Internal Fit and Marginal Gap Evaluation of Zirconia Copings Using Microcomputed Tomography: An In Vitro Analysis

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The purpose of this in vitro study was to measure the marginal and internal fit of single-unit all-ceramic zirconia copings (ZCs) fabricated through three different computer-aided design/computer-assisted manufacture (CAD/CAM) systems using microcomputed tomography (microCT). A total of 10 ZCs were produced for each experimental group. Scanning of the stainless steel (SS) model with its respective copings was conducted with a SkyScan machine. DataViewer software was used to acquire cross-sectional images. Locations of cross-sections for all specimens were standardized to reduce errors. Seven different cross-section locations were selected: four transverse and three sagittal. Adobe Photoshop CS3 was used for the measurements. One-way analysis of variance and Tukey post hoc test were used for the statistical analysis for each group. In addition, t-test (α = .05) was used to compare values at each measurement location for the different groups. The results of this study show significant differences in the precision of fit of the experimental groups at the axio-occlusal transition (AOT) location, with a significant gap present in the DeguDent CAD/CAM System compared to the other two systems. Tukey test results indicate a significant difference in the marginal gap between the DeguDent CAD/CAM System and KaVo Everest Dental CAD/CAM System (P = .004). In addition, there is a significant difference in gap size values in the sagittal sections distal to the midline between the DeguDent CAD/CAM System and the Lava Ultimate CAD/CAM System (P = .002). The different CAD/CAM systems showed a clinically acceptable internal fit and marginal adaptation. Different levels of fit were found between the experimental groups. Marginal adaptation was the best in all experimental groups. The gap at the AOT area varied among the three groups, with the DeguDent CAD/CAM System showing the greatest value.


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a mirror and explorer is considered the simplest method and usually gives a rough direct estimate, while indirect use of an electron microscope is more accurate. In vitro, a direct microscopic assessment can be conducted after sectioning the tooth restoration sample. In a non-destructive approach, microcomputed tomography (microCT) has been used to assess the fit of the prosthetic framework by evaluating the marginal and internal gap at different locations using slices for different cross-sectional levels, with the advantage of specimen preservation.

The purpose of the present study was to measure and compare the amount of the marginal gap presented in zirconia copings (ZCs), which is fabricated using three different CAD/CAM systems and the microCT technique.

**Materials and Methods**

**Sample Size and Experimental Groups**

For this in vitro study, 30 ZCs in total were divided into three experimental groups (n = 10). Samples were designed and manufactured using three different CAD/CAM systems (KaVo Everest Dental CAD/CAM System [ED], Lava Ultimate CAD/CAM System [LU], and DeguDent CAD/CAM System [CN]) according to the manufacturers’ instructions (Table 1).

**Assessment Method**

The copings were clamped to the SS model and then scanned using a microCT (SkyScan) machine. Data-Viewer software (SkyScan) was used to acquire cross-sectional images. The locations of the sections were standardized in all specimens to minimize errors, as shown in Fig 2a. Adobe Photoshop CS5 was used to measure the gaps. The contrast of each image was adjusted to delimit the space area. All internal and marginal gap measurements were performed by a single examiner. The presence of small radiographic artifacts did not allow automatic tool measuring. The ruler was calibrated using the information taken from SkyScan image settings, where 1 pixel = 15.10 μm. The shift button was used while recording to

<table>
<thead>
<tr>
<th>Group</th>
<th>Framework material and basic composition</th>
<th>Company</th>
<th>Group notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Everest Dental CAD/CAM System</td>
<td>Aidite zirconia block: ZrO₂ + HfO₂ + Y₂O₃ 99.6 wt%, Y₂O₃ 5.2 wt%, Al₂O₃ 0.2 to 0.5 wt%, other oxide &lt; 0.2 wt%</td>
<td>KaVo</td>
<td>ED</td>
</tr>
<tr>
<td>Lava Ultimate CAD/CAM System</td>
<td>Lava frame zirconia block: ZrO₂ + HfO₂ + Y₂O₃ 99.6 wt%, Al₂O₃ 0.2 to 0.5 wt%, other oxide &lt; 0.2 wt%, sintering density &gt; 6.06 g/cm³, average grain size 0.3 μm</td>
<td>3M ESPE</td>
<td>LU</td>
</tr>
<tr>
<td>DeguDent CAD/CAM System</td>
<td>Cercon base: ZrO₂ 94.3%, Y₂O₃ 5.27%, Al₂O₃ 0.248%, SiO₂ 0.004%, Fe₂O₃ 0.002%, Na₂O 0.013%, Lg-loss 3.36%, grain size 0.36 μm.</td>
<td>Dentsply</td>
<td>CN</td>
</tr>
</tbody>
</table>

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ensure measurements were perpendicular to the model surface. In addition, measurements were made on \( \times 3 \) magnified images (300%) to enhance visibility and ensure accuracy.

Four transverse and three sagittal sections were selected for the measurement, for a total of seven different cross-sections for each specimen (Fig 2b). In the transverse direction, the cross-sections were identified as follows: marginal gap (MG), measured perpendicular from the margin of the model to the internal surface of the coping; chamfer area (CA), measured occlusally at 800 µm from the margin of the model; axial wall (AW), measured occlusally at 2,000 µm from the margin of the model; and axio-occlusal transition (AOT) area, measured occlusally at 3,300 µm from the margin of the model. The sagittal sections were identified as follows: midline (MD), measured at the middle of the model; mesial (M), measured horizontally at +3,000 µm from the midline; and distal (D), measured horizontally at +3,000 µm from the midline. In each transverse section, four readings opposite each other were recorded and the mean was considered the
cross-section measurement (Fig 3). In each sagittal section, three measurements were recorded, and their mean was considered the cross-section measurement (Fig 4).

One-way analysis of variance (ANOVA) and Tukey post-hoc tests were used for statistical analysis of each material. A t test at $\alpha = .05$ was used to compare values at each measurement location among the different groups, and Pearson correlation test was used to determine the correlation between the measurement and locations.

### Results

The mean gap and the standard deviation at seven locations between the preparation and the ZCs for the three CAD/CAM systems are summarized in Table 2 and Figs 5 to 8. An analysis of the precision fit of ZCs in the AOT location showed a significantly larger gap in the DeguDent CAD/CAM system compared to the other two systems. Tukey test results showed a statistically significant difference in the marginal gap between the DeguDent and KaVo Everest Dental CAD/CAM Systems ($P = .004$) (Table 3 and Fig 6).

### Table 2 Mean Gaps (SD) in Study Groups

<table>
<thead>
<tr>
<th>CAD/CAM system</th>
<th>MG (μm)</th>
<th>CA (μm)</th>
<th>AW (μm)</th>
<th>AOT (μm)</th>
<th>M (μm)</th>
<th>MD (μm)</th>
<th>D (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DeguDent</td>
<td>128.2 (23.2)</td>
<td>75.0 (9.1)</td>
<td>91.5 (8.0)</td>
<td>241.8 (7.2)</td>
<td>82.50 (19.1)</td>
<td>91.40 (16.6)</td>
<td>108.4 (25.4)</td>
</tr>
<tr>
<td>Everest Dental</td>
<td>160.7 (23.6)</td>
<td>62.8 (9.2)</td>
<td>62.9 (9.2)</td>
<td>62.20 (5.0)</td>
<td>190.6 (13.8)</td>
<td>164.4 (19.7)</td>
<td>155.6 (11.7)</td>
</tr>
<tr>
<td>Lava Ultimate</td>
<td>112.5 (13.3)</td>
<td>63.8 (9.1)</td>
<td>54.0 (6.8)</td>
<td>53.50 (5.5)</td>
<td>99.70 (19.7)</td>
<td>75.70 (12.7)</td>
<td>78.80 (12.0)</td>
</tr>
</tbody>
</table>

**Fig 5** Mean gap per section for the three CAD/CAM systems. Vertical lines represent standard deviations. MG = marginal gap (transverse section); CA = chamfer area (transverse section); AW = axial wall (transverse section); AOT = axio-occlusal transition area (transverse section); M = mesial to midline (sagittal section); MD = midline (sagittal section); D = distal to midline (sagittal section).
addition, a statistically significant difference was detected in the chamfer area between DeguDent and KaVo Everest Dental \((P = .005)\) (Table 4). A statistically significant difference in the distal-to-midline section between DeguDent and Lava Ultimate was also seen \((P = .002)\) (Table 5).

**Discussion**

The use of CAD/CAM technology in the fabrication of fixed dental prostheses could improve the adaptation and mechanical properties of the final prosthesis and produce minimal marginal and internal gaps that are considered clinically acceptable. This study assessed the marginal and internal gaps of three different CAD/CAM-fabricated ZCs made for single crowns. There were significant variations in the adaptation of ZCs produced by the different systems tested.

The low capacity of the discrimination of microCT is considered a disadvantage compared to optical or electron microscopes (1.8 μm for microCT and 0.3 and 0.25 nm for optical and electron microscopes, respectively).\(^1\) Radiation artifacts, which resulted from differences in the coefficient of radiation absorption, prevent the use of luting cement for coping stabilization during measurements.\(^8\) The measurements were made on as-milled (as-sintered) copings for two reasons. First, studies have reported that grinding fully sintered zirconia will affect its mechanical properties.\(^12\) As adjustment is performed, subsurface microcracks are created,

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**Table 3 Comparison of Mean Marginal Gap Recorded**

<table>
<thead>
<tr>
<th>CAD/CAM systems</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>DeguDent</td>
<td>KaVo Everest Dental</td>
</tr>
<tr>
<td>DeguDent</td>
<td>Lava Ultimate</td>
</tr>
<tr>
<td>KaVo Everest Dental</td>
<td>Lava Ultimate</td>
</tr>
</tbody>
</table>

**Table 4 Comparison of Mean Chamfer Area Gap Recorded**

<table>
<thead>
<tr>
<th>CAD/CAM systems</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>DeguDent</td>
<td>KaVo Everest Dental</td>
</tr>
<tr>
<td>DeguDent</td>
<td>Lava Ultimate</td>
</tr>
<tr>
<td>KaVo Everest Dental</td>
<td>Lava Ultimate</td>
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</tbody>
</table>

**Table 5 Comparison of Mean Distal-to-Midline Gap Recorded**

<table>
<thead>
<tr>
<th>CAD/CAM systems</th>
<th>P</th>
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<tbody>
<tr>
<td>DeguDent</td>
<td>KaVo Everest Dental</td>
</tr>
<tr>
<td>DeguDent</td>
<td>Lava Ultimate</td>
</tr>
<tr>
<td>KaVo Everest Dental</td>
<td>Lava Ultimate</td>
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</table>
jeopardizing the integrity of the prosthesis. Second, internal adjustment will introduce bias as adjusted specimens may show better seating and a better marginal fit with lower recorded values.

The reported marginal gap in the present study is the shortest distance from the inner surface of the crown to the closest outer tooth structure. Over- and underextended margins were not reported in this study.

Many studies have reported significant differences in the marginal gaps of copings made with different CAD/CAM systems. These differences are inevitable due to the distinctive features of scanners and design software and the variability of machining capabilities among milling units. In this study, standardization of the master die was accomplished by using an identical SS model for all systems. The parameters with regard to die spacer and cement gap were all set to a predetermined value. The scanning, design, and measurement were all done by one examiner to decrease interexaminer variability. Therefore, the results of this study could be explained in part by the variability among the three systems.

Clinical studies have emphasized the importance of marginal accuracy and fit for successful prostheses. It was determined that the ideal cement thickness should be 25 to 40 μm. However, this is rarely achievable in clinical practice. Hung et al suggested that a range of 50 to 75 μm would be clinically acceptable for marginal fit, where others have reported that up to 120 μm of a marginal separation is clinically accepted.

When evaluating the internal fit, specifically the AW gap, all groups were within the range of the acceptable gap dimension, as reported by Tuntiprawon and Wilson. Their suggestion was an optimal mean AW gap dimension of 73.0 μm, where any increase in this gap may result in lower failure strength.

In the present study, the copings produced by the DeguDent CAD/CAM system had the highest AOT (241.8 μm). However, the MG and average occlusal gap were 128.2 and 94 μm, respectively. The KaVo Everest Dental CAD/CAM system had a significantly lower AOT value at 62.2 μm, but a significantly higher MG at 160.7 μm and an average occlusal gap at 170 μm. This suggests the possibility of binding at the AOT area for the Everset Dental CAD/CAM system, preventing complete seating and increasing the marginal gap, while a larger cement space at the AOT for the DeguDent CAD/CAM system allowed for better seating of copings.

The results of this study did not show agreement with a previous study conducted by Hamza et al with regard to the MG of the Everest CAD/CAM system. The present study reported a mean MG of 160.7 μm, where Hamza et al reported only 14 μm. This huge difference may be attributed to differences in the preparation design, including the height, diameter, and finish line design. In addition, the premilling settings, including die spacer thickness and coverage percentage, could cause discrepancies in the results. Furthermore, the limitations of the two evaluation techniques (optical viewing vs microCT) could propose a difference in the accuracy of the reading. Hamza et al studied the ZCs after they were layered with veneering porcelain, while in the present study only ZCs were examined.

Regarding the Lava CAD/CAM system, a study with similar results was conducted by Abdel-Azim and colleagues. The MG of the Lava CAD/CAM system was similar in both studies, despite the differences in the tested material (e.max) and methods (×45 magnification with stereomicroscope). However, both studies reported clinically acceptable MGS.

The discrepancy of the results between the three CAD/CAM systems could also be attributed to the scanning technology used in each system to capture die images. The KaVo Everest scanner uses a visible light system with a fringe projection. Each data point is calculated based on triangulation principles after the distortion in the position in relation to coded illumination is calculated and a 3D image is created. The Lava CAD/CAM system uses three CMOS sensors to determine the in-focus and out-of-focus points and recreate 3D models with the help of a specially developed algorithm. The DeguDent CAD/CAM system creates 3D models using contact-free laser scanners. The 3D image is reformed from raw data and overlapping images using algorithms. Inaccuracies in the overlapping process will result in a defective 3D image. In the present study, the Lava CAD/CAM system showed the smallest gap measures where it would be considered the most precise scanner.
The die model used in this study had a rounded form, which may have limited the accuracy of the results. Any imperfection in the form of the die could cause a blind spot that could affect the fit of the coping. This study evaluated the fit of the ZC before veneering with porcelain. The further application and firing of porcelain may produce a change in gap dimensions.

Conclusions

Within the limitations of this study, it could be concluded that the different CAD/CAM systems showed clinically acceptable internal adaptation and marginal fit. Different levels of adaptation were found in the experimental groups. Marginal fit showed the best adaptation in all experimental groups. The gap present in the AOT area varied among the three different groups, with a greater gap present with the DeguDent CAD/CAM system. The Lava CAD/CAM system produced ZCs with the least marginal gap discrepancy.

Acknowledgments

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References