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An In Vitro Comparison of Vertical Marginal Gaps of CAD/CAM Titanium and Conventional Cast Restorations

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Abstract

Purpose: To determine if there was a significant difference between the vertical marginal openings of cast restorations, computer-aided design, and computer-aided machining restorations.
Materials and Methods: Ten working dies were created from a single master die and used to fabricate ten restorations in each of the following groups: computer-aided design/computer-assisted machining (CAD/CAM), WAX/CAM, and WAX/CAST. The CAD/CAM titanium restorations were fabricated using the scanning and crown design modules of the KaVo Everest system. The WAX/CAM titanium restorations were fabricated using the double scan technique with the KaVo Everest system. The WAX/CAST high noble copings were fabricated using the conventional lost wax casting technique. The restorations were seated on the master die, and high-resolution digital photographs were made of the marginal area on all four sides. The vertical marginal opening was then measured using a calibrated digital software program. One-way ANOVA and Tukey's post hoc tests were used to determine the presence of statistically significant differences.
Results: The vertical margin openings were CAD/CAM: 79.43 ± 25.46 μm; WAX/CAM: 73.12 ± 24.15 μm; WAX/CAST: 23.91 ± 9.80 μm. There was a statistically significant difference between the WAX/CAST group and the remaining groups.
Conclusions: There was no difference between the vertical marginal gaps of the CAD/CAM and WAX/CAM. The WAX/CAST technique resulted in smaller vertical marginal gaps than either CAD/CAM or WAX/CAM.

The minimization of crown and fixed partial denture marginal gaps is an important goal in prosthodontics. Smaller marginal gaps produce less gingival irritation[1,2] and cement washout,[3,4] improving the clinical outcome and longevity of the restoration. The absolute value of the vertical marginal gap deemed to be clinically acceptable has been debated in the literature with proposed values ranging from to 39 to 120 μm.[5] A definitive value has not been identified as the benchmark for clinical acceptability, because clinical identification and quantification of the gap can be difficult[6] depending on location[5] and instrumentation used.[7,8] This emphasizes the need for fabrication techniques that can produce restorations with minimal vertical marginal gaps in a repeatable fashion. The vertical marginal gaps of full cast restorations and porcelain shoulders have been reported to be statistically similar[9,10] and are the current benchmark for emerging technologies.

Titanium is gaining popularity as a restorative material for implant, fixed, and removable prosthodontics. There have been a variety of published reports regarding the vertical marginal gaps of computer-aided design/computer-assisted machining (CAD/CAM) titanium crowns. Samet et al[11] reported that the Titan system (DCS Dental AG, Allschwil, Germany) produced crowns with a mean marginal opening of 175 μm. Bessimo et al,[12] using the same system, found lower marginal gaps in the range of 47 μm. Karlsson[13] found that the mean marginal discrepancy for Procera (Nobel Biocare USA, Inc., Yorba Linda, CA) titanium crowns was 70 μm when measured in vivo. Importantly, none of these reports included a control restoration.

Reports comparing the marginal gap of CAD/CAM titanium crowns and their cast equivalents have presented mixed results. All have compared Procera titanium crowns with a cast noble metal crown. Leong et al[14] showed that the titanium crowns had a statistically greater marginal gap (54 μm) than cast noble crowns (25 μm). Harris and Wickens[15] found that the titanium copings yielded larger marginal gaps than cast copings. Valderrama et al[16] reported that there were no significant differences between the vertical marginal gaps of titanium crowns and cast metal ceramic crowns.

KaVo USA (Lake Zurich, IL) released the Everest CAD/CAM system to the US market in 2003. It uses an optical scanner to read the stone die/replica of the tooth. The restoration design can be generated with the computer software, or alternatively, a scan can be made of a waxed crown. The final restoration is then cut from a prefabricated blank in the milling engine. The distinguishing features of this system are the noncontact scanner that does not alter the stone die, five-axis milling capability, and the ability to mill a variety of materials, one of which is titanium.

The purpose of this study was to compare the vertical marginal gaps of CAD/CAM titanium copings made with Everest (KaVo USA) to that of cast high noble copings.

Materials and methods

An ivorine (Columbia Dentoform, New York, NY) right maxillary first molar was prepared with diamond rotary cutting instruments (6878K, Brasseler USA, Savannah, GA) to receive a full coverage restoration. The marginal design consisted of a 0.8-mm, 360° chamfer with 12° of total occlusal convergence. Occlusal reduction of 1.5 mm was performed to receive a complete crown. An impression of the dentoform tooth was made with light viscosity (Aquasil LV, Dentsply Caulk, Milford, DE) and putty poly(vinyl siloxane) (Exaflex, GC America, Alsip, IL). The impression was poured in acrylic resin (GC pattern resin, GC America), invested in a phosphate-bonded invested material (Fujivest, GC America), and cast in a high palladium alloy (76SF, W. E. Mowrey, Minneapolis, MN) to produce a master die. This master die, which served as the "patient" (Fig 1), was then refined with the same rotary instrumentation used previously and polished with Brownie and Greenie rubber points (Shofu Dental Coorporation, San Marcos, CA).

Twenty impressions were made of the master die using light viscosity (Aquasil LV) and putty (Exaflex) poly(vinyl siloxane). The ten impressions were randomly selected and poured in pink type IV die stone (Silky Rock, Whip Mix, Louisville, KY). The dies were then applied with four layers of die spacer (Tru-Fit Die Relief and Visual Aid Kit, George Taub Products & Fusion Co., Inc., Jersey City, NJ) and one layer of die hardener (Stone Die & Plaster Hardener; George Taub Products & Fusion Co., Inc.). The remaining ten dies were poured in Everest Rock.

Thirty restorations (20 titanium, 10 high noble metal) were fabricated, using the following technique: The Everest Rock dies were scanned in the optical scanner (1.002.1708, KaVo USA) (Fig 2) following the manufacturer's instructions to record the external die form. The CAD design module (version 3.04.04) (Fig 3) determined the margin location, and copings were programmed to be 1-mm thick. The appropriate emergence profile was selected (design #2) to follow the emergence profile of the die. Simulated die spacer was set at 80 μm, starting 1 mm from the margin. One titanium coping (test group: CAD/CAM, n = 10) for each die was then machined in the milling engine (version 3.3.2.3) from a titanium blank (1.003.0249, KaVo USA).

The Everest Rock dies were then sealed (Everest Die Hardner; KaVo USA), and wax separator (Everest Insulation, KaVo USA) was applied. Everest Scan Wax (KaVo USA) was used in the production of 1-mm thick wax copings with the

Figure 1 Finished master die.

Figure 2 Die in Everest scanner.

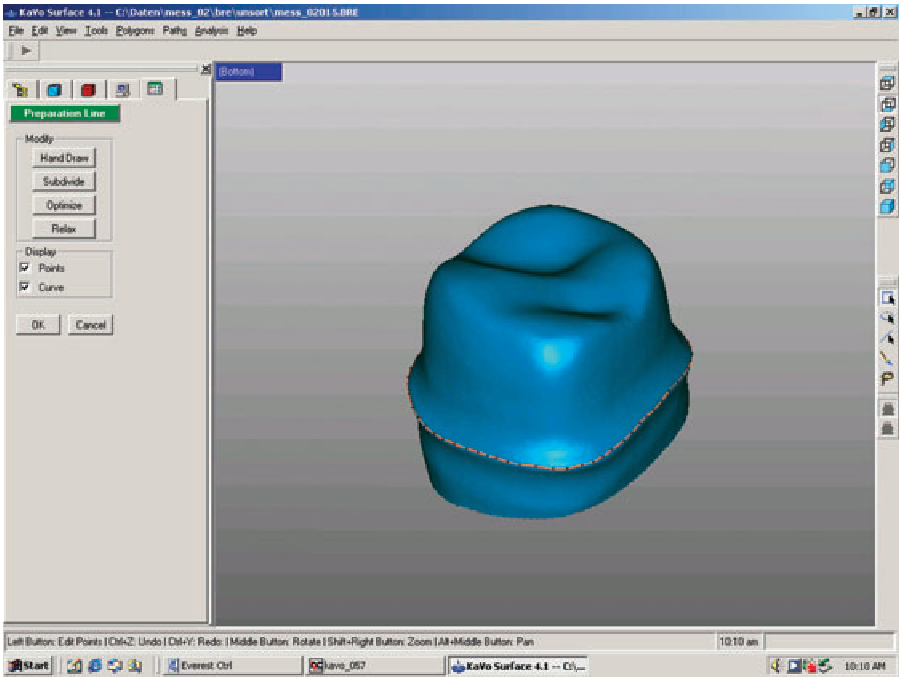

Figure 3 Screen shots of Everest program.

following standardized procedure: a poly(vinyl siloxane) split mold was constructed around a preexisting titanium coping, which had been seated on spare stone die. The mold was filled with molten wax, and the stone die was inserted. Once the wax had cooled sufficiently, the mold was separated, and the die/coping combination removed. The thickness of the copings was verified using an Iwanson gauge, and the margins were adapted and finished using 10× magnification (OPMI Pico, Carl Zeiss Surgical, Inc., Thornwood, NY). The dies and their wax copings were sequentially scanned in the optical scanner (1.002.1708), and using the CAD design module (version 3.04.04), the simulated die spacer was programmed at 80 μm, starting 1 mm from margin. One titanium coping (test group: WAX/CAM, n = 10) for each die, was machined in the milling engine (version 3.3.2.3) from a titanium blank (1.003.0249). The internal fit of all the titanium restorations was checked on the master die using Fit-checker (GC America) to ensure that no internal binding was occurring.

Wax copings (1 mm thick) were fabricated for the Silky Rock dies selected for the casting technique. The thickness of the copings was verified using an Iwanson gauge, and the margins were adapted and finished using 10× magnification (OPMI Pico). Wax sprues were attached, and all ten copings were invested together in a phosphate-bonded investment (Fujivest II, GC America) with a 3:2 special liquid:distilled water ratio. After heating to 1350°C (Temp Master A, Jelrus, Hicksville, NY) the copings were cast in high noble alloy (52SF, W. E. Mowrey) using a centrifugal casting machine (Centrifico, KerrLab Co, Orange, CA). The castings (test group: WAX/CAST, n = 10) were removed from the investment and cleaned with 50-μm aluminum oxide. The internal fit of the cast restorations was checked on the master die using Fit-checker, and internal relief was provided with a rotary carbide bur (H379.31018, Brasseler USA) to remove areas of internal binding.

Fiduciary marks were made apical to the margin on the master die to indicate the line angles. All copings were sequentially placed on the master die and loaded with a 5-kg weight centered on the coping. A 1:1 photograph (6.3 Megapixels, RAW format) was made of each of four sides of the die using a digital SLR camera (Canon 10D with 100-mm macro lens, Canon USA, Inc., Lake Success, NY) mounted on a tripod. Photographs (Fig 4) were taken sequentially with no change in the horizontal inclination of the camera. A digital photograph was made of a millimeter ruler, at the same magnification, for use in calibration of the measurement software.

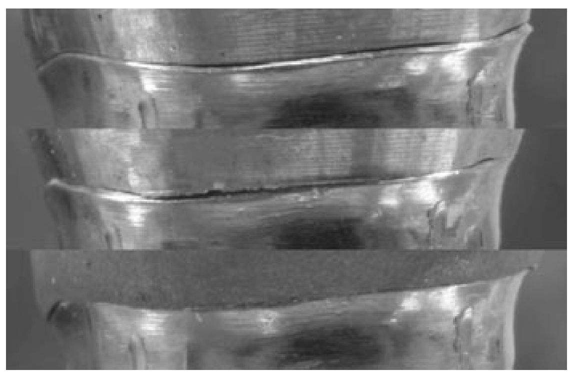

Figure 4 Lingual surface of CAD/CAM (top), WAX/CAM (middle), and WAX/CAST (bottom) samples.

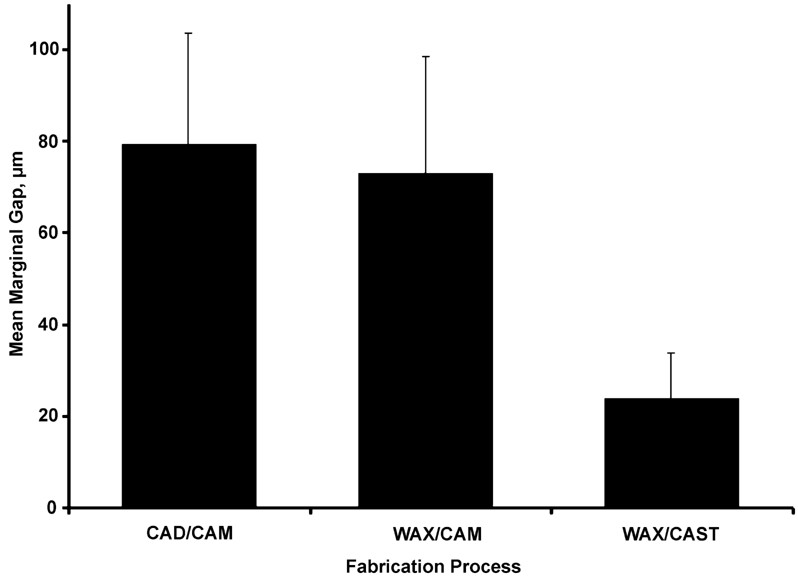

Figure 5 Mean marginal gaps (μm) for experimental groups.

The pictures were converted from RAW format to 16 channel TIFF files and imported into measurement software (Image Pro Plus version 2.0, Media Cybernetics, Silver Spring, MD). The coping and master die margins were manually traced between the areas of the fiduciary marks. The software determined the mean separation between the lines in micrometers. To ensure that the software was correctly calibrated for the data collection, a periodic measurement of a known distance was made. Mean separation for all four sides of the 30 copings was recorded for statistical analysis. One-way ANOVA was used to determine if the fabrication technique (CAD/CAM, WAX/CAM, WAX/CAST) influenced the vertical marginal gap. A Tukey's post hoc test was performed to determine the significant differences between groups.

Results

Figure 5 charts the mean vertical marginal gaps for the three test groups. The descriptive statistics for the test groups are as follows:

- CAD/CAM: 79.43 ± 25.46 μm
- WAX/CAM: 73.12 ± 24.15 μm
- WAX/CAST: 23.91 ± 9.80 μm.

The summary of the one-way ANOVA ($\alpha = 0.05$) is reported in Table 1. The analysis revealed that there was no statistical difference between the CAD/CAM and WAX/CAM test groups. The vertical marginal gap for the WAX/CAST test group was significantly smaller than CAD/CAM and WAX/CAM test groups.

Discussion

The noncontact scanning technique of the Everest scanner allowed the CAD/CAM restorations to be scanned and fabricated without any damage being inflicted on the die. The WAX/CAM technique required that the die be subjected to additional material application (die harder and separator) and instrumentation (wax carving), which has the potential to alter the marginal geometry and decrease intimacy of the marginal fit. There was, however, no statistical difference detected between the CAD/CAM and WAX/CAM techniques, suggesting that the additional steps did not interfere with marginal adaptation. The results also suggest the automatic margin detection feature of the CAD/CAM program functions as well as human determination. Given the simplicity of automatic margin detection and restoration design compared to manual waxing, it makes the most sense to use the CAD/CAM features where possible.

This study found that the WAX/CAST restorations had a significantly smaller vertical marginal gap compared to both the CAD/CAM and WAX/CAM groups. It is important to note that the measurements obtained were specific to this hardware/software combination. While the lost wax technique

Table 1 One-way ANOVA for vertical marginal gaps ($p = 0.05$)

ANOVA Source of variation	SS	df	MS	F	*p*-value	F crit.
Between groups	73,927.67	2	36,963.83	50.13746	1.88E-16	3.073763
Within groups	86,258.23	117	737.2499			
Total	160,185.9	119				

SS = Sum of squares; df = degrees of freedom; MS = mean square.

Figure 6 Undercontoured emergence profile of titanium coping.

has been used in dentistry for a significant period of time, computer-aided techniques for dental restorations are improving rapidly, and it is expected that the revisions to the system will result in system accuracy. The 5-axis milling engine is unique in the dental industry and represents state-of-the-art precision milling. There have been multiple software revisions to the KaVo Everest system since the time of experimentation to best use the milling technology. Further experimentation with these improvements is needed to determine the magnitude of the improvements. As of August 2004, and in the light of the findings of Leong et al[14] and Harris and Wickens,[15] it appears that the cast restorations remain the gold standard for vertical marginal adaptation.

It was noted that the restorations from both the CAD/CAM and WAX/CAM groups exhibited areas of significant undercontouring at the margin (Fig 6). With the necessary procedures to polish the restoration, the undercontoured areas may become more exaggerated and detract from the overall fit of the restoration. Given the similarity in marginal gaps between porcelain shoulders and full cast margins,[9,10] application of a porcelain shoulder to the copings would allow for the creation of well-fitting margins and the appropriate contours.

All WAX/CAST restorations required selective internal relief, in contrast to the lack of internal binding for any of the CAD/CAM or WAX/CAM restorations. This demonstrated the effectiveness of using 80 μm of simulated die spacer starting 1 mm from the margin. Further investigation of varying amounts of simulated die spacer is needed to determine if there is an optimal amount of simulated die spacer.

The limitations of this research include measurement of only the vertical marginal gap. The horizontal relationship was not quantified. The degree of over/undercontouring may have a significant influence on plaque accumulation and gingival irritation.

This study only investigated the marginal openings of milled titanium copings. The Everest system can also mill leucite-reinforced glass ceramic, presintered zirconium oxide, and yttrium-stabilized zirconium oxide. How the marginal openings of copings generated with either of these materials compares to more conventional techniques is not known at this point. Investigation of the other materials that can be milled by the Everest system is also desirable, as well as controlled comparisons with other manufacturer's products. It should be determined if other types of dental stone are more suitable for the optical scanning process and will yield further reductions in marginal gap opening. There are also a plethora of parameters that can be altered to optimize the system. Published data on the effect of each of these variables is lacking, and investigation to determine the best setting is needed.

This study did not attempt to determine if the vertical marginal gaps of the restorations were clinically acceptable. It did, however, represent state-of-the-art technology at the time of experimentation. The lost wax casting technique has been used in dentistry for a significant period of time, which is in stark contrast to computer-aided techniques for dental restorations. Since the time of experimentation, there have been multiple hardware and software revisions to the optical scanner and milling engine of the KaVo Everest system. These changes may well serve to decrease the marginal openings observed in this study.

Conclusions

1. There was no difference between the vertical marginal gaps of the CAD/CAM and WAX/CAM groups.
2. The WAX/CAST technique resulted in smaller vertical marginal gaps than either CAD/CAM or WAX/CAM.

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