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Marginal Gap of Milled versus Cast Gold Restorations

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Abstract

Purpose: This in vitro study evaluated and compared the vertical marginal gap of cast and milled full coverage gold copings using two margin designs (chamfer and chamfer bevel) before and after fitting adjustments.

Materials and Methods: Ten impressions were made of two metal master dies (one chamfer margin, one chamfer-bevel margin) and poured twice in Type IV stone. The 20 subsequent casts with 40 dies were split into four groups ($n = 10$); cast gold bevel, cast gold chamfer, milled gold bevel, and milled gold chamfer groups. The cast specimens received approximately 40 μm die relief no closer than 1 mm from the finish line. Cast copings were hand waxed, cast in a high noble gold alloy, chemically divested, and the sprues were removed. For milled gold copings, casts were scanned and copings designed using 3shape D900 scanner and software. Parameters were set to approximate analog fabrication (cement gap = 0.01 mm; extra cement gap = 0.04 mm, drill radius = 0.65 mm). Copings were milled from the same high noble alloy. All copings were seated on their respective master die in a custom scanning jig and measured using a measuring microscope at 90× (60 measurements per specimen, 15 per surface). Following initial measurements, all copings were adjusted on stone dies. The number of adjustment cycles was recorded and post-adjustment measurements were made using the same method. Data were analyzed using independent and paired *t*-tests.

Results: Milled gold copings with a beveled margin (11.7 ± 20.4 μm) had a significantly ($p < 0.05$) smaller marginal gap than cast gold copings with a beveled margin (43.6 ± 46.8 μm) after adjustment. Cast gold copings with a chamfer margin (22.7 ± 24.7 μm) had a significantly ($p < 0.05$) smaller marginal gap than milled gold copings with a chamfer margin (27.9 ± 31.6 μm) following adjustments. Adjustments significantly decreased marginal gap for both cast groups ($p < 0.05$) and the milled chamfer bevel group ($p < 0.05$) but had no significant effect on the milled chamfer group.

Conclusions: Within the limitations of this study, results indicate that gold restorations milled with the tested parameters provide a vertical marginal gap that is an acceptable alternative to traditional gold crown casting techniques.

Cast gold is a clinically proven, biocompatible material that has been used for dental restorations for over 100 years[1] and found to have very similar wear characteristics to enamel. Teeth to receive cast gold restorations can often be prepared with minimal reduction to conserve tooth structure, decrease trauma to the tooth and pulp, and maintain esthetic requirements when using partial coverage preparations. Metals remain the only clinically proven materials for many long-term dental applications.[2]

Despite the many advantages of cast gold restorations, increased costs, esthetic requests, and laboratory technique demands have resulted in decreased usage. Gold alloy casting is a routine procedure in most dental labs, but it is time consuming and contains numerous technique-sensitive steps. An additional consideration is the cost of material lost during finishing and polishing procedures.

The fit of a restoration, a vital component to longevity and success, is often evaluated by marginal adaptation. Implications of poorly adapted margins on periodontal health include increased plaque retention, gingival inflammation, recurrent caries, and microleakage involving the dentinal tubules.[3,4] Gingival inflammation and sulcular fluid rates increase around full-coverage restorations.[5] The biologic response to changes

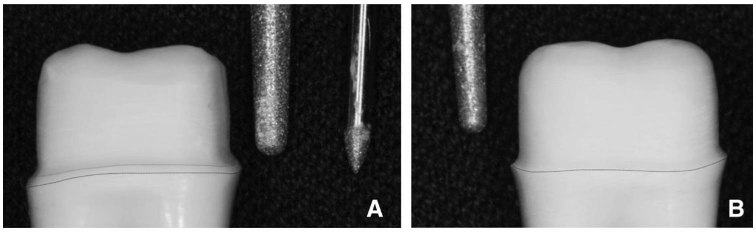

Figure 1 Typodont preparations with chamfer finish line with bevel (A) and chamfer finish line (B). Dashed lines delineate start of bevel and location of finish lines.

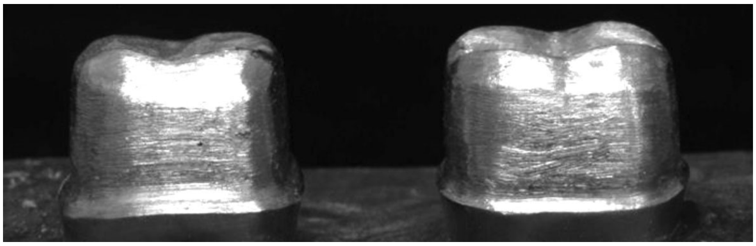

Figure 2 Ticonium master dies embedded in acrylic resin block.

in tooth surface material and plaque retention can lead to a deterioration of soft tissues and an increase in periodontal disease.[6,7]

Marginal fit is a significant factor for the clinical success of a full-coverage restoration. This is often a comparative factor when evaluating new materials or fabrication methods. Holmes et al discussed different types of misfit, suggesting the term *vertical marginal discrepancy* for the more common term, "open margin," which applies to the vertical measurement between restoration edge and finish line along a line directly parallel to the path of draw.[8]

Marginal adaptation of conventional waxing and casting techniques has been compared using a nickel-chrome alloy.[9] Mean marginal gaps in conventionally waxed and cast groups were significantly smaller than those cast from wax patterns fabricated by CAD/CAM. Cast and milled titanium restorations have also been compared, noting an improved marginal adaptation with conventional casting techniques and significantly larger marginal discrepancies with knife-edge margins using both techniques.[10] Another study with similar comparisons noted that manual refinement improved the fit of both the cast and milled titanium restorations.[11] Casting techniques vary distinctly for titanium as compared to gold, however, and conclusions cannot be uncritically extrapolated to gold restorations.

Until recently, noble alloys for full-coverage restorations were not milled. To use CAD/CAM technology, wax patterns could be milled and then cast by conventional methods. Milled gold alloys have recently become available in the dental marketplace (Strategy Milling, Leetsdale, PA). This new product line has not been evaluated as to accuracy of marginal fit. The purpose of this study was to evaluate and compare the vertical marginal gap of copings made with a conventional casting technique and milled full-coverage gold copings using two margin designs (chamfer and chamfer bevel).

Materials and methods

An in vitro study was designed with four groups of gold copings ($n = 10$): cast gold with a chamfer margin (CGC), cast gold with a chamfer bevel margin (CGB), milled gold with a chamfer margin (MGC), and milled gold with a chamfer bevel margin (MGB).

Master die fabrication

Following suggested preparation guidelines,[12] two typodont mandibular second molar teeth (#31) were prepared by a single operator (Fig 1) and impressed using an extra-light viscosity polyvinyl siloxane (PVS) (Aquasil; Dentsply, York, PA) impression material in medicine cups, then duplicated in autopolymerizing acrylic resin (GC Pattern Resin; GC America, Alsip, IL). The duplicate dies were cast in nickel-chrome alloy (Ticonium; Nobilium Company, Albany, NY) and polished using rubber wheels immediately below the finish lines. The preparation and finish line surface were refined using the same burs as the initial preparation to obtain a surface finish on the Ticonium master dies that would simulate a natural tooth preparation. The cast metal dies were then embedded in a block of autopolymerizing acrylic resin (GC Pattern Resin) (Fig 2).

Impressions

A 2 mm resilient mouthguard material (Biostar; Great Lakes Orthodontics, Tonawanda, NY) was thermoformed over the master cast to create a uniform spacer.[13] Ten trays were made with a visible light-cured resin (Triad; Trubyte International, York, PA). The custom trays were fabricated over a spacer with a cast stop at the periphery. PVS tray adhesive (Genie; Sultan Healthcare, Hackensack, NJ) was applied to trays at least 15 minutes prior to impression making.[14] Ten impressions were made using PVS (Aquasil) heavy-body tray material and extra-light viscosity material injected around the finish lines. The impression material was allowed to set a minimum of 8 minutes at room temperature before removal from the Ticonium master dies.

Die fabrication

All impressions were poured twice in a Type IV stone (Silky Rock; Whip Mix Corp, Louisville, KY). Casts were allowed to

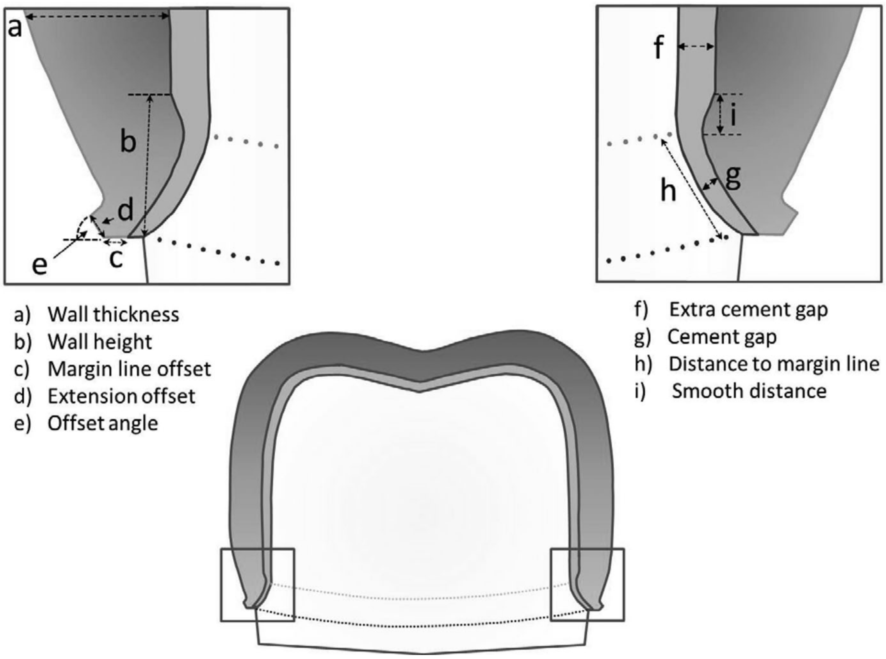

Figure 3 CAD coping parameters (left) and relief parameters (right). Not to scale.

set for 48 hours. Each study group (CGB, CGC, MGB, MGC) was fabricated with five casts from the first pour and five casts from the second.

CAD/CAM fabrication

Casts from all 10 impressions (5 first pours, 5 second pours) were scanned using a 3Shape D900 scanner (3Shape, Copenhagen, Denmark). Using the manufacturer's software for crowns/copings, material settings were programmed to allow for 40 μm of die relief 1 mm from the finish line of the scanned preparations. CAD relief parameters and material settings (Fig 3) were selected to closely approximate conventional methods for cast restorations (wall thickness = 0.5 mm; wall height = 1.0 mm; margin line offset = 0.05 mm; extension offset = 0.05 mm; offset angle = 70°; extra cement gap = 0.04 mm; cement gap = 0.01 mm; distance to margin line = 1.0 mm; smooth distance = 0.5 mm; drill radius = 0.65 mm). The settings permitted comparison to current workflow protocols. The digital .stl files were electronically transmitted to a milling center (Strategy Milling, Leetsdale, PA). Copings were milled using a commercial 5-axis milling machine (RXD5; Roeders Gmbh, Soltau, Germany) in SM 55 (Atlantic Precious Metal Refining, Leetsdale, PA), a type IV high noble alloy (Au 55.0%, Pd 5.2%, Ag 30.0%, Cu 9.0%, In<1%, Ir<1%).

The CAD parameters that must be considered are as follows: (a) *wall thickness*—minimum thickness of coping, (b) *wall height*—distance from the margin where "wall thickness" is enforced, (c) *margin line offset*—horizontal offset to allow for finishing and polishing, (d) *extension offset*—additional horizontal offset at specified offset angle, (e) *offset angle*—angle at which extension offset projects to allow for mill access and adequate thickness at the margin, (f) *extra cement gap*—programmed die relief on die surface, (g) *cement gap*—programmed space at the margin, (h) *distance to margin line*—distance from finish line to beginning of "*extra cement gap*," (i) *smooth distance*—distance over which relief transitions from cement gap to extra cement gap dimensions. *Drill radius* programs additional relief over the die in areas that otherwise could not be milled to accommodate for the drill size used.

Cast coping fabrication

Casts from 10 impressions (5 first pour, 5 second pour) were painted with two coats of die spacer (Euro Classic; KerrLab, Orange, CA), approximately 40 μm total, located approximately 1 mm from the finish line. Conditioner (Die Stone Conditioner; Dental Ventures of America, Corona, CA) was placed at the finish lines, and separator (Very Special Separator; Dental Ventures of America) was applied over the preparation surface. Margin wax and green inlay wax were hand applied and trimmed to appropriate contours. All margins were evaluated under 3.5× magnification during separation. Wax patterns were sprued and invested using phosphate-bonded investment (Bellavest SH; BEGO, Bremen, Germany) and cast using identical type IV high noble alloy (SM55) and a broken arm centrifugal casting machine. All copings were cast with new alloy. Copings were chemically divested using Strip-It (Keystone Industries, Myerstown, PA) and then separated from their sprues.

Measurements

Prior to adjustment of cast or milled copings, vertical marginal gaps were measured as described by Holmes et al[8] using a measuring microscope (FMA050; AmScope FMA050, Irvine,

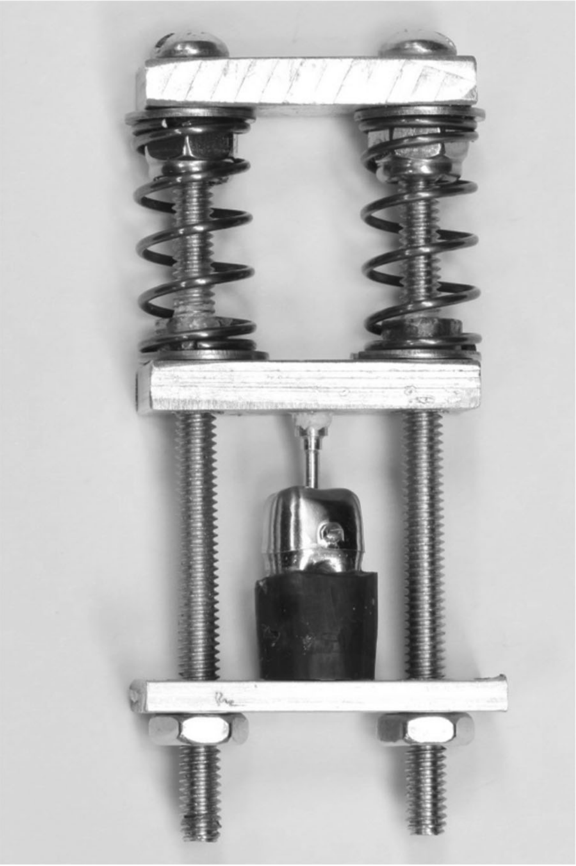

Figure 4 Seating device for measuring microscope measurements.

CA). All copings were seated on the master Ticonium die using spring-loaded pressure in a custom jig that applied a uniform 13-N force in the same occlusal location for all copings (Fig 4). Sixty measurements were made per specimen (15 per surface) perpendicular to the surface as described by Groten et al.[15]

After initial measurements, all copings were fitted to their respective stone dies by using a disclosing agent (Occlude spray; Pascal Co., Bellevue, WA) applied to the internal of the copings. Copings were adjusted as needed until margins appeared either visually acceptable at 3.5× magnification or until a maximum of five adjustment cycles were completed. The number of adjustment cycles was recorded for each specimen. An adjustment cycle was considered to be all adjustments made from a single Occlude coating. Adjustment cycles were separated by steam cleaning of the residual disclosing agent on the coping and die followed by reapplication of disclosing agent to the intaglio surface of the coping. After adjustments, all copings were placed on the master die, mounted in the scanning jig, and measured in the same fashion as initial measurements (Fig 5).

Statistical analysis

Marginal discrepancy data were analyzed using independent *t*-tests. Paired samples tests were completed to evaluate the effects of adjustments, and ANOVA was used to analyze effects of multiple variables (SPSS 21.0 Software for Windows; SPSS Inc., Chicago, IL).

Results

Tables 1 and 2 provide the mean (standard deviation) vertical marginal gap of all copings before and after adjustment and the number of adjustments required. Table 3 summarizes the vertical marginal discrepancy of cast and milled margins. Figure 6 displays the mean vertical margin discrepancies of each group before and after adjustment. MGB had significantly ($p < 0.05$) smaller marginal discrepancies than CGB before and after adjustment. MGC had significantly smaller marginal discrepancies than CGC prior to adjustment ($p < 0.05$), but CGC had significantly ($p < 0.05$) smaller discrepancies following adjustment. Paired samples tests found significant differences in vertical marginal discrepancies for CGC ($p < 0.05$), CGB ($p < 0.05$), and MGB ($p < 0.05$) before and after adjustment. No significant difference was found between MGC margin discrepancies before or after adjustments. Both cast groups required more manual refinement than corresponding milled groups. Statistical analysis using one-way ANOVA revealed a significant difference between the method of manufacture (cast and milled) and between the adjustments (before and after) ($p < 0.05$), but no significant compounding interactions between variables (Table 4).

Discussion

Marginal adaptation is an important feature of an indirect restoration;[4] however, adaptation of a restoration is much more

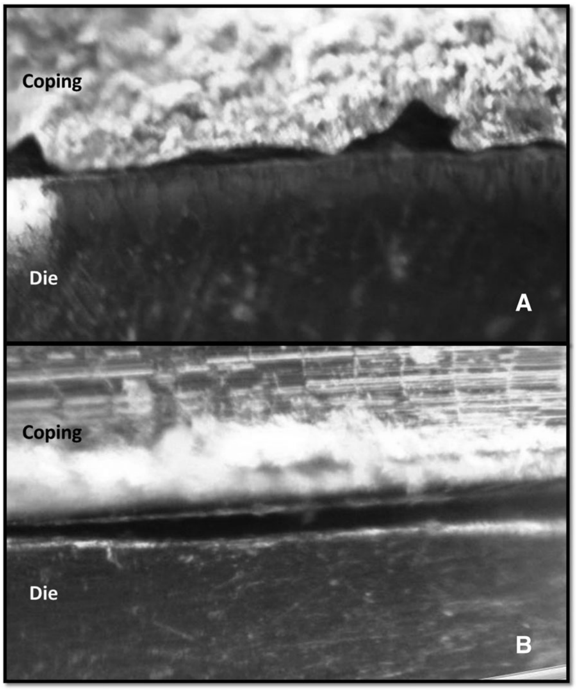

Figure 5 Measuring microscope photos (90×) of cast (A) and milled (B) margins.

Table 1 Chamfer mean marginal gap (standard deviation) before and after adjustments and number of adjustment cycles per specimen.

Specimen	Milled pre (μm)	Milled post (μm)	# Adjustments	Cast pre (μm)	Cast post (μm)	# Adjustments
1	49.1 (36.1)	47.1 (38.5)	1	35.7 (31.4)	30.2 (32.1)	1
2	26.2 (31.8)	23.5 (33.0)	1	44.1 (32.9)	31.4 (27.8)	2
3	28.1 (25.1)	22.3 (24.8)	1	25.8 (21.0)	10.7 (10.1)	2
4	24.6 (27.9)	32.9 (36.9)	1	44.2 (41.2)	26.6 (24.8)	2
5	16.3 (17.4)	17.0 (21.7)	1	37.9 (31.7)	23.4 (26.6)	1
6	17.0 (20.5)	23.1 (24.0)	1	33.6 (30.6)	23.9 (25.6)	1
7	27.5(25.3)	26.8 (28.3)	1	28.5 (21.3)	26.6 (21.7)	1
8	26.8 (25.5)	22.2 (25.0)	1	72.5 (46.3)	14.6 (13.9)	2
9	29.0 (33.1)	32.1 (34.9)	1	60.0 (37.2)	30.2 (27.8)	2
10	32.5 (35.1)	32.5 (34.8)	1	14.6 (22.7)	9.5 (15.6)	1

Table 2 Chamfer-bevel mean marginal gap (standard deviation) before and after adjustments and number of adjustment cycles per specimen.

Specimen	Milled pre (μm)	Milled post (μm)	# Adjustments	Cast pre (μm)	Cast post (μm)	# Adjustments
1	38.6 (29.3)	28.5 (34.5)	1	116.1 (49.7)	77.4 (50.7)	2
2	23.7 (24.5)	14.4 (15.4)	1	98.9 (51.1)	52.9 (50.5)	2
3	8.0 (9.9)	6.2 (11.4)	1	39.1 (43.0)	26.4 (31.1)	1
4	6.0 (9.8)	2.4 (7.3)	1	244.1 (85.3)	59.7 (57.8)	3
5	13.8 (20.3)	18.3 (24.1)	1	42.9 (37.4)	32.6 (36.4)	5
6	14.2 (17.3)	4.1 (8.6)	1	22.5 (24.6)	22.9 (27.9)	3
7	19.6 (18.3)	10.7 (20.4)	1	27.6 (21.8)	14.5 (18.0)	1
8	12.3 (19.6)	7.3 (15.5)	1	213.3 (59.9)	81.1 (43.5)	2
9	7.5 (10.8)	11.6 (18.2)	1	50.4 (43.3)	36.2 (38.5)	3
10	14.8 (24.1)	13.8 (21.3)	1	100.0 (57.7)	51.1 (50.4)	2

complex that a single component, as discussed by Holmes et al.[8] This study evaluated a new fabrication method for currently available full coverage gold restorations. Numerous methods are available to evaluate accuracy of full coverage restorations.[3] Measurements are completed by direct visualization, cross-section, or impression replica techniques. This report is limited to vertical marginal gap analysis before and after refinement by direct measurement. Internal adaptation and evaluation following cementation were not evaluated.

The research methodology was designed to simulate expected workflow (digital or conventional) from prepared tooth through fabrication and evaluation of the final restoration on the originally prepared tooth (master Ticonium models/dies). To minimize risk of detrimental or compounding effects on results, several precautions were taken: (1) All impressions were poured twice, and copings in each group were fabricated from half of the first pour casts made and half of the second pour casts to reduce risks of bias based on accuracy of multiple pours. (2) Design and milling parameters were set to closely approximate conventional methods to reduce risk of poor internal adaptation or over/under-seating of milled copings. (3) Cast copings were individually cast to reduce bias from casting/investment anomalies. (4) Castings were divested chemically to eliminate risk of damage to margins from air particle abrasion. and (5) All copings were fitted to their respective stone dies, and then measured on the master Ticonium die to simulate a clinical evaluation.

Table 3 Mean marginal gap (standard deviation) before and after adjustments and mean adjustment cycles for each group.

Group	Pre-adjustment (μm)	Post-adjustment (μm)	Adjustment cycles
CGC	39.7 (36.1)	22.7 (24.7)	1.5
CGB	95.5 (89.4)	43.6 (46.8)	2.4
MGC	27.7 (29.5)	27.9 (31.6)	1
MGB	15.9 (21.4)	11.7 (20.4)	1

Table 4 ANOVA results for the vertical marginal gap of copings.

Treatment	Mean square	F	*p*-value
Margin design (MD)	91.52	1.304	0.288
Manufacture method (MM)	1979.95	11.03	<0.0001
Adjustment (A)	1214.19	4.993	0.005
MD x MM	73.89	1.58	0.401
MD x A	42.7	0.575	0.635
MM x A	447.8	1.458	0.242

Several steps of routine fabrication were noted to have direct effects on marginal adaptation of milled copings. During the scanning and design process, virtual delineation of the finish line determines the extension of the milled copings. Depending on the resolution of the scanning system used, this delineation can be challenging. A virtual finish line is easiest to determine

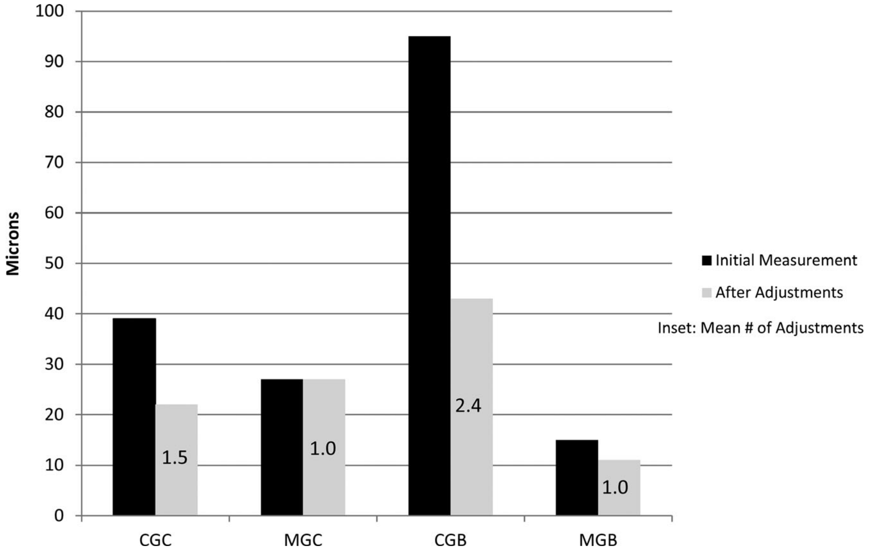

Figure 6 Mean vertical marginal gap per group before and after adjustment.

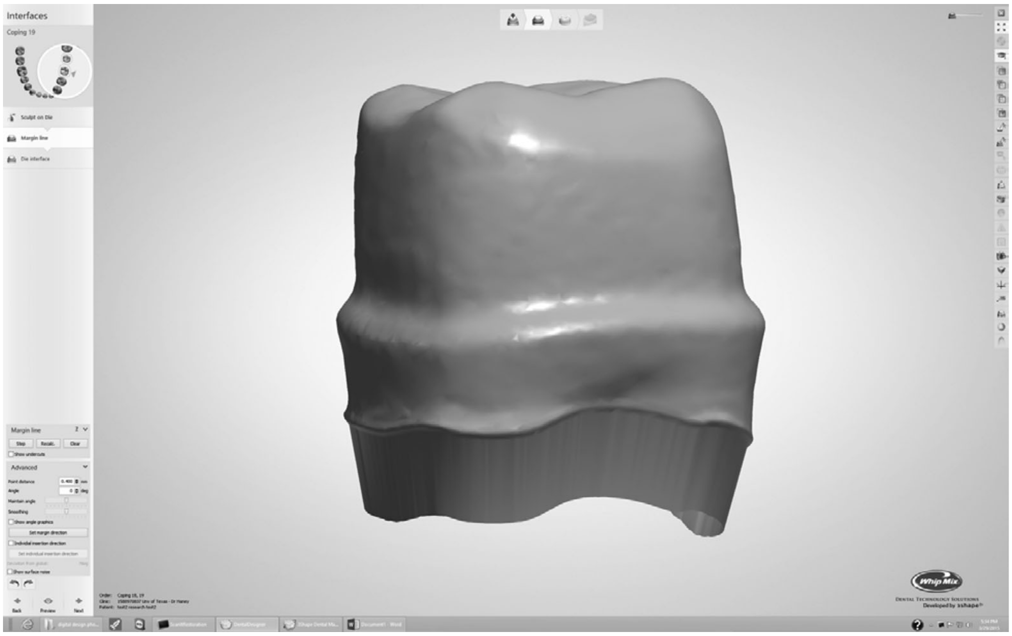

Figure 7 Screenshot of scanned die (MGB group) prior to identification of finish line location.

with a sharply defined finish line on the trimmed die. The finish line of a beveled margin can be difficult to discern on the scanning software (Fig 7), potentially leading to the milled margin being over or under extended.

Another milling factor of significance is that the design software often does not account for minor variations in the finish line and tends to blend the finish line irregularities into a smooth continuous line. This results in a smooth continuous milled margin that is adapted less accurately in the areas of the irregular finish line geometry when viewed under a microscope. If the CAD software were capable of defining a precise finish line location at the micron level, CAM is only capable of milling to the smallest drill size used. As a result, CAM is incapable of exact replication of irregularities less than the drill dimensions. This has been discussed in previous research evaluating the fit of milled ceramic restorations and critically evaluating finish line geometry for errors.[16] The 5-axis mill and drill geometry improves but does not eliminate these challenges.

There is also the possibility that the margin could be extended beyond the finish line. This could be due to inaccurately locating a precise finish line for milled copings or because copings fabricated with die relief may seat further due to the internal relief. There is no method of direct measurement to quantify a negative value for vertical marginal gap. Margins overextended vertically were assigned a 0.0 μm value in the assertion that the margin could be finished or adjusted to the finish line. No manual refinement or manipulation of margins was made for any copings in this study.

There was an attempt at standardizing cement space (approximately 40 μm), and copings were not cemented to avoid additional variables. The CAD parameter "extra cement gap" (virtual die relief) selected was 40 μm, which was less than the manufacturer's recommendation (70 μm). A systematic review on CAD/CAM ceramics listed cement space as a factor impacting marginal adaptation.[17] A pilot study was conducted to address complete seating and resistance to rotation when varying the "extra cement gap" from 20 to 70 μm. A virtual die relief of 40 μm allowed a passive fit and acceptable marginal adaptation. The reduced relief dimension allowed for more direct comparison of internal relief and marginal adaptation between cast and milled groups.

Results showed that milled gold copings on idealized preparations had acceptable vertical marginal gaps. Manual adjustment improved the vertical marginal gap of milled chamfer bevel copings ($p < 0.05$), but in contrast to previous CAD/CAM studies on titanium, manual adjustment did not improve fit of the milled chamfer copings ($p > 0.05$). This may be due to irregularities in casting, including nodules. Milling is a subtractive process and is less likely to have positive nodules affect seating. As a general trend, more improvement was noted adjusting cast restorations, where the statistically significant improvements in the milled chamfer-bevel group may not correlate to a clinical significance.

A unique observation that contrasted general recommendations for CAD/CAM restorations was that the gold alloy could be milled to a beveled margin without negatively affecting marginal adaptation. Also, the continuity of the milled margins was smooth and consistent as opposed to the irregularities noted in the cast groups (Fig 5).

Due to the large number of measurements per coping, it was possible to show significance as noted previously.[15] Significant difference was noted among several comparisons including MGB before and after adjustment compared to CGB as well as measurements of MGC and CGC after adjustments. Adjustments improved the milled chamfer bevel copings approximately 4 μm, which was statistically significant, but may not be of clinical significance. Adjustment of cast copings appeared to be necessary to maximize fit compared to those milled (Table 1). All copings exhibited clinically acceptable vertical margin discrepancies following adjustment. Other types of misfit were not assessed, and statements cannot be made for internal or horizontal discrepancies.

Further studies should evaluate marginal adaptation to irregular finish lines, box and groove adaptation for partial coverage restorations, and internal adaptation compared to conventional cast gold restorations.

Conclusions

Within the limitations of this study and given the specific milling strategy used, the following conclusions can be drawn:

1. For chamfer preparations, milled copings had a significantly smaller vertical marginal gap than cast copings before adjustments but cast copings were more accurate following adjustments.
2. For chamfer bevel preparations, milled copings had a significantly smaller vertical marginal gap than cast copings before and after adjustments.
3. Adjustments significantly improved the fit of both cast groups, but may not make a clinically significant difference for the milled groups.
4. Both milled groups required less internal refinement than the cast groups.

Results indicate that gold restorations milled to the tested parameters may provide an alternative to traditional lost-wax casting techniques, but further study is needed to evaluate fit for scalloped and irregular preparations.

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