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RESEARCH AND EDUCATION

Comparison of loupes versus microscope-enhanced CAD-CAM crown preparations: A microcomputed tomography analysis of marginal gaps

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ABSTRACT

Statement of problem. Long-term restoration success depends on a precision marginal fit to prevent marginal leakage and caries. The successful fit of a computer-aided design and computer-aided manufactured (CAD-CAM) crown may be affected by different workflow variables, including preparation, scanning, crown design, milling, sintering, and cementation. Discrepancies in any of these steps may result in poor marginal and internal fit. Evidence suggests that tooth preparation may be the most important step in the workflow for a successful outcome. Compared with the traditional means of crown preparation using the naked eye or loupes, the dental operating microscope provides higher magnification and more direct illumination. However, the impact of high magnification during preparation on the marginal quality of CAD-CAM crowns is unclear.

Purpose. The purpose of this in vitro study was to compare marginal fits of CAD-CAM crowns fabricated after initial preparation with loupes and subsequent preparation refinement with either loupes or a microscope. The null hypothesis was that no significant difference would be found in the marginal gap between the preparations with loupes and those with a microscope.

Material and methods. Mounted extracted molars (N=18) received initial crown preparations with a coarse grit, rounded shoulder, diamond rotary instrument with loupes of ×3.0 magnification. The teeth were then randomly divided into 2 groups and refined for an additional 2 minutes with fine grit, rounded shoulder, diamond rotary instruments with either loupes (LOUP) or a microscope up to ×10.0 magnification (DOM). The prepared teeth were scanned with an intraoral scanner to fabricate zirconia-reinforced lithium silicate crowns manufactured with a 4-axis milling machine, sintered in a dental furnace in accordance with the manufacturer's instructions, and cemented with self-adhesive resin cement. All teeth with crowns were mounted and scanned with a microcomputed tomography (µCT) system at 21-µm nominal voxel size. The resulting Digital Imaging and Communications in Medicine (DICOM) images were imported into a semiautomatic segmentation software program. Marginal and absolute gaps were measured at 24 consistent circumferential points per specimen. Absolute gaps were labeled, and the total volume was calculated. Paired and unpaired *t* tests were used for statistical analysis (α=.05).

Results. The mean marginal gap was 145.0 ±259.6 µm for LOUP and 35.6 ±110.6 µm for DOM, with a statistically significant difference (P<.001). The mean gap volume for LOUP was 0.975 ±0.811 mm^3, and 0.250 ±0.477 mm^3 for DOM, also statistically significantly different (P=.023). A significant difference was found between the absolute and marginal gaps for LOUP (P=.007), but for DOM, the difference was not significant (P=.063).

Conclusions. This study demonstrated that the higher magnification used during tooth preparation played a significant role in the size of marginal gaps present around CAD-CAM crowns. Crown preparations finished by using fine grit diamond rotary instruments with a microscope at higher magnification than loupes resulted in a more precise marginal fit with smaller gaps. (J Prosthet Dent 2022;■:■-■)

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Clinical Implications

The implementation of a dental microscope for crown preparation may enable better crown adaptation by reducing marginal gaps and the risk of coronal leakage, thus extending the longevity of the CAD-CAM crowns. The results obtained indicate that precision tooth preparation protocols may be the critical component in the digital workflow for CAD-CAM crown fabrication.

Enhanced magnification with binocular surgical loupes has been commonly used to enable the dentist to visualize teeth and surrounding oral tissues better than with the naked eye.[1] Most loupes used by dentists are in the ×2.5 to ×3.5 magnification range while the dental microscope provides magnification from ×4.0 to ×25.0. However, compared with loupes, the application of a dental microscope in general dental practice has not been adopted to the same extent as in endodontic specialty practices.[2] A systematic review by Tsesis et al[3] reported significantly higher success rates for both microscope- and endoscope-assisted endodontic procedures than for loupes. The success of endodontic therapy utilizing the microscope suggests that a clinician may achieve greater precision with microscope implementation in restorative dentistry.

Computer-aided design and computer-aided manufacturing (CAD-CAM) crown fabrication offers instantaneous feedback about the quality of the preparation through the scanning capture and the subsequent digital design software program.[4,5] This coupled with an enhanced assessment of the marginal fit and internal adaptation can provide critical information about the future success of the crown, as marginal gaps may result in secondary caries and premature failure.[5,6]

Restorative dentists may have difficulties with tooth preparations for CAD-CAM crowns, leading to marginal gaps and premature failure. The marginal gap has been defined as the perpendicular measurement from the internal surface of the margin of a crown to the outermost edge of the finish line of the tooth margin.[7] Absolute marginal discrepancy is the extension (over or under) of the crown margins in relation to the margins of the tooth substrate, leading to misfit, plaque accumulation, and compromised periodontal status.[7] Agreement regarding a clinically acceptable marginal gap is lacking, but accepted values for a marginal gap have been reported to be between 10 and 220 μm.[8-11] An evaluation of preparations for zirconia crowns and fixed partial dentures showed that only 13 of 305 abutment teeth achieved the clinical threshold for acceptable zirconia restorations.[12] General dentists had difficulties with the preparation finish line design around the entire circumference and angle of convergence.[12] Thus, inadequate preparation for CAD-CAM zirconia crowns could lead to premature failure.[12]

Renne et al[13] evaluated the significance of tooth preparation for CAD-CAM crowns fabricated by an integrated chairside system. The results of preparations performed by 62 dentists with varying clinical experience ranged from marginal gaps of 38.5 μm for ideal preparations with no errors to marginal gaps of 90.1 μm for poor preparations with multiple errors.[13] The authors concluded that the preparation quality had a significant effect on the marginal gap of CAD-CAM crowns.[13] Improper tooth preparation also affected milling precision, especially when a flaw or defect was smaller than the diameter of the milling tool, creating misfits and resulting in larger marginal gaps.[13] In contrast, hot-pressed lithium disilicate crowns were found to exhibit smaller marginal gaps than CAD-CAM crowns.[14] Preparation errors at the margins of lithium disilicate crowns were better managed if a lost wax technique was used.[15] A systematic review of the marginal adaptation of ceramic crowns, mostly CAD-CAM fabricated, showed 94.9% of the values measured were less than or equal to 120 μm.[6] The widest marginal gap measured 174 μm, and the smallest 3.7 μm.[6] The authors concluded that 4 factors may influence the marginal fit: the cementation, veneering process, value of the cementing space, and finish line configuration.[6]

An association between marginal gap size and clinical failure has been demonstrated.[16,17] Patients with a high risk of caries were more susceptible to secondary caries development when marginal gap sizes exceeded 68 μm.[16] Moreover, at the restoration-tooth substrate interface, gaps as small as 30 μm demonstrated increased bacterial colonization, caries, and premature restoration failures, independent of a patient's level of caries activity.[17]

Several techniques have been used to evaluate the marginal fit of crowns,[18] including examination with mirrors and explorers, silicone-replica techniques, light and scanning electron microscopy, and more recently, microcomputed tomography (μCT) evaluation[19] allowing nondestructive assessment.[20,21] Micro-CT also allows for high-resolution imaging of the space surrounding the crown, providing detailed cross-sectional information concerning the crown-to-die fit.[22] Micro-CT use has expanded from evaluating the adaptation and leakage of composite resin restorations and pit and fissure sealing[23] to determining marginal gaps on CAD-CAM crowns when studying the effect of different scanners, milling machines, software design systems, finish lines, and cementation on the fit.[24-26]

The clinical advantages of dental microscopy may be beneficial for the preparation of CAD-CAM crowns but have not been well documented. The authors are unaware of a previous study that evaluated the effect of

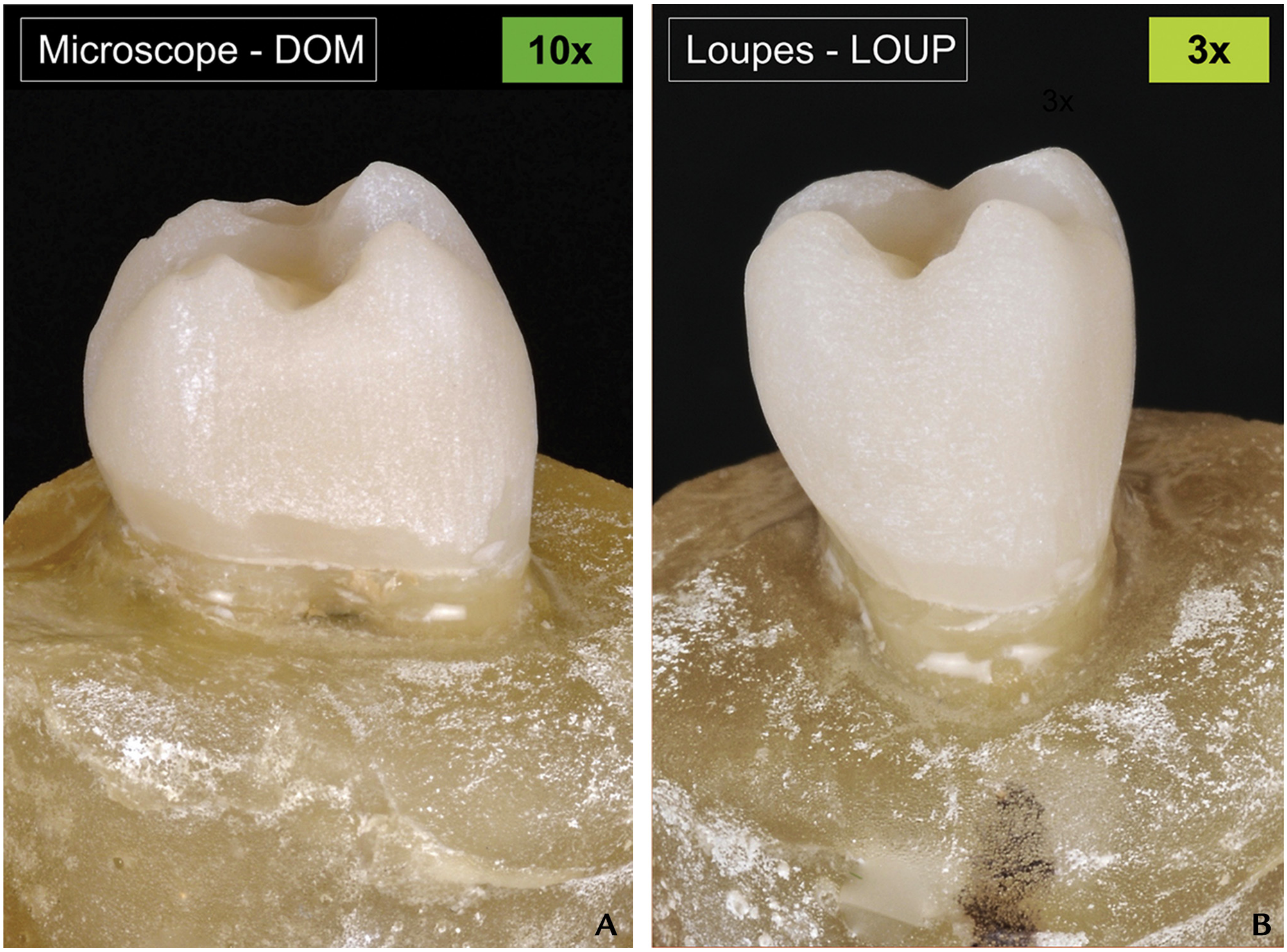


Figure 1. Representative cemented crowns on tooth in acrylic device after preparation. A, Microscope refined (×10.0). B, Loupes refined (×3.0).

preparing teeth at different magnification levels on the marginal gap of CAD-CAM crowns. This investigation aimed at comparing the effect of finishing preparations at different magnifications on the marginal gaps of CAD-CAM crowns by using μCT. The null hypothesis was that no significant difference between loupe and microscope preparations would be found in the marginal gap.

MATERIAL AND METHODS

The effect size was estimated at 1.79 based on the results of a previous study.[24] Assuming an alpha-type error of .05 and a power beta of .95, a total of 16 specimens were determined as the minimum sample size needed to run an unpaired Mann-Whitney U-test to observe significant differences (G*Power 3.1 software; Heinrich-Heine-University Düsseldorf). One sample per group was added as a reserve specimen.

Eighteen extracted human molars (N=18) were mounted in orthodontic resin (Dentsply Sirona) placed in circular acrylic resin holders. The teeth were centered and stabilized with a dental surveyor, and the roots were submerged. The tooth structure was exposed 3.0 mm apical from the cement-enamel junction to improve visibility and ensure a marginal seal. The mounted teeth were stored in distilled water for 24 hours for rehydration before tooth preparations. A polyvinyl siloxane putty template of each tooth was prepared to standardize tooth reduction in accordance with the guidelines for ideal crown preparation with glass-ceramics established by Rosenstiel et al[27] and Shillingburg et al.[28] Occlusal reduction was set to 1.5 mm and axial reduction to 1.0 mm circumferentially. All teeth were prepared by an experienced clinician (A.M.A.). The occlusal and axial reductions were achieved with a coarse grit diamond rotary instrument (847.016 KR; Komet USA) under a steady stream of water with an electric high-speed handpiece (Midwest E; Dentsply Sirona) at 200 000 rpm, producing a rounded shoulder finish line with ×3.0 magnification loupes (Orascoptic). The multiplane uniform reduction was evaluated by placing a cross-

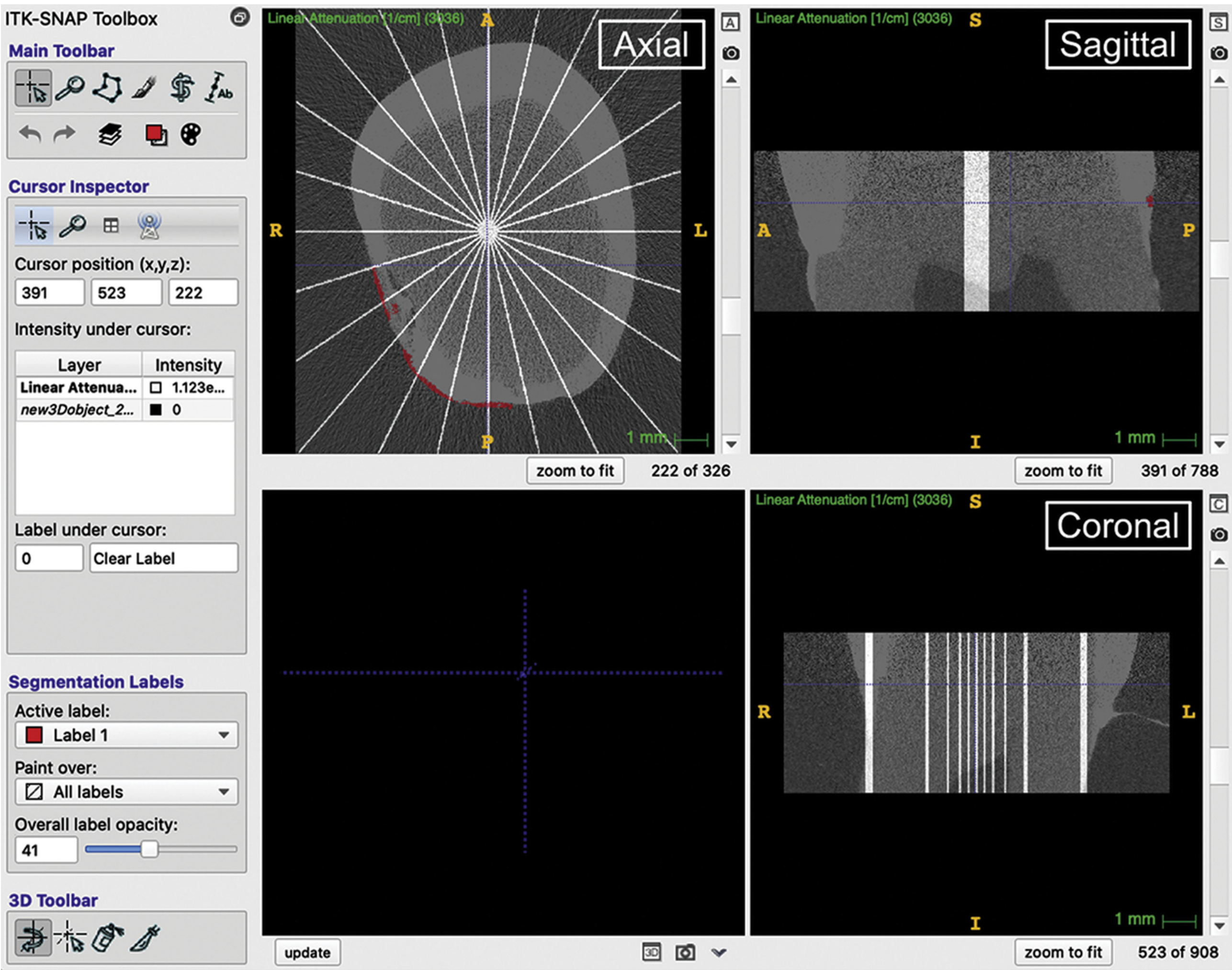


Figure 2. Screenshot of DICOM images imported into ITK-SNAP open-source software program after µCT scan. Superimposed NRRD 3D object to standardize measurement points throughout test groups (24 clockwise sections) in axial, sagittal, and coronal views. Gap spaces labeled in *red*. µCT, microcomputed tomography; 3D, three-dimensional; DICOM, Digital Imaging and Communications in Medicine; NRRD; Nearly Raw Raster Data.

sectioned impression over the prepared tooth and was verified with a periodontal probe (Qulix CP-18; Hu-Friedy).

The prepared teeth were randomly assigned by coin flip into 2 groups that received further refinement either under a microscope (group DOM; ZEISS EXTARO 300; Carl Zeiss Meditec AG) at a magnification of ×10 or with the same loupes magnification (group LOUP) of ×3.0 each for an additional 2 minutes with the rounded shoulder, fine grit, diamond rotary instrument (8847.016 KR; Komet USA) under a steady stream of water with the same electric high-speed handpiece at 40 000 RPM. The teeth were placed in a custom device and scanned with an intraoral scanner (CEREC Omnicam; Dentsply Sirona) to fabricate zirconia-reinforced lithium silicate (ZLS) crowns. The resultant images were processed into virtual casts, and the crowns were designed by using the initial proposal calculated by the integrated software program (CEREC 4.6.1; Dentsply Sirona) and minimally corrected where required. The sprue positions were standardized for ZLS ceramic blocks (CELTRA DUO; Dentsply Sirona). The resulting CAD design for each prepared tooth was sent to a 4-axis milling machine (CEREC MCXL; Dentsply Sirona) for wet milling of the ceramic blocks. The milling tools were changed after 3 milling cycles. The milled crowns were observed at ×20 magnification under a microscope to ensure that the margins were free of cracks and chips. The milling sprues were separated with a diamond wheel and polished with a CAD-CAM ceramic polishing system (Hager & Meisinger) for 10 minutes. A uniform coat of spray glaze was applied, and the milled crowns were sintered in a dental furnace (CEREC SpeedFire; Dentsply Sirona) in accordance with the manufacturer's instructions. An evaluation was conducted to ensure the marginal and internal fit accuracy for each crown. The crowns were cemented with a dual-

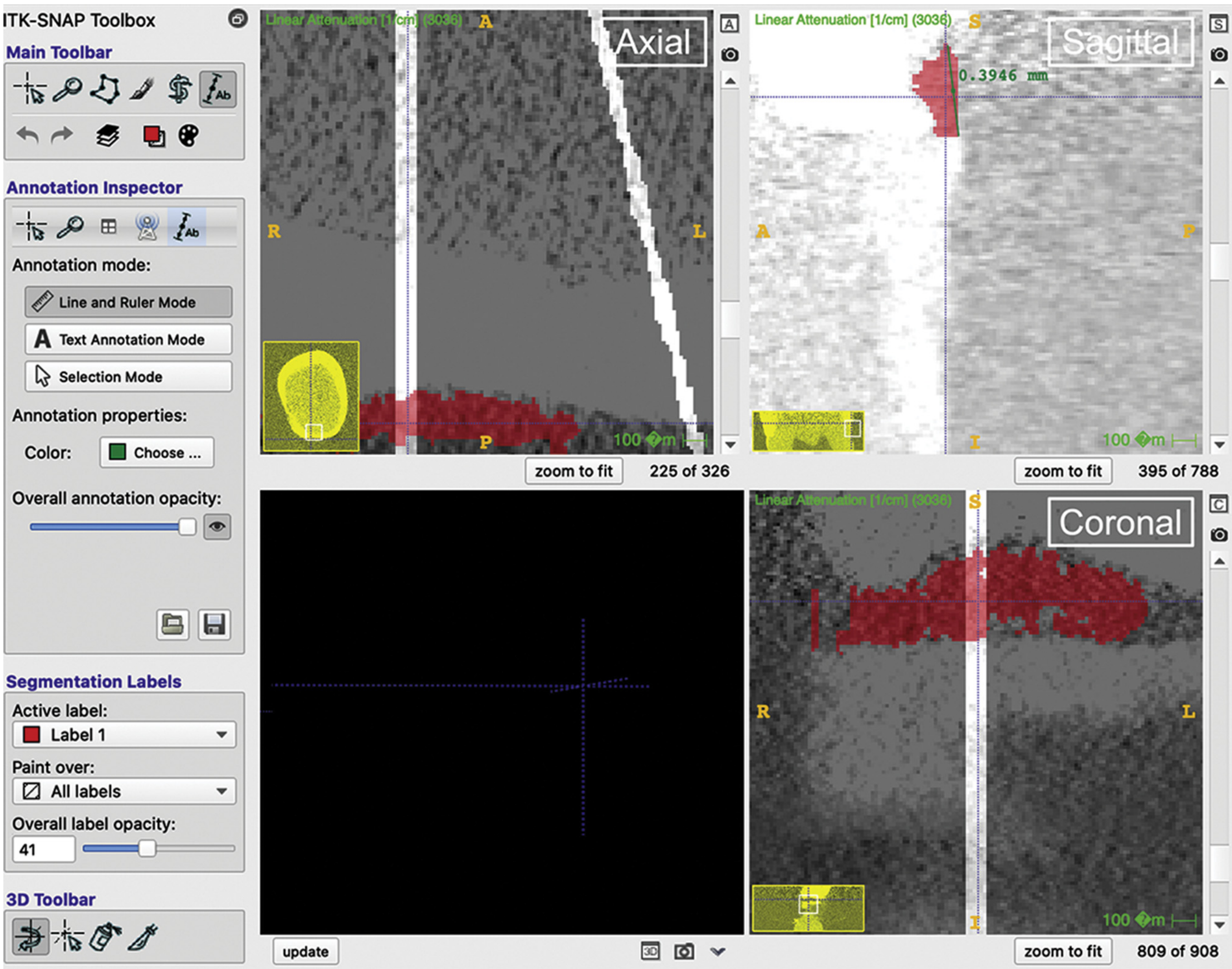


Figure 3. Screenshot of ITK-SNAP open-source software program. Enlarged gap space at intersection of gap and radial 3D object plane in axial, sagittal, and coronal views. Squares in *yellow* orientation boxes identify enlarged areas in planes. Gap spaces labeled in *red*. Sum of all individual voxels labeled *red* in all planes and slices allowed for calculation of volumetric gap. Linear measurement of marginal gap depicted in sagittal view.

polymerizing self-adhesive resin cement (Calibra Universal; Dentsply Sirona) under a load of 50 N for 5 minutes. Excess cement was removed with a bristle brush after 1 minute of placement, and any excess was removed while the cement was still in a gel phase. The cement was light polymerized with a light-emitting diode polymerization light (SmartLite Focus; Dentsply Sirona) from the occlusal aspect and around the margins for 40 seconds. The teeth with the cemented crowns were again stored in distilled water (Fig. 1).

All teeth with crowns were de-identified comparing the DOM versus LOUP groups by the principal investigator and coded with a random number from 1 to 18. They were mounted and scanned with a µCT system (vivaCT 40; SCANCO Medical) at 21-µm nominal voxel size by a scan operator (R.E.) blinded to the groups. Both linear and volumetric gap calculations were performed by using an open-source software program (ITK-SNAP) and following the protocols established in previous studies.[29,30] The Digital Imaging and Communications in Medicine (DICOM) images exported from the µCT system were imported into the software program and converted into the Neuroimaging Informatics Technology Initiative (NIFTI) format. All operations were processed by co-investigators (R.E., E.A., F.C.S.) unaware of the experimental groups.

A semiautomatic segmentation algorithm sequence[31] was used to label gap volumes and subsequently annotate and calculate true marginal gaps (the perpendicular measurement from the finish line of the tooth to the crown margin) and absolute marginal gaps (the extension over or under the crown margin in relation to the margin of the tooth). The software program allowed for axial, coronal, and sagittal views to be shown simultaneously. Regions of interest were defined, and the gap volumes were selected for semiautomatic recognition and

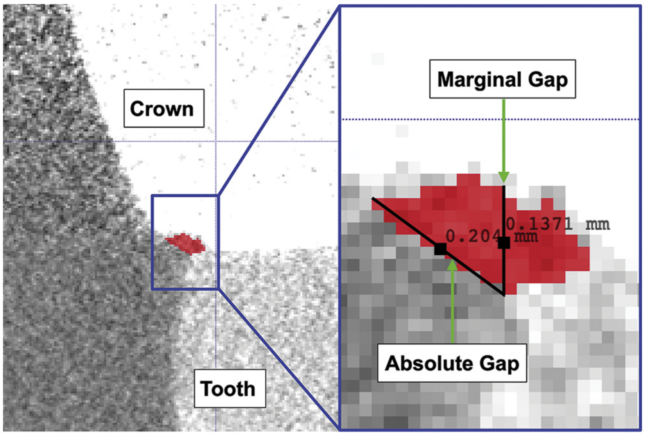


Figure 4. Illustration of marginal gap versus absolute gap. Labeled gap (*red*) at interface of crown and tooth in enlarged example of µCT scan (left) with magnified section (*blue outline*, right) demonstrating measurements of marginal gap (perpendicular measurement from finish line of tooth) versus absolute gap (extension over or under crown margins in relation to margins of tooth).

calculation by using automated spherical fillers ("seed bubbles") that repeatedly populated the gap volume until it was filled completely. Manual correction was applied in case additions and/or subtractions to the gap volumes were needed. The software program allowed for corrections as small as individual voxels. The NIFTI format allowed for the direct expression of the number of voxels and conversion to mm/mm^3. Marginal and absolute gaps were measured in millimeters at 24 consistent circumferential points per specimen. Therefore, a three-dimensional (3D) object was created in an image-processing software program (ImageJ; National Institutes of Health) and exported in Nearly Raw Raster Data (NRRD) format. The object consisted of 12 vertically intersecting planes, with a single intersection in the center of the cylindrical volume. This resulted in 24 "half-planes" radiating from the center axis of the volume in 15-degree segments in an axial view (Fig. 2). An open-source image-processing package (Fiji) was used to adapt the 3D object to the exact dimensions of each individual µCT volume imported into the ITK-SNAP software program. Marginal and absolute gaps were measured at the exact intersection of each radial plane with the volumetric gap (Figs. 3, 4). After all linear and volumetric measurements had been completed, the investigator (A.M.A.) reassigned the individual results to either the DOM or LOUP group and subjected them to statistical analysis.

Kolmogorov-Smirnov (Lilliefors) tests were used to assess normal distribution. Mann-Whitney U-tests for independent samples were used for statistical comparison of marginal, absolute marginal, and volumetric gaps between DOM and LOUP. A Wilcoxon signed-rank test for paired samples was used to compare marginal versus absolute marginal gaps for each sample in DOM and LOUP groups, respectively, with a statistical analysis software program (IBM SPSS Statistics, v24; IBM Corp) (α=.05). For marginal and absolute marginal gaps, all 24 measured points per specimen, for a total of 216 measurement points each for DOM and LOUP, were analyzed. For the volumetric gap, the total gap volume per sample was evaluated for 9 samples each for DOM and LOUP.

RESULTS

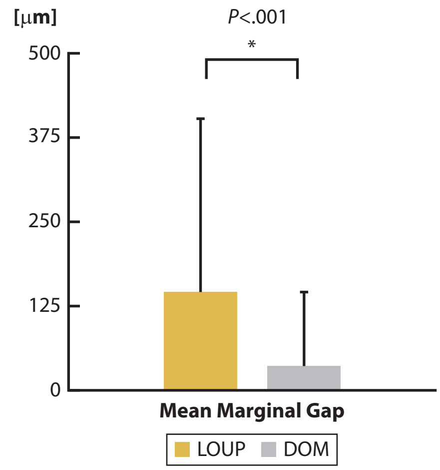
A significant difference from the normal distribution was found for the marginal gap data sets (D(432)=0.46, P<.001) and the absolute marginal gap data sets (D(432) =0.46, P<.001). For the volumetric gap data sets, Shapiro-Wilk tests showed a significance departure from normality (W(18)=0.78, P<.001).

The mean marginal gap was 145.0 ±259.6 µm for LOUP and 35.6 ±110.6 µm for DOM, statistically significantly different (P<.001) (Fig. 5). The mean absolute gap was 148.0 ±263.2 µm for LOUP and 36.5 ±113.0 µm for DOM, also statistically significantly different (P<.001) (Fig. 6). The mean gap volume for LOUP was 0.975 ±0.860 mm^3 and 0.250 ±0.477 mm^3 for DOM, which was statistically significantly different (P=.023) (Fig. 7). No significant difference between the absolute and marginal gaps was found for DOM (P=.063), but for LOUP, the difference was significantly different (P=.007).

DISCUSSION

This µCT evaluation demonstrated that crown preparations finished with ×10.0 magnification under a microscope resulted in a significantly more precise marginal fit of CAD-CAM crowns, with smaller marginal gaps than crown preparations finished with ×3.0 magnification under loupes. Therefore, the null hypothesis was rejected.

In 1971, an in vivo study of over 1000 crowns concluded that restorations with a gap and luting space of less than 120 µm were clinically acceptable.[11] This figure remains a standard reference for acceptable marginal gaps despite the limited evaluation methods available at that time. Studies by Nawafleh et al,[8] Tsirogiannis et al,[9] and Ng et al[10] suggested that marginal gap sizes up to 200 µm may be acceptable. In contrast, this in vitro study demonstrated that a mean marginal gap size of 35.6 µm can be achieved with microscopic preparation refinement. This result was consistent with marginal gap sizes for excellent preparations reported by Renee et al [32] who identified marginal gaps on CAD-CAM crowns ranging from 104 µm for poor preparations to 36.6 µm for excellent preparations. The authors considered preparation quality a significant factor for improved marginal fit and concluded that errors may have been overlooked or were too small to detect with ×2.5 magnification loupes.[32]

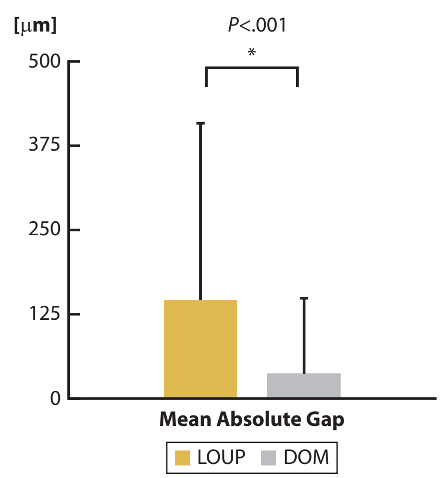


Mean Marginal Gap

Marginal Gap (µm)	
LOUP	145.0±259.6
DOM	35.6±110.6
***P*-value**	*P*<.001

[n=18]

Figure 5. Results for mean marginal gap: loupes (LOUP) versus microscope (DOM).

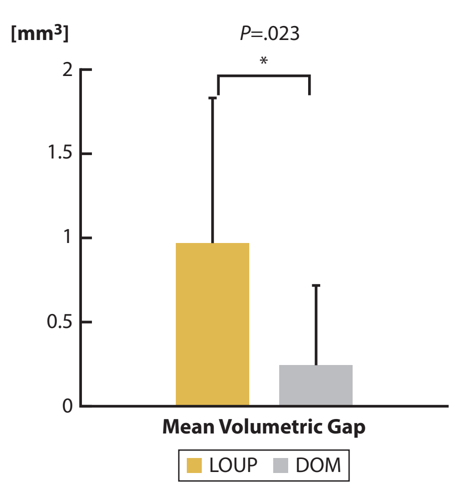


Mean Absolute Gap

Absolute Gap (µm)	
LOUP	148.0±263.2
DOM	36.5±113.0
***P*-value**	*P*<.001

[n=18]

Figure 6. Results for mean absolute marginal gap: loupes (LOUP) versus microscope (DOM).



Mean Volumetric Gap

Volumetric Gap (mm^3)	
LOUP	0.975±0.860
DOM	0.250±0.477
***P*-value**	*P*=.023

[n=18]

Figure 7. Results for mean volumetric gap: loupes (LOUP) versus microscope (DOM).

To improve preparation quality for this study, each group was finished for no more than 2 minutes by using a fine grit, rounded shoulder, diamond rotary instrument under 2 different magnifications to produce a smoother finish line. A rounded shoulder preparation was found to provide the best marginal fit for lithium disilicate milled crowns in a μCT study by Rizonaki et al [24] who evaluated marginal gaps by using different finish line configurations. Moreover, a systematic review and meta-analysis determined ceramic crowns with chamfer finish lines showed wider marginal gaps than those with rounded shoulder finish lines.[33] The use of a fine grit rotary instrument was supported by Li et al [34] who concluded that teeth prepared with finer grit rotary instruments had smoother tooth surfaces, resulting in cast metal crown restorations with better internal adaptation. Taman et al,[35] using μCT, also showed that feldspathic CAD-CAM crowns had lower marginal gaps with preparations done with fine grit diamond rotary instruments than when done with coarse grit diamond rotary instruments.

The present study used 1 integrated restorative workflow system (CEREC), 1 milled material (CELTRA DUO), and 1 cement (Calibra Universal). The only deviating factor between the groups was the preparation protocol of finishing the margin by using either ×3.0 magnification with loupes or ×10.0 magnification with a microscope. The differences between the mean marginal gaps and the mean volumetric gaps of the LOUP versus DOM groups were statistically significantly different. The overextension or underextension of crown margins was limited for the DOM group, as no statistical difference between marginal gap and absolute marginal gap was observed. However, a significant difference between marginal gap and absolute marginal gap was found for the LOUP group. These findings indicate that microscope-assisted preparation may achieve higher precision for restorative dentistry procedures. While this in vitro study cannot determine that CAD-CAM crowns prepared by using the microscope have an improved clinical prognosis, in other dental specialties, a possible correlation for improved long-term success has been reported. Tsesis et al[3] and Setzer et al[36] showed significantly better cumulative success rates for endodontic surgery performed with a microscope than when using loupes.

Limitations of this study included using a chairside 4-axis milling machine instead of a 5-axis laboratory milling machine. Future studies may apply the nano-CT imaging technology with higher resolutions for better accuracy in gap detection. The present study demonstrated that the higher magnification used during preparation played a significant role in the extent of marginal gaps around CAD-CAM crowns. The results obtained indicate that precision tooth preparation protocols may be the beneficial component in the digital restorative workflow for CAD-CAM crown fabrication.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. Marginal adaptation and fit of CAD-CAM crowns differed based on the level of magnification used to finish the margin preparation.
2. The marginal gap around CAD-CAM-fabricated ceramic crowns was significantly reduced when the preparation was finished with higher magnification under a microscope at ×10.0 magnification compared with the same finishing protocol under ×3.0 magnification with loupes.
3. There was no significant difference in marginal gap versus absolute marginal gap for DOM.

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