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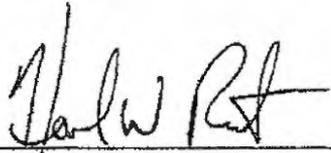
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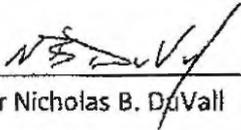
The Effect of Molar Preparation Axial Height on Retention of Adhesively-luted
CAD/CAM Ceramic Crowns

Captain Robert E. Wake

APPROVED:



Colonel Howard W. Roberts



Major Nicholas B. DuVall



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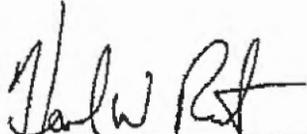
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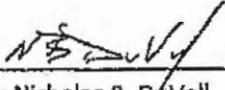
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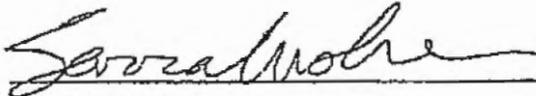
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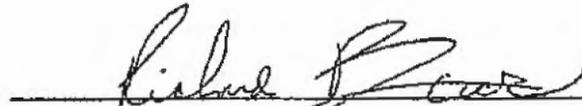
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Abstract

Objective: To analyze the significance of axial wall height in CEREC e.max CAD/CAM crown retention.

Methods: 60 recently extracted third molars were randomly divided into 5 groups for ceramic crown preparations with axial wall heights of zero, one, two, three, and four millimeters (n=12). Specimens were scanned using a CEREC CAD/CAM unit with crowns manufactured using IPS e.max CAD blocks. Proper seating verified, followed by 6% hydrofluoric acid etch, primer application and cementation with RelyX Unicem. Each specimen was then loaded until failure.

Results: 2mm specimens were found to have the greatest resistance to failure while the 0mm specimens had the least.

Conclusions: Under the conditions of this study, maxillary molars restored with IPS e.max CAD crowns have the highest resistance to failure when prepped with a 2mm or 3mm axial wall height. The results of this study may suggest that adhesive technology may possibly compensate for preparation retentive features.

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INTRODUCTION

Tooth preparation for successful fixed prosthodontic restorations has traditionally established parameters that include degrees of taper, minimal preparation reduction recommendations as well as features that provide proper retention and esthetics, with the overall goal of also conserving tooth structure.¹ These guidelines were formulated in the era on non-adhesive and aqueous-based luting cements. These luting agents provided largely macro-mechanical retention by filling the space between the intaglio restoration surface and the prepared tooth surface.² However, with the advent of all-ceramic restorations, adhesively-bonded resin cements are utilized more to provide both micromechanical means as well as chemically adhering the restoration to the prepared tooth surface.³ Adhesive luting agents have been suggested to be able to overcome weaker retentive features.^{4,5,6,7}

Finish lines and occlusal convergence are two preparation elements that the clinician usually has significant control over. A four-millimeter occlusal-cervical (OC) molar preparation height has been traditionally recommended for adequate retention and long term stability.¹ This recommended height, however, is not always achievable and preparations could be less than ideal as crown lengthening may not be a financial, esthetic or functional option. A restorative treatment option which can surmount these challenges is desirable.

Proponents of computer aided design and computer aided manufacturing (CAD/CAM) dentistry have anecdotally claimed that adhesion can overcome some traditional preparation requirements that were based on aqueous-based luting agents. The benefits of these claims include recoupment in time, money and avoidance of unnecessary surgical intervention. The purpose of this study was to determine if adhesion technology can compensate for reduced occlusal-cervical axial wall preparation height in CAD/CAM fabricated

maxillary molars. The null hypothesis was that there would be no difference in the failure strength between preparations of four, three, two, one, and zero axial wall preparation height.

METHODS

Sixty freshly-extracted human maxillary molar teeth were collected from local oral and maxillofacial surgery clinics which had been removed as per routine clinical indications under the 81rst Medical Group Institutional Review Board (IRB) protocol approval.

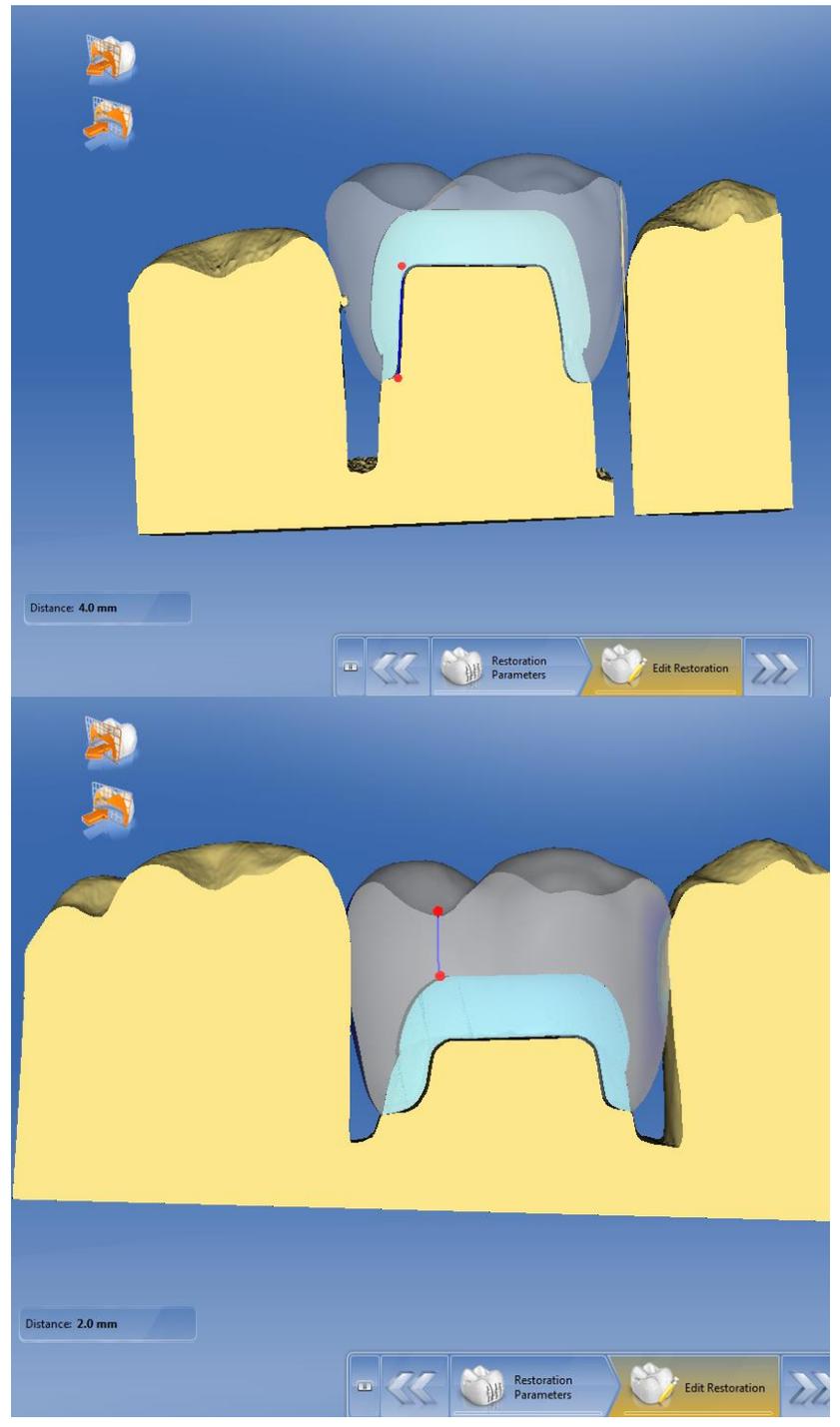
The teeth were randomly grouped and the occlusal surfaces removed to one millimeter below the marginal ridge with a slow-speed, water cooled diamond saw (Buehler, Lake Bluff, IL, USA). The sectioned teeth were then mounted in autopolymerizing denture base methacrylate resin (Diamond D, Keystone Industries, Cherry Hill, NJ, USA). All ceramic crown preparations were prepared following the recommended guidelines (CEREC 3D Preparation Guidelines, Sirona Dental Systems, Charlotte, NC, USA) for CAD/CAM restorations. These guidelines include use of shoulder margins and rounded internal line angles and were accomplished by one operator (HR) 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. Preparation taper was standardized as much as possible with the handpiece placed in a fixed lathe arrangement.

Crown preparations were performed with five groups (n = 12) consisting of occlusal cervical preparation wall heights of four, three, two, one, and zero millimeters. To facilitate correct placement of restorations, the group with no OC axial wall heights had a facial-lingual groove the approximate width and half-depth of a #8 round bur placed. The orientation of this feature was in the same direction as the loading force so as to present a negligible impediment

to dislodging forces. All final preparations were reviewed and margins refined by a board-certified prosthodontist. All specimens then had both interproximal and facial-lingual OC preparation convergence measured as well as preparation surface area using a digital measuring microscope (KH-1300, Hirox USA, Hackensack, NJ, USA).

The prepared tooth specimens were restored by one operator (RW) using a CAD/CAM acquisition device (CEREC AC/CEREC MC XL, Sirona Dental Systems, Charlotte, NC, USA, Software version 4.2.4.72301) according to manufacturer instructions and/or recommendations. All specimens were scanned using a standardized template to simulate clinical conditions. The occlusal table was replicated for all specimens and was used to maintain the same restoration minimum height of 6mm for all restorations with a minimum occlusal thickness of 2mm (Figure 1). The design of each restoration was then completed to ensure proper contours and adequate restoration thickness following manufacturer and/or material recommendations (CEREC 3D Preparation Guidelines, Sirona Dental Systems, Charlotte, NC, USA). The restorations were milled from a lithium disilicate ceramic restorative material (e.max CAD, Ivoclar-Vivadent, Amherst, NY, USA). Upon milling, the restorations were given 2 coats of glaze (IPS e.max CAD Crystall/Glaze spray, Ivoclar-Vivadent) and then crystallized following manufacturer protocol in a dental laboratory ceramic furnace (Programat P700, Ivoclar-Vivadent).

Figure 1. 2mm Occlusal Thickness For 4mm OC Preparation; 4mm Occlusal Thickness For 2mm OC Preparation

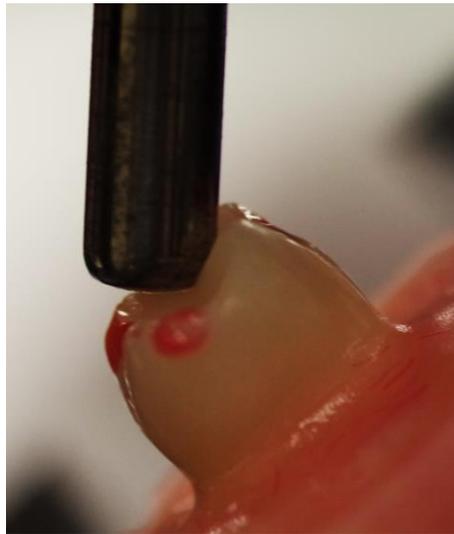


The milled restorations were adjusted and seated for each prepared tooth using a disclosing agent (Occlude, Pascal International, Bellevue, WA, USA). The restoration's intaglio surface was steam cleaned, dried and then prepared with a 5% hydrofluoric acid etch (IPS Ceramic Etching Gel, Ivoclar-Vivadent) for 20 seconds, rinsed with water spray, and dried with oil-free compressed air. A coat of silane agent was applied to the etched ceramic intaglio surface (Monobond Plus, Ivoclar-Vivadent) using a monobrush following manufacturer instructions.

After 60 seconds of reaction time, the silane agent was air-dried using oil-free compressed air. The tooth surface was prepared for cementation by cleaning with a pumice and water slurry, rinsed, and dried using oil-free compressed air. A self-adhesive resin cement (RelyX Unicem, 3M ESPE, St. Paul, MN, USA) was placed into the intaglio surface of the ceramic restoration. The restoration was then seated onto the tooth using digital finger pressure of approximately two pounds of seating pressure verified by a calibrated weight. Restorations were flash cured for 1 second (Bluphase LCU 1,200 mW/cm² Ivoclar-Vivadent), excess cement was removed, further light curing ensued for a total of 60 seconds. The completed specimens were stored under dark conditions at 37 ± 1 °C and 98 ± 1% humidity.

Twenty four hours after cementation each specimen was placed into a vise fixture on a universal testing machine (RT-5, MTS Corporation, Eden Prairie, MN, USA) with the long axis of the tooth at a 45-degree angle to the testing fixture (Figure 2).

Figure 2. Sample Testing Configuration



The palatal cusp was loaded with a three millimeter diameter hardened, stainless steel piston with a 0.5 meter radius of curvature as described by Kelly *et al.*⁸ Specimens were loaded at a rate of 0.5 millimeter per minute until failure with the failure load recorded in Newtons and a resultant failure stress calculated based on preparation surface area. Failure mode for each specimen was determined by visual examination under 20X magnification (KH-1300, Hirox USA) to determine if the failure was cohesive for the lithium disilicate ceramic, adhesive failure between the ceramic and the tooth structure, or fracture of the tooth material, as well as mixed failures. Failed specimens were also evaluated using microtomography (MicroCT) (Skyscan 1172, Bruker MicroCT, Kontich, Belgium) at a resolution of 13.6 microns using 100kV energy with a 0.4-degree step size. Individual images were combined into a 3D image using recombination software (nRecon, Bruker MicroCT) and analyzed with a volume-rendering 3D software (CTVox, Bruker MicroCT).

The Shapiro-Wilk Test and Bartlett's Test ascertained the normal distribution and homogenous variance of the mean failure load and calculated stress data. Analysis of variance (ANOVA) and Tukey's *post hoc* test was performed with a computer-based program (SPSS 20, IBM SPSS, Chicago, IL, USA) with a 95 percent level of confidence ($p = 0.05$).

RESULTS

Mean Preparation Wall Height (mm)	Failure Load (N)	Failure Stress (MPa)
0	291.1 (124.0) A	3.50 (1.4) A
1	735.1 (310.9) B	6.78 (2.6) B
2	1170.0 (297.6) C	10.33 (3.2) C
3	1253.4 (210.0) C	9.01 (2.4) BC
4	996.2 (424.1) BC	6.85 (1.92) B

n = 12

Groups identified with same capital letter are similar within each column (Tukey, $p = 0.05$)

Failure load and stress results are listed in Table 1. The 2mm OC axial wall height specimens were found to have the greatest failure stress resistance that was statistically similar to the 3mm specimens. The failure stress of the four, three, and one millimeter OC axial wall height groups were also similar, while the zero millimeter OC axial wall height demonstrated the least resistance to failure stress.

Table 2. Failure Mode Analysis

Occlusogingival Axial Wall Height	0 mm	1 mm	2 mm	3 mm	4mm
Failure Mode					
Cohesive Ceramic	0	5	3	1	2
Adhesive Crown/Tooth	12	6	5	3	0
Tooth/Crown Fracture	0	1	4	4	3
Root Fracture/Crown Intact	0	0	0	4	7

n = 12

Failure mode analysis can be seen in Table 2. All of the zero millimeter OC axial wall height preparations failed adhesively between the restoration and tooth surface. Numerically, the one millimeter group demonstrated the highest number of cohesive ceramic fractures which was followed by the two millimeter axial wall height group. Tooth fractures not involving the preparation and/or restoration were more numerous in the three and four millimeter axial wall height groups.

DISCUSSION

For full coverage indirect restorations, retention and resistance form is determined by a combination of preparation taper, surface area, and axial wall height.^{1,9,10,11} For the full-coverage traditional restoration of molars, Goodacre *et al.* recommends a minimum of four millimeters OC axial wall height within the recommended 10 to 20 degrees total occlusal convergence.^{9,10}

Tooth preparation for CAD/CAM restorations differs significantly from traditional tooth preparation. With traditional metal substructure crowns the addition of secondary factors, such as boxes and grooves, has been shown to increase retention and resistance form to compensate

for insufficient preparation height and taper. However, CAD/CAM restoration features can be limited in design due to limitations of the milling unit as well as the dimensions of the milling burs to incorporate minute details.

Anecdotally, proponents of CAD/CAM dentistry promote that adhesive technology compensates for traditional preparation features required for aqueous-based cements. Accordingly, this current study attempted to evaluate that if the adhesion involved with all-ceramic CAD/CAM restorations could compensate for OC axial wall height using a standardized OC total convergence angle. This could be of an advantage clinically where tooth structure has been compromised due to disease and other processes which might alleviate the need for additional endodontic and periodontal procedures.

Specimens were prepared in a standardization device using a high-speed handpiece with water cooling spray as in the clinical situation. Prepared tooth surfaces were evaluated at 20x magnification with a digital measuring microscope that allowed the determination of surface area (Figures 3 and 4) as well as for OC convergence (Figure 5). The total preparation convergence was determined by taking the mean of the four convergence measurements (facial/lingual, mesial/distal).

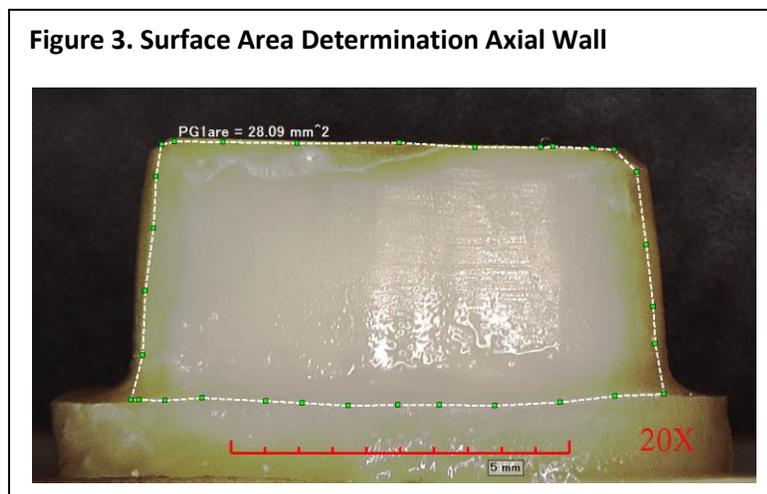


Figure 4. Occlusal Table and Margin Surface Area Determination

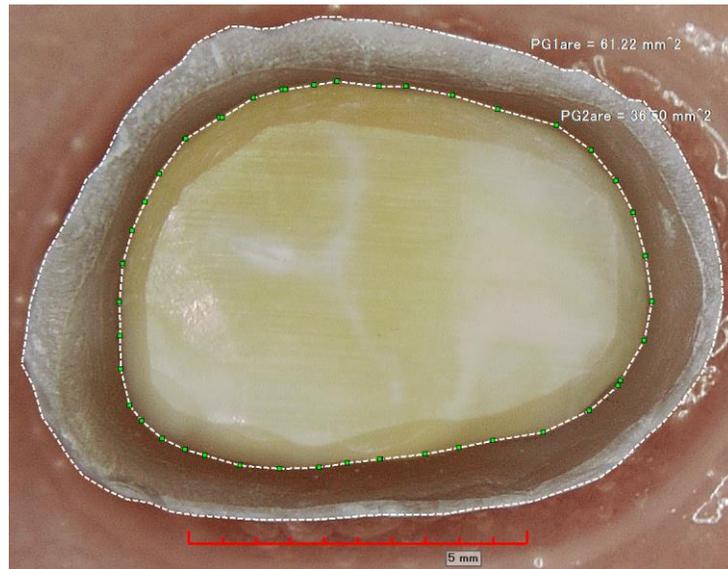


Figure 5. Occlusogingival Convergence Determination

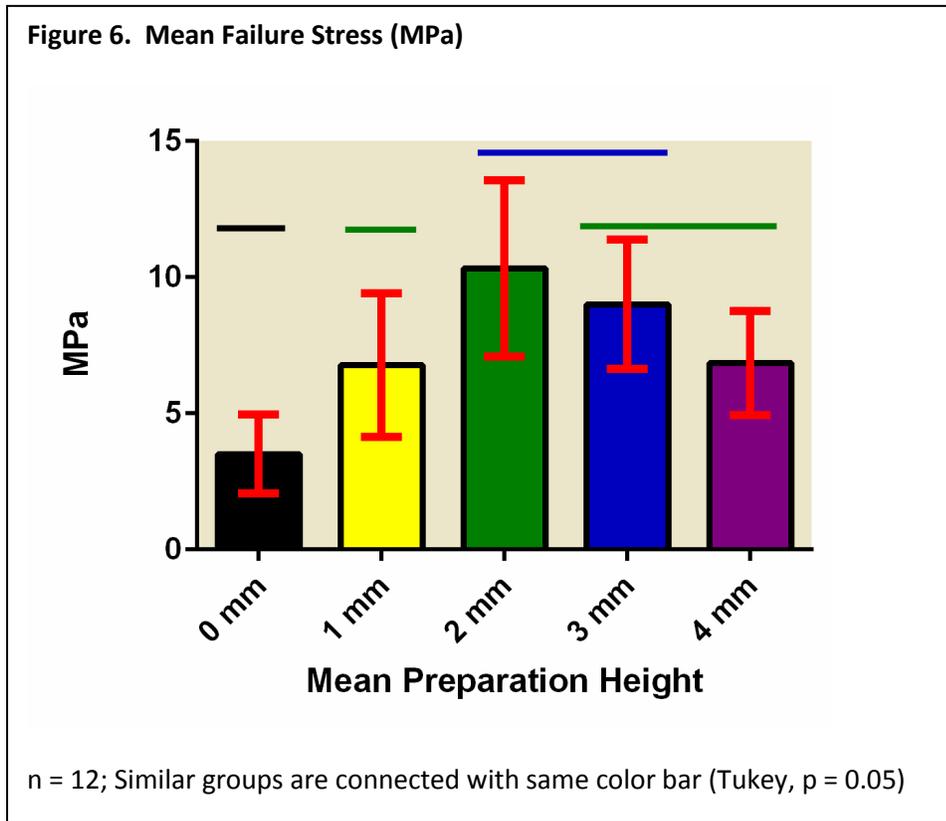


Table 3. Mean Tooth Preparation Parameters

Group (axial wall height)	Axial wall height (mm)	Total Occlusogingival Convergence (°)	Surface area (mm ²)
0mm			85.1 (6.9)
1mm	1.2 (0.07)	10.1 (0.7)	107.8 (15.7)
2mm	2.1 (0.09)	9.2 (1.5)	116.0 (16.0)
3mm	3.2 (0.1)	9.6 (0.7)	143.6 (20.5)
4mm	4.1 (0.07)	9.6 (1.1)	164.82 (10.7)

n = 12

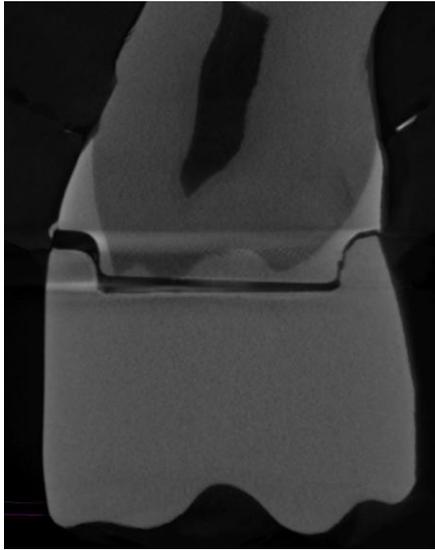
The mean measured parameters for the five groups are listed in Table 3. Under the conditions of this study, OC convergence was standardized at ten degrees. The surface area determination allowed failure stress calculation, which the authors feel such compensates better for different tooth specimen size during testing.



The graphical results of the mean failure stress is shown in Figure 6. Furthermore, this study simulated the clinical situation of reduced preparation features with a stable occlusal table height. Accordingly, the same occlusal table height mandated that the occlusal surface thickness increased as the OC axial wall height decreased. Thus, if the occlusal thickness of the e.max CAD material was to be a determining factor of ceramic cohesive fracture, it would be anticipated that the three- and four-millimeter axial wall height groups would represent the most cohesive ceramic failures. However, this was not observed under the conditions of this study. Contrastingly, the restorations with the thickest occlusal ceramic (one millimeter group) demonstrated the highest number of cohesive ceramic fractures. These findings may indicate interactions between the adhesive cement and the ceramic material that deserves further investigation.

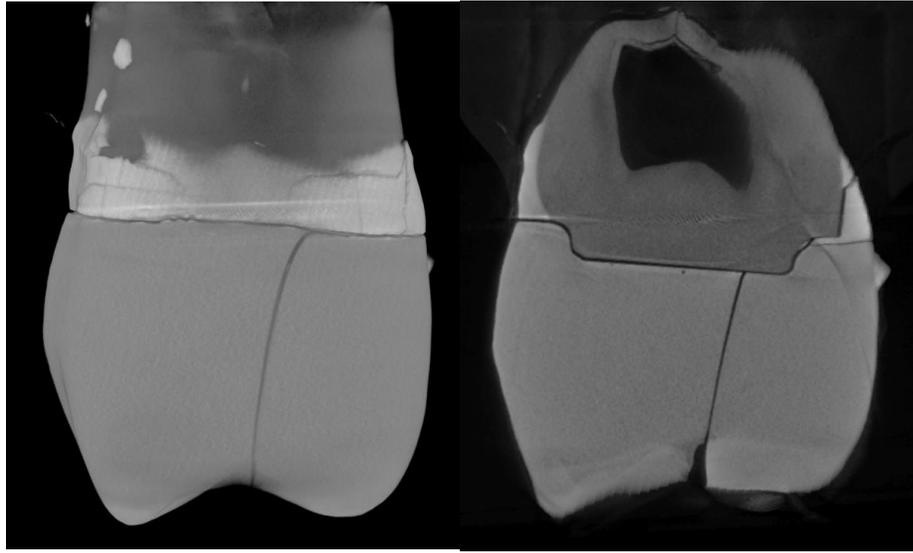
All of the preparations with zero axial wall height failed adhesively between the ceramic crown and the tooth material. For the one millimeter axial wall height group, half of the specimens failed adhesively between the crown material and tooth (Figure 7).

**Figure 7. MicroCT Slice Image
Adhesive Failure**



The remainder failed via cohesive fracture of the lithium disilicate crown without damage to the tooth, except for one sample that demonstrated both crown and tooth fracture—that except for surface enamel crazing, was detected only with MicroCT analysis (Figure 8). The reason for these failures could be due to increased lever arm for 5mm of restorative material. This in combination with the opposing forces from adhesion to the tooth resulted in cohesive failures.

Figure 8. Combination Crown/Tooth Fracture MicroCT Slice Image



The number of purely cohesive ceramic failures decreased with increasing axial wall height. The three and four millimeter axial wall height groups demonstrated more catastrophic crown / root fractures, of which MicroCT examples are illustrated in Figures 9-11.

Figure 9. Three Millimeter Axial Wall Height Failure

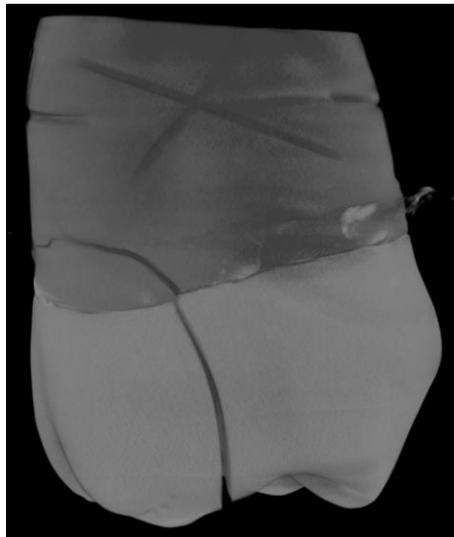
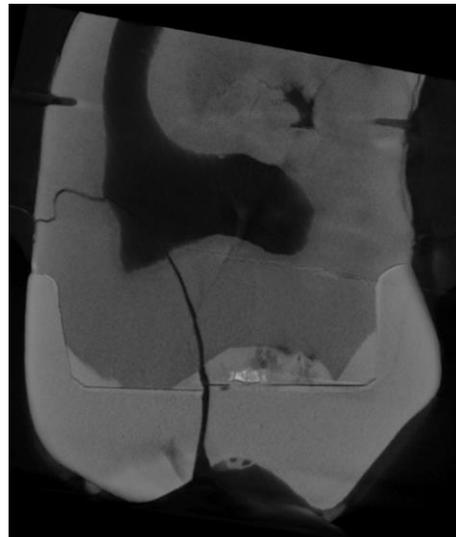
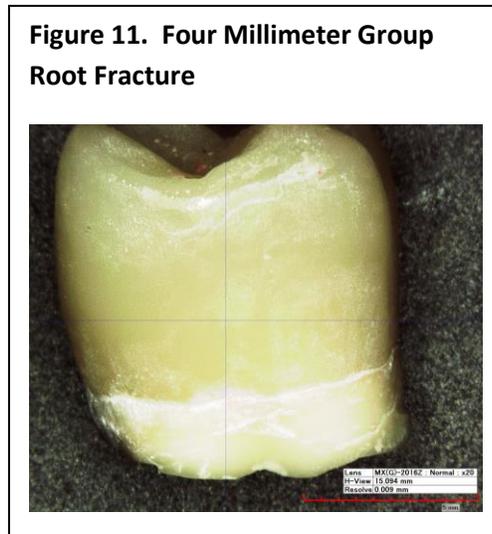


Figure 10. Four Millimeter Axial Wall Height Failure



Furthermore, over half of the four millimeter axial wall height specimens experienced root fracture that was apical to the crown margins.



This may account for the lower failure stresses observed with the three- and four millimeter axial wall height groups; the true adhesive nature of the ceramic-luting agent-tooth bond could not be evaluated before the tooth itself experienced cohesive failure.

The normal occlusal load in the molar region has been reported to be near the range of 100–200 N¹² and has been estimated as high as 965 N in situations of accidental occlusal biting and/or trauma.¹²⁻¹⁸ Accordingly, a fracture resistance greater than 1000 N has been recommended for good clinical performance.¹⁹ It should be observed that all preparations/restorations with axial wall height of one millimeter and greater failed at loads higher than that reported for the normal range.

The methods and materials of this study are somewhat unique and not many studies that correlate with these results are reported in the dental literature. A separate in vitro study found preparations of four-millimeter zirconia copings to have failure strengths of 5.0-6.0 MPa.

²⁰ However, the conditions of this study contrast with that of Marocho *et al.*²¹ for the zero

millimeter OC axial wall height group. Yet that study involved a micro-tensile bond strength study of individual specimens rather than the full occlusal surface of which this study reported. To the authors' knowledge, this is the first study comparing OC height on prepared molars all scanned and using the same biogeneric copy preserving a consistent occlusal table across all specimens.

CONCLUSIONS

Under the conditions of this study, maxillary molars restored with IPS e.max CAD crowns have the highest resistance to failure when prepped with a 2mm or 3mm axial wall height and 4mm or 3mm of occlusal restorative material thickness respectively. The true adhesion of molars with 4mm axial wall height could not be fully evaluated, as the majority of specimens suffered catastrophic root fracture before the adhesively-luted ceramic crown failed. The situation of reduced OC axial preparation heights with matching occlusal thickness is the subject for future studies.

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