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Original paper

Effect of the scanner type on the marginal gap and internal fit of two monolithic CAD/CAM esthetic crown materials: An in vitro study

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Abstract

Background. The durability of indirect restorations is significantly influenced by marginal adaptation and internal fit. The use of computer-aided design/computer-aided manufacturing (CAD/CAM) with digital impressions has reduced dental prosthesis fabrication errors, improving the long-term survivability of the restorations.

Objectives. The present study assessed the impact of intraoral and extraoral scanning methods on the marginal adaptation and internal fit of 2 different types of monolithic crowns manufactured using CAD/CAM.

Material and methods. A total of 40 three-dimensional (3D) resin-printed dies were randomly assigned to 2 groups based on the type of crown material ($n = 20$ per group). Each group was divided into 2 subgroups ($n = 10$ per group) according to the die-scanning technique: subgroup A, scanned using the intraoral scanner (IOS) Primescan; and subgroup B, scanned using the extraoral scanner (EOS) inEos X5. The digitized photos were converted into a 3D virtual crown design using CAD software. The internal discrepancy values, and the marginal gap between the 3D resin-printed die and the crown were assessed using a ×50 digital microscope. The data was checked for normality with the Kolmogorov–Smirnov test, and the Mann–Whitney *U* test was used to compare the tested groups. The collected data was analyzed at a significance level set at $p < 0.05$.

Results. The different scanning techniques used had a statistically significant effect on the vertical marginal gap and the internal fit [μm] ($p < 0.05$). As far as the crown materials are concerned, BRILLIANT Crios showed a significantly higher marginal gap as compared to Tetric CAD when scanned with inEos X5 ($p = 0.004$), whereas the differences were insignificant with regard to the internal fit ($p > 0.05$).The crown parameters tested with both scanning systems were within the clinically acceptable ranges.

Conclusions. Scanning methods and crown materials had an impact on the internal fit and vertical marginal gap of monolithic crowns.

Keywords: marginal gap, internal fit, monolithic crowns, digital scanning

Introduction

Since its advent in 1985, the computer-aided design/computer-aided manufacturing (CAD/CAM) technology has brought significant progress in dentistry. What mostly benefited from the CAD/CAM technology is chair-side dental treatment, which involves preparing the teeth and applying restorations at a single clinical appointment.[1]

Due to advances in software and technology, numerous companies were able to develop highly precise scanners capable of capturing three-dimensional (3D) virtual images of the prepared teeth. These scanners started to be widely used in clinical dentistry to create digital models without the need for traditional impressions. Additionally, CAD software is utilized to build prostheses based on the collected data, which acts as a virtual wax-up. Owing to digital scanning techniques, the marginal accuracy of restorations has improved. The CAD/CAM technology helps to overcome some of the limitations associated with traditional impression processes by allowing quick and accurate saving of the scanned pictures without distortion.[2,3]

Digital impression systems utilize intraoral (direct digitalization) or extraoral (indirect digitalization) scanners.[4] Intraoral scanners enable direct scanning of the implant body, oral tissues and dental arches, eliminating the need for taking traditional impressions, and thus reducing patient discomfort – pain, a gag reflex and a bad taste. Intraoral scanning also enables instantaneous communication with the laboratory and the real-time assessment of the preparation. However, the quality of intraoral scanning may be adversely affected by blood, saliva and other moisture contamination, the movement of the patient or dentist, limited space within the oral cavity, and a smaller measuring area. Extraoral scanning involves scanning the impression of the dental arch or the stone model. The drawbacks of this method include the deformation of the impression material, dimensional changes in the impression material and discomfort for the patient in the event that a new impression is required.[5]

During intraoral scanning, images are acquired using a step-by-step approach. When capturing extra scans of complex angled surfaces, different angles are utilized as compared to the flat axial surface. Moreover, when scanning extensive and intricate angled areas, multiple single images are combined. The software uses the first image obtained with the scanner as a reference point, onto which subsequent images are merged. Each overlapping area introduces an error, which increases with each stitching process.[6] However, the extraoral scanner consistently captures laser plane projections and records their reflections simultaneously from all angles. Consequently, neither the area nor the complexity of the surface affects the performance of the extraoral scanner. Conversely, intraoral scanners produce fewer deviations for shorter directly measured distances and more deviations for longer directly measured distances.[7]

In comparison with veneered crowns, monolithic crowns are related to lower manufacturing costs, require less production time and preserve more tooth tissue due to the reduced ceramic thickness required. However, they also have significant drawbacks, such as increased brittleness, limited esthetics and being difficult to repair.[8]

Since many of the materials used in CAD/CAM resin composites are relatively new,[9] the data on their marginal adaptability and internal fit is still lacking. However, CAD/CAM resin blocks offer certain advantages over glass-ceramic blocks. In addition to having fewer microcracks during manufacture and less wear to the opposing dentition, they are also less fragile, which can improve the marginal adaptation of restorations.[10] This is the outcome of an industrial process that is standardized, and involves curing the material at high temperature and/or pressure values to enhance the material characteristics and maximize polymer cross-linking.[10]

Prosthetic crown success requires satisfactory marginal adaptation. The marginal gap is the distance between the edge of the prepared tooth and the cervical margin of the restoration. The presence of marginal holes in the cement increases the likelihood of disintegration, biofilm buildup, secondary caries, pulp inflammation, and periodontal disease. The recommended threshold for CAD/CAM crowns is between 50 and 100 μm, with a clinically acceptable marginal difference of less than 120 μm.[11] Marginal adaptation may be influenced by various factors, including the design of the preparation, the placement of the margin, the waxing processes, the precision of the milling system, the size of the milling bur, the thickness of the cement space, and the restorative material.[11] Additionally, the internal fit of a ceramic crown is a critical factor. The internal fit is the gap between the crown and the occlusal/incisal and axial surfaces.[12] Inadequate internal fit can decrease the fracture resistance of the restoration.[13] One of the most important contributing elements with regard to the development of CAD/CAM systems was the advancement of high-precision restorations. Recent studies have shown that CAD/CAM restorations typically exhibit small discrepancies within clinically acceptable limits, and the accuracy of the new technology matches or excels that of traditional lost-wax techniques.[14]

A limited amount of research has focused on the impact of different types of scanners on the internal fit and marginal adaptability of CAD/CAM-made crowns.[15] We aimed to assess the effects of intraoral and extraoral scanning methods on the internal fit and vertical marginal gap distance of 2 types of milled monolithic crowns. The null hypothesis stated that there would be no significant difference between the Primescan (intraoral) and inEos X5 (extraoral) scanners in terms of marginal and internal fit.

Material and methods

Die preparation

The study employed a typodont (Nissin Dental Products Inc., Kyoto, Japan) for an upper first premolar. The unprepared typodont was scanned using CEREC Primescan AC (Dentsply Sirona, Bensheim, Germany). A standardized virtual all-ceramic preparation was then performed using the Blenderfordental® CAD software, v. 3.6 (B4D, Gold Coast, Australia). The virtual preparation comprised rounded line angles, a 1.5-millimeter axial surface reduction, a 1.5-millimeter occlusal reduction, a 6-degree axial inclination, and a well-defined 1-millimeter-deep circumferential chamfer. Subsequently, the virtual preparation was 3D printed into 40 individual resin dies, using a resin 3D printer (Halot-Mage Pro; Creality, Shenzen, China) and resin material (ProShape Egypt, Cairo, Egypt).

Based on the data extracted from a study by Jalali et al.,[15] a minimum sample size of 12 (n = 6 in each group) would result in 95% power at the significance level. The sample size was increased to 10 in each group to ensure the reliability of the statistical analysis. The 40 samples were divided into 2 groups based on the type of crown material (n = 20 per group): group 1 specimens were milled from Tetric® CAD (Ivoclar Vivadent, Schaan, Liechtenstein); and group 2 specimens were milled from BRILLIANT Crios (Coltène/Whaledent, Altstätten, Switzerland) (Table 1). Subsequently, each group was divided into 2 subgroups (n = 10 per group) based on the digital scanning technique used – for subgroup A, an intraoral digital scanner (IOS) (Primescan; Dentsply Sirona) was used, while in subgroup B, an extraoral scanner (EOS) (inEos X5; Dentsply Sirona) was used.

Die scanning

Twenty dies were digitally scanned using IOS (Primescan) that required no powder, and the remaining 20 dies were digitally scanned using the laboratory EOS (inEos X5). The scanner was held quite closely over the resin die. Scanning started at the occlusal surface, proceeded to the lingual surface and ended at the buccal surface. Then, the image was automatically taken.

The scanners were calibrated before scanning. The uniform scanning procedure was followed based on the manufacturer's instructions. The same skilled operator carried out all scanning to increase repeatability and prevent any inconsistencies.

Fabrication of crowns

After determining the finish line, the dies scanned with IOS were used to create 3D virtual crown designs, utilizing the CAD software library (CEREC 5.0.2; Dentsply Sirona), which was pre-installed in the intraoral camera (Primescan). The crowns were then fabricated based on these virtual designs. In contrast, inLab CAD SW 19.0 (Dentsply Sirona) was used for the dies scanned with EOS. The scanned file was then converted to a DXD file to standardize the designing software with IOS. The CAD software (CEREC 5.0.2) imported the DXD file. The thickness of the crowns was set at 1.5 mm at the occlusal surface and 0.8 mm at the axial walls, with the cement spacing fixed at 60 μm. The data was sent to the milling software (CEREC 5.0.2) and the CEREC MC XL milling device (Dentsply Sirona) was used to produce the crowns. After calibrating the milling machine, 20 samples were milled from Tetric CAD blocks and the remaining 20 samples were machined using BRILLIANT Crios blocks. The crowns were installed on appropriate dies, and correct seating was verified using a sharp dental explorer under good lighting conditions and magnification. The intaglio surface of the crowns was cleaned, and any pressure spots disclosed by spraying powder (Arti-Spray®; Bausch Germany, Hainspitz, Germany) were removed with a round diamond bur.

Vertical marginal gap evaluation

Each sample was photographed using a digital microscope (Dino-Lite AM3111; AnMo Electronics Corporation, New Taipei City, Taiwan) with a built-in camera connected to an IBM-compatible personal computer at a fixed magnification of ×50. The gap width was quantified and assessed subjectively using a digital image analysis system (ImageJ 1.43u; National Institutes of Health, Bethesda, USA; https://imagej.net/ij). The marginal gap was calculated using the criteria set by Holmes et al.[16] The crowns were positioned over the matching dies. The images of the margins

Table 1. Characteristics of the investigated materials

Product	Type	Organic matrix	Inorganic filler	Manufacturer
Tetric CAD	CAD/CAM composite	Bis-GMA, Bis-EMA, TEGDMA, UDMA	barium aluminum silicate glass with a mean particle size <1 μm and silicon dioxide with an average particle size <20 nm (71.1% wt.)	Ivoclar Vivadent, Schaan, Liechtenstein
BRILLIANT Crios	CAD/CAM composite	cross-linked methacrylates (Bis-GMA, Bis-EMA, TEGDMA)	barium glass with a particle size of 1 μm and silicon dioxide with a particle size of 20 nm (70.7% wt.)	Coltène/Whaledent, Altstätten, Switzerland

CAD/CAM – computer-aided design/computer-aided manufacturing; Bis-GMA – bisphenol A-glycidyl methacrylate; Bis-EMA – bisphenol A-ethoxylated dimethacrylate; TEGDMA – triethylene glycol dimethacrylate; UDMA – urethane dimethacrylate.

were captured for each specimen. Next, using the digital image analysis system, morphometric measurements were made for each image at 28 landmarks indicated by the system throughout the cervical circumference of the specimen (6 equidistant points on the buccal and lingual surfaces, and 8 equidistant points on each proximal surface). After taking measurements for each surface, the mean value of the entire marginal gap was calculated (Fig. 1).

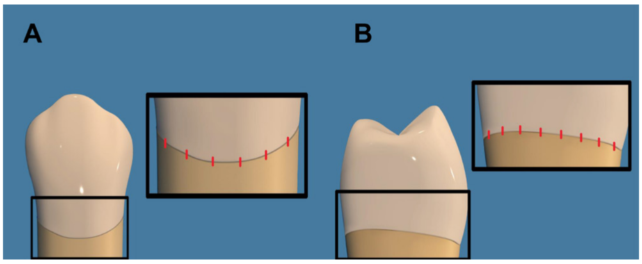

Fig. 1. Diagrammatic illustration of vertical marginal gap measurement
A – buccal aspect; B – proximal aspect.

Internal fit evaluation

The internal fit of the crown was measured using the silicone replica technique. Light-body silicon impression material (Panasil; Kettenbach, Eschenburg, Germany) was injected into the fitting surface of the crown. The crown was then placed over the printed die and pressed for 3.5 min under a load of 5 kg until the impression material was fully set according to the manufacturer's instructions. Subsequently, the crown was removed, leaving a light silicone impression on the abutment that represents the thickness of the cement space.[12] Then, the residual light impression was covered with putty silicone material (Panasil; Kettenbach) to address the challenges of cutting and managing the thin layer of the light body. Two siloxane layers were detached from the crown after setting. Using surgical blade number 15, the silicone replica was taken out and cut bucco-palatally. The handheld digital microscope was used to measure the light body thickness and assess the internal fit.[17] Prior to measurements, the microscope calibration procedures were meticulously followed. The evaluation of the internal fit included the measurements of the axial gap (AG) and the occlusal gap (OG). Eight points were measured for the buccal surface, 8 points for the lingual surface, 4 points for one occlusal slope, and 4 points for the other occlusal slope. The digital image analysis system was used to measure each point (Fig. 2).

Statistical analysis

The data was analyzed using the IBM SPSS Statistics for Windows software, v. 27.0 (IBM Corp., Armonk, USA). The normality of the data was assessed using the Shapiro–Wilk test. Both the marginal gap and the internal fit exhibited non-parametric distribution. The Mann–Whitney *U* test was used to compare between the groups. The significance level was set at $p < 0.05$.

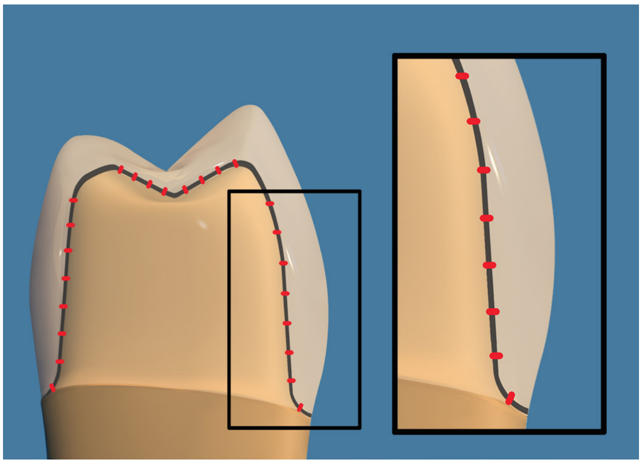

Fig. 2. Diagrammatic illustration of internal fit measurement (axial and occlusal gaps), showing measuring points for the buccal aspect, the lingual aspect and each cusp slope

Results

Marginal gap

When comparing the scanners, the results showed significant differences for both Tetric CAD and BRILLIANT Crios ($p < 0.05$) in terms of marginal gap. The marginal gap values were significantly lower for Primescan as compared to inEos X5 in both material groups ($p < 0.05$), although the difference between the Primescan Tetric CAD and Primescan BRILLIANT Crios subgroups was non-significant ($p > 0.05$). When comparing the materials within the inEos X5 group, Tetric CAD showed a significantly lower marginal gap value as compared to BRILLIANT Crios ($p < 0.05$). The marginal gap values are presented in Table 2.

Internal fit

With regard to the internal fit, both scanners showed significant differences in the Tetric CAD and BRILLIANT Crios groups ($p < 0.05$). For both tested materials, Primescan exhibited significantly lower values than inEos X5 ($p < 0.05$). When comparing the materials, no significant differences were observed for either scanner ($p > 0.05$). The internal fit values are presented in Table 3.

Table 2. Comparison of the marginal gap values [µm] in different groups

Group	Primescan	inEos X5	*Z*	*p*-value
Tetric CAD	12.0 ±8.3 (8.1–15.9)	44.8 ±14.9 (37.8–51.7)	−5.505	0.001*
BRILLIANT Crios	12.0 ±11.9 (6.5–17.5)	58.0 ±19.7 (48.8–67.2)	−5.276	0.001*
Z	0.184	−2.848	–	–
p-value	0.854	0.004*	–	–

Data presented as mean ± standard deviation (*M* ±*SD*) (95% confidence interval (*CI*)).
* statistically significant (Mann–Whitney *U* test).

Table 3. Comparison of the internal fit values [µm] in different groups

Group	Primescan	inEos X5	*Z*	*p*-value
Tetric CAD	41.8 ±22.7 (26.6–57.1)	86.0 ±49.0 (50.9–121.1)	−2.501	0.012*
BRILLIANT Crios	37.0 ±27.5 (17.3–56.7)	90.9 ±12.2 (82.7–99.1)	−3.853	0.001*
Z	0.260	1.043	–	–
p-value	0.795	0.297	–	–

Data presented as $M \pm SD$ (95% CI).
* statistically significant (Mann–Whitney *U* test).

Discussion

The results of the study showed that there is a statistically significant effect on the marginal and internal fit due to the differences between the acquisition systems. The intraoral scanner showed significantly better results, leading to the rejection of the null hypothesis.

Digital 3D imaging has become increasingly popular in dentistry, as it allows creating the imprints of the oral cavity. Intraoral scanners are comparable in accuracy to extraoral scanners. To evaluate their impact on the fit accuracy of the final restoration, 2 popular and readily available scanners were used in the present study.[18] To ensure consistency and a more dimensionally stable die for use during the scanning and testing of the milled crown, 3D printed resin dies were used. Additionally, to minimize difficulties while scanning larger areas, single upper premolar dies were utilized to assess the accuracy of the restorations with anatomical occlusal morphology.[19]

The longevity of the restoration is directly correlated with its precision, both internally and marginally. Good marginal adaptation helps prevent cement disintegration, and subsequent cavities and discoloration. Improved internal adaptability may increase the resistance and retention of the restoration. Thus, to verify the accuracy of scanners, measurements of marginal and internal fit were taken.[20,21]

There are various methods to test and measure the marginal gap, but the direct view method using a digital microscope is considered the most practical, accurate, quick, and easy way to determine the gap distance. In addition, unlike with the cementation, embedment and sectioning methods, which destroy the crown, the crown can be recovered.[22] In the present study, the marginal accuracy of the crown was determined by calculating the vertical difference between the margin of the die and the margin of the monolithic crown without cementation. After cementation, factors such as the cement type, cement viscosity and the cementation technique can affect the accuracy of the primary adaptation, potentially increasing the marginal discrepancy.[23] In addition, this non-destructive method has been previously used in dental studies.[24–26] Similarly, various techniques have been employed to evaluate the internal fit of restorations. In the present study, the silicon replica technique, a prevalent non-destructive method for in vitro internal fit evaluation, was utilized. The technique is known for its simplicity and efficiency.[21] Furthermore, a 50-newton force was applied to the crowns, using a unique mechanism to ensure uniformity and eliminate potential data variability.

In our study, the average gap obtained when using the Primescan system was significantly lower than in the case of scanning with inEos X5. This result is consistent with the findings of Zimmermann et al.[27] and Nulty,[28] who reported significantly higher accuracy with Primescan as compared to other scanning systems. Malaguti et al. determined that the marginal and internal fit in the case of intraoral scanners were significantly better in comparison with laboratory scanners.[29] However, these results contradict the findings of Lee et al., who reported that extraoral scanners were more accurate than intraoral scanners.[30] Conversely, Da Costa et al. did not find any difference in the marginal gap of restorations when the optical impression was taken either intraorally or extraorally.[31]

Primescan uses structured light–confocal microscopy with a high-precision Smart Pixel Sensor that evaluates the contrast of each pixel at a high resolution. Primescan provides an exceptional level of scanning precision by combining over 50,000 photos and capturing up to 1,000,000 3D points per second for each 3D image. The patent scanning principle consists in using an optical high-frequency contrast analysis to calculate 3D points, which results in increased accuracy.[27,28,32] On the other hand, inEOS X5 is a blue light scanner with a narrow wavelength, which enables better filtering of interference from ambient light and improved scanning repeatability.[33]

The marginal and internal fit of the crowns produced using the CAD/CAM technology were within the clinically acceptable ranges. The mean marginal gap ranged from 12.0 µm to 58.0 µm, and the internal gap varied between 37.0 µm and 90.9 µm. Clinically acceptable marginal and internal fit results are the outcome of the full CAD/CAM process, which includes milling and scanning. It has been found that the 4-axis milling machine used in the CAD/CAM systems under investigation provides better results in terms of internal adaptation of the milled restorations. Rotating the milling spindle with a higher number of milling axes may improve the accuracy of the milling machine. This may be related to improved finishing in the cervical region of the restoration, which in turn can affect marginal adaptation.[19]

Although the internal fit is clinically less significant than the marginal fit, it still affects the durability of the crown. To ensure the proper crown seating, resistance and retention, the internal fit of the crown must be appropriate.[34]

The CAD/CAM technology can potentially improve the mechanical behavior and marginal integrity of tooth restoration systems when using restorative materials with a low elastic modulus. These materials are more resilient and machinable due to their lower Young's modulus, and are less prone to chipping and fractures. Despite their clinical advantages, they may be a subject of recurring deterioration combined with microleakage, and the consequent restorative failure caused by repetitive elastic deformation at the margins. This result could be attributed to differences in the mechanical characteristics, chemical composition and microstructure of the studied CAD/CAM restorative crowns. Crowns that are milled from blocks and disks produced industrially at high temperatures and pressures exhibit increased filler volume fractions and conversion rates.[35] This study selected Tetric CAD and BRILLIANT Crios, as they revealed superior mechanical properties in comparison with other resin composite ceramic materials,[9] with little data about their fit and marginal adaptation.

Although the extraoral scanner showed higher marginal gap and internal fit values than the intraoral scanner, it was concluded that scanners using blue light, including inEos X5, are accurate.[36] The ceramic material could also have an impact on the marginal accuracy of the crowns created using the CAD/CAM technology.

Limitations

There are some limitations to this research. The reflectance of the 3D printed dies differed from that of natural teeth. Additionally, scanning a single die without the presence of the neighboring teeth is another limitation. Moreover, the absence of complex environmental factors, such as patient movement, saliva, limited space, the presence of blood and gingival crevicular fluid (GCF), and humidity, when using the intraoral camera, as well as the lack of an impression or a model when employing the extraoral camera, are also considered the limitations of the study. More research is required to determine the optimal cement space value for the CAD design. This is crucial for maximizing retention and resistance, improving clinical outcomes and minimizing the marginal gap without compromising the internal fit. In vivo investigations are required to accurately simulate the clinical situation.

Conclusions

The crowns scanned using Primescan and milled with the MC XL milling machine showed better internal fit and marginal accuracy. The intraoral scanning approach was found to be superior in influencing the vertical marginal gap distance and internal fit of monolithic crowns. However, the marginal accuracy and internal fit shown by the extraoral scanner were also within the clinically acceptable ranges. Furthermore, the examined monolithic crowns displayed marginal gap distance and internal fit values that were within the accepted clinical limits.

Ethics approval and consent to participate

Not applicable.

Data availability

The datasets supporting the findings of the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

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