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RESEARCH AND EDUCATION

Influence of scanner, powder application, and adjustments on CAD-CAM crown misfit

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ABSTRACT

Statement of problem. The manufacturers of computer-aided design and computer-aided manufacturing (CAD-CAM) systems emphasize that new technologies can improve the marginal fit of dental crowns. However, data supporting this claim are limited.

Purpose. The purpose of this in vitro study was to investigate the differences among the following fabrication methods on the marginal discrepancy of dental crowns: intraoral optical scanners, powder application, and adjustments of intaglio surface.

Material and methods. A single human premolar was fixed on a typodont and prepared to receive crowns prepared by the CEREC CAD-CAM system. Three fabrication techniques were used: digital impressions using the CEREC Bluecam scanner with titanium dioxide powder (TDP), digital impressions using the CEREC Omnicam scanner without TDP, and digital impressions using the Omnicam scanner with TDP. Five experimental groups (n=10) were designated: Bluecam (group B), Bluecam with adjustments (group BA), Omnicam (group O), Omnicam with adjustments (group OA), and Omnicam with TDP (group OP). The specimens were scanned using microcomputed tomography to measure the vertical, horizontal, and internal fit and volumetric 3-dimensional (3D) internal fit values of each luting space. The paired *t* test was used to evaluate mean marginal fit change after adjustments within the same group. One-way analysis of variance and post hoc tests were used to compare groups B, O, and OP (α=.05).

Results. Mean vertical fit values ±standard deviations of group B=29.5 ±13.2 μm; BA=26.9 ±7.7 μm; O=149.4 ±64.4 μm; OA=49.4 ±12.7 μm; and OP=33.0 ±8.3 μm. Adjustments in the intaglio surface and TDP application statistically influenced the vertical fit of group O (P<.001). The percentage of vertical fit values <75 μm in group B=89.3%, BA=92.7%, O=31.0%, OA=73.5%, and OP=92.0%. Mean horizontal fit values for group B=56.2 ±21.5 μm; 85.8 ±44.4 μm for group BA; 77.5 ±11.8 μm for group O; 102.5 ±16.2 μm for group OA; and 91.4 ±19.4 μm for group OP. Results from group B were significantly different from those of the other test groups (P<.05). The percentages of horizontal misfit were 61.2% in group B; 73.5% in group BA; 88.1% in group O; 92.4% in group OA; and 85.0% in group OP. Volumetric 3D internal fit values in group B were 9.4 ±1.3 mm^3; 10.7 ±1.0 mm^3 in group BA; 11.8 ±2.1 mm^3 in group O; 11.0 ±1.3 mm^3 in group OA; and 9.6 ±0.9 mm^3 in group OP. The overall results from groups B and OP were better than those of group O, with regard to vertical misfit and volumetric 3D internal fit.

Conclusions. Different intraoral optical scanners, powder application, and internal adjustments influenced the marginal discrepancy of crowns. Crowns fabricated using the Omnicam system had significantly higher vertical discrepancy and volumetric 3D internal fit than those fabricated using the Bluecam scanner with TDP. Adjustments of the intaglio surface improved the vertical fit of crowns made using the Omnicam scanner; however, TDP application before Omnicam scanning improved the vertical fit as well as the volumetric 3D internal fit value of the luting space of crowns. (J Prosthet Dent 2017;■:■-■)

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Clinical Implications

Powder application before Omnicam scanning improves the vertical fit of crowns and decreases the 3D luting space.

The use of computer-aided design and computer-aided manufacturing (CAD-CAM) systems in dentistry permitted the production of ceramic restoration in dental laboratories and offices in less time and with acceptable fitting accuracy.[1-3] This technology was developed for dental offices (chairside CAD-CAM) and has become an alternative to conventional techniques.[4,5]

Historically, each step and upgrade in the CAD-CAM system, from optical impression to machining, have influenced the marginal discrepancy of restorations.[3] The first feldspathic ceramic inlays produced by CEREC (Dentsply Sirona) chairside CAD-CAM in 1984 presented a marginal discrepancy of 140 to 256 μm.[6-9] In 1988, software upgrades were added for onlays and veneers.[8] In 1994, the CEREC 2 system added a cylinder diamond capability, enabling the grinding of partial coverage and complete crowns with a marginal fit of 50 to 150 μm.[10] In 2000, the CEREC 3 included an enhanced intraoral optical camera that reproduced images with more detail and scaled depth, the wheel of the CAM was removed, and a 2-bur system[9] was introduced. All data acquisitions using CEREC 1, 2, and 3 generated 2-dimensional (2D) images.[8]

In 2003, CEREC 3 was updated with a charge-coupled device camera that could make 3D images.[8,11] According to recent studies, the CEREC Bluecam system obtained a marginal crown fit of 39.2 μm with 3D image capture by using a titanium powder application before scanning.[12,13] The powder application improved the image quality and created a matte surface in different materials, which improved the crown's fit.[12-14]

Recently, CEREC introduced a new camera, Omnicam, which generates a 3D model with real color and in real time using a video camera but without a powder application before scanning.[15] The Omnicam scanning process should be conducted under dry conditions, and the camera should be held as close to the tooth as possible to acquire an accurate digital intraoral scan.[16] Software upgrades for the system have minimized scanning errors,[17] and the evolution of the CAD-CAM system in general has reduced marginal discrepancy.[8] Cameras with new technologies are attractive, but they should provide similar or better results than existing technologies.[18] The goal of testing the accuracy of the scanning, designing, and milling steps of the CAD-CAM technology was to ensure the health of tissues.[19]

Table 1. Description of study groups

Group	Abbreviation	Powder Used	Intaglio Surface Adjustment
Bluecam	B	Yes	No
Bluecam with adjustments	BA	Yes	Yes
Omnicam	O	No	No
Omnicam with adjustments	OA	No	Yes
Omnicam with powder	OP	Yes	No

Therefore, the purpose of this study was 3-fold: to investigate the differences between 2 different technologies of intraoral optical scanners (Omnicam and Bluecam), to investigate the differences between adjustments of the intaglio surface, and to understand the differences that applying powder before the Omnicam scanning may have on the vertical, horizontal, and internal discrepancy of crowns. The null hypotheses of this study were that the vertical, horizontal, and internal fit of crowns would be similar using different technologies of intraoral optical scanners, intaglio surface adjustments, and prior powder application.

MATERIAL AND METHODS

After Ethics Committee approval (381/06) was obtained, a recently extracted human premolar was fixed on a typodont and prepared to receive a ceramic crown with a total angle of convergence of 6 degrees to the occlusal surface, 1.5-mm-wide shoulder margins, and rounded axiogingival angles. The 5 experimental groups (n=10) used lithium disilicate (IPS e.max CAD; Ivoclar Vivadent AG) to obtain crowns as shown in Table 1.

For the Bluecam (B) and Bluecam with adjustments (BA) groups, powder was applied to the preparation surface of a typodont with an aerosol (CEREC Optispray; Dentsply Sirona). An intraoral scanner (CEREC 3D Bluecam scanner v4.0; Dentsply Sirona) was used to obtain optical impressions. Single 3D frames were captured, creating a 3D model in the software.

The surfaces of the preparations and surrounding teeth of the Omnicam (O) and Adjusted Omnicam (OA) groups were scanned with a powder-free camera. The camera (Omnicam; Dentsply Sirona) was positioned perpendicularly and as closely as possible to the specimen, rather than at a 45-degree angle, and operated in dry conditions.[16] Appropriate software was used (CEREC v4.2.5; Dentsply Sirona).

The Omnicam with titanium dioxide powder (TDP) group (OP) was also scanned with a camera (Omnicam), but a thin layer of powder (CEREC Optispray; Dentstply Sirona) was applied to the surface of the preparation and surrounding teeth of the typodont.

The Bluecam crowns were designed using the Bluecam v4.0 software with a luting space for adhesive

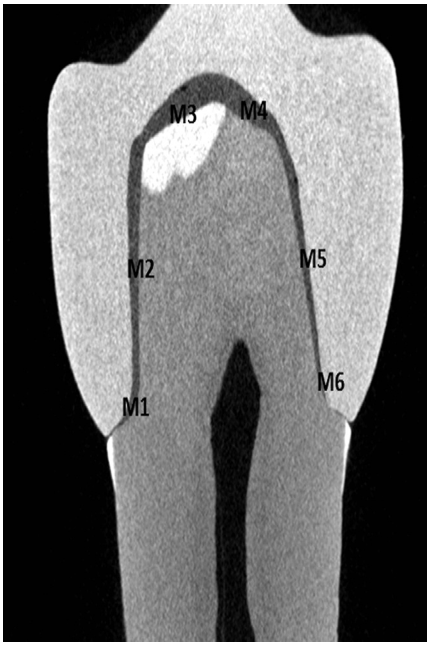

Figure 1. Six points (M1-M6) used to measure internal misfit.

cementation of 70 µm, according to the manufacturer's instructions. The Omnicam crowns were designed using the CEREC v4.2.5 software, and the luting space for adhesive cementation was set at 80 µm, according to the manufacturer's instructions. A milling unit (CEREC inLab MC XL; Dentsply Sirona) was used to mill the crowns of all groups. No internal adjustments, glazing, or polishing were performed for the B, O, and OP group crowns before the marginal fit measurements.

Each crown was fitted and fixed on the premolar with a silicone material (GC Fit Checker; GC Dental Industrial Corp) and scanned using microcomputed tomography (micro-CT; Skyscan 1272) at the CPBio Dental Research Center to obtain the images used to measure the marginal[12-14] and internal discrepancy.[11,17]

Micro-CT scanning was performed at 100 kV and 100 µA, with a pixel size of 9.4 µm, a filter Cu of 0.11 mm, and resolution of 1632×1092 pixels. The selected scanning was performed at 0.4-degree rotation steps to 360 degrees. To diminish artifacts, an average of 2 frames were collected with 20-pixel random movements, resulting in a scanning time of 2 hours per specimen.

After the B and O group crowns had been scanned, the thin layer of silicone material was examined, guiding the adjustments of the intaglio surfaces of the crowns. After adjustments, the BA and OA group crowns were created and scanned.

Before analysis, the micro-CT images required reconstruction. In this step, artifacts in the images were eliminated. The images were reconstructed using software (NRecon v1.6.8.0; SkyScan) with the following parameters: smoothing of 5%, ring artifact correction of 10%, and beam hardening correction of 5%. After image reconstruction, software (DataViewer v1.5.0.2; SkyScan) was used to obtain datasets of sagittal and coronal images. Next, 13 images from the sagittal set and 13 images from the coronal set were selected to illustrate specimen extension in 2 different planes, according to previous studies.[12–14] The 13 selected images were evenly distributed between the first and last images that presented the tooth cervical margin. Thirteen coronal and 13 sagittal images, equally distributed between the first and last images selected, were analyzed.

In each image selected, the measurements for vertical and horizontal fit were performed at ×300 magnification using processing software (CTAN v1.12.0.0; SkyScan). Fifty-two measurements per specimen were made (according to previous studies), and the means were calculated.[12-14] The maximum acceptable vertical fit was set to 75 µm with a recordable percentage value.[12-14] The horizontal fit was calculated considering all values to be positive; however, the percentages of underextended, equally extended, and overextended data were calculated.

Internal fit between the crown and prepared tooth was also evaluated using micro-CT. The central images of all selected coronal and sagittal cuts were selected, and 6 points were measured for both images: 2 axial, 2 occlusal, and 2 internal margins (Fig. 1).

The space between the intaglio surface of the crown and the prepared tooth is known as the luting space. To obtain the volumetric 3D internal fit value of the luting space for each specimen, software (CTAN v1.12.0.0) was used; all images without cement were excluded. The luting space for each specimen was identified manually and determined using a binary selection based on the gray scale indexes. To record the volumetric 3D internal fit value of each cement space, a morphometric analysis was performed based on the individual 3D object analysis.

Statistical analyses were performed with statistical software (SigmaPlot v12.0; Systat Software Inc). The means and standard deviations were calculated for each group. The paired *t* test was used to evaluate the mean marginal discrepancy change after adjustments (B and BO) and (O and OP) within the same group. One-way analysis of variance and post hoc tests were used to compare the B, O, and OP groups (α=.05).

RESULTS

For the groups of scanners tested, the mean data, standard deviations, percentages of values <75 µm, and coefficients of variation of the vertical fit, horizontal fit, and volumetric 3D internal fit values (µm) are shown in Table 2. Considering the vertical fit and volumetric 3D internal fit values, the results were significantly better for

Table 2. Mean ±SD vertical, horizontal, and volumetric 3D internal fitting values without adjustments (n=10)

Group	Vertical (μm)	Coefficient of Variation (%)	Percentage <75 μm	Horizontal (μm)	Volumetric 3D Internal Fit (mm^3)
B	29.5 ±13.2^{A}	44.7	89.3	56.2 ±21.5^{A}	9.4 ±1.3^{A}
O	149.4 ±64.4^{B}	43.0	31.0	77.5 ±11.8^{B}	11.8 ±2.1^{B}
OP	33.0 ±8.3^{A}	25.0	92.0	91.4 ±19.4^{B}	9.6 ±0.9^{A}

B, Bluecam crown; O, Omnicam crown; OP, Omnicam crown with powder. Values with same superscript letters were not significantly different in columns, based on 1-way analysis of variance test.

Table 3. Mean data of internal fit values (μm) for buccolingual and mesiodistal dimensions (n=10)

	M1		M2		M3		M4		M5		M6	
Group	BL	MD	BL	MD	BL	MD	BL	MD	BL	MD	BL	MD
B	83.0	49.7	29.9	85.7	129.7	230.9	132.4	161.6	16.0	74.1	69.7	55.1
BA	119.1	29.0	46.9	57.6	64.7	137.1	183.9	196.3	45.4	124.1	49.4	98.4
O	168.3	143.0	28.8	28.2	51.7	87.9	276.9	105.1	0	21.6	220.5	189.7
OA	217.9	100.8	76.9	65.1	55.6	111.5	256.2	95.9	26.2	55.8	128.8	171.0
OP	132.6	100.6	35.1	72.9	119.8	156.6	171.7	134.1	16.0	39.9	77.3	115.0

B, Bluecam crown; BA, Bluecam crown with adjustments; BL, buccolingual; M1-M6, 6 points used to measure internal misfit; MD, mesiodistal; O, Omnicam crown; OA, Omnicam crown with adjustments; OP, Omnicam crown with powder.

Table 4. Bluecam mean ±SD vertical, horizontal, and volumetric 3D internal fit values before and after adjustments (n=10)

Group	Vertical (μm)	Coefficient of Variation (%)	Percentage <75 μm	Horizontal (μm)	Volumetric 3D Internal Fit (mm^3)
B	29.5 ±13.2^{A}	44.7	89.3	56.2 ±21.5^{A}	9.4 ±1.3^{A}
BA	26.9 ±7.7^{A}	28.0	92.7	85.8 ±44.4^{B}	10.7 ±1.0^{B}

B, Bluecam crown; BA, Bluecam crown with adjustments. Values with same superscript letter not significantly different on columns based on paired *t* test (P>.05).

Table 5. Mean ±SD Omnicam values for vertical, horizontal, and volumetric 3D internal fit before and after adjustments (n=10)

Group	Vertical (μm)	Coefficient of Variation (%)	Percentage <75 μm	Horizontal (μm)	Volumetric 3D Internal Fit (mm^3)
O	149.4 ±64.4^{A}	43.0	31	77.5 ±11.8^{A}	11.8±2.1^{A}
OA	49.4 ±12.7^{B}	25.7	73.5	102.5 ±16.2^{B}	11.0±1.3^{A}

O, Omnicam crown; OA, Omnicam crown with adjustments. Values with same superscript letter not significantly different on columns based on paired *t* test (P>.05).

group B than for O (P<.001, P<.006) and for OP than for O (P<.001, P=.011). Considering horizontal fit, the results for group B were significantly different from the other tested groups (P<.001; P=.036). The intaglio contact of group O (Omnicam crowns) to the prepared teeth on point M5 of the axial wall was shown by the internal fit measurement (Table 3). The TDP application statistically influenced the values for the vertical fit (P<.001) and volumetric 3D internal fit (P=.011) of group O but not the horizontal fit (P=.214). The results of group OP (Omnicam) were similar to those of group B (Bluecam) for the vertical fit (P=.975) and volumetric 3D internal fit (P=.969) and negatively affected the horizontal fit (P<.001).

Adjustments in intaglio surface for the Bluecam group with TDP negatively affected the horizontal fit (P=.015) and volumetric 3D internal fit (P=.029) but did not affect the vertical fit (P=.579) (Table 4). For group O, the adjustments in the intaglio surface statistically improved the vertical fit of the crowns (P<.001) and negatively affected the horizontal fit (P=.005). Considering volumetric 3D internal fit, no significant differences in volume were found after surface adjustments of the intaglio of the crowns for group O (P=.270) (Table 5).

The percentages of the horizontal fit values were also calculated for each group (Fig. 2). The underextended and overextended values were added to represent the horizontal fit of each group. The horizontal misfit percentages were 61.2% for group B, 73.5% for group BA, 88.2% for group O, 92% for group OA, and 85% for group OP. Of all groups tested, the results for the Bluecam group were the best.

DISCUSSION

The null hypotheses of this study were rejected. Vertical fit, horizontal fit, and volumetric 3D internal fit of crowns were influenced by the use of different intraoral optical scanner technologies, the adjustments to the intaglio surfaces, and the preprocedural application of TDP.

Different chairside intraoral optical scanners and software influenced the discrepancy of the vertical and volumetric 3D internal fit measurements of lithium disilicate crowns. For vertical and internal fit, the results favored the Bluecam scanner and Omnicam scanner with TDP application. The Bluecam scanner is based on blue-light scanning technology, which uses short wavelengths resulting in a higher degree of accuracy.[18]

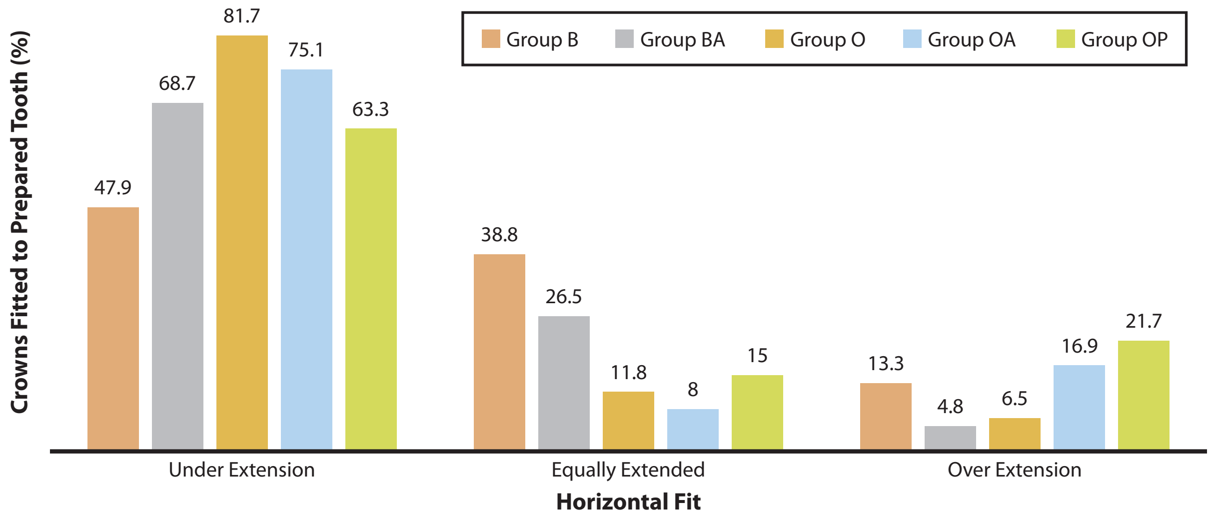

Figure 2. Percentage of horizontal misfit values for each test group.

The Bluecam scanning process also requires the use of a thin layer of powder to generate a matte finish on the surface and to prevent reflections during image capture.[5] The matte finish could improve the marginal fit of the crowns by improving detection of the finish line of the preparation.[12-14] The Omnicam scanner technology is based on an optical 3D video scanner system that captures data in real time and in true color and does not require a powder application; it can generate several 3D video data images per second.[5] The crowns produced by this system presented a higher fit of 149.4 μm (using software v4.2.5), which is a similar result to that in a recent study that reported 149 μm (using software v4.2.1).[15]

The alternative method (group OP) using the Omnicam scanner included the application of TDP on the prepared tooth to improve the marginal fit of the crowns. A previous study using an E4D laser scan (D4D Technologies) chairside CAD-CAM (powder-free scanner) indicated that using powder before digital impression making resulted in significantly smaller vertical crown fit results.[14] Based on the results of this study, the powder application improved the vertical fit as well as volumetric 3D internal fit and should be considered an option for reducing the need for adjustments of the intaglio surface of the crowns. Group OP also produced results that reduced the coefficient of variation of data (Table 2) and improved the percentage of values less than 75 μm (group O, 31%; group OP, 92%). These numbers emphasize the benefit of including a powder application before scanning with the Omnicam scanner; the marginal discrepancy of crowns fabricated improved, which may reduce the risk of microleakage, periodontal disease, and recurrent caries.[19]

The lower volumetric 3D internal fit values for groups B and OP could be beneficial because less cement is required for optimized fixation of crowns; conversely, the highest values presented by group O would indicate that more cement would be required. A thicker layer of cement can reduce the effectiveness of bonding by jeopardizing the fixation of the crowns because of an increase of polymerization shrinkage stresses.[20] Thicker cement is more prone to polymerization shrinkage (causing tensile stresses in the intaglio surface of crowns), which could lead to microcracks and fracture.[20] Cement shrinkage was also a factor that could cause debonding of the cement from the ceramic.[20]

Different scanning technology resulted in noticeable horizontal fit results (group B, 56.2 μm). A recent study produced similar results (69.7 μm) using the Bluecam technology to create crowns.[21]

For this study, the intaglio surfaces of the crowns were adjusted with the aid of a silicone material and diamond rotary instruments. Clinically, adjustment of the prepared tooth has been recommended[22] to avoid ceramic damage[23] and improve clinical longevity. Moreover, only 1 prepared tooth was used for all the specimens in this study, so it was impossible to perform any adjustments on the tooth. This procedure reduced the vertical fit of crowns significantly for group O (149 μm) to OA (49.3 μm); however, the horizontal fit increased (77.5 to 102.5), and the volumetric 3D internal fit was not affected. For groups B and BA, this procedure did not improve the vertical fit, horizontal fit, or volumetric 3D internal fit. The coefficient of variation of the data (Table 2) was lower after adjustments on the intaglio surface of the crowns, and the percentage of values less than 75 μm was 31% for group O and 73.5% for group OA.

A parameter of the study that could be manually modified is the internal luting space selection. In this study, the manufacturer's recommendations were followed for all groups. The space selection for groups B and BA was 70 μm (for software v4.0); for groups O, OA, and OP, it was 80 μm (for software v4.2.5). These parameters were analyzed to verify the reproducibility between the luting space settings in the software and the measurements of the internal area. For this study, the 70-μm parameter selected for software version 4.0 for group B generated a space range of 16 to 230 μm and 9.4 mm^3 of volumetric 3D internal fit, and the 80 μm parameter for software version 4.2.5 for group O generated a space range of 0 to 276.9 μm and 11.81 mm^3 of volumetric 3D internal fit. Another study determined that a selection of 30 μm for this parameter in the CEREC 3 software showed an internal space with a range of 116 to 162 μm.[11] As the results of the present study indicate, reproducing the defined space was not exact, as expected.

It was expected that the highest luting space could avoid crown intaglio surface contact with the tooth and reduce the marginal fit. However, group O had the highest values of marginal discrepancy, which could be due to the reduced internal luting space at the M5 point of group O (Table 2). Group B, with 70 μm of luting space, had the lowest values of marginal discrepancy. When the Omnicam system with software version 4.2.5 was used, the luting space could be set higher than 80 μm to prevent the greatest marginal discrepancy. A previous study reported that different luting spaces did influence marginal discrepancy.[11] However, a more recent study showed that different cement space settings did not seem to affect the marginal accuracy of the CEREC Bluecam system (using software 3.8).[21]

The range of the horizontal fitting among the groups studied could be explained by how different technologies capture the images or, possibly, by operator error in the selection of the preparation finish line. Another possible limitation of the study was the lack of reproducibility of design by the machine during the milling step. In the present study, the captured images and the design of the preparation finish line was easily realized in groups B and OP. These groups had previously undergone powder application on the preparation tooth. The horizontal fit could be improved clinically, promoting adjustments in the ceramic crown (overextended) or teeth (under-extended) with diamond rotary instruments and water spray.

This study evaluated vertical, internal, and horizontal fits to establish and minimize the possible clinical implications of the risk of microleakage, periodontal disease, and recurrent caries.[19] Recent studies have indicated that a marginal fit within 120 μm is considered acceptable.[24] However 75 μm was considered acceptable by other authors and by the present study[12–14] in determining the efficiency of intaglio surface adjustments or the powder application technique.

Further studies should be conducted to examine whether the luting space parameters influence the fit of ceramic crowns created by CAD-CAM. Technologies may become available that would improve the scanning, design (CAD), or manufacture (CAM) of crowns. The collection of long-term clinical data would also help verify the efficacy and importance of these techniques.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. Different intraoral optical scanners, prescanning powder application, and intaglio adjustments influenced the marginal discrepancy values of the crowns.
2. Crowns fabricated with the Omnicam scanner system had significantly higher vertical discrepancy values than those fabricated with the Bluecam scanner system.
3. For crowns made with the Omnicam system, only the vertical fit was improved with adjustments of the intaglio surface.
4. A powder application before Omnicam scanning improved the vertical fit of crowns and reduced the volumetric 3D internal fit.

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