©Operative Dentistry, 2016, **41-6**, 666-671

Premolar Axial Wall Height Effect on CAD/CAM Crown Retention

C Gillette • R Buck • N DuVall • S Cushen • M Wajdowicz • H Roberts

Clinical Relevance

Although not applicable for all clinical situations, CAD/CAM adhesive technology may compensate for shorter occlusogingival axial wall height in premolar full-coverage, all-ceramic restorations.

SUMMARY

Objective: To evaluate the significance of reduced axial wall height on retention of adhesively luted, all-ceramic, lithium disilicate premolar computer-aided design/computer-aided manufacturing (CAD/CAM) crowns based on preparations with a near ideal total occlusal convergence of 10°.

Methods: Forty-eight recently extracted premolars were randomly divided into four groups (n=12). Each group received all-ceramic CAD/CAM crown preparations featuring axial wall heights of 0, 1, 2, and 3 mm, respectively, all with a 10° total occlusal convergence. Scanned preparations were fitted with lithium disilicate all-ceramic crowns that were luted with a self-etching resin cement. Specimens were tested to failure at a 45° angle to the tooth long axis with failure load converted to megapascals (MPa) based on the measured bonding surface area. Mean data were analyzed using analysis of variance/Tukey's post hoc test (α=0.05).

Results: Lithium disilicate crowns adhesively luted on preparations with 0 axial wall height demonstrated significantly less failure resistance compared with the crowns luted on preparations with axial wall heights of 1 to 3 mm. There was no failure stress difference between preparations with 1 to 3 mm axial wall height.

Conclusions: Under conditions of this study, adhesively luted lithium disilicate bicuspid crowns with a total occlusal convergence of 10° demonstrated similar failure resistance independent of axial wall height of 1 to 3 mm. This study provides some evidence that adhesion combined with an ideal total occlusal convergence may compensate for reduced axial wall height.

Christopher Gillette, DMD, MS, Deputy Director, AEGD-1, Wright-Patterson AFB, OH, USA

Richard Buck, DMD, MS Director, Prosthodontics, 48th Dental Squadron, RAF Lakenheath, GB

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

Sarra Cushen, DDS, MS, Director, Prosthodontics, Air Force Postgraduate Dental School, Keesler AFB, MS, USA

Michael Wajdowicz, DDS, Director AEGD-2, Air Force Postgraduate Dental School, Keesler AFB, MS, USA

*Howard Roberts, DMD, MS, Director, Graduate Dental Research, AGED-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

DOI: 10.2341/16-086-L

INTRODUCTION

Full-coverage restorations, either metal or ceramic, have tooth preparation guidelines that include degree of total occlusal convergence (TOC), axial wall height, and specific intracoronal features.[1-3] Specifically, a 3 mm occlusocervical (OC) axial wall height is recommended for adequate retention of premolar crowns.[1,3] These guidelines were formulated in the era of aqueous-based luting agents before the advent of resin cements. At that time, full-coverage restorations relied largely on preparation retention and resistance features as aqueous-based cements could only provide macromechanical retention by filling the space between the restoration intaglio surface and the prepared tooth surface. The increased clinical use of all-ceramic full-coverage restorations provided the impetus for the development of adhesively bonded resin cements that are touted to provide macro- and micromechanical retention as well as chemical bonding to selected materials.[4,5] Finish lines, intracoronal features, and TOC degree are preparation elements that the clinician usually has significant control over. However, the axial wall may be compromised due to disease or trauma and ideal axial wall heights may not be within the clinician's control, especially in situations where crown-lengthening surgery is not feasible. The purpose of this study was to evaluate if adhesion technology can compensate for reduced axial wall height in premolar all-ceramic crowns luted to preparations containing a 10° TOC. The null hypothesis was that there would be no difference in failure stress between preparations containing 0, 1, 2, or 3 mm axial wall height.

METHODS AND MATERIALS

Human premolar teeth that contained no restorations or caries were used in this study. All teeth, collected and used under the guidance of the local Institutional Review Board, were obtained from local oral and maxillofacial surgery clinics and had been removed per routine clinical indications for orthodontic expediency.

Forty-eight freshly extracted premolar teeth were randomly assigned to one of four groups (n=12) with the occlusal surfaces removed to 1 mm 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 methyl-methacrylate resin (Diamond D, Keystone Industries, Cherry Hill, NJ, USA). Preparations were accomplished following manufacturer's recommendations for lithium disilicate all-ceramic crowns (IPS e.max CAD, Ivoclar Vivadent, Amherst NY, USA) by a single operator using a high-speed electric dental handpiece (EA-51LT, Adec, Newburg, OR, USA) equipped with a diamond bur (8845KR.31.025, Brassler USA, Savannah, GA, USA) under continuous water coolant spray. Preparation features and TOC of 10° was standardized as much as possible with the handpiece placed in a fixed lathe arrangement. Teeth in the four groups received occlusal reduction resulting in OC preparation heights of 0, 1, 2, and 3 mm, respectively. The 0 mm axial wall height group received a buccal lingual groove preparation featuring the approximate width and half depth of a no. 8 round bur across the total occlusal surface. This feature was required to allow the correct restoration alignment to the preparation, and the orientation of this groove was designed not to add resistance features to the preparation as it was parallel to the testing force vectors. All preparations underwent final review and any necessary refinement by a board-certified prosthodontist. The prepared tooth surface area was then measured using a digital recording microscope (KH-7700, Hirox USA, Hackensack, NJ, USA) that allowed for the determination of bonding surface area.

The specimens were restored by one operator using a computer-aided design/computer-aided manufacturing (CAD/CAM) acquisition device (Cerec AC, version 4.2.4.72301/Cerec MC XL, Sirona Dental Systems, Charlotte, NC, USA) according to the manufacturer's instructions and/or recommendations. All specimens were scanned using a standardized template to allow the establishment of suitable clinically relevant restoration contours. The occlusal table was established at the same height regardless of axial wall height and had an occlusal thickness not less than 2 mm. The restorations were milled from a lithium disilicate ceramic material (IPS e.max CAD) followed by crystallization and glaze (IPS e.max CAD Crystall Glaze Spray, Ivoclar-Vivadent) following the manufacturer's protocol in a dental laboratory ceramic furnace (Programat P700, Ivoclar-Vivadent).

The milled restorations were adjusted and seated to the preparations using a disclosing agent (Occlude, Pascal International, Bellevue, WA, USA), after which the restoration was steam cleaned and dried. The restoration's intaglio surface was then prepared with a 5% hydrofluoric acid-etch solution (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 (Monobond Plus, Ivoclar Vivadent) was applied to the etched surface using a monobrush following manufacturer's instructions. After 60 seconds of reaction time, the silane agent was air-dried using oil-free compressed air.

Table 1: *Mean Failure Load (N) and Stress (MPa) (n=12)*[a]

Mean Preparation Axial Wall Height (mm)	Failure Load (N)	Failure Stress (MPa)
0	148.3 (70.1) A	2.89 (1.1) A
1	374.8 (150.9) B	6.35 (2.5) B
2	499.7 (117.5) BC	7.16 (1.6) B
3	622.4 (142.1) C	7.52 (1.7) B

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

Table 2: *Failure Mode Analysis*

Failure Mode	Occlusocervical Axial Wall Height			
	0 mm	1 mm	2 mm	3 mm
Cohesive ceramic	0	0	1	4
Adhesive crown/ tooth material	12	12	2	2
Tooth fracture	0	0	9	6

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 and then seated on the preparation using digital finger pressure. Restorations were tack cured for 1 second using a visible light curing unit (Bluphase G2, Ivoclar Vivadent). After the excess cement was removed, the restoration was light cured at the buccal, lingual, and proximal marginal areas for a total of 80 seconds. The specimens were stored under dark conditions at 37°C ± 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° angle to the vertical axis of the testing fixture. The testing fixture consisted of a 3 mm-diameter hardened, stainless steel piston with a 0.5-m radius of curvature as described by Kelly and others.[6] Specimens were loaded on the facial cusps at a rate of 0.5 mm per minute until failure; failure load was recorded in Newtons with a resultant failure stress calculated based on preparation surface area. Failure mode for each specimen was determined by visual examination under 20× magnification (KH-7700, Hirox USA) as well as microtomography (MicroCT) (Skyscan 1172, Bruker MicroCT, Kontich, Belgium) at a resolution of 13.6 μm using 100 kV energy with a 0.4° step size. Individual images were combined into a three-dimensional (3D) image using recombination software (nRecon, Bruker MicroCT) and analyzed with a volume-rendering 3D software (CTVox, Bruker MicroCT).

Mean failure load and stress were first evaluated using the Shapiro-Wilk test and Bartlett's test to ascertain normal distribution and homogenous variance of the data. Analysis of variance identified a difference within the groups followed by the Tukey's *post hoc* test. Statistical analysis was performed with a computer-based program (SPSS 20, IBM SPSS, Chicago, IL, USA) with a 95% level of confidence (α=0.05).

RESULTS

The failure results are listed in Table 1. When based on failure load, the preparations with 3 mm axial preparation height exhibited significantly greater failure resistance than the preparations containing 0 and 1 mm axial wall heights. There was no difference in failure load between the 2 and 3 mm axial wall height groups. When bonded surface area was taken into consideration, there was no significant difference in the failure stress between preparations of 1, 2, and 3 mm axial height.

The failure analysis mode results can be seen in Table 2.

All restorations in the 0 and 1 mm axial height preparation groups experienced restoration debonding without any tooth or crown material failure. The major failure mode for the 2 and 3 mm axial height preparation groups was root fracture that did not involve the tooth preparation.

DISCUSSION

Proponents of CAD/CAM dentistry anecdotally promote that adhesive technology may compensate for loss of preparation features required when luting castings with aqueous-based cements. This current study attempted to evaluate whether the adhesion involved with all-ceramic premolar CAD/CAM restorations could compensate for loss of OC axial wall height using a standardized TOC angle of 10°. This could identify possible advantages in clinical situations where tooth structure loss might alleviate the need for elective endodontic or surgical periodontal procedures to gain adequate tooth structure for a full-coverage restoration.

The tooth preparations were standardized as much as possible with one operator using a lathe-type arrangement. The TOC of 10° was chosen as Goodacre and others[1] recommend a TOC between

Table 3: *Mean Tooth Preparation Parameters (n=12)*

Group (Axial Wall Height)	Axial Wall Height (mm)	Total Occlusocervical Convergence (°)	Surface Area (mm^2)
0 mm	–	–	50.2 (18.5)
1 mm	1.16 (0.07)	10.3 (0.8)	61.0 (8.33)
2 mm	2.10 (0.05)	9.61 (0.51)	71.0 (13.56)
3 mm	3.1 (0.04)	10.19 (0.9)	83.1 (6.22)

10° and 20°; those authors concluded that TOCs <10° are rarely clinically achieved. The mean preparation parameters are listed in Table 3.

The use of a digital recording microscope (KH 7700, Hirox USA) allowed the confirmation of tooth preparation parameters that also allowed the measurement of preparation surface area that could be available for adhesive bonding.

The total preparation convergence was determined by taking the mean of the four convergence measurements (facial/lingual, mesial/distal). Under the conditions of this study, TOC convergence was standardized at 10°. The surface area determination allowed the calculation of failure stress, which is uncommon in the dental scientific literature and may compensate for the disparities in tooth size inherent with the usual failure load reporting. Preparation surface area within the 2 and 3 mm groups was similar to that reported in an evaluation of preparation stone dies in a commercial dental laboratory.[7] Preparation surface area within each group was fairly consistent, as covariance ranged from 7% to 18% among the preparations that contained axial wall height. The surface area variability increased within the 0 mm axial wall height group, as surface area was largely dependent on tooth size. Failure load results found that the 3 mm preparation axial wall height was found to be significantly greater not only than the 0 mm group but also the 1 mm axial wall height group. Failure stress determination contrasted the more traditional failure load results in that no difference in failure stress was noted between OC preparation heights of 1, 2, and 3 mm, and all three were significantly greater than the preparations with no axial wall height. Failure stress, which is based on preparation surface area, may normalize failure load results, but more evaluation is incumbent in this area before definitive judgments can be proffered. Regardless of analysis, the null hypothesis was rejected. The results should be considered with the understanding that the preparation TOC of 10° in this study may be considered very conservative and may not be routinely achieved in the clinical environment.[8] Furthermore, it should be noted that all OC axial wall height preparations demonstrated failure loads greater than that reported for the normal human bite strength,[9,10] and follow-up fatigue load/stress studies are planned.

Failure mode analysis revealed that mode of failure depended largely on the preparation axial wall height. The 0 and 1 mm OC axial wall height groups failed predominately by adhesive failure of the resin cement with occasional minor reparable tooth material fracture. One-third of the OC 3 mm axial wall height group displayed cohesive ceramic fracture, but tooth fracture was the leading failure mode of both the 2 and 3 mm OC axial wall height groups. Microtomographic analysis found that these fractures were mostly initiated near the lingual margins and the base of the lingual preparation wall (Figures 1 and 2).

This study is one of the first to evaluate the effect of premolar OC axial wall height using CAD/CAM adhesive technology. Ersu and others[11] found that OC axial wall height affected zirconia coping retention, which led them to reinforce the philosophy that for preparations with <3 mm of OC axial wall height consideration should be given to endodontic therapy with post and core fabrication to gain additional retention and resistance features. However, that study differs from the present work in that stainless steel copings served as the foundation preparation material. Leong and others,[12] in their study involving maxillary premolars, found no difference in fatigue strength between 2 and 3 mm OC axial wall heights when a resin luting agent was used, even with a 20° TOC. The failure loads in this study were lower than those reported by Attia and Kern,[13,14] who studied two other leucite-reinforced ceramics in two separate studies. However, the conditions of their research applied forces along the specimen long axis, and preparation parameters were more conservative; they used a 5 mm OC axial wall height with an even more conservative TOC of 6°.[13,14] Lastly, failure loads of this study are also less than that reported by Good and others[15] who also used a TOC of 6° and an earlier leucite-reinforced ceramic. Although the failure loads may seem to be less than those in other reports, the authors maintain that the conditions of the present study may more closely represent those encountered in clinical practice.

Figure 1. *MicroCT image slice showing 3-mm occlusocervical axial height failure.*
Figure 2. *MicroCT image slice showing 2-mm occlusocervical axial height failure.*

CONCLUSIONS

Under the conditions of this study, premolars restored with adhesively luted, CAD/CAM fabricated, lithium disilicate crowns based on a 10° TOC displayed similar failure stress resistance with OC axial wall heights of 1, 2, and 3 mm. This study provides some evidence that adhesion may compensate for less than ideal axial wall height in all-ceramic premolar preparations with a conservative total occlusal convergence.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the 81 Medical/Dental Group. The approval code for this study is: FKE20140016N.

Disclaimer

Any opinions expressed in this work are of the authors only and do not represent the official opinion of the United States Air Force, the Department of Defense, or the United States government. The authors have no commercial interest in any of the products or processes described and mention of such does not imply endorsement.

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.

(Accepted 13 July 2016)

REFERENCES

1. Goodacre CJ, Campagni WV, & Aquilino SA (2001) Tooth preparations for complete crowns: An art form based on scientific principles *Journal of Prosthetic Dentistry* **85(10)** 363-376.
2. Wiskot HW, Nicholls JI, & Belser UC (1996) The relationship between abutment taper and resistance of cemented crowns to dynamic loading *International Journal of Prosthodontics* **9(2)** 117-130.
3. Wiskot HW, Nicholls JI, & Belser UC (1997) Effect of tooth preparation height and diameter on the resistance of complete crowns to fatigue loading *International Journal of Prosthodontics* **10(3)** 207-215
4. Rosenstiel SF, Land MF, & Crispin BJ (1998) Dental luting agents: A review of the current literature *Journal of Prosthetic Dentistry* **(80)3** 280-301.
5. Hikita K, Van Meerbeek B, De Munck J, Ikeda T, Van Landuyt K, Maida T, Lambrechts P, & Peumans M (2007) Bonding effectiveness of adhesive luting agents to enamel and dentin *Dental Materials* **23(1)** 71-80
6. Kelly RJ, Rungruanganunt P, Hunter B, & Vailati F. Development of a clinically validated bulk failure test for ceramic crowns (2010) *Journal of Prosthetic Dentistry* **104(4)** 228-38
7. Tiu J, Al-Amleh B, Waddell JN, & Duncan WJ (2015) Reporting numeric values of complete crowns. Part 2: Retention and resistance theories *Journal of Prosthetic Dentistry* **114(1**) 75-80.

8. Tiu J, Al-Amleh B, Waddell JN, & Duncan WJ (2015) Reporting numeric values of complete crowns. Part 1: Clinical preparation parameters *Journal of Prosthetic Dentistry* **114(1)** 67-74

9. Sinn DP, DeAssis EA, & Throckmorton GS (1996) Mandibular excursions and maximum bite forces in patients with temporomandibular joint disorders *Journal of Oral and Maxillofacial Surgery* **54(6)** 671-679

10. Ferrario VF, Sforza C, Serrao G, Dellavia C, & Tartaglia M (2004) Single tooth bite forces in healthy young adults *Journal of Oral Rehabilitation* **31(1)** 18-22

11. Ersu B, Narin D, Aktas G, Yuzugullu B, & Canay S (2012) Effect of preparation taper and height on strength and retention of zirconia crowns. *International Journal of Prosthodontics* **25(6)** 582-584

12. Leong EWJ, Tan KBC, Nicholls JI., Chua EK, Wong KM, & Neo JCL (2009) The effect of preparation height and luting agent on the resistance form of cemented cast crowns under load fatigue. *Journal of Prosthetic Dentistry* **102(3)** 155-164

13. Attia A, & Kern M (2004) Influence of cyclic loading and luting agents on the fracture load of two all-ceramic crown systems *Journal of Prosthetic Dentistry* **92(6)** 551-556

14. Attia A, & Kern M (2004) Fracture strength of all-ceramic crowns luted using two bonding methods *Journal of Prosthetic Dentistry* **91(9)** 247-252

15. Good M-L, Orr JF, & Mitchell CA (2008) *In vitro* study of mean loads and modes of failure of all-ceramic crowns cemented with light-cured or dual-cured luting cement, after 1 and 30 d of storage *European Journal of Oral Sciences* **116(1)** 83-88