate fewer fractures within endodontically treated teeth, whereas intracoronal posts have the potential to lessen fracture resistance due to root dentin removal.[2]

Dental computer-aided design/computer-aided manufacturing (CAD/CAM) is increasingly used for full-coverage ceramic restorations due to reported esthetics, marginal accuracy, and expedient restoration production, with the restoration relying more on adhesive technology for retention.[6-15] In restoring endodontically treated teeth some CAD/CAM proponents emphasize the endocrown method.[6] The endocrown prosthesis consists of a merged crown-core unit that is adhesively bonded to the remaining tooth structure and is purported to provide a more conservative option to traditional post-and-core restorative strategies as well as providing equitable results.[6-15] Furthermore, some CAD/CAM proponents anecdotally maintain that the endocrown bond to dentin is superior to the bond of a ceramic crown to either amalgam or composite core materials. Moreover, adhesive technology is purported to be able to compensate for traditional macroretentive preparation features that are required for aqueous-based luting agents.[9]

General guidelines for endocrown preparations include 2- to 3-mm cuspal reduction, 90° butt margins, smooth internal transitions, a 6° pulp chamber taper, a relatively flat pulp chamber floor with sealed radicular spaces, and supragingival margins when possible.[8-10,15] Although a flat pulp chamber floor may not be an absolute requirement, the authors feel that it could be more difficult to achieve a symmetrical pulp chamber taper without a stable internal reference. There are no definitive guidelines concerning the pulp chamber extension depth required for adequate retention and resistance form. However, one report suggests that a 2-mm extension into the pulp chamber is sufficient.[14] The purpose of this study was to evaluate the effect of CAD/CAM endocrown restorations with pulp chamber extension depths of 2, 3, and 4 mm on molar fracture resistance. The null hypothesis was that there would be no difference in fracture resistance among the three groups.

METHODS AND MATERIALS

The human mandibular third molars used in this study were collected from local oral and maxillofacial surgery clinics and had been removed as per routine clinical indications under local institutional review board–protocol approval.

A total of 36 recently extracted mandibular third molars of approximately 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 tooth long axis. Access to the pulp chamber was accomplished using a high-speed handpiece (EA-51LT, Adec, Newburg, OR, USA) and a diamond bur (6847.33.016, Brassler USA, Savannah, GA, USA) with copious water spray. Pulpal remnants were removed with barbed broaches and gross instrumentation with hand files (Miltex, York, PA, USA). The prepared teeth were randomly subdivided into three groups (n=12) and received pulp chamber restorations to achieve symmetrical pulp chamber floors approximately parallel to and at depths of 2, 3, and 4 mm from the sectioned molar occlusal table using a three-step etch-and-rinse adhesive (Optibond FL, Kerr Corporation, Orange, CA, USA) and a flowable resin composite (Tetric Evo Flow, Ivoclar Vivadent, Amherst, NY, USA). All materials were placed following manufacturer recommendations with light polymerization accomplished using a polywave LED-based visible light curing (VLC) unit (Bluephase G2, Ivoclar Vivadent) whose irradiance was verified (1000 mW/cm2) using a laboratory-grade laser power meter (10A-V1, Ophir-Spiricon, North Logan, UT, USA). The specimens were then prepared to final form with the same handpiece and diamond bur to the desired configurations, with the preparations modified as needed from measurements from the digital two-dimensional microscope (Hirox 7700, Hirox USA, Hackensack, NJ, USA). Preparation standardization was assisted with a locally established covariance upper limit of 25%.

Specimens were then embedded in auto-polymerizing denture base resin (Impak Self Cure, CMP Industries, Albany, NY, USA) and surface area available for adhesive bonding determined using a digital recording microscope (KH-7700, Hirox USA) (Figure 1). The chamber surface area was determined by measuring a polyvinylsiloxane-impression replica of the prepared chamber. Mean chamber depth was determined by the mean of six measurements obtained at the mesial, distal, and middle chamber extensions. The restored resin chamber floor was also included in the surface area determination. Specimens were scanned using a standardized template simulating clinical conditions (Figure 2a,b) using a chairside CAD/CAM unit (Cerec AC/Cerec MC XL, Sirona Dental Systems, Charlotte, NC, USA; version 4.2.4.72301), with the crown milled from a lithium disilicate glass–ceramic material (IPS e.Max CAD HT A2, Ivoclar Vivadent). The occlusal table was established approximately 4 mm in height for all specimens. This provided consistent coronal thickness and form for all restorations, with the only parameter difference being the pulp chamber extension depth. Crystallization firing was accomplished following manufacturer protocol in a dental laboratory ceramic furnace (Programat P700, Ivoclar Vivadent). The restoration's intaglio surface was then steam cleaned and dried, followed by a 5% hydrofluoric acid etch (IPS Ceramic Etching Gel, Ivoclar Vivadent) for 20 seconds. Etched surfaces were thoroughly rinsed with water for 15 seconds and dried with oil-free compressed air, after which two thin coats of a silane agent (Monobond Plus, Ivoclar

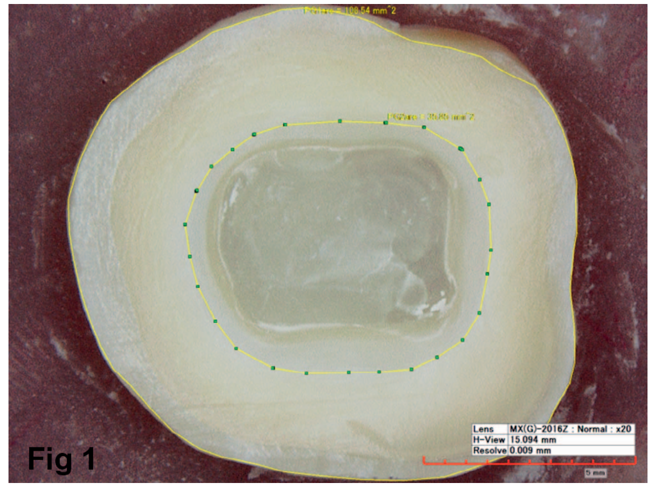


Figure 1. *Surface area assessment measurements.*

Vivadent) was applied with a microbrush to the treated surface for two 60-second intervals with the excess dispersed with a strong stream of air. The recipient tooth was prepared for cementation using pumice slurry in a prophylaxis cup (Extended Straight Attachment DPA, Preventech, Indian Trail, NC, USA) using a slow-speed handpiece (Midwest Shorty, Dentsply, York, PA, USA), rinsed thoroughly with water for 5 seconds, and then air dried. Restorations were cemented with a self-adhesive resin luting agent (Rely-X Unicem, 3M ESPE, St Paul, MN, USA) with firm digitally applied pressure and stabilization to allow the restoration to fully seat. A 2-second VLC tack cure was accomplished (Bluephase G2, Ivoclar Vivadent) with the excess cement removed, followed by each surface receiving additional light curing for 20 seconds. Restorations were then stored in dark conditions at 37°C ± 1°C and 98% ± 1% humidity.

Twenty-four hours after cementation, specimens were placed into a vise fixture mounted on a universal testing machine (RT-5, MTS Corporation, Eden Prairie, MN, USA) with the long axis of the tooth oriented at a 45° angle to the testing device. The facial functional cusps were loaded with a 3-mm diameter, hardened, stainless steel piston with a 0.5-m radius of curvature as described by Kelly and others[16] and were loaded at a rate of 0.5 mm per minute until fracture, with the failure load recorded in newtons. Failure load was converted into stress for each specimen using the available surface area for bonding. Each fractured specimen was also examined visually at 20× magnification (Hirox KH-7700, Hirox USA) to determine whether the failure was cohesive for the ceramic material, adhesive between the ceramic and the tooth structure, or

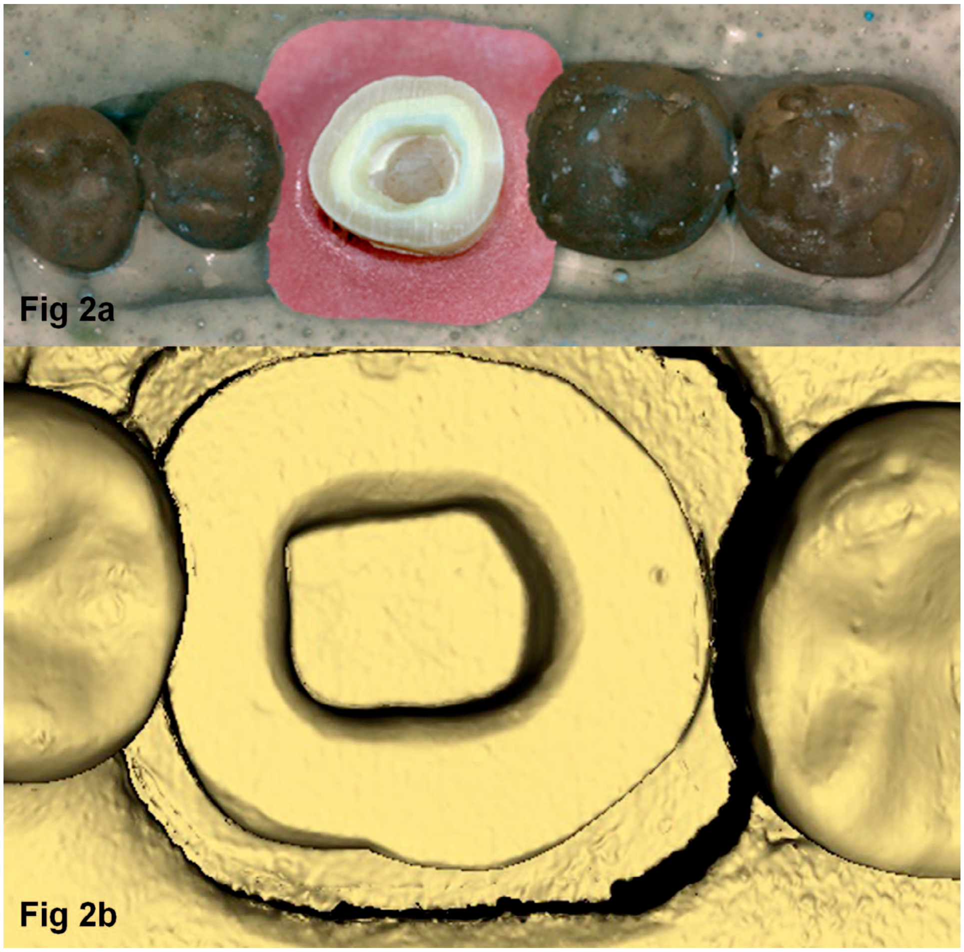


Figure 2a. *Prepared specimen in template for scanning.*
Figure 2b. *Resultant scanned image.*

fracture of the tooth material. Further failure analysis was accomplished with microradiographic tomography (microCT) (Skyscan 1172, Bruker microCT/Micro Photonics, Allentown, PA, USA), with samples scanned over a 180° radius with 13.6-μ resolution, 100-kV power, 100-mA resolution, aluminum filtration, and a 0.4° step size. Resultant individual images were recombined with software (nRecon, Bruker microCT), with resultant recombined images visualized using CTan and CTVox software (Bruker microCT). The mean failure force and stress values were evaluated by the Shapiro-Wilk and Bartlett tests, which verified both the normal distribution and variance equality. The mean data were then analyzed with an analysis of variance (ANOVA) with a Tukey post hoc test at a 95% confidence level (α=0.05).

RESULTS

The mean preparation features of each group are presented in Table 1. Consistency within the sample groups was achieved with relative success, indicated by the low covariance noted with the mean chamber extension depth and surface area covariance being less than 18%.

Resultant mean failure forces and stress are listed in Table 2. The ANOVA identified differences between the failure force groups (p=0.02) and the failure stress groups (p=0.008). The results of the *post hoc* testing are shown in Table 3. In regard to failure force, the 3-mm chamber extension groups demonstrated the lowest fracture resistance trend. It is interesting that the 4-mm chamber extension group demonstrated the highest fracture force resistance, which was contrasted by the 2-mm chamber extension group having the highest stress fracture resistance.

Failure mode results are identified in Table 4. The 3- and 4-mm chamber extension depth group specimens demonstrated nearly universal catastrophic tooth fracture, whereas eight of the twelve 2-mm chamber depth extension group demonstrated nonrestorable fractures.

Table 1: *Mean (Standard Deviation) of Tooth Preparation Parameters (n=12)*

Group (Chamber Extension Depth)	Mean Chamber Extension Depth (mm)	%COV	Surface area (mm^2)	% COV
2 mm	2.2 (0.05)	2.0	118.5 (16.6)	14.1
3 mm	3.1 (0.06)	1.9	139.2 (19.5)	14.3
4 mm	4.1 (0.09)	2.2	162.1 (28.1)	17.4

Abbreviation: COV, covariance.

DISCUSSION

The need for proper restoration of endodontically treated teeth is well known. Tang and others[2] reported that failure to provide permanent restorations after endodontic treatment resulted in greater than 65% tooth loss during a mean follow-up time of three years. They emphasized the need for expedient sealing of all endodontic access cavities followed by cuspal coverage restorations[2] to alleviate bacterial recontamination of obturated root canals, which has been reported to occur as quickly as 25 to 30 days after re-exposure.[17,18] The endocrown method offers an expedient clinical option in regard to the sealing and restoration of the endodontically treated tooth as well providing clinical alternatives in the situations of teeth with calcified, short, or dilacerated root canals.[7]

The endocrown method was first described by Pissis,[10] followed by Bindl and Mormann[6] who reported clinical results demonstrating a 95% endocrown survival rate over a mean recall rate of 26.6 months.[6] Lander and Dietschi[11] described that endocrowns could provide suitable restorations in situations with minimal compromised vertical height and ferrule. In an *in vitro* finite element analysis model, Dejak and Młotkowski[13] reported molars restored with endocrowns transferred less functional stress to dentin compared with molars restored with posts and cores.

In this study, we investigated the effect of endocrown chamber depth extension on mandibular molar fracture resistance. Specimens were prepared as uniformly as possible by one researcher with the mean specimen parameters previously listed in Table 1. Surface area available for adhesion was determined by the area measurement function of the digital measuring microscope (Figure 2). The authors feel that preparation standardization within each group was reasonably achieved, given that the chamber depth measurement covariance was approximately 2%, whereas surface area measurements covariance ranged from 14% to 17%. Furthermore, the increase in surface area associated with each chamber depth level was demonstrated to be a linear function (r^2=0.99), as shown in Figure 3.

Under the conditions of this study, the null hypothesis was rejected in that the 2- and 4-mm groups demonstrated higher resistance to failure as compared with the 3-mm chamber extension group. However, due to the similarity of the data ranges, the results may not be clinically significant. Perhaps the most clinically relevant findings of this study is revealed by the failure analysis. Ninety-two percent of the 3-mm chamber extension group and 83% of the 4-mm chamber extension group demonstrated catastrophic fracture, whereas 66% nonrestorable failures were observed with the 2-mm chamber extension group. Upon initial visual analysis, the 2-mm pulp chamber extension group was thought to comprise mostly restoration debonding accompanied with repairable tooth fracture (Figure 4). However, microCT imaging proved to be a valuable tool in failure mode assessment. Some specimens that were initially thought repairable on the basis of visual examination alone were found after microCT assessment to also contain irreparable root fractures, which, depending on location, may or may not be visible on a standard periapical film (Figure 5). Accordingly, after microCT evaluation a total of six

Table 2: *Mean (Standard Deviation) of Failure Force and Stress Results (n=12)*

Endocrown Chamber Extension Depth (mm)	Failure Force (N)	Failure Stress (MPa)
2	843.4 (106) AB[a]	7.29 (1.6) A
3	762.8 (240) A	5.33 (1.2) B
4	943.5 (110) B	6.04 (1.6) AB

[a] *Groups identified with same capital letter within each column are similar (Tukey,* p*=0.05).*

Table 3: *Tukey Multiple Comparison Test Results (n=12)*

Comparison	Failure Force	Failure Stress
2 vs 3 mm	$p = 0.377$*	$p = 0.007$
2 vs 4 mm	$p = 0.262$	$p = 0.109$
3 vs 4 mm	$p = 0.015$	$p = 0.471$

* p = *0.05.*

Table 4: *Failure Mode Analysis Results (n=12)*

Endocrown Chamber Extension Depth (mm)	Failure Mode		
	Adhesive	Restorable Fracture	Catastrophic Fracture
2	3	1	8
3	1	0	11
4	1	1	10

of the specimens with a 2-mm chamber depth were found to have catastrophic tooth fracture.

The results of the current study are comparable to that of Biacchi and Basting[8] who reported a mean endocrown failure load of approximately 675 N in preparations with pulp chamber extensions ranging from 2.0 to 2.7 mm, which also demonstrated tooth fracture in 90% of the specimens. However, results of the present study are much lower than those of Magne and others,[19] who reported a mean failure load of 2606 N for endocrowns with 1.5-mm chamber depth extensions, as well as of those of El-Damanhoury and others,[14] who found that endocrowns with 2-mm chamber depth extensions demonstrated a failure resistance of 1368 N. However, these studies' methodologies differed from that of the present study in that the loads to failure were applied at different vectors, axially and at 35°, respectively. However, failure mode results of this study compares favorably with that of El-Damanhoury and others,[14] who found that approximately 70% of the endocrowns demonstrated catastrophic failure. Also, fracture resistance reported by Carvalho and others[20] as well as Gresnigt and others[21] was higher than that found in the present study, but those previous studies involved axial loading after fatigue stressing the specimens. However, all of these findings should be considered with the fact that failure loads of this study as well as other studies are above the reported human functional load. Accordingly, molar region occlusal load has been reported to be near the range of 100 to 200 N and has been estimated as high as 965 N in situations of accidental occlusal contact, parafunction, and/or trauma.[22-29]

This is the first endocrown *in vitro* study that produced failure stress data that was based on tooth surface available for bonding. Failure stress calculation was undertaken to evaluate whether stress results, on the basis of surface area available for bonding, might serve to normalize failure force results that may be affected by different tooth specimen size. However, under the conditions of this study no clear normalization effect was noted. This aspect will continue to be evaluated with future studies, and more comparative studies will be required before definitive recommendations may be proffered. In addition, microCT analysis was found to be a valuable failure analysis tool, given that this modality allowed nondestructive failure analysis permitting fracture detection that was not usually not discernable visually and might be beyond

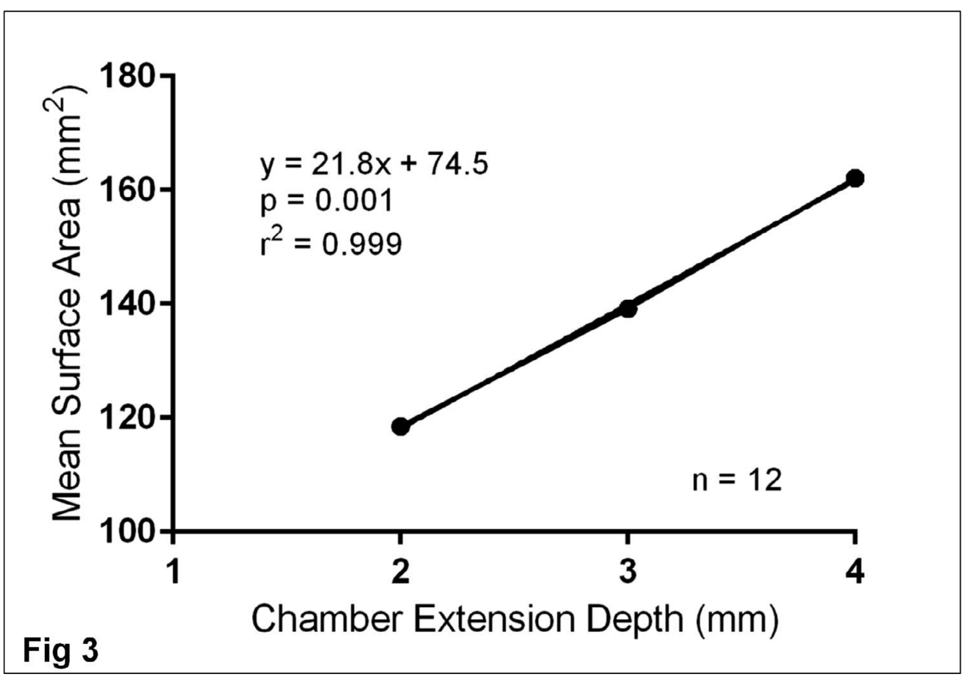
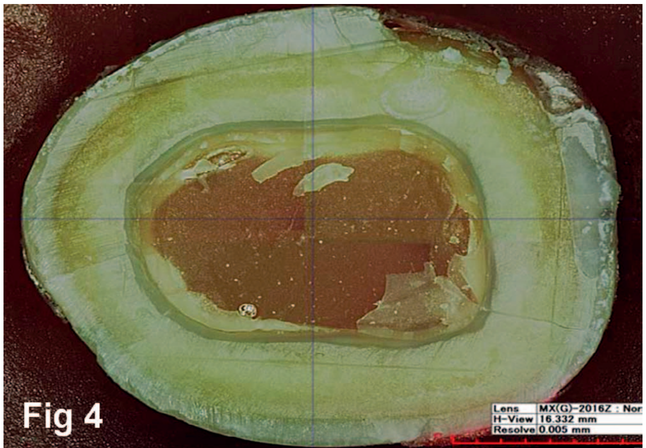


Figure 3. *Surface Area Increase Per Chamber Depth*



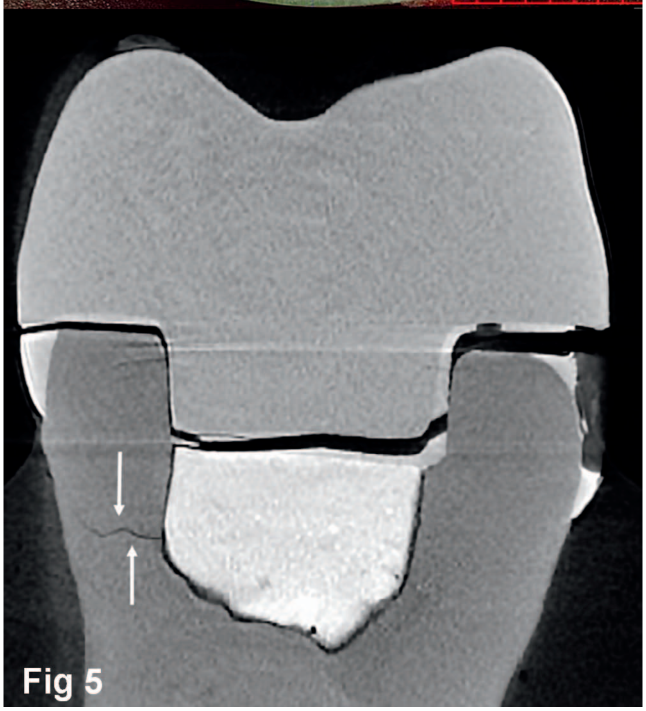


Figure 4. *Failure analysis visual assessment revealing restorable tooth damage.*

Figure 5. *MicroCT assessment of Figure 4 specimen. (Arrows denote fracture)*

detection with the usual clinical radiographic techniques.

One limitation of this study was the choice of a fixed crown height. Reports suggest that internal stresses to both the endocrown and supporting tooth structure increase as the force application location increases vertically from the endocrown buccal margin.[21,30] Accordingly, different force application heights would involve different lever-arm tipping forces as well as force vectors between the supporting tooth and restoration—all of which may change fracture load results. The authors chose to limit the force application level to evaluate solely the effect of different pulp chamber extension depths, but this load was applied at the same height as the marginal ridge to, one hopes, represent a worst-case scenario.

The findings of this laboratory study reinforces CAD/CAM proponents' recommendations of a 2-mm endocrown pulpal extension. However, this study identified a remarkable number of irreparable fractures, and this recommendation requires further investigation. Because the identified failure forces were above the published range reported with normal human function as well as parafunction, fatigue analysis is planned as well as research evaluating endocrown preparations with ferrule preparation features.

CONCLUSIONS

Under the conditions of this study, mandibular molars restored with the endocrown technique with 2- and 4-mm pulp chamber extensions displayed greater tooth fracture resistance. All groups demonstrated a high number of catastrophic fractures, but these results may not be clinically significant because the fracture force results are higher than normal reported values of masticatory function.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of 81 Medical Group. The approval code for this study is FKE20140012N.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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