Axial Wall Height Effect on Adhesively Luted Ceramic Crown Failure on Preparations Containing Advanced Total Occlusal Convergence

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Abstract

Objective: To analyze the axial wall height (AWH) significance in adhesively-luted CAD/CAM crowns on preparations containing a 20 degree total occlusal convergence (TOC).

Methods: 60 recently-extracted maxillary third molars were randomly divided into 5 groups (n=12) and prepared for CAD/CAM ceramic crowns with a 20-degree TOC with AWH of 0,1,2,3, and 4mm. Scanned preparations (CEREC) were restored with full-coverage lithium desilicated restorations and luted with a self-adhesive resin luting agent after hydrofluoric acid etching and silanation. All manufacturer recommendations were followed. Stored specimens (37C/98% humidity) were tested to failure (0.5mm/min) after 24hrs on a universal testing machine with load applied to the palatal cusp at 45 degrees to the root long axis. Failure load was converted to MPa using the bonding surface area with the mean data analyzed using Kruskal-Wallis/Dunn's (p=0.05). Failure mode was analyzed for all specimens.

Results: Preparations containing two, three and four millimeters of AWH demonstrated a greater failure load resistance to dislodgement when compared to zero and one millimeter AWH groups, which was similar to calculated failure stress results.

Conclusions:

Under the conditions of this study, maxillary molar preparations with a 20° OC convergence restored with adhesively-luted lithium disilicate CAD/CAM full coverage restorations require at least 2mm of AWH for adequate resistance to dislodgment. This study provides some evidence that adhesion technology may compensate less than optimal preparation features.

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INTRODUCTION

Recommendations that include occlusal reduction, total occlusal convergence (TOC) and recommended axial wall height (AWH) have been established for full coverage preparations to optimize clinical success. The achievement of these guidelines, however, is largely dependent on the remaining tooth structure. Historically, molar occlusal-cervical height of four millimeters is recommended in order to allow stability and retention with a TOC (total occlusal convergence) ranging between 2-12 degrees. [1-4]. These recommendations were developed in the era of aqueous-based luting agents before the advent of adhesively-luted, all ceramic restorations. Furthermore, studies have shown that molar axial wall heights of four millimeters may not always be clinically achievable, and TOC between 2-12 degrees cannot consistently be produced, rather garnering a TOC consistently above 20 degrees. [1-4] Traditional preparation recommendations have been questioned by some clinicians in the current era of adhesive technology. These questions have not changed traditional parameters; however shifted attention more towards adhesive bonded resin cements as well as greater available surface area in which to bond to. [6,7] The avocation for the use of computer aided design and computer aided manufacturing (CAD/CAM) ceramic restorations with resin bonding may offer alterations to assist in the gap between ideal and actual full coverage restoration preparations. The purpose of this study was to evaluate if CAD/CAM adhesive technology may compensate for a reduced occlusal-cervical (OC) molar AWH of four, three, two, and one millimeters containing a 20 degree TOC. The null hypothesis was there would be no difference in failure load and stress between any of the groups with different preparations features.

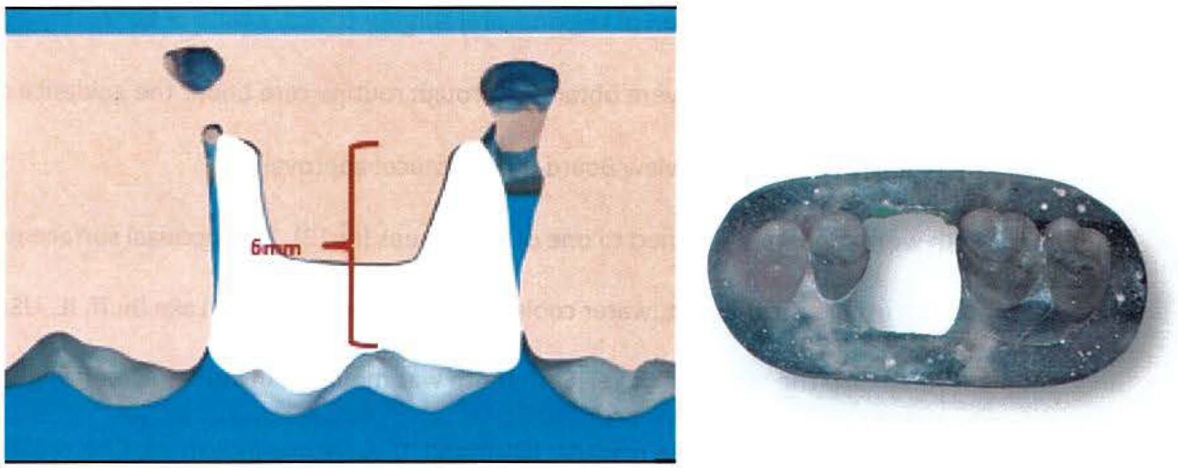
METHODS

Through a collective combination of regional oral surgery clinics, a total of 60 freshly extracted human maxillary third molars were obtained through routine care under the guidance of the 81st Medical Group Institutional Review Board (IRB) protocol approval.

The teeth were randomly assigned to one of five groups (n=12). The occlusal surface was reduced flat using a slow-speed, water cooled diamond saw (Buehler, Lake Bluff, IL, USA) at a depth 1mm below the marginal ridge. Each tooth was mounted in auto polymerizing methacrylate resin denture base material (Diamond, D, Keystone industries, Cherry Hill, NJ, USA). Each specimen was prepared following recommended lithium disilicate guidelines for CAD/CAM restorations (CEREC 3D Preparation Guidelines, Sirona Dental Systems, Charlotte, NC, USA) by a single operator using diamond burs (8845KR.31.025, Brassler USAA, Savannah, GA, USA) and high-speed electric dental handpiece (EA-51LT, Adec Newburg, OR USA) with copious water spray. Finish lines were standardized at a level 1mm above cervical enamel junction (CEJ) with the overall OC axial wall height achieved by further occlusal reduction. Twenty degree TOC standardization was obtained by using a fixed lathe device. To allow for correct placement, the zero millimeter AWH group was additionally prepared with a facial-lingual groove using the half depth of a #8 round carbide bur. This groove was placed parallel to the planned loading force vectors in order to minimally affect dislodging forces. All specimens were examined and refined by board-certified specialist with preparation features confirmed and recorded with a digital microscope (KH-4400, Hirox USA, Hackensack, NJ, USA).

Preparation scans were obtained utilizing a CEREC Omni Cam acquisition unit (CEREC® AC/CEREC MC XL, Sirona Dental Systems, Charlotte, NC, USA) and using standardized resin template (Figure 1). The occlusal table and anatomy were standardized for each preparation (Figure 1).

Figure 1. 2mm Occlusal Thickness for 4mm OC Preparation; Resin Template

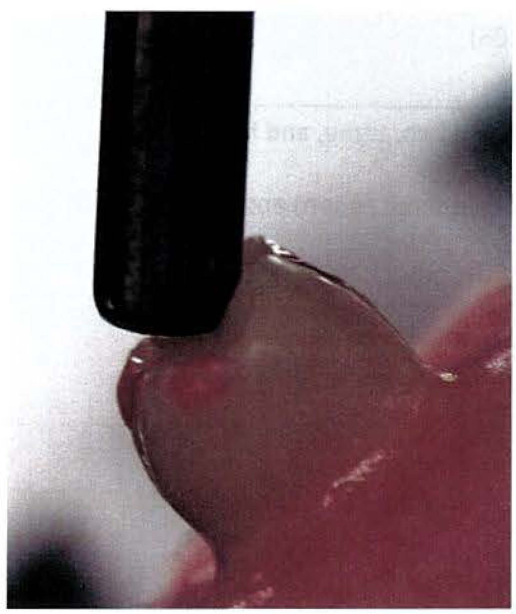


Restoration features were accomplished by a single operator with contours, anatomy and material thickness verified with manufacture's recommendations. All sixty restorations were milled from lithium disilicate ceramic blocks (e.max® CAD, Ivoclar-Vivadent, Amherst, NY, USA). After milling two coats of glaze material (IPS e.max® CAD Crystall/Glaze spray, Ivoclar-Vivadent) were applied to each restoration and crystallized in a ceramic furnace (Programat P700, Ivoclar-Vivadent) following manufacturer's instructions. After crystallization each restoration was adjusted to confirm complete seating and readied for final cementation.

Specimen tooth surfaces were prepared for cementation using pumice/water slurry cleaning, rinsed and air dried. Intaglio surfaces of each restoration were steam cleaned, treated with 5% hydrofluoric acid etch (IPS® Ceramic Etching Gel, Ivoclar-Vivadent) for a total of 20 seconds, rinsed and dried. The recently etched intaglio surface was then coated for 60 seconds with a silane agent (Clearfil™ Ceramic Primer Plus) following manufacturer's instructions and then air-dried. A dual-cure self-adhesive resin cement (Rely-X™ Unicem, 3M ESPE, St. Paul, MN, USA) was prepared and placed into the intaglio surface followed by complete seating using digital finger pressure. Excess cement was removed with a microbrush and tack cured using a light emitting diode (LED) (Bluphase G2, Ivoclar-Vivadent) for approximately 2 seconds on facial and lingual surface. Remaining excess cement was then removed and followed by a final cure of 20 seconds completed for the buccal, lingual and occlusal surfaces to simulate a clinical environment. Specimens were then stored under dark conditions at 37 ± 1 °C and 98 ± 1% relative humidity.

After 24 hours specimens were tested using a universal testing machine (RT-5, MTS Corporation, Eden Prairie, MN, USA) at a 45-degree angle to long axis of the tooth. Following recommendations from Kelly *et al*[6], the palatal cusp was loaded by a stainless steel piston at a rate of 0.5 millimeters/minute until failure (Figure 2) with corresponding failure results recorded in Newtons (N).

Figure 2. Sample Testing Configuration



Failure stress MPa was calculated using the available bonding surface area. Mean data was first analyzed using Shapiro-Wilk/Bartlett's Test to asses normal distribution and homogeneity of variance. The data was found to be not normally distributed therefore a non-parametric Kruskal-Wallis/Dunn's (p=0.05) tests was utilized at a 95% confidence level (p=0.05). Failure mode analysis was determined at 20x magnification (KH-4400, Hirox USA) at 20x and micro tomography (Skyscan 1172, Bruker Micro CT, Kontich, Belgium).

RESULTS

Mean results are displayed in Table 1.

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

Axial Wall Height	Failure Load (N)	Failure Stress (MPa)
0 mm	129.5 (97.6) A	1.9 (1.6) A
1 mm	174.3 (74.0) A	1.6 (0.7) A
2 mm	474.7 (207.1) B	4.2 (1.4) B
3 mm	798.8 (371.4) B	7.2 (2.6) B
4 mm	862.9 (360.0) B	6.4 (2.1) B

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

Preparations containing two, three, and four millimeters of AWH demonstrated a significantly greater failure load compared to zero and one millimeter groups, which was identical for the failure stress results.

Failure Mode Analysis displayed in Table 2.

Table 2. Failure Mode Analysis

Axial Wall Height	Failure Mode			
	Adhesive	Catastrophic Fracture Tooth/Restoration Complex	Cohesive Root Fracture	Cohesive Ceramic Fracture
0 mm	12	0	0	0
1 mm	12	0	0	0
2 mm	12	0	0	0
3 mm	7	4	0	1
4 mm	7	4	0	1

n = 12

Failure mode analysis was performed both visually at 20x magnification and by Micro CT imaging. Failure modes included adhesive failure, catastrophic fracture, cohesive root fracture and cohesive ceramic fracture. Accordingly, adhesive failure occurred between the tooth/cement or cement/restoration interface. A catastrophic failure involved the tooth/restoration complex and a cohesive root fracture referred to a failure of the root surface apical to the marginal finish line. Finally, cohesive ceramic failure identified that the failure remained confined within the ceramic restorative material. All of the preparations with zero thru two millimeter AWH exhibited adhesive failures exclusively. However, the three and four millimeter axial wall height groups demonstrated equivalent failure modes as to adhesive, catastrophic as well as cohesive ceramic failures.

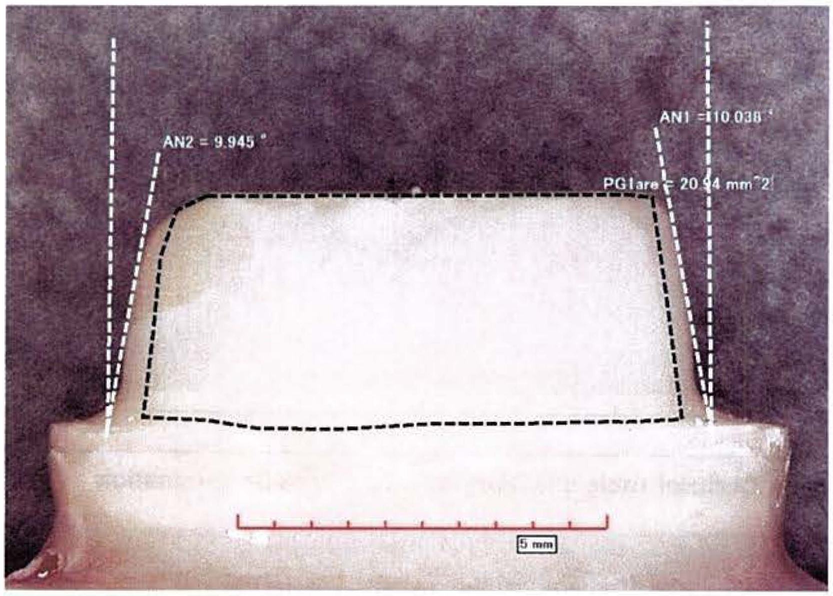
DISCUSSION

Retention may be defined as the feature of a tooth preparation that resists dislodgement of a crown in a vertical direction or along the path of placement, while resistance refers to tooth preparation features that enhance restoration stability and resists dislodgement along an axis other than the path of insertion. Both resistance and retention form are determined and influenced by preparation features that include axial wall height, total occlusal convergence, and overall surface area.[3,4,7] Molar preparation guidelines traditionally have included a 4mm axial wall height minimum, total occlusal convergence between 10 and 20 degrees, and an occlusal-cervical/facial-lingual ratio of 0.4 or greater.[4,7] However, these parameters may not always be achievable, for instance, Parker *et al* found only 46% of molars presented with 0.4 or greater occlusal-cervical/facial-lingual ratios while Tiu *et al* found total occlusal convergence ranged from 23-78% of cases submitted to dental laboratories.[8-10]

Clinical situations do not always lend themselves to produce preparations that meet traditional guidelines. CAD/CAM technology may provide additional options for the restoration of teeth with less than ideal preparations. As CAD/CAM preparation guidelines, however, largely differ from the traditional preparations featuring rounded line angles and rounded shoulder margins. However, additional features may be limited by limitations of milling devices.

The aim of this current study was to evaluate if adhesive dentistry and ceramic CAD/CAM restorations have on the potential to compensate for less than ideal preparation features.

Figure 3. Occlusogingival Convergence Determination



Total occlusal convergence was determined by mesio-distal and facial-lingual measurements (Figure 3). To ensure standardization amongst groups with respect to TOC, a lathe device with a fixed electric high-speed handpiece was used for preparations followed by careful examination at 20x magnification with digital microscope, which in addition allowed for the calculation of surface area (Figure 4 and Figure 5).

Figure 4. Surface Area Determination Axial Wall

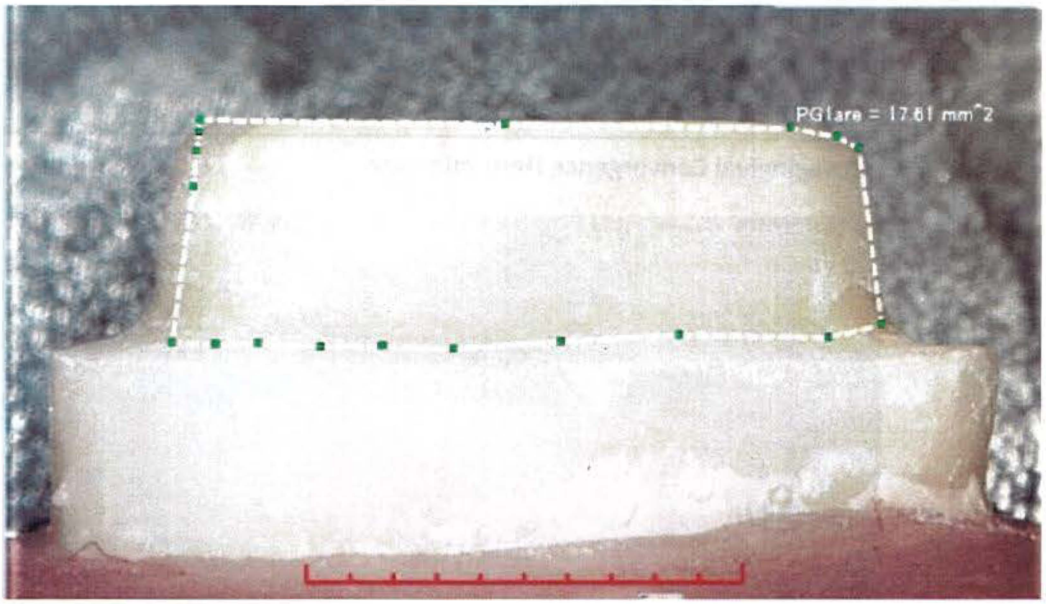
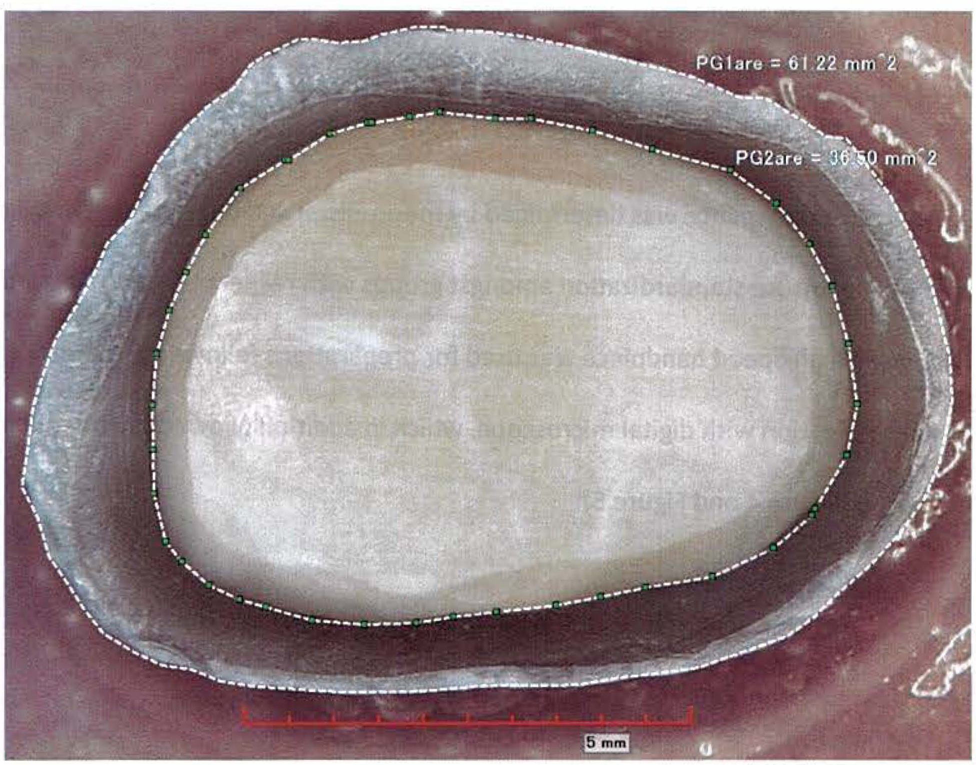


Figure 5. Occlusal Table and Margin Surface Area Determination



The surface area data was obtained to both ensure preparation uniformity as well as the calculation of failure stress. This calculation is important as it may provide compensation due to variations in tooth sizes. Mean tooth parameters can be seen in Table 3. Failure stress calculation was analyzed to evaluate any normalizing effect to failure load disparities that could be caused by difference in tooth size.

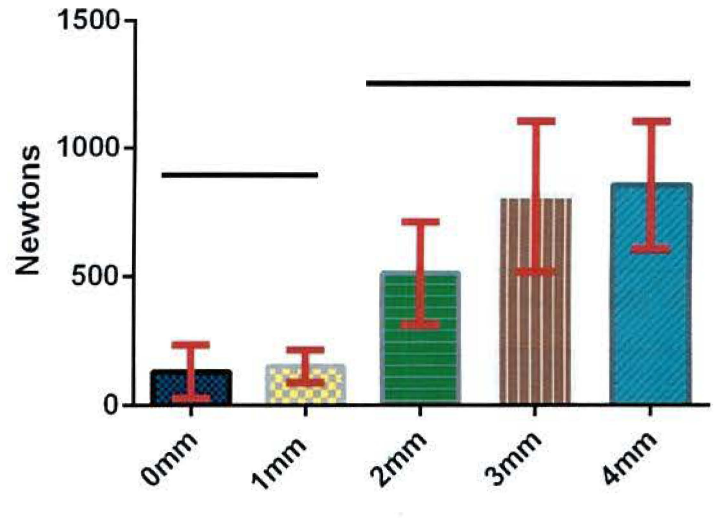
Table 3. Mean Tooth Preparation Parameters

Group Axial Wall Height	Axial Wall Height (mm)	Total Occlusal Convergence (°)	Dentin Surface Area (mm^2)
0 mm			86.8 (17.1)
1 mm	1.05 (0.03)	16.8 (0.5)	95.6 (9.9)
2 mm	2.04 (0.02)	16.5 (0.4)	117.8 (15.1)
3 mm	3.08 (0.04)	16.3 (0.7)	136.5 (12.3)
4 mm	4.04 (0.03)	16.3 (0.3)	169.4 (18.9)

n = 12

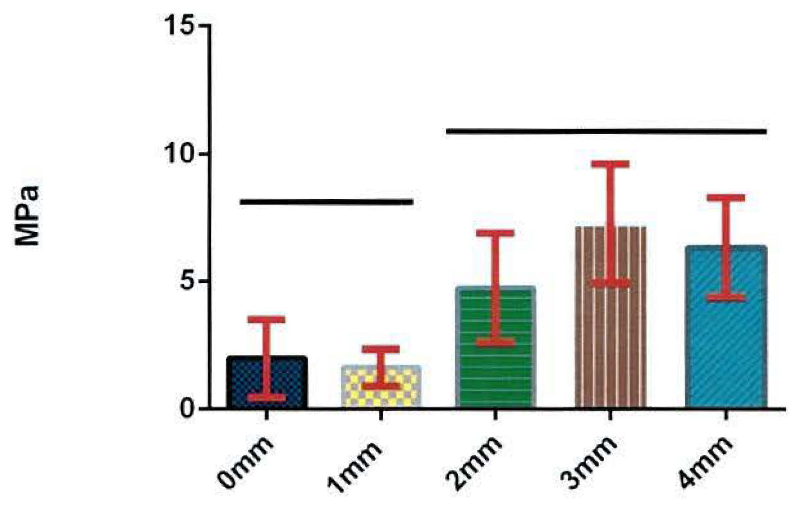
The bar graphs below (Figure 6 and Figure 7) represent mean failure load and stress respectively. The null hypothesis that there would be no difference in failure stress and failure load between the 5 groups of varying axial wall heights was rejected. However, failure stress calculation revealed no discernable normalizing effect, which may be limited by the chosen sample size.

Figure 6. Mean Failure Load (N)



n = 12; Similar groups are connected with same color bar (Dunn's, p = 0.05)

Figure 7. Mean Failure Stress (MPa)



n = 12; Similar groups are connected with same color bar (Dunn's, p = 0.05)

To fully appreciate the failure results, a review of human functional molar occlusal load is warranted. Molar region occlusal loads ranging from 100-200 Newtons may be considered normal with parafunction and certain traumatic situations approaching 1000 Newtons.[11-14] Interestingly, the results of this study showed all groups failed at applied loads less than that expected for parafunction with AWH groups of two, three, and four millimeters failing above that considered for normal load range. Before definitive guidelines can be made, it is imperative that these initial static load results be reassessed by fatigue load studies.

For the purpose of this study, one of four failure modes were assigned to each tested specimen at the conclusion of testing. These modes include; (1) adhesive (Figure 8) where failure occurred in the cement layer between tooth and restoration; (2) catastrophic failure involving both tooth and restoration deeming the tooth non-restorable (Figure 9 and 10); (3) cohesive ceramic fracture in which the fracture remained isolated to the restorative material; (4) cohesive root fracture. The zero and one millimeter groups, which were statistically similar with regards to failure load and stress, all failed adhesively. While the two, three, and four millimeter AWH groups exhibited similar failure load and stress results, failure mode between the groups was observed to vary. The two millimeter AWH group failed exclusively adhesively, while the three and four millimeter groups failing identically with the other three failure modes.

Figure 8. 20x Microscopic Image of Adhesive Debond in a Three Millimeter Sample

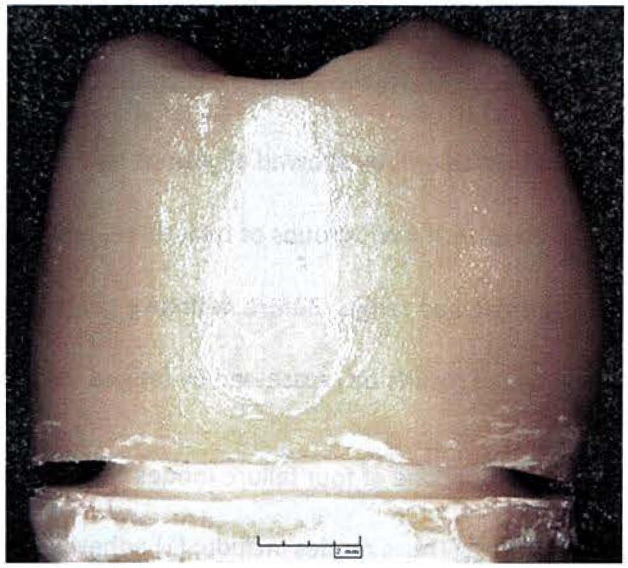


Figure 9. 20x Microscopic image of Catastrophic Failure in a Three Millimeter Sample

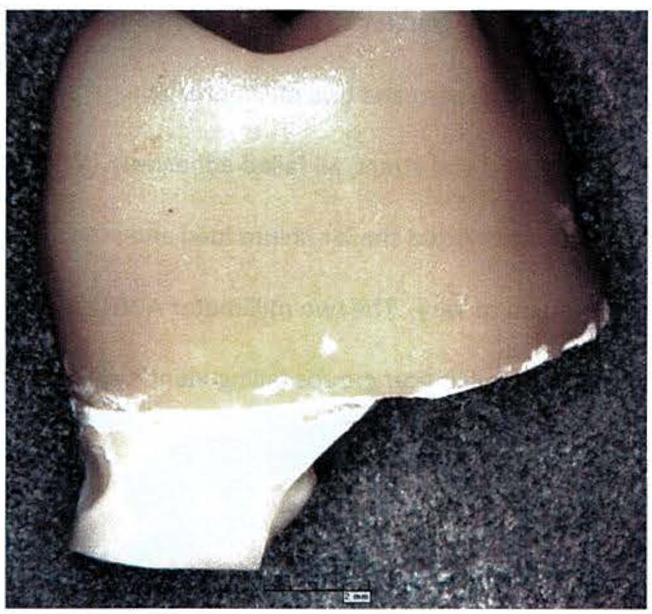
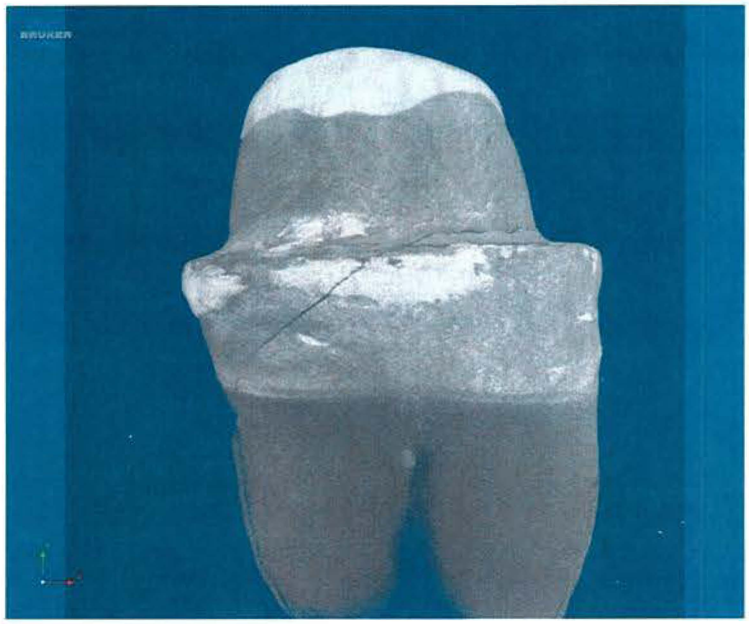


Figure 10. Micro CT image of Catastrophic Failure in Three Millimeter sample



Under the design of this study a stable occlusal table was maintained which required occlusal thickness to be reduced as axial wall height was increased. Although force vectors were not standardized, only two cohesive ceramic fractures were noted in the groups with thinner occlusal ceramic thickness

The overall results of this study may provide some evidence that CAD/CAM adhesive dentistry may compensate for less than ideal preparation features. Based on the limitations of this study, maxillary molar preparations require a minimum of 2 millimeters of AWH when using adhesive CAD/CAM technology.

CONCLUSIONS

Under the conditions of this study, some evidence is provided suggesting that CAD/CAM adhesive technology may compensate for less than ideal preparation features.

REFERENCES

1. Ayad MF, Johnston WM, Rosenstiel SF. Influence of tooth preparation taper and cement type on recementation strength of complete metal crowns. J Prosthet Dent 2009; 102:354-361.

2. Bowley JF, Kieser J. Axial-wall inclination angle and vertical height interactions in molar full crown preparations. J Dent 2007; 35:117-123.

3. Gilboe DB, Teteruck WR. Fundamentals of extracoronal tooth preparation. Part I. Retention and resistance form. J Prosthet Dent 2005; 94:105-107.

4. Goodacre CJ. Designing tooth preparations for optimal success. Dent Clin N. Am 2004; 48:359-385.

5. Simon JF, de Rijk WG, Hill J, Hill N. Tensile bond strength of ceramic crowns to dentin using resin cements. Int J Computer Dent 2011; 14 (4) 309-19.

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

7. Goodacre C, Campagni W, Auilino S. Tooth preparations for complete crowns: An art form based on scientific principles. J Prosthet Dent. 2001; 85:363-76.

8. Parker MH, Malone KH, Trier AC, Striano TS. Evaluation of resistance form for prepared teeth. J Prosthet Dent. 1991; 66:730–3.

9. Tiu J, Al-Amleh B, Waddell N, Duncan WJ. Reporting numeric values of complete crowns. Part 1: Clinical preparation parameters. J Prosthet Dent 2015; 114:67-74.

10. Tiu J, Al-Amleh B, Waddell N, Duncan WJ. Reporting numeric values of complete crowns. Part 2: Retention and resistance theories. J Prosthet Dent 2015; 114:75-80.

11. Chen C, Trindade FZ, de Jager N, Kleverlaan C, Feilzer AJ. The fracture resistance of a CAD/CAM Resin Nano Ceramic (RNC) and a CAD ceramic at different thicknesses. Dent Mater 2014; 30:954-962.
12. Gibbs CH, Mahan PE, Mauderli A, Lundeen HC, Walsh EK. Limits of human bite strength. J Prosthet Dent 1986; 56:226-9.
13. Gibbs CH, Mahan PE, Lundeen HC, Brehnan K, Walsh EK, Sinkewiz SL, et al. Occlusal forces during chewing - influences of biting strength and food consistency. J Prosthet Dent 1981; 46:561-7.
14. Puschmann D, Wolfart S, Ludwig K, Kern M. Load-bearing capacity of all-ceramic posterior inlay-retained fixed dental prostheses. Eu J of Oral Sc 2009; 117:312-8.