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Evaluation of fit accuracy of computer-aided design/computer-aided manufacturing crowns fabricated by three different digital impression techniques using cone-beam computerized tomography

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ABSTRACT

Purpose: The aim of this *in vitro* study was to evaluate the fit accuracy of computer-aided design (CAD)/computer-aided manufacturing lithium disilicate full contour crowns fabricated by three different digital impression techniques. **Materials and Methods:** An acrylic upper first molar was prepared to receive a full ceramic crown and used to fabricate ten ceramic master dies using lost wax and heat press techniques. Each ceramic die was seated in a typodont model and ten polyvinyl siloxane impressions were made for the dies and neighboring teeth to fabricate ten stone casts. Three groups of lithium disilicate crowns ($n = 10$) were fabricated; Group E: Crowns were fabricated by scanning the ten stone casts with in Eos X5 extraoral scanner. Group O: Crowns were fabricated by powder-free scanning of the ten ceramic dies in their typodont models with CEREC Omnicam. Group B: Crowns were fabricated by CEREC Bluecam optical impressions of the ceramic dies in their typodont models after titanium dioxide powder application. All the specimens were milled from IPS e-max CAD blanks. Each crown was evaluated on its die for fit accuracy using computerized cone-beam tomography at seventy measuring points. The variability among the three groups was evaluated using one-way ANOVA test at $P < 0.05$. **Results:** No statistically significant difference was found among the three groups for overall results at ($P = 0.658$), whereas Group E showed significantly better marginal fit with a mean value of 76 ± 39.0 µm at $P = 0.047$. **Conclusions:** All tested digital impression techniques showed clinically acceptable accuracy and extraoral scanning significantly enhanced the marginal fit.

KEYWORDS: Computer-aided design/computer-aided manufacturing, cone beam, digital, fit, impression, lithium disilicate

Introduction

Fit accuracy is one of the main factors for the success of fixed restorations. A uniform cement space of 25–40 µm between the restoration and its abutment, as recommended by American Dental Association specifications, is necessary for optimum seating, retention, and mechanical behavior of the prosthetic component.[1]

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There is no consensus in the literature about fit values of ceramic crowns, and the reported results are widely diverse ranging from 7.5 to 206.3 µm,[2,3] such variation can be attributed to the lack of agreement about the definition of "fit," differences in methods employed, testing parameters, and ceramic systems investigated.

Holmes *et al*. suggested a clear terminology in 1989. They defined the internal gap as the perpendicular measurement from the internal surface of the restoration to the axial wall of the preparation. The same measurement at the margins is called the marginal gap. Another important measurement; the absolute marginal discrepancy (AMD) is the angular combination of the marginal gap and extension error and reflects the total crown misfit vertically and horizontally, so it is considered the best alternative measurement to marginal gap, and it was the measurement assessed in this current research.[4]

Several studies demonstrated that restorations fabricated from digital scanners were equally or more accurate than those produced from traditional impression materials.[5-8] On the other side, less researches have investigated and compared the marginal and internal accuracy of restorations produced by different scanning protocols either extraoral or intraoral, with powder or powder-free scanning in addition to comparing accuracy of systems using different scanning light wavelength and technologies.

The null hypothesis of this study is that there would be no significant difference between fit accuracy of crowns fabricated by the tested digital impression techniques, and the results would be within clinically acceptable limits.

Materials and Methods

Master dies fabrication

An acrylic upper first molar was prepared to receive a full ceramic crown with the following criteria: Occlusal reduction 1.5–2 mm, axial reduction 1–1.2 mm, axial taper 10–12°, and 1 mm supragingival circumferential chamfer finish line. A putty index was used to adjust the amount of reduction. All transitions from the axial to the occlusal surface were rounded, smooth, and free from sharp angles or undercuts. The prepared acrylic tooth was scanned using a laboratory optical scanner (ZirkonZahn S600 ARTI, Italy), and ten wax patterns were milled from white wax (CopraPlex, WhitePeaks, Germany). The wax patterns were invested, burn out and ceramic ingots (IPS e-max press, Ivoclar Vivadent, USA) were heat-pressed into the mold space to produce ten ceramic master dies. Each ceramic die was seated in a typodont model to get ten models for making impressions.

Stone casts fabrication

Ten sectional impressions for the ceramic dies and neighboring teeth were made with addition silicon impression material (Express™ VPS Impression, USA), and poured with computer-aided design/computer-aided manufacturing (CAD/CAM) stone (Super Gemma, Korea); an extrahard Type IV dental stone with optimized optical properties allowing powder-free scanning (Group E).

Sampling and grouping

Group E: Ten stone casts were scanned without powder application using CEREC inLab inEos X5 blue light scanner (Sirona Dental Systems, Bensheim, Germany) [Figure 1]. Group O: The ceramic dies in the typodont models were scanned without application of powder using white LED light of CEREC AC Omnicam (Sirona Dental Systems, Bensheim, Germany) [Figure 2]. Group B: The ceramic dies in the typodont models were scanned after application of titanium dioxide powder (Vita CEREC Powder, Patterson Dental Company, USA) using blue LED light of CEREC AC Bluecam (Sirona Dental Systems, Bensheim, Germany) [Figure 3].

Computer-aided design/computer-aided manufacturing stage

Thirty crowns were designed using (CEREC 3D software, Version 4.2, Sirona Dental Systems, Bensheim, Germany) by making a copy of the anatomy of the contralateral tooth or "bioreference" mode with 50 µm die spacer. A Cerec inLab MC XL milling unit was used for CAM process of the designed crowns using lithium disilicate blanks (IPS e.max CAD, Ivoclar Vivadent, USA) followed by crystallization firing at 840°C for 25 min in the Programat CS furnace. No internal adjustments were made to the crowns before the marginal gap measurements to avoid any human interference.

Computerized tomography

Each master die was fixed to an acrylic base to stabilize it during imaging process. Each crown was fixed temporarily on its die with water soluble try-in paste, and a static load device was used to hold the crown under a static load of 5 kg for 3 min to ensure complete seating of each crown during scanning. A highly accurate computerized cone-beam tomography system was used (Morita R100 Veraview Wepocs, USA) to evaluate the fit accuracy of the crowns on their corresponding master dies. Three dimensional images were reconstructed on a computer monitor with special software (On Demand VeraView Wepocs). Five sectional images for each specimen were made in a sagittal plane (buccolingual) and other five slices in a coronal plane (mesiodistal). A slice every 1 mm was made so that ten slices were made for each specimen. On each slice image, the cement thickness was measured, so that a total of

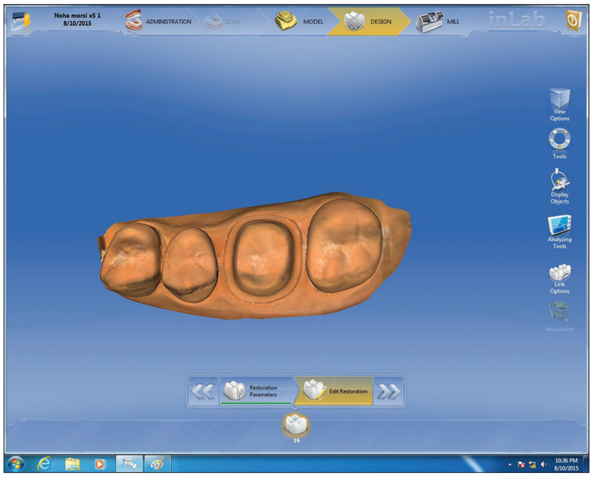

Figure 1: Virtual model from CEREC inEos X5 scanning

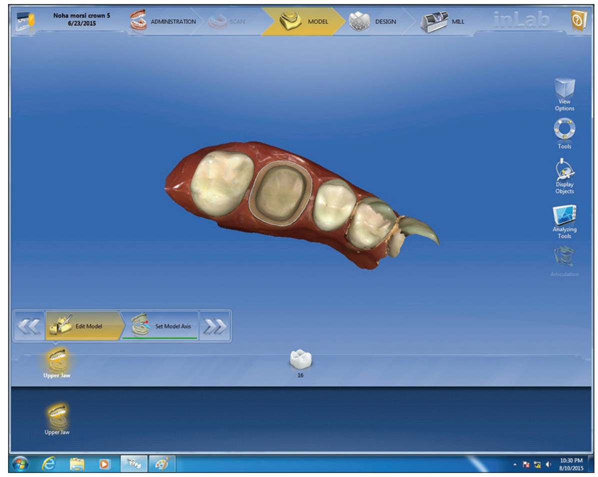

Figure 2: Virtual model from CEREC Omnicam scanning

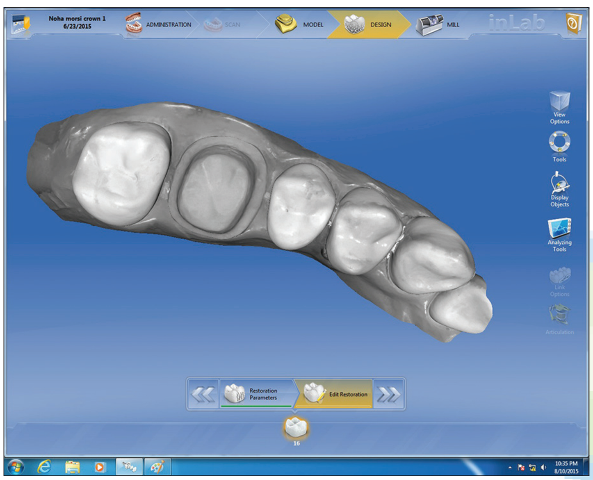

Figure 3: Virtual model from CEREC Bluecam scanning

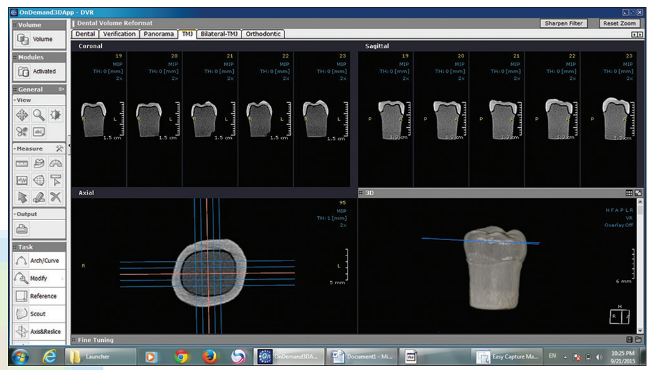

Figure 4: Cone-beam computerized tomography software three-dimensional, axial, sagittal, and coronal images

seventy measuring points were obtained for each specimen: Mid-occlusal gap, axio-occlusal gap, mid-axial gap, and AMD [Figures 4 and 5].

The ratio of horizontally overextended, under extended, and properly extended margins also was determined for the three groups and compared using Mont Carlo exact probability ($P < 0.05$) as presented in Figure 6.

Results

The variability among the three groups was calculated using one-way ANOVA test; no statistically significant difference was found ($P = 0.658$). The mean value for overall results was 125 ± 51 µm for Group E, 134 ± 49 µm for Group B, and 134 ± 45 µm for Group O.

A statistically significant difference was found between Group E and other groups for AMD results ($P = 0.047$); AMD mean value for Group E was 76 ± 39 µm, 113 ± 29 µm for Group B, and 103 ± 43 µm for Group O.

Discussion

The aim of the this study was to compare the internal and marginal fit of lithium disilicate crowns fabricated by three different digital impression techniques; powder-free scanning with intraoral CEREC Omnicam, powder scanning with intraoral CEREC Bluecam, and laboratory CEREC inEos X5 scanner without powder using computerized tomography.

The stated null hypothesis was supported by the results of the study as no statistically significant difference was found among the three tested groups for overall results ($P < 0.05$).

This study was performed *in vitro* which offered standardized and optimized conditions in the experimental performance, which may not be possible to achieve *in vivo*. All ceramic master dies were fabricated from one prepared acrylic tooth to eliminate the variability in preparation dimensions which was found to affect the accuracy of optical impression taken with CEREC Omnicam in a similar study by Renne *et al*.[9] All the specimens were fabricated using optical impression scanners applying active triangulation technique, designed with the same CAD software, and milled with a single milling machine from the same ceramic material.

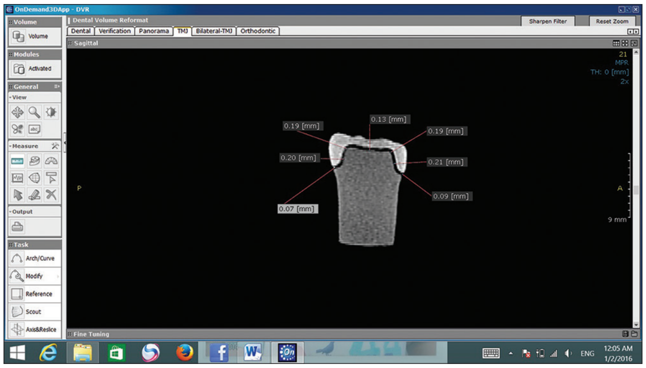

Figure 5: Measuring points on a cone-beam computerized tomography image

The methodology followed in this study was first applied by Pelekanos *et al*.[10] using computerized tomography to measure internal and marginal gap as a radiographic method. According to Pelekanos *et al*., to discriminate the gap between two materials using radiography, both should have the same coefficient of radiation absorption or similar radio density, so the master dies and the crowns in this study were fabricated from lithium disilicate ceramic.

In the present study, the die spacer was set at 50 µm according to the recommendations by Nakamura *et al*.[11] In addition, Kokubo *et al*.[12] concluded that when using a die spacer of <50 µm, the marginal gap will increase remarkably. This was also stated in a recent study by Stona *et al*.[13] who recommended a die spacer of 50 µm for CEREC machined lithium disilicate crowns.

The measurements were performed using cone-beam computerized tomography which allows accurate sub-millimeter resolution images with short scanning time and low radiation exposure dose. In addition, CBCT is a nondestructive method that does not require sectioning, which may disturb the assembly of crown and die and allow three-dimensional analysis of the fit accuracy at greater number of measuring points using the on-screen software tools without affecting the original dimensions of the specimens. Among CBCT limitations is that it is expensive and time consuming.[14]

In this study, no statistically significant difference was found between the three groups for the mean value of overall results, the mean values for the three groups are considered within the clinically acceptable results of 150 µm according to Fransson *et al*. and 120 µm according to McLean and von Fraunhofer.[15,16]

A statistically significant difference was found between Group E and other groups for marginal results with the inEos X5 group having the best results, and this may be attributed to intraoral camera misalignment that occurs when the camera tilt angle exceeds the axial wall angle of divergence so the gingival margins can be visually "blocked out" and whenever there is an undercut in the die preparation.[17]

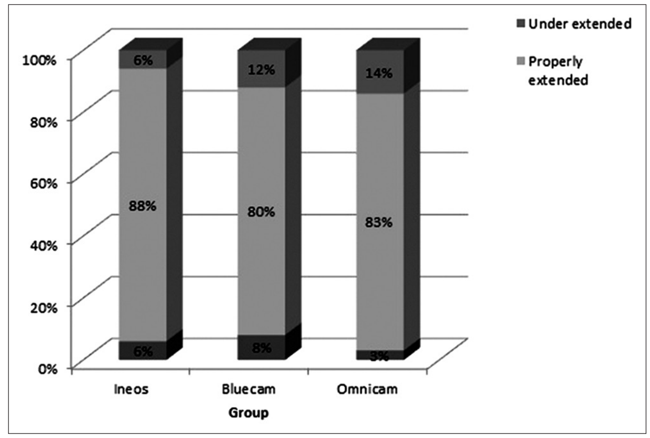

Figure 6: Percentage of overextended, properly extended, and underextended margins of the three groups

Visual interference is less possible for the extraoral scanner used in the current study as it provides better accessibility of the scanning beam with automated five axis rotation of the scanned model by the robotic arm. The accuracy of the extraoral scanning may be also attributed to the CAD/CAM stone used in the study that have optimal optical properties which allow powder-free scanning and minimize or eliminate the modified and scattered light, which result in a poor reading by the camera and create image noise.

The minimal accuracy difference between Omnicam and Bluecam in marginal results may be attributed to the wavelength difference between blue and white light used for scanning with the white light being shorter, so more accurate as it is less susceptible to bending, scattering, and transmission by the scanned object. In addition to errors of powder application as areas of over application or washout of powder also may affect the accuracy. Another factor is the speed of continuous flow scanning of Omnicam compared to slower and more error susceptible single image scanning with Bluecam as multiple images are attached together to form the visual model.[18,19]

The results of this study are in accordance with the results of Luthardt *et al*.,[20] Renne *et al*.,[9] and Boeddinghaus *et al*.,[21] who found a statistically significant difference between the accuracy of extraoral scanners and intraoral scanners, with extraoral having the best marginal results. Furthermore, the current results are in agreement with those of Ender and Mehl[22] who concluded that powder-free scanning system provides the same level of accuracy compared to scanning system with surface pretreatment. This agreement with those studies may be attributed to use the same type of scanner and ceramic material to fabricate the specimens.

There is a disagreement between the results of the present study and those of D'Arcy *et al*.[23] and das Neves *et al*.,[24] who found no statistically significant difference between the marginal results of direct and indirect scanners. Also there is another disagreement between our results and those of the study by Alaa *et al.*,[25] who concluded that the accuracy of powder free scanning by Omnicam is significantly inferior to that of powder scanning with Bluecam. This disagreement may be attributed to the different material used to fabricate the master die and specimens, and different measuring methods adopted by the researchers.

Further *in vivo* studies are recommended to investigate the accuracy of optical impression strategies as scanning a typodont in absence of oral fluids is not indicative of how challenging it can be to scan intraorally.

Conclusions

Within the limitations of this study, the following conclusions can be drawn:
1. All digital impression techniques tested in the current study produced full contour crowns of clinically acceptable fit accuracy
2. Extraoral optical impression of CAD/CAM stone cast significantly enhanced the marginal fit of the crowns
3. Powder-free intraoral scanning facilitates the clinical procedures of the optical impression for both dentist and patient although it did not show significantly better fit accuracy.

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Conflicts of interest
There are no conflicts of interest.

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