CAD/CAM Preparation Design Effects on Endodontically Treated and Restored Molars

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Acknowledgements

Special thanks to Col Howard Roberts, Maj Nicholas DuVall, and Col Michael Wajdowicz.

Date 23 May 16

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Abstract:

Objective: To evaluate the fracture resistance of adhesively-bonded, full coverage ceramic restorations manufactured by a CAD/CAM technique on endodontically treated molars restored with the endocrown method versus ceramic full coverage based on amalgam cores with different ferrule design.

Methods: 84 recently-extracted mandibular third molars were randomly divided into 7 groups (n=12) with the coronal tooth structure removed perpendicular to the root long axis at the facial-lingual height of contour with a water-cooled, slow-speed diamond saw. The pulp chamber was exposed using diamond burs in a high speed handpiece, pulpal remnants removed, and canals instrumented using endodontic hand instruments. Specimens were embedded in autopolymerizing denture base resin. One group was restored with a lithium disilicate endocrown with a two millimeter pulp chamber extension. The other three groups were restored with an amalgam core using a dispersed phase, high copper amalgam that were prepared for a full coverage lithium disilicate crown with preparation designs including one and two millimeters of ferrule, plus one group with an external marginal finish line approximating the intracoronal dentin amalgam interface (minimal ferrule). Another three amalgam core groups were likewise restored but with added retention afforded by an adhesive amalgam technique. Completed preparation surface area was determined using a digital measuring microscope and scanned preparations (CEREC) were fitted with lithium disilicate crowns that were bonded with a self-adhesive luting cement. After 24 hours, specimens were tested after 24 hours loaded to failure on a buccal functional cusp at a 45 degree-angle to the tooth long axis. Both mean failure load and calculated failure stress was determined and analyzed with Kruskal-Wallis/Dunn's (p=0.05).

Results: The amalgam core group with a preparation including one millimeter of ferrule demonstrated the highest failure load but was similar to the groups consisting of the two millimeter ferrule unbonded amalgam core, bonded amalgam core with two millimeters ferrule, and the bonded amalgam core with one millimeter ferrule groups. There was wide overlap of failure load similarity and the endocrown largely demonstrated the same failure load as the majority of the amalgam core groups. Failure stress calculation found that there was more general overlap in similarity in almost all of the amalgam core and endocrown restored groups. However, the amalgam core groups generally demonstrated a more favorable failure mode, as the endocrown group demonstrated nearly universal catastrophic failure.

Conclusions: Under the conditions of this study, lithium disilicate full coverage restorations with amalgam core foundations overall displayed the same resistance to crown displacement as endocrown restorations with a 2mm pulp chamber extension. However, the endocrown restorations displayed almost universal catastrophic failure compared to amalgam core based restorations.

Introduction:

Restoration of endodontically treated teeth remains a challenge for clinicians, as endodontic treatment results in a tooth that represents a stark biomechanical difference compared to their vital counterparts. This dissimilarity is multifactorial to include changes in tissue composition, dentin micro and macrostructure, as well as the more evident loss of tooth structure. [1] To compensate, many different treatment strategies have been used, that includes different intracoronal post systems, directly placed restorations, different core material designs and materials, as well as adhesive considerations. [1] Full coverage crown restoration is the most popular restoration method for the restoration of endodontically treated teeth, and some authors report an increased survival rate as. [2,3]

All ceramic CAD/CAM full coverage restorations are becoming more popular with clinicians with marginal accuracy due to improved esthetics, expedient production of prosthesis, and improved marginal accuracy. [4-13] Compared to their traditional laboratory-fabricated counterparts, CAD/CAM-generated restorations rely more on adhesive technology, which CAD/CAM promoters propose can compensate for lack of traditional preparation features. [5] For the restoration of endodontically treated teeth, CAD/CAM promoters emphasize the "endocrown" method. [4] The endocrown restoration consists of a merged crown and core unit that is adhesively bonded into the pulp chamber and the remaining tooth structure. [4] The endocrown method is said to provide a more conservative option to traditional post and core restorative strategies while providing equitable results. [4-11]

Dejak and Mlotkowski 2013 [9] in an *in vitro* study used finite element analysis to compare stresses in molars restored with endocrowns compared to post and cores supporting ceramic crowns. Under the conditions of their study it was reported that under simulated masticatory function the endocrown had the lowest dentin stress concentrations that was reported to be approximately 23 percent lower than that of an intact tooth model. The model simulating including a fiber-reinforced composite (FRC) posts and resin composite core supporting a ceramic crown displayed 31 percent higher crown stress concentration while 61 percent higher stress levels were observed in the simulated resin luting cement. Additionally, tensile stresses in the adhesive cement–dentin interface around FRC posts achieved 4 times higher values than in the cement interface with endocrowns.

For the restoration of endodontically treated molars, the purported philosophy of different CAD/CAM promoters state that the endocrown method is superior to more traditional full coverage ceramic restorations based on either an amalgam or resin core. This philosophy is seemingly based on the proponent's statement that the endocrown provides ample dentin surface for adhesive bonding, and that the adhesive bond to either an amalgam or resin cores is not as effective, even in the face of a sparsity of supporting data. [14] The purpose of this study was to evaluate the retention of adhesively bonded, CAD/CAM generated, all-ceramic, full-coverage restorations on endodontically treated molars restored with either the endocrown method or an amalgam-core-supported restoration based with different preparation features. The null hypothesis was that there would be no difference in the retention between the methods.

Materials and Methods:

Eighty-four freshly extracted human mandibular third molar teeth were used in this study which had been removed as per routine clinical indications. These teeth were collected from local oral and maxillofacial surgery clinics under the Keesler AFB Institutional Review Board (IRB) protocol approval.

The molars were randomly divided into 7 groups (n=12) with the coronal tooth structure removed perpendicular to the root long axis at the facial-lingual height of contour with a water-cooled, slow-speed diamond saw (Buehler, Lake Forest , IL USA). The pulp chamber was exposed using diamond burs (6847.33.016, Brassler USA, Savannah, GA, USA) in a high speed handpiece (EA-51LT, Adec, Newburg, OR, USA), pulpal remnants removed, and canals instrumented using endodontic hand instruments (Miltex, York, PA, USA). Canal orifices were further opened using Gates-Glidden rotary instruments (DENTSPLY-Maillefer, Tulsa, OK, USA). The specimens were then imbedded in self-curing denture base resin (Impak Self-Cure, CMP Industries, Albany, NY, USA).

The endocrown group had the pulp chambers restored with a dual-cure resin core material (Gradia Core, GC America, Alsip, IL, USA) that was adhesively bonded using a two-step, self-etch adhesive (Clearfil SE, Kuraray USA, Houston, TX, USA). The pulp chamber floor was finished parallel to and at a uniform distance of two millimeters from the endocrown occlusal table. All visible light polymerization were accomplished using a LED-based visible light curing (VLC) unit (Bluephase G2, Ivoclar-Vivadent, Amherst, NY, USA) whose irradiance was periodically verified (1000 mW/cm2) using a laboratory grade laser power meter (10A-V1, Ophir-Spiricon, North Logan, UT, USA).

Specimens in three groups received an amalgam core buildup restoration using a high-copper, dispersed-phase amalgam (Permite, SDI Limited, Bayswater, Victoria, AUS) with the pulp chamber (>4mm) as the sole retentive feature. Three additional groups were likewise restored but with an additional retentive feature provided by an adhesive amalgam technique (Amalgabond Plus, Parkell, Edgewood, NY, USA). All amalgam core restorations were carved to contour and after 24 hours all restored specimens were prepared following CAD/CAM guidelines for all-ceramic e.max CAD full coverage restorations (CEREC 3D Preparation Guidelines, Dentsply Sirona, Charlotte, NC, USA) for CAD/CAM restorations. One group in each amalgam retentive scheme was prepared with one and two millimeter ferrule preparation features, respectively, as well as a minimal ferrule preparation group whose external marginal finish line approximated the same level as the internal amalgam-dentin interface. Preparations were accomplished by one operator using a high speed electric dental handpiece (EA-51LT, Adec Newburg, OR, USA) with a diamond bur (8845KR.31.025, Brassler USA, Savannah, GA, USA) under continuous water coolant spray. All specimens were then measured to affirm preparation parameters and available surface area for bonding with a digital measuring microscope (KH-7700, Hirox USA).

All specimens were scanned using a standardized template to simulate clinical conditions using a CAD/CAM unit (Cerec AC/Cerec MC XL, Dentsply-Sirona, software version 4.2.4.72301) to fabricate crowns milled from a lithium disilicate ceramic (IPS e.max CAD HT A2 Ivoclar-Vivadent). The occlusal table and anatomy was replicated for all specimens with a minimum occlusal thickness of two millimeters. The milled pre-sintered restorations received two coats of spray glaze (IPS e.max CAD Crystall/Glaze spray, Ivoclar-Vivadent) followed by crystallization firing following manufacturer protocol in a dental laboratory ceramic furnace (Programat P700, Ivoclar-Vivadent).

Prior to adhesive cementation, the restoration's intaglio surface was steam cleaned and dried using oil free compressed air. The intaglio surfaces were then etched for 20 seconds using a five percent hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) followed by a thorough rinse with water and dried with oil free air. A thin coat of silane agent (Monobond Plus, Ivoclar Vivadent) was applied with a microbrush to the pre-treated intaglio surface for one 60 second interval. Excess was dispersed with a strong stream of air. Each tooth was prepared for adhesive luting with a pumice slurry applied by a prophylaxis cup (Extended Straight Attachment DPA, Preventech) using a slow speed dental handpiece (Midwest Shorty, Dentsply International, York, PA, USA) followed by a thorough water rinse and air dried. The treated restorations were then cemented with a self-adhesive resin luting agent (RelyX Unicem, 3M ESPE, St. Paul, MN, USA) with digital pressure applied until fully seated onto the tooth margin. Excess cement was removed with a rubber tipped gingival stimulator (GUM latex free stimulator, Sunstar Americas, Inc.) and then each surface was light cured for 20 seconds. All materials were used following manufacturer recommendations and when not in use, all specimens were stored in distilled water under dark conditions at 37 ± 1 °C and 98 ± 1% humidity.

Twenty four hours after cementation each specimen was placed into a fixture on a universal testing machine (Alliance 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 1).

Figure 1: 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.*[17] Specimens were loaded at a rate of 0.5 millimeter per minute until failure with the failure load recorded in Newtons. Also, failure stress was calculated using the measured available dentin surface area for bonding. Specimens were examined to determine if failure 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 (Hirox 4400, Hirox 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) with resultant recombined images visualized CTan and CTVox software (Bruker microCT).

Mean failure stress and load was first subjected to the Shapiro-Wilk Test and Bartlett's Test which identified both a abnormal data distribution as well as the existence of unequal variance between some of the groups. The mean data was then analyzed with Welch's test with Ryan-Einot-Gabriel-Welsch Range *post hoc* test after Bonferroni correction of the data. Statistical analysis was accomplished using a computer based software program (SPSS 20, IBM SPSS, Chicago, IL, USA) using a 95 percent level of confidence ($p = 0.05$).

Results:

Resultant mean failure loads and stress are listed in Table 1.

Table 1: Mean Failure Loads (N) and Stress (MPa)

	Failure Load (N)	Failure Stress (MPa)
Endocrown	663.5 (242.9) AB	11.8 (4.3) A
Amalgam core minimal ferrule	567.7 (254.0) A	14.9 (7.7) AB
Amalgam core 1mm ferrule	980.7 (299.3) C	14.8 (4.3) AB
Amalgam core 2mm ferrule	831.5 (220.4) ABC	9.4 (2.6) A
Bonded amalgam core minimal ferrule	614.9 (273.2) A	19.6 (8.5) B
Bonded amalgam core 1mm ferrule	851.6 (281.1) ABC	15.5 (5.0) AB
Bonded amalgam core 2mm ferrule	950.9 (217.9) BC	12.9 (2.9) A

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

Analysis of the failure load results identified the amalgam core with one millimeter ferrule demonstrated the highest failure load but was statistically similar to the two millimeter amalgam core, the bonded amalgam core with two millimeters ferrule, and the bonded amalgam core with one millimeter ferrule groups. There was considerable statistical overlap between the groups and the lowest numerical values were found with the two minimal-ferrule amalgam core groups. Groups analyzed with the calculated failure stress provided different results. The bonded amalgam core with minimal ferrule provided the highest numerical failure stress results, and was similar to the one millimeter ferrule bonded amalgam core, as well as to the one millimeter and minimal ferrule amalgam core groups. As with the failure load results there was significant overlap between the groups but the lowest failure stress resistance was observed with the endocrown and two-millimeter ferrule amalgam core groups.

Results of the failure mode analysis are presented in Table 2.

Table 2: Failure Mode Analysis Results

	Debond	Amalgam Core Fracture Crown Intact	Restorable Fracture	Catastrophic Fracture Tooth/Restoration Complex	Cohesive Root Fracture	Cohesive Ceramic Fracture
Endocrown	0	0	0	11	1	0
Amalgam Core Minimal Ferrule	0	10	0	1	1	0
Amalgam Core 1mm Ferrule	0	7	0	2	2	1
Amalgam Core 2mm Ferrule	0	3	0	1	7	1
Bonded Amalgam Core Minimal Ferrule	0	10	2	0	0	0
Bonded Amalgam Core 1mm Ferrule	0	3	2	4	3	0
Bonded Amalgam Core 2mm Ferrule	0	0	0	4	7	1

n = 12

Catastrophic failure = non restorable tooth fracture which involves restoration and preparation features

Root fracture = Cohesive root fracture that does not involve restoration/apical to restoration

Failure mode analysis revealed that the endocrown restorations demonstrated almost universal catastrophic failure. The restorations based on amalgam cores with minimal ferrule (both bonded and unbonded) predominately failed by amalgam core fracture at the margin level with the crown intact. Of the unbonded amalgam cores with ferrule, the number of amalgam core fractures decreased with ferrule width increase as well as cohesive root fractures. Bonded amalgam cores demonstrated approximately the same amount of cohesive root fractures as the unbonded cohort, but interestingly displayed more catastrophic non-restorable fractures.

Discussion:

The importance of proper and expedient tooth restoration after endodontic therapy is well known. Conclusions from Tang *et al* [2] reported that failure to replace interim restorations with permanent restorations after endodontic treatment resulted in 65 percent tooth loss over a mean follow-up time of 3 years. These authors also stressed the need for sealing all endodontic access cavities and to provide cuspal coverage restorations as soon as possible after endodontic treatment. The need for sealing the endodontic access preparation was stressed by Torabinejad *et al* [15] who reported that obturated teeth with gutta percha exposed to bacteria demonstrated recontamination of the obturated root canals in 24 days with almost all specimens totally infected before 30 days. Moreover, in a similar study Khayat et al [16] showed that exposed canals obturated with lateral condensation had total contamination in 28 days while vertical condensation samples were contaminated entirely in 25 days.

The restoration of endodontically treated teeth has been traditionally accomplished with full coverage crown restorations supported by either direct resin or amalgam core materials as well as post and cores when insufficient coronal tooth structure is present to retain the core material. The use of posts in molar teeth is controversial due to the additional loss of tooth structure required to for placement of the post and increased risk of vertical root fractures. [2]

Furthermore, intracoronal posts are not a viable option in the situation of teeth with dilacerated, calcified, or short root canals. [17] To provide both a cuspal coverage protection and coronal sealing of the root canal system, the endocrown may provide an efficient treatment option. Using chairside CAD/CAM technology, tooth preparation, crown fabrication, and permanent restoration can occur in one appointment.

However, review of the literature suggests the endocrown method may not be successful for all clinical situations. Lin et al 2010 [8] reported that bicuspids restored with the endocrown demonstrated less fracture resistance as compared to cast restorations. In contrast, other studies report the endocrown restoration involving premolars are ill-advised, as Biacchi et al [17] suggested limiting endocrowns for molar restoration because endocrown-restored bicuspids have lower survival potentially due to mastication forces. [17] Moreover, Bindl et al [5] suggests also that the bicuspid endocrown lower success rate may be due to less surface area available for bonding, a greater height to width ratio, and smaller pulp chamber dimensions which may all serve to intensify lever force vectors. [5,17] Long term clinical studies involving molar endocrown survival have not been accomplished due to the fairly recent introduction of this restorative method. However, limited short term studies and case reports seem to suggest the endocrown method may be viable treatment option, at least in the short-term. For instance, Bindl and Mormann 1999 [4] reported a 95 percent endocrown survival over 26 months, which was recently reinforced by Lander and Dietschi. [7]

This study evaluated the retention of full coverage, all ceramic restorations on endodontically treated mandibular molars with adhesive CAD/CAM techniques. More specifically, the full-coverage restorations involved either the endocrown method or amalgam core supported, all-ceramic restorations based on preparations of varying adhesive and ferrule design methods.

All specimens were prepared as uniformly as possible before restoration by one researcher with restoration parameters confirmed as well as the available dentin surface for bonding determined via a digital measuring microscope (Hirox 4400, Hirox USA) (Figure 2). The endocrown pulpal extension surface was measured indirectly using a polyvinylsiloxane impression replica of the prepared chamber with the mean chamber depth determined by the mean of measurements obtained at each chamber wall edge and middle. All amalgam core specimens were prepared while determining the available dentin surface area for bonding using the same digital microscope (Figure 3). The resultant mean specimen parameters are listed in Table 3. Due to the nature of the self-adhesive bonding agent, the resin-restored endocrown chamber floor was also included in the surface area available for bonding. The prepared specimens were scanned and restored by a singular additional researcher to further provide procedure standardization of the restorative process.

Figure 2: Occlusal Table and Margin Surface Area Determination

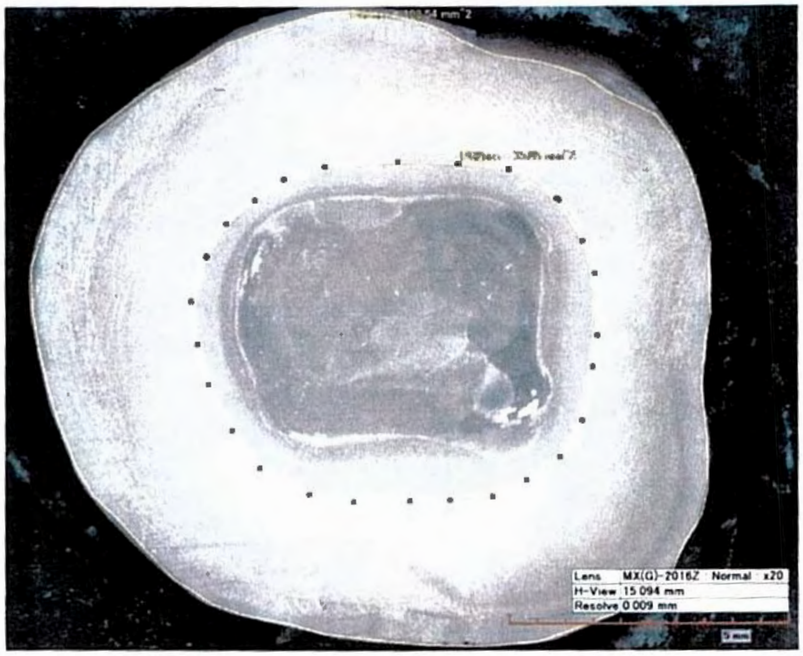


Figure 3: Axial wall dentin surface area determination

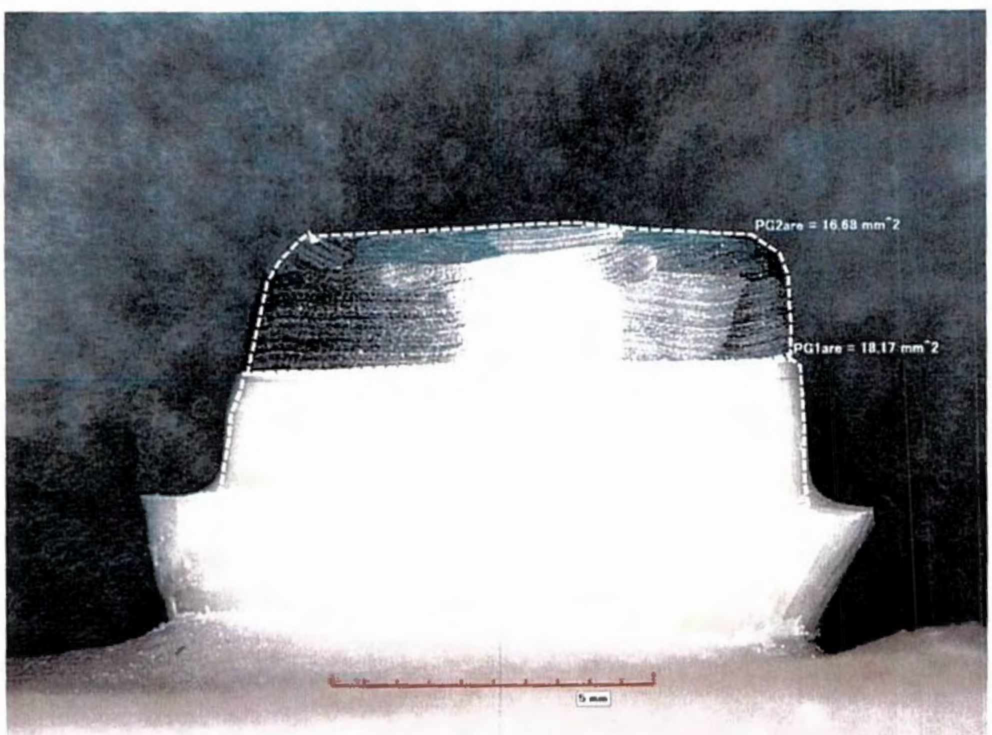


Table 3: Mean Preparation Parameters

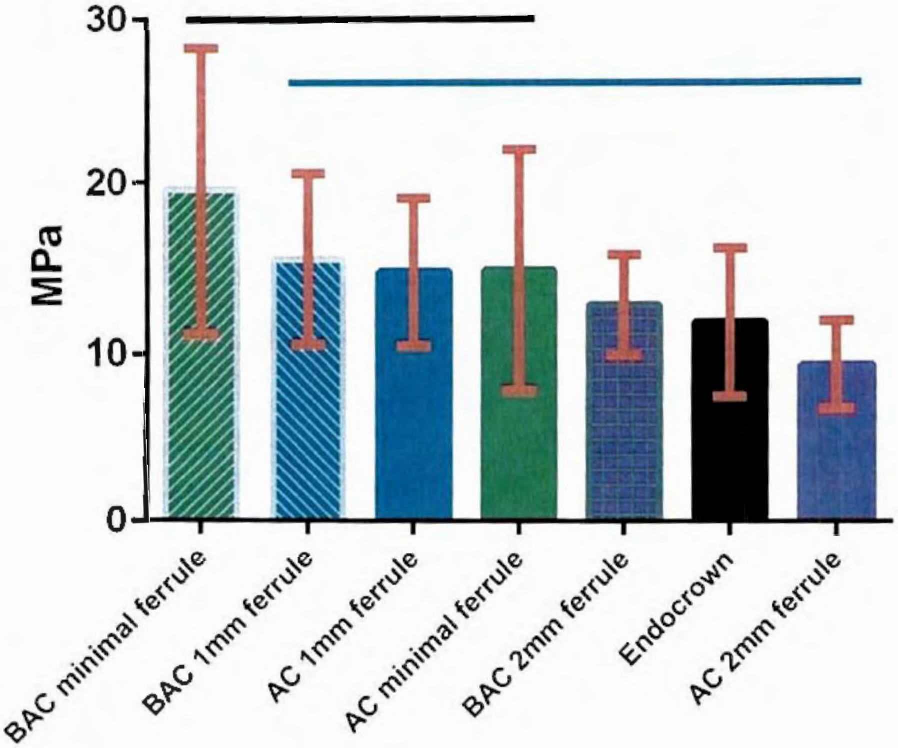
	Mean Dentin Surface Area (mm^2)	Mean Amalgam Surface Area (mm^2)	Mean Total Axial Wall Height (mm)	Mean Dentin Ferrule Wall Height (mm)	Mean Total Occlusal Convergence (degrees)
2mm Endocrown	111.4 (8.0)				
Amalgam Core Minimal Ferrule	38.5 (2.6)	112.3 (14.3)	3.8 (0.06)		9.8 (0.4)
Amalgam Core 1mm Ferrule	66.2 (6.3)	98.6 (12.0)	3.8 (0.07)	1.07 (0.05)	10.6 (0.5)
Amalgam Core 2mm Ferrule	88.8 (3.7)	74.1 (12.4)	3.8 (0.1)	2.03 (0.3)	10.5 (0.7)
Bonded Amalgam Core Minimal Ferrule	31.3 (5.2)	92.3 (13.3)	3.7 (0.08)		10.3 (0.3)
Bonded Amalgam Core 1mm Ferrule	54.6 (4.5)	72.7 (9.3)	3.7 (0.09)	1.04 (0.03)	10.4 (0.4)
Bonded Amalgam Core 2mm Ferrule	73.8 (5.6)	66.9 (8.3)	3.7 (0.09)	2.03 (0.3)	10.3 (0.3)

n = 12

The endocrown design averaged approximately 30 percent more dentin surface available for bonding than the amalgam core-based restorations containing two millimeters ferrule, over 40 percent more dentin surface than the one millimeter ferrule, and almost 70 percent more than the minimal ferrule groups. Even so, this advantage in bondable dentin surface area did not seem to impart any advantage to the endocrown restoration, as under the conditions of this study, there was no difference with endocrown failure stress compared to almost all of the amalgam-core based groups.

Under the conditions of this study, an all-ceramic crown with both bonded and unbonded amalgam core foundations with different preparation ferrule features displayed essentially the same failure stress as the endocrown group. Use of adhesively-bonded amalgam cores did not seem to influence restoration failure stress values, but did appear to influence the molar/restoration fracture resistance. However, when under failure load conditions some of the amalgam core groups with ferrule demonstrated significantly greater failure loads that the endocrown group. The failure stress and load graphical results are depicted in Figures 4 and 5, respectively.

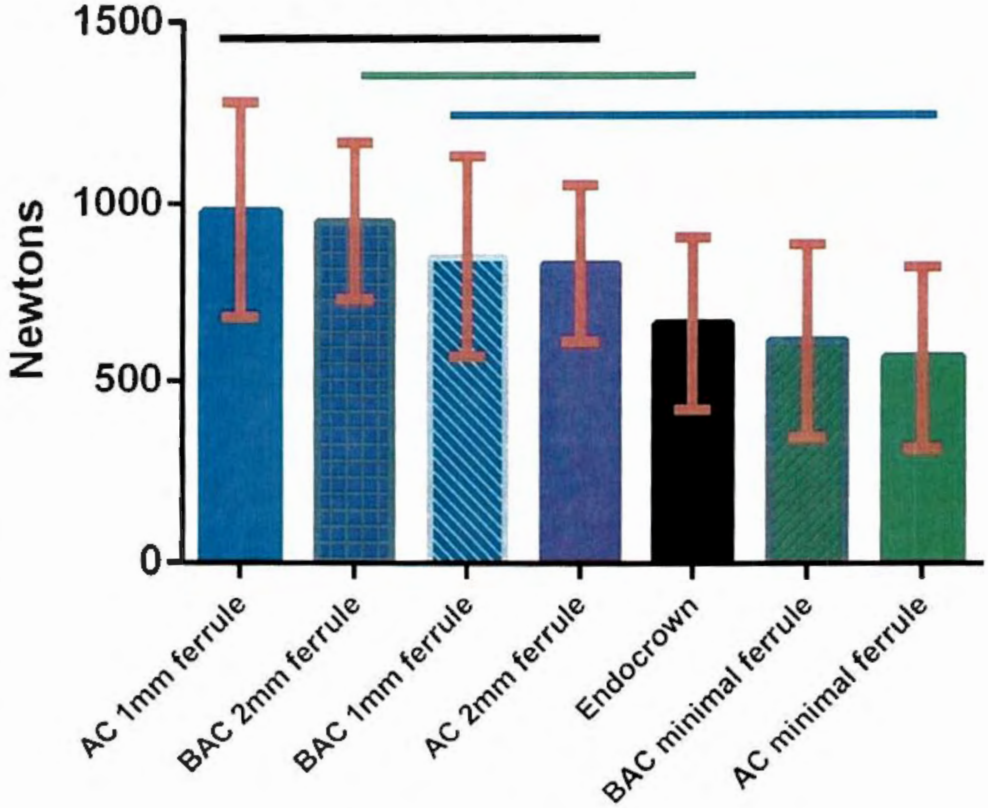
Figure 4: Mean Failure Stress Results (MPa)



n = 12

AC = Amalgam Core; BAC = Bonded Amalgam Core

Figure 5: Mean Failure Load (N)



n = 12

AC = Amalgam Core; BAC = Bonded Amalgam Core

The most clinically relevant findings of this study may be based upon the failure mode analysis. Five failure modes were depicted under the conditions of this study:

1) Crown dislodgement (Figure 6) with amalgam core fracture;

2) Restorable fracture (Figure 7) defined as either separate or combined fracture of restoration and tooth deemed restorable;

3) Catastrophic fracture (Figure 8) defined as a non-restorable fracture that involves the restoration and restoration preparation,

4) Root fracture (Figure 9) defined as a cohesive dentin failure apical to and not involving the restoration/preparation complex; and

5) Ceramic fracture (Figure 10).

Figure 6: Crown Dislodgement

Figure 7: Restorable Fracture

Figure 8: Catastrophic Fracture

Figure 9: Root Fracture

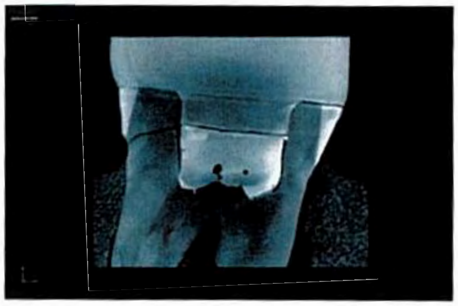
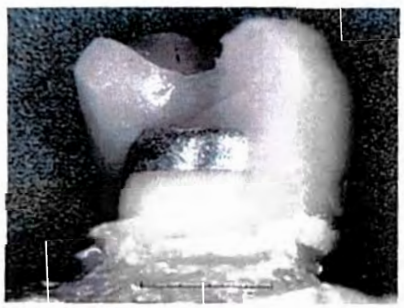


Figure 10: Ceramic Fracture



Under the conditions of this study, nearly all of the endocrown samples failed with catastrophic tooth fracture, evident via visual microscopy (Figure 11) and microCT analysis (Figure 12).

Figure 11: Endocrown Failure (20X)

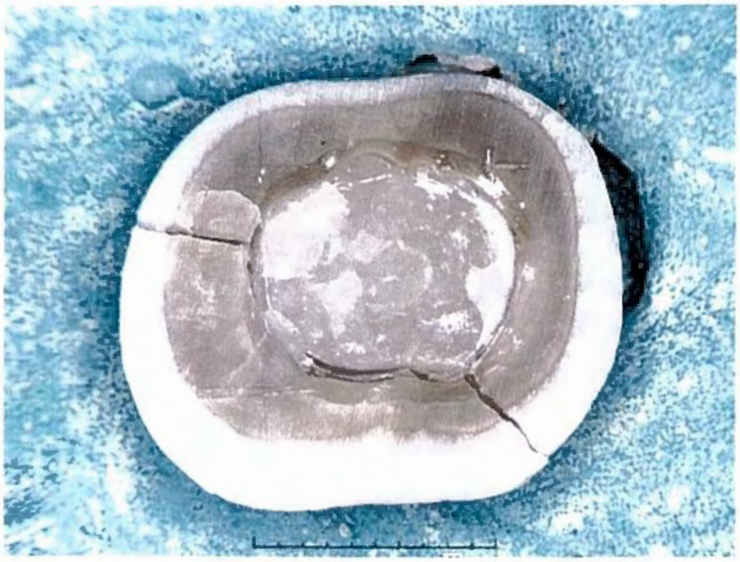
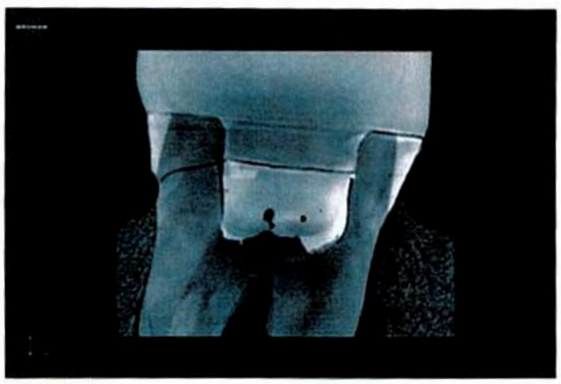


Figure 12: MicroCT Image 2mm Endocrown Failure



MicroCT analysis proved to be a valuable tool in assessing failure modes, as some specimens with visually judged repairable damage were found to contain irreparable damage that, depending on location, may not be visible on a standard periapical film (Figures 13-16).

Figure 13:

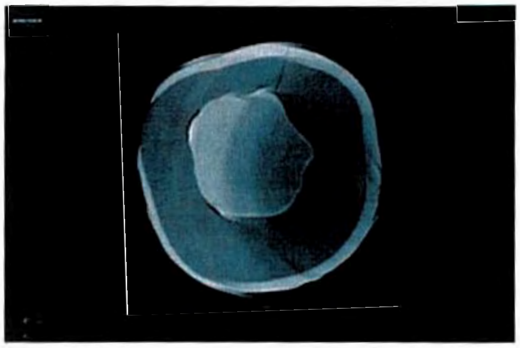


Figure 14:

Figure 15:

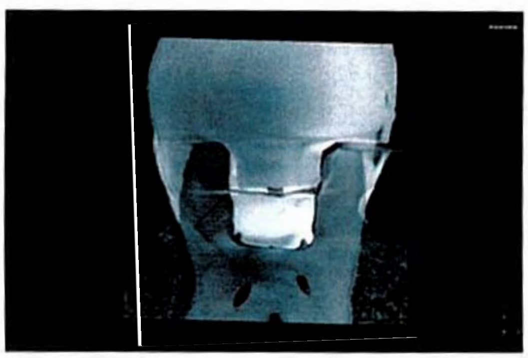
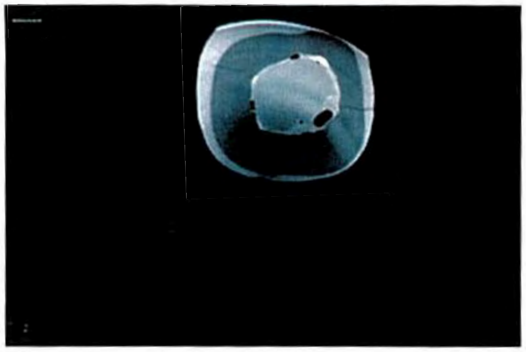


Figure 16:



While the endocrown group suffered almost universal catastrophic failure, the amalgam core groups demonstrated a more favorable outcome. Both bonded and unbonded amalgam core groups with minimal ferrule almost singularly failed due at the amalgam core-dentin interface with crown displacement. However, some divergence of failure outcomes was noted with the different ferrule height groups depending on the use or non-use of the amalgam adhesive. Accordingly, approximately half of the unbonded specimens with one millimeter ferrule failed by crown displacement in the same manner as the groups with minimal ferrule. With the unbonded two millimeter ferrule group, the additional resistance form provided by the ferrule became evident as fewer crown displacements occurred and over half of the specimens failed by cohesive root fracture apical to the margin. Interestingly, the adhesively-bonded amalgam groups demonstrated some difference in failure modes. Accordingly, the adhesive amalgam core groups displayed fewer crown displacements than their non-adhesive counterparts while producing similar number of cohesive root fractures. Additionally, both of the bonded amalgam core groups with ferrule displayed more catastrophic failure than their non-adhesive counterparts. Based on this failure analysis, it may be assumed that the adhesive amalgam technique used in this study provided some evidence of reinforcement between the amalgam core and tooth structure. Ensuing, under this study's conditions there was no apparent advantage observed with the use of amalgam adhesive when failure load and stress are considered, as there was wide overlap in the mean failure stress and load results. However, the adhesive amalgam core groups with both one and two millimeter ferrule demonstrated more catastrophic failure, which may imply that the adhesively bound amalgam core may have imparted more stiffness. This trend demonstrated in here would require further evaluation with larger sample sizes before any definitive judgement can be made.

Another failure mode analysis trend found that the two millimeter ferrule amalgam core groups (both bonded and unbonded) tended to fail more catastrophically than the one millimeter and minimal ferrule groups. This could be associated with increased surface area available for bonding or the additional ferrule transferring more forces to the remaining tooth structure. Nevertheless, the amalgam core with minimal and one millimeter ferrule and the adhesively bonded amalgam core with minimal ferrule resulted in more favorable failure outcomes.

The results of this study compare favorably with those of Biacchi and Basting [18] who reported similar endocrown failure loads and modes of failure. Contrastingly, results of this study are in variance with that of Magne et al [19] and El-Damanhoury et al 2015 [10] who reported endocrown failure loads of 2606 N and 1368 N, respectively. Both of these studies had variant methods and materials as compared to the present study, including nanoceramic materials as well as resin composite cores.

This study is one of the first to report both failure loads and stress involving full coverage restoration displacement. The dentin surface available for bonding was measured in order to calculate failure stress in the anticipation the results of failure load could be normalized due to the vagaries of different specimen size. In view of the results, calculation of failure stress results did result in a different assessment. For instance, failure load results identified the minimal ferrule groups as having the lowest failure values. However, when failure stress was calculated the same minimal ferrule groups were found to have the highest failure resistance. Under the conditions of this study, the calculation of stress resulted in no real differences amongst the groups containing ferrule. The significance and value of calculating failure stress deserves further consideration and study.

The findings of this laboratory study does not entirely support the endocrown concept in terms of increased failure resistance as compared to full coverage restorations supported by amalgam cores. Accordingly, under both failure load and stress analysis there were amalgam core-supported restorations that demonstrated higher resistance to restoration dislodgement than the endocrown. Therefore, the null hypothesis was rejected. Moreover, failure mode analysis found that the endocrown restorations resulted in nearly universal non-restorable, catastrophic failures. The amalgam core groups largely demonstrated similar failure loads as the endocrown-restored group, but displayed more favorable failure modes.

The findings of this in vitro study should be viewed in the context that the failure forces demonstrated during this study were higher than the reported loads that can be generated during normal function by the human dentition. The normal occlusal load in the molar region has been reported to in the range of 100 – 200 N [20] and has been estimated to be as 965 N in situations of accidental occlusal biting and/or trauma. [20-24] This translates into that the minimal mean failure loads experienced under the conditions of this study were at levels almost three times that reported for normal human function and approached the estimated higher limit of accidental/parafunctional human biting force of 1000N. [24,25] The next planned research concerning these restorative scenarios involves fatigue studies with microCT failure mode assessment.

Conclusions:

Lithium disilicate full coverage restorations with amalgam core foundations overall displayed the same resistance to crown displacement as endocrown restorations with a 2mm pulp chamber extension. However, the endocrown restorations displayed almost universal catastrophic failure compared to amalgam core based restorations.

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