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MARGINAL FIT OF CEREC CROWNS
AT DIFFERENT INTERPROXIMAL MARGIN ANGLES

by

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A thesis submitted to the Faculty of the
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Master of Science
in Oral Biology

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

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2020

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ABSTRACT

MARGINAL FIT OF CEREC CROWNS
AT DIFFERENT INTERPROXIMAL MARGIN ANGLES
ROBERT GARY HOLMES
M.S., PROSTHODONTICS, 2020

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Introduction: Marginal fit is one of the most important criteria for the long-term clinical success of crowns. Insufficient marginal adaptation may result in increased plaque accumulation, periodontal disease, secondary caries, and restoration failure. Preparation finish line configuration has a direct effect on the marginal fit of restorations. **Objective:** This study examined marginal fit (marginal discrepancy) of full coverage ceramic restorations milled to different finish line margins. **Methods:** Ivorine teeth were prepared with 0º, 45º, or 90º interproximal angled finish lines for full coverage ceramic crowns. The 3 abutments were duplicated in CoCr to serve as master dies. CAD-CAM software was used to generate models (.stl files) of the master dies and design crowns for each die. Restorations for each angle were fabricated from pre-sintered lithium disilicate blocks (n=12) using a 4-axis mill (CEREC MC XL, DensplySirona). Each restoration was securely seated on its respective master die using a device to ensure uniform pressure and proper seating for analysis. Multiple measurements were recorded on each surface (buccal, lingual, mesial, and distal) to assess horizontal and vertical marginal discrepancies (50X) using digital microscopy (Hirox). Data were analyzed using 1-way ANOVA (α=0.05) and post hoc T-tests with a Bonferroni correction. **Results:** Preliminary analyses revealed mean horizontal discrepancies of; 0º, 47.39±30.45µm, 45º, 53.16±35.89µm, and 90º, 87.37±48.97µm and mean vertical discrepancies of; 0º, 92.05±51.48µm, 45º,

90.29±53.04µm, and 90º, 143.15±79.65µm. ANOVA revealed significant differences for horizontal ($p<0.001$) and vertical ($p<0.001$) discrepancies between the 3 angles. Post hoc analyses revealed the following; horizontal, 0º vs. 45º $p=0.231$, 0º vs. 90º $p<0.001$, 45º vs 90º $p<0.001$, vertical; 0º vs. 45º $p=0.815$, 0º vs. 90º $p<0.001$, 45º vs 90º $p<0.001$. **Conclusions:** Interproximal margin angulation had a significant effect on marginal fit. This study found a trend of increasing horizontal and vertical marginal discrepancies with increasing margin angle.

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LIST OF ABBREVIATIONS

ACR	all-ceramic restoration
ANOVA	analysis of variance
CAD/CAM	computer-aided design/computer-aided manufacture
CEREC	chairside economical restoration of esthetic ceramics / ceramic reconstruction
Co-Cr	cobalt-chromium
LED	light-emitting diode
MCR	metal-ceramic restoration

REVIEW OF THE LITERATURE

CAD/CAM digital workflow

Since the introduction of the CEREC 1 in 1985, dental Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) technology has increased in popularity. Using this technology involves scanning, designing, and milling prefabricated ceramic blocks into a clinically viable restoration.[1] The CEREC system consists of an intraoral scanner connected to a computer workstation that communicates wirelessly to a separate milling unit. The handheld intraoral scanner allows the practitioner to digitally scan a preparation and facilitate the design and milling steps to produce a full coverage all ceramic restorations (ACRs) in one appointment with the laboratory steps occurring on site.

CEREC history

Improvements to the system's scanning technology has greatly improved the overall capabilities of the digital workflow. CEREC 1 used a 2-dimensional optical impressions system which was replaced with 3-dimensional video capture equipment with greatly increased capabilities. The RedCam used an infrared laser operating at 820 nm to achieve 3-dimensional images. It was replaced with the BlueCam that used a light emitting diode (LED) at 470 nm that allowed a greater depth of field and an increase in image resolution. With improvements in resolution, positioning was less critical and angular views as well as occlusal could be captured.[2,3] The latest iteration, the OmniCam, was released in 2013. It uses a white light which provides increased accuracy and faster image acquisition compared to the RedCam and BlueCam.

Digital impression capture

Advantages of digital impressions include reduced patient discomfort, better communication with the laboratory technician, and increased time efficiency. First-generation intraoral scanners required powder coating of the surfaces to be scanned for the camera to detect them. More recent innovations eliminate the need for this step and are capable of 3D color scans.[4] Capturing the crown margin is the most critical step in the digital workflow. Minimizing error during data collection is important in reducing errors that can be compounded in the design and manufacturing process.[5] Several studies have investigated the scanning accuracy[6 7 8] and the digital impression system[9] and shown that the ceramic crowns manufactured using the digital workflow (digital impression, design, milling) demonstrated internal fit and marginal fit that was comparable to or better than an analog workflow (conventional impression, wax up, and pressing). Mean margin gap using an analog workflow has been measured at 71 microns while a digital workflow resulted in 49 microns.[10] Vertical margin gap with digital impressions was 48 ± 25 microns, significantly larger at 74 ± 47 microns when using conventional impressions.[11] Digitally fabricated crowns provided better marginal fit than crowns fabricated by conventional means.[11] Through the evolution of CEREC 1, the RedCam, the BlueCam, and currently the OmniCam, acquiring an intraoral optical impression has become easier, faster, and more accurate than in the past.

Clinical effect of margin gap

A consensus among practitioners of what constitutes a clinically acceptable marginal gap remains controversial. The larger the marginal discrepancy, the greater the likelihood of microleakage and cement dissolution.[12] Lack of acceptable marginal fit may lead to plaque

retention, localized periodontal inflammation, cement wash out, or secondary decay.[12] In addition to esthetics and fracture resistance, superior internal crown adaptation and marginal fit are also valued criteria for the clinical success of all ceramic restorations.[1,13,14,15,16] An in vitro study by Jacobs and Windeler reported the solubility rate of a type I zinc phosphate cement, and a cement gap below 75 microns had a lower dissolution rate than a cement gap at 150 microns.[12] Abbate et al reported marginal gaps ranging from 56-81 microns for all ceramic and metal ceramic crowns.[17] Fransson et al reported margin gaps of 50 to over 150 microns with a mean marginal gap of 100 microns for metal ceramic crowns.[18] Provisional crowns fabricated using CAD/CAM techniques demonstrated less marginal gap when compared to direct fabrication methods.[19] Full-arch zirconia restorations fabricated by conventional analog workflow compared to two different CAD/CAM digital workflows showed a statistically significantly better fit for analog at 48.59 microns compared to 53.50 and 56.47 microns for digital systems.[20]

Margin gap with CEREC

According to McLean and von Fraunhofer, the acceptable marginal gap for crowns may be up to 120 microns.[21] Bindl and Mörmann reported that the CEREC 3 CAD-CAM ACRs showed a marginal gap between 53-108 microns depending on the selected cement spacer setting. They concluded that the accuracy of fit for the CEREC crown is well within the clinically acceptable limit for crown marginal fit.[1] Akbar et al used the CEREC system to fabricate crowns with a mean marginal gap of 66 microns.[22] Nakamura et al measured marginal gaps ranging from 53-67 microns depending on the CEREC software and convergence of the preparation.[23] Vennerstrom et al revealed mean marginal gaps of 79 microns for CEREC crowns.[9]

Kim et al reported that the internal and marginal fit were affected by sintering (crystallization) of the CEREC lithium disilicate. The internal fit was statistically smaller and the marginal gap was statistically larger after crystallization. However pre- and post-crystallization marginal gap measurements were clinically acceptable. The authors conclusion was that crystallization has no major effect on the clinical acceptability of the restoration (Kim et al. 2016).[24]

Definition of fit (Holmes 1989)

Holmes et al stated that the definition of "fit" varies among clinicians. The authors also stated using the term "fit" may encompass clinical adaptation, internal adaptation, marginal adaptation, radiographic appearance, and vertical seating. Several factors ultimately lead to the final fit of the restoration including design of the preparation, configuration of the margin, finishing of the margin, and thickness of the cement.[16]

Marginal gap, vertical marginal discrepancy, horizontal marginal discrepancy defined

According to Holmes et al, a metal alloy cast crown is evaluated relative to points on the internal surface and external surface of the casting, or at the margin. Marginal gap is defined as the perpendicular measurement from the axial wall of the tooth preparation to the internal surface of the casting at the margin. Vertical marginal discrepancy is the misfit in a vertical direction measured parallel to the path of draw. Horizontal marginal discrepancy is measured perpendicular to the path of draw. This vertical and horizontal discrepancy can be summarized in terms of "misfit" with the casting either being overextended or underextended. In summary, a casting having no marginal gap and no over or under extension that completely seats with perfect

intimate adaptation to the tooth structure is a well-fitting restoration. Any other scenario with open or closed margins and either over or underextended may be categorized as a misfitting restoration.[16]

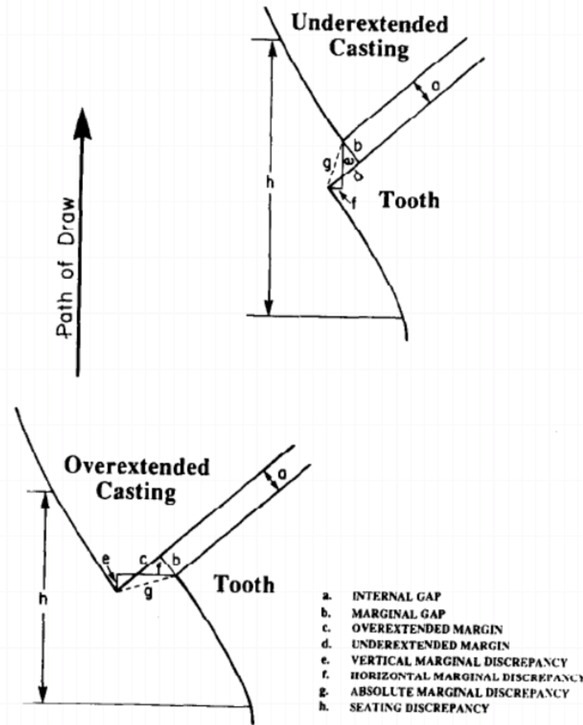

Figure 1. Casting misfit terminology according to Holmes et al (1989).
(Holmes JR et al., Consideration in measurement of marginal fit. J Prosthet Dent 1989;62:405-8.)

Marginal gap of MCR vs. ACR

The predecessor to the ACR is the metal ceramic or porcelain fused to metal crown. Marginal fit of the metal ceramic crown has been well documented and serves as the reference point to evaluated the marginal fit of all ceramic crowns.[252627] The fit of all ceramic crown restorations was investigated in the late 1990s.[152528] Several accepted methods exist for measuring marginal fit of all ceramic crowns. These include SEM analysis of the restoration

seated on a die and measured. Digital microscopes at 180x and 225x [14,15] and stereomicroscopes at 100x magnification[13] have also been used in the research.

Recently, pressed and CAD/CAM ceramic crowns fabricated from conventional and digital impressions were compared using digitized versions of the master die and the intaglio of the crowns.[29] For conventionally fabricated all ceramic crowns, marginal gaps have been reported from 1-161 microns.[15,29,30,31]

Effect of preparation design on restoration fit

Factors that can affect the marginal adaptation of a ceramic crown have been described previously: finish line configuration (straight shoulder preparation, chamfer design, rounded shoulder design), cement space value (as designated in design software), presence of veneering porcelain, and cementation system used in final delivery.[1,16,32,33,34,35,36,37,38,39,40]

Anatomic preparation design and milling accuracy have been described in the literature. Cook and Fasbinder observed that crown preparations with poor internal adaptation in the occlusal region could be attributed to the Sirona step diamond burs over-milling the internal restoration surface. It also suggested that the step diamond bur diameter may be too large to precisely reproduce internal restoration geometry.[2] The CEREC software algorithm calculates whether to over or under mill the intaglio of the restoration. If there is fine detail to the preparation, the software will over-mill the intaglio of the restoration to ensure complete seating. Attia and Fasbinder concluded that a more anatomic crown preparation resulted in decreased adaptation of the restoration to the tooth surface.[41] An anatomic tooth preparation requires a more complex tool path. Over milling of restorations also produces a larger cement gap. Gold crowns fabricated from digital and conventional impression techniques had statistically similar

and clinically acceptable results when comparing margin gap and internal axial gap, but the internal occlusal gaps were significantly increased with the digital technique.[42] In a load-bearing study May et al found an increased degree of occlusal misfit of milled CEREC crowns, the load bearing ability of the crown decreased with an increasing thickness of the cement gap.[28]

In the fabrication stage, the digital design can be manufactured by milling units of varying capabilities. Three-axis units were capable of moving the milling burs in three dimensions (x, y, and z). With 4-axis mills, a rotation/tilting axis (around the x-axis) is introduced to the material being milled. A 5-axis mill introduces a rotation around the y-axis. This fifth axis of movement allows machining of undercuts in more complex designs. The 3-axis mill is faster, but not as capable of detail as the 4- or 5-axis mill. Studies have demonstrated that if the milling burs are identical, the 5-axis mill is capable of achieving a smaller marginal gap.[43 44 45] However, the 3- and 4-axis mills still produced a clinically acceptable margin.[46 47]

Nakamura et al concluded that when luting space is set in the design program to 30 or 50µm, occlusal convergence of the preparation does not affect the marginal fit or the internal fit of the crown.[23] Tuntiprawon and Wilson reported that when cement thickness exceeds 70 microns in ceramic crowns, the fracture strength decreases compared to crowns with more intimate internal adaptation.[48] A lithium disilicate ACR is commonly bonded to the tooth using resin cement. ISO standard 4049:2009 states, during the working time, low viscosity resin cement should produce a thickness less than 50 microns.

MATERIALS AND METHODS

This study is a continuation of WRNMMC-EDO-2017-0057. It was determined to be non-human use study. The Methods and Materials section was modified from WRNMMC-EDO-2017-0057.

Specimen fabrication

Three ivorine dentoform teeth (tooth #4) were prepared by a single operator according to manufacturer's guidelines for a full coverage lithium disilicate (e.Max, Ivoclar Vivadent Inc., Schaan, Lichtenstein) restoration. For each of the teeth, the mesial and distal surfaces were prepared with different interproximal margin angles (0, 45, 90 degrees) (see Figure 2).

Figure 2. Ivorine teeth prepared with interproximal margin angles of (left to right) 0°, 45°, and 90°

Each die was impressed and duplicated in polymethylmethacrylate (GC pattern resin, GC Coproration, Tokyo, Japan). Using the lost wax technique, each pattern was cast in cobalt-chrome (Co-Cr) alloy (Wironium, BEGO, Bremen, Germany) to fabricate a master die that would resist abrasion when crowns were seated repeatedly for measurement. Each die was

placed in the dentoform and scanned with a CEREC Omnicam (Dentsply Sirona, York, PA) into the CEREC design software (version 4.4.4.139706).

One crown was designed for each interproximal margin angle. Crowns were designed in the software to full contour to 1) replace missing tooth structure and 2) be in occlusion with the opposing arch. The designed crowns were placed in an identical position in the virtual lithium disilicate block to insure a milling strategy in the software that was identical for each of the designs. The digital design files for each crown was transferred to an MC XL 4-axis mill (Dentsply Sirona, York, PA).

Twelve crowns were milled from lithium disilicate (IPS e.max LT A1 size C14, Ivoclar Vivadent, Schaan, Liechtenstein) for each of the margin designs. One set of diamond burs were used for each group's crowns fabrication. Each crown was stored in order of fabrication. After the twelve specimens for a group were fabricated, the diamond burs were replaced in the MC XL mill so that each group's crowns were milled with new diamond burs.

Thirty-six crowns were fabricated in total. Crowns were separated from the unused portion of the lithium disilicate block using diamond burs to facilitate placement on the Co-Cr master dies for measurement.

Measurement of marginal discrepancy

After using a device to seat each crown on its respective die with uniform pressure, each crown was examined using a digital microscope (Hirox KH-7700, Hirox-USA, Hackensack, NJ) at 50x magnification. To measure horizontal discrepancy, the margin was viewed along the long axis of the die. To measure vertical discrepancy, the margin was viewed perpendicular to the long axis of the die. Each axial surface (buccal, mesial, distal, and lingual) was examined for

margin discrepancy at two points. Measurements in microns were made equidistant (1000 μm) from a center line scribed on each surface of the Co-Cr master dies. For each crown, eight measurements were recorded for vertical discrepancy, and eight measurements were recorded for horizontal discrepancy. All measurements were completed by a single investigator.

Statistical analysis

Preliminary statistical analysis was carried out using a single-factor analysis of variance (ANOVA) with the $\alpha=0.50$. Post hoc analysis using t-tests with a Bonferroni correction was used to further compare groups. Further statistical analysis will be undertaken with more robust statistical methods. This paper discusses the preliminary analysis only.

RESULTS

Horizontal marginal discrepancy

The marginal horizontal and vertical discrepancies were measured on 36 crowns with 3 different interproximal margin angles. The means of horizontal marginal discrepancies of the 0-, 45-, and 90-degree interproximal margin angle groups increased as the interproximal margin angle increased (Fig. 3).

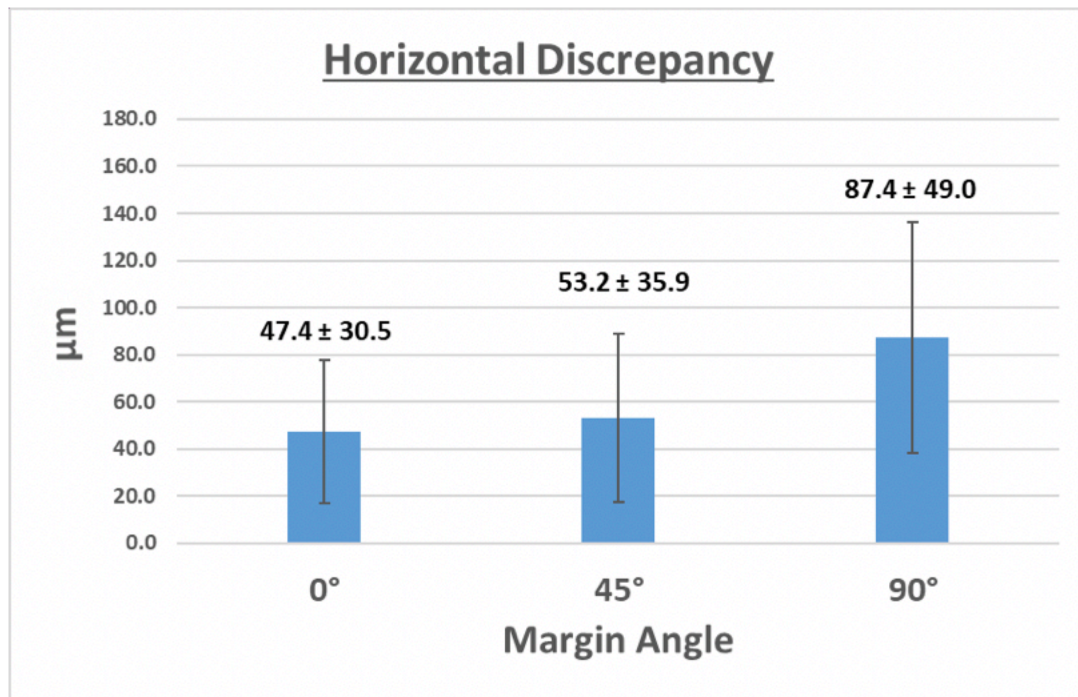

Figure 3. Horizontal marginal discrepancies. Mean and standard deviation for each interproximal angle group are in µm.

The mean horizontal marginal discrepancies for the 0-, 45-, and 90-degree groups were analyzed with a single-factor ANOVA, and results were found to be significantly different ($p<0.001$) (Table 1).

Table 1. One-way ANOVA results of significant effects of horizonal marginal discrepancy results.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	89689.37092	2	44844.69	29.16428	2.99727E-12	3.027443
Within Groups	438232.4561	285	1537.658			
Total	527921.827	287				

Bonferroni correction was calculated (α=0.05; *m*=3) to be 0.016 (α/*m* or 0.05/3). Post hoc analysis revealed no significant difference between the 0- and 45-degree groups (Table 2).

Table 2. t-test: Two-sample assuming equal variances comparing 0° and 45°. Bonferroni correction is 0.016 and p=0.231, the result was not significantly different.

	0°	*45°*
Mean	47.38791667	53.15895833
Variance	927.4074988	1287.874645
Observations	96	96
Pooled variance	1107.641072	
Hypothesized Mean Difference	0	
df	190	
t Stat	-1.201365906	
P(T<=t) one-tail	0.115552343	
t Critical one-tail	1.652912949	
P(T<=t) two-tail	0.231104687	
t Critical two-tail	1.972528182	

Post hoc analysis revealed a significant difference between the 0- and 90-degree groups (Table 3).

Table 3. t-test: Two-sample assuming equal variances comparing 0° and 90°. Bonferroni correction is 0.016 and p<0.001, the result was significantly different.

	0°	*90°*
Mean	47.38791667	87.37354167
Variance	927.4074988	2397.691078
Observations	96	96
Pooled variance	1662.549288	
Hypothesized Mean Difference	0	
df	190	
t Stat	-6.794183037	
P(T<=t) one-tail	6.81389E-11	
t Critical one-tail	1.652912949	
P(T<=t) two-tail	1.36278E-10	
t Critical two-tail	1.972528182	

Post hoc analysis revealed a significant difference between the 45- and 90-degree groups (Table 4).

Table 4. t-test: Two-sample assuming equal variances comparing 45° and 90°. Bonferroni correction is 0.016 and $p<0.001$, the result was statistically different.

	45°	*90°*
Mean	53.15895833	87.37354167
Variance	1287.874645	2397.691078
Observations	96	96
Pooled variance	1842.782862	
Hypothesized Mean Difference	0	
df	190	
t Stat	-5.521979524	
P(T<=t) one-tail	5.45353E-08	
t Critical one-tail	1.652912949	
P(T<=t) two-tail	1.09071E-07	
t Critical two-tail	1.972528182	

Vertical marginal discrepancy

The highest mean vertical discrepancy group was the 90-degree group (Fig. 4).

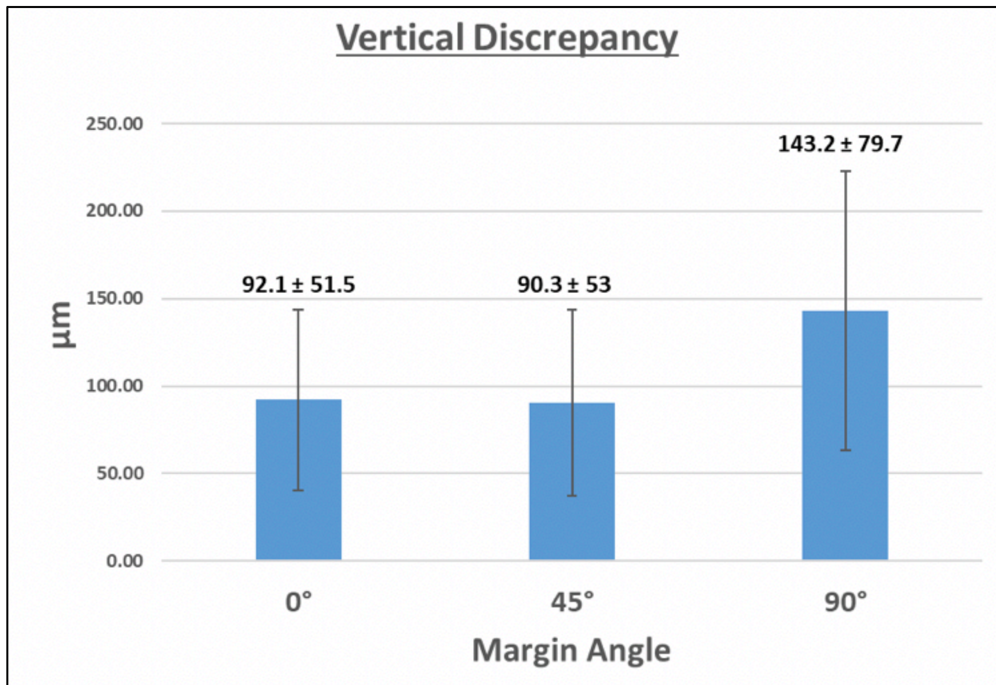

Figure 4. Vertical marginal discrepancies. Mean and standard deviation for each interproximal angle group are in µm.

The mean vertical marginal discrepancies for the 0-, 45-, and 90-degree groups were analyzed with a single-factor ANOVA, and results were found to be significantly different ($p<0.001$) (Table 5).

Table 5. One-way ANOVA results of significant effects of vertical marginal discrepancy results.

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	173100.0896	2	86550.04	21.98995	1.31449E-09	3.027443
Within Groups	1121728.941	285	3935.891			
Total	1294829.03	287				

Previously calculated Bonferroni correction (0.016) was used in the post hoc testing. Post hoc analysis revealed no significant difference between the 0- and 45-degree groups (Table 6).

Table 6. t-test: Two-sample assuming equal variances comparing 0° and 45°. Bonferroni correction is 0.016 and p=0.815, the result was not significantly different.

	0°	*45°*
Mean	92.05072917	90.28615
Variance	2649.699272	2813.067
Observations	96	96
Pooled variance	2731.38318	
Hypothesized Mean Difference	0	
df	190	
t Stat	0.23392222	
P(T<=t) one-tail	0.40764861	
t Critical one-tail	1.652912949	
P(T<=t) two-tail	0.81529722	
t Critical two-tail	1.972528182	

Post hoc analysis revealed a significant difference between the 0- and 90-degree groups (Table 7).

Table 7. t-test: Two-sample assuming equal variances comparing 0° and 90°. Bonferroni correction is 0.016 and p<0.001, the result was significantly different.

	0°	*90°*
Mean	92.05072917	143.1526
Variance	2649.699272	6344.907
Observations	96	96
Pooled variance	4497.302987	
Hypothesized Mean Difference	0	
df	190	
t Stat	-5.279361249	
P(T<=t) one-tail	1.76095E-07	
t Critical one-tail	1.652912949	
P(T<=t) two-tail	3.52191E-07	
t Critical two-tail	1.972528182	

Post hoc analysis revealed a significant difference between the 45- and 90-degree groups (Table 8).

Table 8. t-test: Two-sample assuming equal variances comparing 45° and 90°. Bonferroni correction is 0.016 and $p<0.001$, the result was significantly different.

	45°	*90°*
Mean	90.28614583	143.1526
Variance	2813.067087	6344.907
Observations	96	96
Pooled variance	4578.986894	
Hypothesized Mean Difference	0	
df	190	
t Stat	-5.412727149	
P(T<=t) one-tail	9.28591E-08	
t Critical one-tail	1.652912949	
P(T<=t) two-tail	1.85718E-07	
t Critical two-tail	1.972528182	

DISCUSSION

The null hypothesis was partially rejected for both the horizontal and vertical marginal discrepancy. The results for both horizontal and vertical marginal discrepancies revealed that the measurement of the 0- and 45-degree interproximal margin angle groups were statistically equivalent (horizontal $p=0.231$; vertical $p=0.82$). However, the 90-degree margin angle group was significantly different in both the horizontal ($p<0.001$) and vertical ($p<0.001$) measurements when compared to the 0- and 45-degree groups.

This study examined the effect of the interproximal margin angle on the horizontal and vertical marginal discrepancy. Other factors shown to have an effect on vertical margin gap were identical in each of the groups in this study: finish line configuration (i.e. chamfer versus rounded shoulder preparation), total occlusal convergence of the preparation, cement space setting in the design software, presence of veneering porcelain, and viscosity of the cementation system for delivery of the final restoration.[32 36 37]

The 0- and 45-dgree groups confirmed the findings of previous studies that a CAD/CAM system can fabricate a full-coverage restoration with a clinically acceptable margin gap.[1 23] These results also confirmed that the CAD/CAM system can produce a marginal fit comparable to conventionally produced crowns.[11]

Previous studies have concluded that an increased finish line curvature resulted in an increased margin gap.[38] A comparison of MCRs and CAD/CAM ACRs showed a more significant effect of finish line curvature on MCRs than on CAD/CAM ACRs.[39] Other studies have shown that increased finish line curvature significantly increased the vertical margin gaps in multiple CAD/CAM ceramic systems.[40]

Limitations of the current study

This study measured marginal discrepancy of pre-sintered lithium disilicate on the master dies. The sintering process will result in a 0.2% linear shrinkage, which has been shown to significantly affect internal and marginal gap.[24] A further comparison involving the specimens fabricated for this study could be utilized for additional examination.

The current study utilized a commercially available 4-axis mill for fabrication of specimens. Studies have shown that while 5-axis mills can produce a more exact duplication of the digital design, the 4-axis mill was able to produce a clinically acceptable margin in less time.[43] [44] [45] [46] Previous comparisons of 3- and 5-axis mills showed significantly better marginal adaptation for the 3-axis mill based on the milling tool diameter, so the number of axes of mill is only one factor in marginal adaptation.[47]

Clinical implications

The results of the current study indicate a flatter finish line curvature is indicated for all-ceramic CAD/CAM restorations. As the preparation's interproximal finish line curvature increased, the vertical and horizontal marginal discrepancy increased to a clinically unacceptable vertical marginal gap (90-degree study group). Preparations with a higher degree of interproximal finish line curvature/margin angulation should be avoided.

Further studies

Further statistical analysis on the data collected will give an indication of the effect of sequence of milling on the marginal discrepancy. The comparison of sides (e.g. 0-degree group

buccal surface to 45-degree group buccal surface to 90-degree buccal surface) between groups will indicate if the marginal discrepancy is localized to a surface or surfaces.

Sintering of the crowns produced for this study could show the effect of 0.2% linear shrinkage on the marginal discrepancy. Comparisons of the same crown pre-sinter and post-sinter would be possible.

CONCLUSIONS

Within the limitations of this study, the interproximal margin angle had a significant effect on the horizontal and vertical discrepancy. When increased to 90 degrees, the effect was a clinically unacceptable crown margin.

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