Premolar Axial Wall Height Effect on CAD/CAM Crown Retention

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Objectives: To evaluate bicuspid axial wall height effect on retention of adhesively-luted, all-ceramic CAD/CAM crowns with a 16-degree total occlusal convergence (TOC).

Methods: Recently-extracted premolars were randomly divided into 4 groups (n=12) with all-ceramic crown preparations accomplished using a high speed hand piece inserted into a milling device. Preparations contained a 16-degree TOC with each group consisting of axial wall heights of 0, 1, 2, and 3 millimeters. Completed preparation surface area was determined using a digital measuring microscope (Hirox). Scanned preparations (CEREC) were fitted with e.max CAD crowns and cemented with RelyX Unicem after HF acid etching and silanation. All manufacturer recommendations were followed. Specimens were stored at 37C/98% humidity for 24 hours and tested to failure at a 45-degree angle on a universal testing machine. Failure load was converted in MPa using the available bonding surface area with mean data analyzed using ANOVA/Tukey's (p=0.05).

Results: The 3mm and 2mm preparation height samples displayed significantly stronger failure load than the 0mm and 1mm samples. There was no difference between the 2mm and 3mm groups.

Conclusions: Under this study's conditions, bicuspids restored with adhesively-luted, CAD/CAM processed, lithium disilicate full coverage restorations based on a preparation with a 16 degree TOC displayed significantly greater failure load with OC axial wall heights of two and three millimeters. Evidence is presented that adhesion may provide some compensation for compromised OC axial wall height in bicuspids. Under the conditions of this study, failure mode analysis strongly suggests bicuspid preparations containing a 16-degree TOC taper require at least two millimeters of OC axial wall height even when adhesive CAD/CAM technology is utilized.

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Introduction:

Computer Aided Design and Computer Assisted Manufacture (CAD/CAM) dentistry is becoming increasing popular as it offers expedient manufacture of all ceramic full coverage restorations along with an acceptable level of accuracy. For the full-coverage restoration of bicuspids, many studies have provided guidance on preparation features that should enable the successful clinical function. A total occlusal convergence (TOC) of two to five degrees has been shown to provide the most optimal retention, [1] and recommended values based on *in vitro* testing range from two to twelve degrees. [1-5] However, recommended TOC parameters can be difficult to achieve under clinical conditions and have been suggested to be the exception rather than the rule. [6-8]

Occlusal cervical (OC) axial wall height is one factor that the clinician may have the least control, as the tooth requiring full coverage restoration will usually have damage or features that must be removed or compensated for. It has been suggested that three millimeters of OC axial wall height is optimal for the full coverage restoration of bicuspids, [9] but this has been difficult to confirm as studies disagree on the proper definition of OC axial wall height. [10,11]

CAD/CAM proponents anecdotally purport that some traditional preparation recommendations made during era of aqueous luting agents may not be required in the face of adhesive technology. This study investigated the effect of OC axial wall height on the retention of CAD/CAM adhesively luted all-ceramic, full-coverage restorations based on a moderate TOC taper of 16 degrees. The null hypothesis was that there would be no difference in failure load and stress between preparations with three, two, one, and zero OC axial wall heights.

Materials & Methods:

Human bicuspid teeth were used in this study. All teeth were collected from local oral and maxillofacial surgery clinics which had been removed as per routine clinical indications for orthodontic expediency. The teeth were collected and used according to local Institutional Review Board (IRB) protocol approval.

Forty-eight freshly extracted human bicuspid teeth were randomly assigned to one of four groups (n=12) 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 accomplished following CAD/CAM Cerec recommendations 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. Preparation taper was standardized with the handpiece placed in a fixed lathe arrangement.

After the establishment of TOC taper of 16 degrees, preparations were finalized by occlusal reduction to produce specimens consisting of three, two, one, and zero OC axial wall heights. The zero OC axial wall height specimens further received a facial-lingual groove the approximate width and half-depth of a #8 round bur. This added feature allowed the restorations to be seated with the proper orientation but was oriented in the same vector as the applied force that added minimal preparation resistance features. All final preparations were reviewed and refined by a board-certified prosthodontist. Prepared tooth surfaces were then evaluated with a digital recording microscope (KH 4400, Hirox USA, Hackensack, NJ, USA) that allowed the determination of surface area available for bonding as well as confirmation of OC axial wall height and TOC taper.

The specimens were restored by one operator using a CAD/CAM acquisition device (Cerec AC Version 4.2.4.72301/Cerec MC XL, Sirona Dental Systems, Charlotte, NC, USA) 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 axial wall height for all restorations with a minimum occlusal thickness of 2mm. The design of each restoration was then completed to ensure proper contours and was milled from a lithium disilicate ceramic restorative material (IPS e.max® CAD, Ivoclar-Vivadent, Amherst, NY, USA). After the milling process the restorations were crystallized and glazed (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 for each prepared tooth 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 treated 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. The etched surface was then treated with a silane agent (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 surfaces were 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 followed by seating of the restoration using digital finger pressure. Restorations were tack cured for one second using a LED-based visible light curing unit (Bluephase G2, Ivoclar-Vivadent) after which excess cement was removed followed by additional light curing of each surface for 20 seconds. The 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 4). 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.* [12] 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 dentin surface area. Failure mode for each specimen was determined by both visual examination under 20X magnification (KH-4400, Hirox USA) to determine if the failure was cohesive for the leucite 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 9.8 microns using 100kV energy with a 0.4-degree 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).

The Shaprio-Wilk Test and Bartlett's Test ascertained the normal distribution and homogenous variance of the mean failure load and calculated stress data. The analysis of variance (ANOVA) identified a difference within the groups using Tukey's *post hoc* test. Statistical analysis 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:

The failure results are listed in Table 1.

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

Mean Preparation Axial Wall Height (mm)	Failure Load (N)	Failure Stress (MPa)
0	262.8 (86.5) A	2.89 (1.1) A
1	318.5 (164.0) A	6.35 (2.5) B
2	512.1 (128.8) B	7.16 (1.6) B
3	612.7 (126.4) B	7.52 (1.7) B
n = 12; Groups identified with same letter are similar within each column (Tukey, p = 0.05)		

When based upon failure load, the preparations with two and three millimeter OC axial wall preparation height exhibited significantly greater failure load than the one and zero millimeter axial wall height preparations. Calculated failure stress results found the one, two, and three OC axial wall height groups exhibited significantly greater failure stress resistance than the zero millimeter axial wall height sample. The failure mode analysis can be viewed in Table 2.

Table 2. Failure Mode Analysis

OC Axial Wall Height (mm)	Failure Mode				
	Adhesive Debonding	Restorable Fracture	Catatrophic Failure Restoration+ Tooth Complex	Cohesive Root Fracture	Cohesive Ceramic Fracture
Zero	9	3	0	0	0
One	7	2	0	2	1
Two	3	2	0	5	2
Three	1	0	0	9	2

n = 12

Catastophic failure = Fracture that involves the restoration and restoration preparation.

Cohesive Root Fracture = Fracture that does not involve restoration/preparation complex at a level apical to the preparation.

The failure analysis results can be seen in Table 2. The zero millimeter OC axial wall height preparation group filed be predominately adhesive debonding of the restoration but exhibited some restorable fractures of the restoration and tooth surface. The one millimeter OC axial wall height group also contained a predominant adhesive failures and restorable fractures similar to the zero millimeter wall height group. However, the one-millimeter OC axial wall height group also displayed two cohesive root failures.

Under the conditions of this study, the authors made a distinctive difference between catastrophic failure and cohesive root fracture. To wit, catastrophic failure was defined as a non-restorable that involves the preparation features and/or the restoration. Cohesive root fracture, on the other hand, was defined as a cohesive tooth material fracture not involving and apical to preparation features. Catastrophic failures implies causation due to preparation features whereas cohesive root fracture represents failures in which the restoration/dentin bond was greater than the cohesive root dentin failure. It was interesting that there were no catastrophic failures observed under the conditions of this study.

Discussion:

For full coverage indirect restorations, retention and resistance form is determined by a combination of preparation taper, surface area, and axial wall height. [5,9,13] For the full-coverage restoration of bicuspids, Goodacre *et al.* recommends a minimum of three millimeters of OC axial wall height in combination of a 10 to 20 degree total occlusal convergence. [9] However, CAD/CAM proponents maintain anecdotally that adhesive technology may compensate for preparation features required in the era of aqueous based luting agents. This current study attempted to evaluate these claims using CAD/CAM generated, adhesively luted, lithium disilisilicate full coverage restorations. The failure load and stress were determined on preparations based on a 16 degree TOC with OC axial wall heights of zero, one, two, and three millimeters.

Preparations were standardized as much as possible using a lathe-type apparatus, with the mean measured parameters presented in Table 3.

Table 3. Mean Tooth Preparation Parameters

OC axial wall height group (mm)	Axial wall height (mm)	TOC Convergence (°)	Surface area (mm^2)
0mm			44.5 (6.4)
1mm	1.05 (0.04)	16.3 (0.5)	53.3 (5.5)
2mm	2.05 (0.03)	16.6 (0.6)	67.5 (10.0)
3mm	3.06 (0.03)	16.4 (0.5)	71.3 (10.6)

n = 12

The preparation TOC was determined by taking the mean of the four convergence measurements (facial/lingual, mesial/distal). The surface area was determined to allow failure stress calculation, which was accomplished to evaluate if failure stress determination had any normalization of the failure load data. However, under the conditions of this study any definitive normalization of the failure load was not evident. Mean failure stress results found the OC axial wall heights of one, two, and three millimeters all similar and significantly greater than the zero OC axial wall height. Mean failure load data reported that the OC axial wall heights of three and two millimeters were significantly greater than the one and zero axial wall height groups. It may require the combination of multiple studies and/or studies with larger sample sizes to evaluate if the failure stress determinations may provide data normalization.

Failure mode analysis perhaps provides more discrimination of the results of this study. Preparations with zero and one millimeter OC axial wall heights failed largely due to adhesive failure of the restoration. This result should be considered with the fact that preparations with two and three millimeters OC axial wall height demonstrated either cohesive ceramic fracture or cohesive root fracture which was confirmed with microCT analysis. Accordingly, the true restoration adhesive strength of the latter two groups are not known because of cohesive tooth failure occurred before any failure involving the restoration failed. Based on failure mode results, the results of this study strongly suggest that a bicuspid preparation containing a 16 degree TOC taper requires a minimum of 2mm OC axial wall height for full coverage restorations based on CAD/CAM adhesive technology.

Other studies involving OC axial wall height are in variance with the results of this study, even with the use of adhesive resin cements. Ersu *et al* [14] reported that three millimeters of OC axial wall height was required in a study that involved zirconia copings cemented on stainless steel dies. The results of this study reinforced the philosophy of when a tooth lacked three millimeters of OC axial wall height that periodontal surgical and elective endodontic procedures should be considered to regain lost axial wall height. Some aspects of the results of Leong *et al* [15] could be considered to be similar to this present study, which evaluated metal full coverage castings on bicuspid teeth. Leong *et al* [15] found that preparations based on a 20 degree TOC containing two or three millimeters OC axial wall height performed better under cyclic fatigue loading than aqueous based luting agents.

This study is one of the first to evaluate the effect of OC axial wall height with adhesive CAD/CAM technology. The failure loads observed with the three millimeter OC axial wall height group in this study are somewhat comparable to that reported by other researchers. Good and colleagues [16] reported slightly higher failure loads with a leucite reinforced ceramic using both dual cure and visible light cure resin cements. However, in that study OC axial wall height was almost four millimeters and a five degree TOC taper was used. Furthermore, load was applied parallel to the long axis of the specimens. The results reported by Attia and Kern [17] were slightly higher than that found in the present study, and differences in method may account for this difference. Accordingly, in their study Attia and Kern bicuspid samples were prepared with a OC taper of six degrees, five millimeter OC axial wall height, and also applied load parallel to the tooth long axis. Furthermore, the same two researchers reported comparable failure load values in a different report where the samples were loaded along the long axis of the specimens and the researchers used two different CAD-CAM materials as well as a different resin cement.[18]

Conclusions:

Under this study's conditions, bicuspids restored with adhesively-luted, CAD/CAM processed, lithium disilicate full coverage restorations based on a preparation with a 16 degree TOC displayed significantly greater failure load with OC axial wall heights of two and three millimeters. Evidence is presented that adhesion may provide some compensation for compromised OC axial wall height in bicuspids. Under the conditions of this study, failure mode analysis strongly suggests bicuspid preparations containing a 16-degree TOC taper require at least two millimeters of OC axial wall height even when adhesive CAD/CAM technology is utilized.

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