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MARGINAL FIT ASSESSMENT OF CAD/CAM ZIRCONIA CROWNS FABRICATED BY DIGITAL SCANNING OF DIES AND SILICONE IMPRESSION (IN VITRO STUDY)

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ABSTRACT

INTRODUCTION: The accuracy of impressions has an important effect on the marginal adaptation of fixed restorations. Fit is the most significant factor influencing the restoration's durability, retention, and periodontal health.
AIM OF STUDY: to compare the marginal fit of CAD/CAM zirconia crowns manufactured using two distinct digital impression techniques.
MATERIALS AND METHODS: A typodont tooth in the upper premolar region was prepared to receive a full ceramic crown. A direct scan of the prepared tooth was used to create twenty 3D-printed resin dies. The master dies were divided into two groups at random (n = 10 per group). Group I: scanning the dies digitally. Group II: Digitization of the silicone, scannable impressions. Using cone beam CT, the vertical and horizontal marginal gap were evaluated.
RESULTS: Group I had a vertical marginal gap of (119.5 ± 27.0) µm, which was substantially smaller than Group II's (144.8 ± 25.23) µm, and a horizontal marginal gap of (107.5 ± 36.36) µm, which was smaller than Group II's (154.3 ± 49.53) µm.
CONCLUSION: Although direct digital scanning was superior to indirect digital scanning in terms of marginal fit, all tested techniques yielded clinically acceptable fit values.
KEYWORDS: Marginal fit, CAD/CAM, digital impression.
RUNNING TITLE: Marginal fit of zirconia crowns fabricated by direct and indirect digital scanning.

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INTRODUCTION

Since the early use of computer-aided design and computer-aided manufacturing (CAD/CAM) system for prosthesis fabrication in the 1980s, digital dentistry has grown exponentially (1).
Digital impressions, such as direct scanning intraorally or indirect scanning, can provide a stereolithography (STL) file, which is the initial step in the digital process. The clinical steps can be transferred to a virtual "cast-free working environment." Rapid prototyping (RP) technologies can still be used to create physical prototypes from the same STL files if necessary. Intra-oral optical scanners (I.O.S.s) have ushered dentistry into its digital time, altering the routines of dentists and dental technicians (2,3).

Restorative dentistry is incorporating computer-based engineering through the use of digital processes, from intraoral scanning to the production of the final prosthesis. These procedures are known as the "digital workflow". The digital workflow may consist of virtual technologies or may also employ conventional methods. The digital file is then transferred to a milling machine or a 3D printer, which produces a resin cast (4).
Performing intraoral scans may improve efficacy in a variety of areas. Eliminating the need of tray selection, the impression materials which must be dispensed, washed and then transported to the laboratory (5).

Extraoral scanning is a typical laboratory technique. After taking impressions, a master cast was created and scanned. With the availability of high-quality scanners, however, extraoral digital scanning of traditional impressions can be done; this eliminates the need for the plaster model fabrication, thereby preventing errors resulting from the setting expansion (6).

Zirconia-based ceramic materials **represent** important development. Zirconia restoration is an attractive metal-free alternative for long-lasting prosthesis due to its high strength, biocompatibility, reduced plaque accumulation, and reduced thermal conductivity (7).

The evolution of CAD/CAM technology employing digital steps yields a superior marginal adaptation. Numerous studies demonstrated that ceramic restorations produced using CAD/CAM technology achieved higher levels of marginal adaptation compared to conventional manufacturing processes (8).

In prosthodontic treatment, marginal fit has a direct impact on the restoration longevity. The distance between the restoration's margin and the prepared tooth's completion line is what determines it. Inadequate marginal fit is destructive to the tooth and surrounding structures because it may cause cement dissolution, percolation of fluid leading to secondary cavities, and modification of the microflora distribution leading to periodontal problems (9).

Diverse authors concur that a mean marginal gap of 120 microns or less is clinically permissible. Other studies showed levels ranging from 50 to 200 microns. McLean and Von Fraunhofer established an upper limit of 120 microns (10).

Therefore, the purpose of this study was to compare the fit accuracy of CAD/CAM zirconia crowns fabricated by digital scanning of dies and scannable silicone impressions. The null hypothesis was that no difference in the fit accuracy of ceramic restorations using direct and indirect digital scanning.

MATERIALS AND METHODS

In the literature, the sample size for assessing marginal fit ranged from 5 to 10 per group (11). Using CBCT software tools, the locations of the measured sites were standardized across all specimens using a sample size of twenty (n = 20).

Methods

Typodont tooth Preparation:

An ivory upper premolar tooth was prepared for a full ceramic crown. 2 mm of occlusal reduction, 1.5 mm of axial reduction, 1mm supra-gingival chamfer finishing line (12). All transitions from the axial to the occlusal surface were rounded, smooth, and free from sharp angles or undercuts (Fig 1).

Master dies fabrication

For the 3D printing of the prototype dies, a desktop SLA 3D printer (Form2, Formlabs, MA, USA) was utilized. Twenty dies were printed in a high-precision resin (Grey Resin, RS-F2-GPGR-04, Formlabs, Massachusetts, United States). In order to standardize the procedure, each die was printed individually in the middle of the construction platform. The dies were post-cured for 30 minutes (Fig 2).

Each die was repositioned in the model in preparation for scanning and impression creation.

Grouping

According to the digital scanning technique, the twenty printed resin dies were divided into two groups of ten dies each.

Group I : Scanning the dies digitally.

Group II: Silicone impressions scanned digitally.

Group I: Scanning the dies digitally

The lens of the omnicam camera was parallel to the occlusal plane. The die and adjacent teeth were scanned using a continuously streaming video image of the buccal and lingual surfaces of the model at the desired location.

Group II: Silicone impressions scanned digitally.

Using a one-step (medium body) impression technique, ten PVS impressions of the master die and adjacent teeth were produced from medium body impression material. To prevent overfilling of the impression tray, ensure uniform thickness of the impression material, and permit reproducible placement of the loaded tray, a special acrylic tray with two stoppers was created.

To compensate for impressions setting at room temperature as opposed to mouth temperature, the setting duration for PVS impressions was increased to 10 minutes. Each impression was affixed to the scanning base so that it could be digitized using the InEos X5 extraoral scanner.

Computer Aided Designing (CAD) of crowns

Twenty crowns were designed using Cerec software (CEREC 3D software, Version 4.2, Sirona Dental Systems, Bensheim, Germany) for the two test groups. The die spacer was adjusted to 50 µm, and the insertion path was mapped out. The zirconia material and type of disc were selected from the CAM software in order to issue a milling command to the connected milling machine (Fig 3).

Computer aided manufacturing (CAM) and sintering of the crowns

Using a monolithic zirconia disc (Super-translucent monolithic zirconia (CubeX2), Dental Direkt GmbH, Germany), the CEREC inLab MC X5 milling unit was used for the CAM procedure of the designed crowns. In accordance with the manufacturer's instructions, the specimens were sintered in a furnace (Dentsply Sirona Inlab Profire furnace) at 1450 degrees Celsius. The temperature was increased until the sintering temperature was reached and then decreased at a rate of 10 °C/min during the chilling process following the final sintering.

The cementation of crowns

Each crown was temporarily bonded to its corresponding die using variolink try-in paste, and a 5 kg static load was applied for 3 minutes to assure proper seating.

CBCT imaging for measuring marginal gaps

A computerized cone beam tomography system with a sensitive x-ray source of 90 kv was utilized. Using specialized software (On Demand Vera View), 3D images were reconstructed on a computer monitor, and the data were stored in DBM files. Each specimen was sectioned in the sagittal plane (bucco-lingual) and the coronal plane (mesio-distal).

Vertical marginal gap measuring

The vertical marginal gaps in two sections, sagittal and coronal, were used to determine the MG values for four regions of each crown (sagittal buccal, sagittal lingual, coronal mesial and coronal distal).

The vertical marginal gap measuring points

Sagittal buccal: The perpendicular distance between the buccal margin of the crown and the die's finish line.

Sagittal palatal: The perpendicular distance between the palatal margin of the crown and the die's finish line.

Coronal mesial: The perpendicular distance between the crown's mesial margin and the die's finish line.

Coronal distal: The perpendicular distance between the crown's distal margin and the die's finish line.

Horizontal marginal gap measuring

The horizontal marginal gaps in two sections, sagittal and coronal, to determine the MD values for four regions of each crown (sagittal buccal, sagittal lingual, coronal mesial and coronal distal).

The horizontal marginal gap measuring points

Sagittal buccal: The angular distance the buccal margin of the crown and the die's finish line.

Sagittal palatal: The angular distance between the crown's palatal margin and the die's finish line.

Coronal mesial: The angular distance between the crown's mesial margin and the die's finish line.

Coronal distal: The angular distance between the crown's distal margin and the die's finish line.

Managements of data and statistical analysis

Data were entered into the computer and analyzed using version 20.0 of the IBM SPSS software programme. Quantitative data were described using range (minimum and maximum), mean, and standard deviation (IBM Corp., Armonk, NY). At the 5% significance level, the derived results were deemed significant.

RESULTS

1) Vertical marginal Gap (VMG)

Sagittal view

- **Buccal surface**: Group I had a mean buccal surface measurement of (108.0 ± 26.16 µm) while Group II measured (145.0 ± 29.15 µm).
- A post-hoc test (Tukey) demonstrated that:
  – A statistically significant difference between Group I and Group II (p=0.008).
- **Palatal surface**: Group I had a mean surface measurement of (127.0 ± 30.57 µm) while Group II measured (148.0 ± 34.90 µm).
- A post-hoc test (Tukey) demonstrated that:
  – There was no statistically significant difference between the palatal surfaces of Group I and Group II (p = 0.169).

Coronal view

- **Mesial surface:** Group I had a mean mesial surface measurement of (126.0 ± 34.38 µm) while Group II measured (142.0 ± 37.36 µm).
- A post-hoc test (Tukey) demonstrated that:
  – There was no statistically significant difference between the mesial surfaces of Group I and Group II (p=0.332).
- **Distal surface:** Group I had a mean distal surface measurement of (117.0 ± 31.99µm) while Group II measured (144.8 ± 25.23µm).
- A post-hoc test (Tukey) demonstrated that:
  – A statistically significant difference between Group I and Group II (p=0.040).
- The statistical analysis of **all surfaces** revealed that Group I had a mean value of (119.5 ± 27.0) µm, while Group II had a mean value of (144.8 ± 25.23) µm (Table 1) (Fig 4).
- Statistical analysis and comparison of Group I and Group II total surface areas using the post hoc Tukey test revealed:
- A statistically significant difference between Group I and Group II (p=0.040) (Fig 5).

2) Horizontal marginal gap (HMG)

Sagittal view:

- **Buccal** surface: Group I had a mean buccal surface measurement of (119.0 ± 43.83 µm), while Group II measured 155.0 ± 64.68 µm.
- A post-hoc test (Tukey) demonstrated that:
  – There was no statistically significant difference between the buccal surfaces of Group I and Group II (p = 0.162).
- **Palatal** surface: Group I had a mean surface measurement of (113.0 ± 47.62µm), while Group II measured (141.0 ± 60.08µm).
- A post-hoc test (Tukey) demonstrated that:
  – There was no statistically significant difference between the palatal surfaces of Group I and Group II (p = 0.263).

Coronal view:

- **Mesial** surface**:** Group I had a mean mesial surface measurement of (99.0 ± 25.58µm), while Group II measured (160.0 ± 47.84µm).
- A post-hoc test (Tukey) demonstrated that:
  – A statistically significant difference between Group I and Group II (p = 0.002).
- **Distal** surface: Group I had a mean distal surface measurement of (117.0 ± 31.99µm), while Group II measured (144.8 ± 25.23µm).

- A post-hoc test (Tukey) demonstrated that:
  – A statistically significant difference between Group I and Group II (p=0.011).
- The statistical analysis of **all surfaces** revealed that Group I had a mean value of (107.5 ± 36.36) µm, while Group II had a mean value of (154.3 ± 49.53) µm (Table 2) (Fig 6).
- Statistical analysis and comparison of Group I and Group II total surface areas using the post hoc Tukey test revealed:
  – A statistically significant difference between Group I and Group II (p=0.027) (Fig 7).

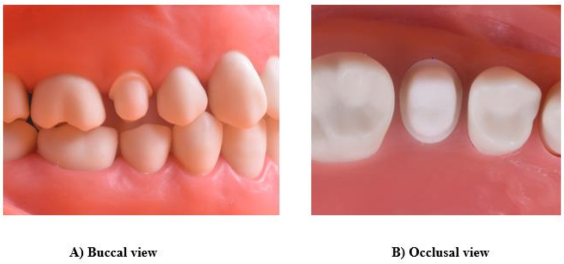

Figure (1): The prepared ivory tooth in a typodont model.

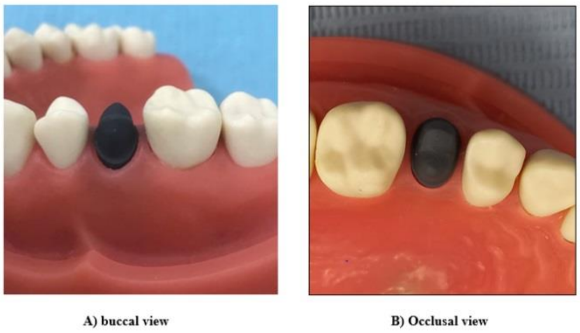

Figure (2): 3D resin printed die in a typodont model.

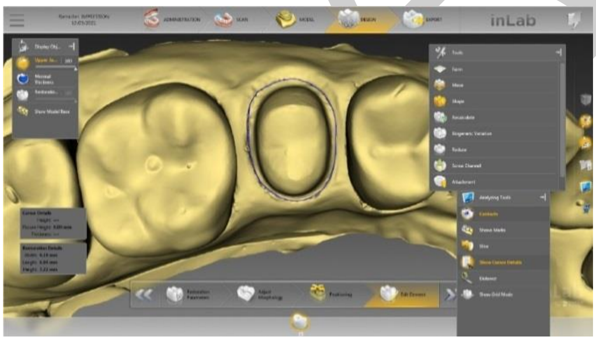

Figure (3): Computer aided design process of the zirconia crowns.

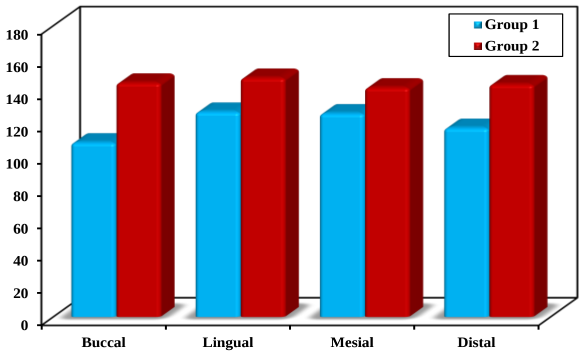

Figure (4): Comparison between the two studied groups according to vertical marginal gap (VMG) of each surface.

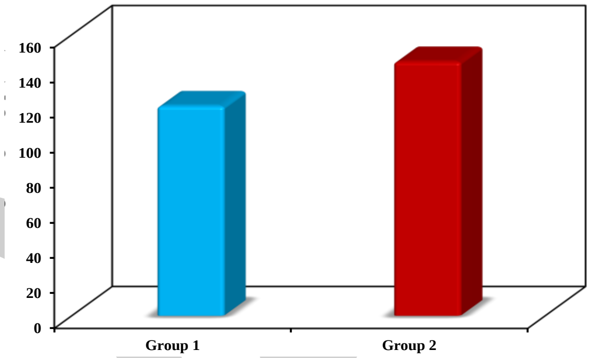

Figure (5): Comparison between the two studied groups according to average vertical marginal gap (VMG).

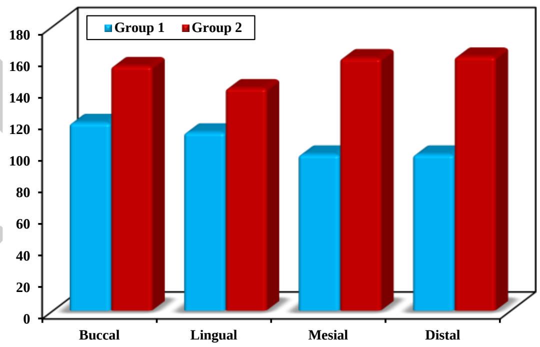

Figure (6): Comparison between the two studied groups according to horizontal marginal gap (HMG) for each surface.

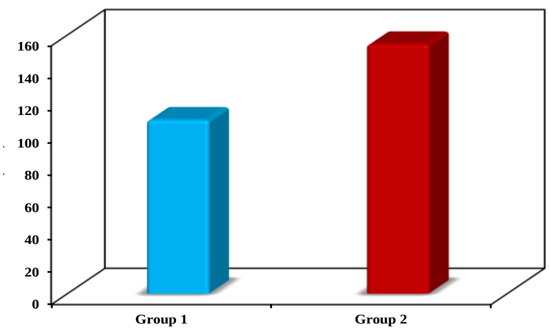

Figure (7): Comparison between the two studied groups according to average horizontal marginal gap (HMG).

Table (1): Comparison between the two studied groups according to marginal gap (MG) in micro-meter.

Marginal Gap (MG)	Group 1 (n = 10)	Group 2 (n = 10)	t	p
Buccal				
Min. – Max.	70.0 – 150.0	90.0 – 190.0	2.987*	0.008*
Mean ± SD.	108.0 ± 26.16	145.0 ± 29.15		
palatal				
Min. – Max.	80.0 – 160.0	110.0 – 210.0	1.431	0.169
Mean ± SD.	127.0 ± 30.57	148.0 ± 34.90		
Mesial				
Min. – Max.	80.0 – 180.0	100.0 – 220.0	0.997	0.332
Mean ± SD.	126.0 ± 34.38	142.0 ± 37.36		
Distal				
Min. – Max.	70.0 – 170.0	110.0 – 180.0	2.209*	0.040*
Mean ± SD.	117.0 ± 31.99	144.0 ± 21.71		
Average				
Min. – Max.	80.0 – 152.5	102.5 – 190.0	2.161*	0.044*
Mean ± SD.	119.5 ± 27.0	144.8 ± 25.23		

SD: Standard deviation t: Student t-test
p: p value for comparing between the studied groups
*: Statistically significant at p ≤ 0.05.

Table (2): Comparison between the two studied groups according to Marginal Discrepancy (MD) in micro-meter.

Marginal Discrepancy (MD)	Group 1 (n = 10)	Group 2 (n = 10)	t	p
Buccal				
Min. – Max.	60.0 – 170.0	70.0 – 260.0	1.457	0.162
Mean ± SD.	119.0 ± 43.83	155.0 ± 64.68		
palatal				
Min. – Max.	60.0 – 180.0	80.0 – 230.0	1.155	0.263
Mean ± SD.	113.0 ± 47.62	141.0 ± 60.08		
Mesial				
Min. – Max.	70.0 – 150.0	100.0 – 240.0	3.556*	0.002*
Mean ± SD.	99.0 ± 25.58	160.0 ± 47.84		
Distal				
Min. – Max.	50.0 – 170.0	80.0 – 250.0	2.844*	0.011*
Mean ± SD.	99.0 ± 43.83	161.0 ± 53.22		
Average				
Min. – Max.	65.0 – 152.5	92.50 – 215.0	2.406*	0.027*
Mean ± SD.	107.5 ± 36.36	154.3 ± 49.53		

SD: **Standard deviation** t: **Student t-test**
p: p value for comparing between the studied groups
*: Statistically significant at p ≤ 0.05.

DISCUSSION

CAD/CAM technology has facilitated and developed the production of restorations using a fully digital workflow with a more precise fit than those manufactured using conventional methods (13).

Marginal fit is an essential clinical success parameter for long-lasting prosthesis. Numerous proposals were made to enhance the marginal adaptation of ceramic restorations using cutting-edge technologies and innovations, such as digital workflow (14). Authors suggested a target of 25 to 40 m for marginal fit, whereas today 75 to 160 m is regarded as clinically successful (15).

The aim of this study **was** to compare the fit accuracy of CAD/CAM monolithic zirconia crowns manufactured by digital scanning of dies versus scannable silicone impressions using cone beam computed tomography.

From the given results of the current study, the null hypothesis was rejected as direct digital scanning had a statistically significant superior marginal fit than the indirect digital scanning.

This study was conducted in vitro to provide standardized experimental performance conditions that may not be achievable in vivo (16).

In this study, the Omnicam intra-oral scanner was used for direct scanning of dies and the Ineos X5 was used for the indirect scanning of the impression as it resembles the clinical situation.

In the literature, the sample size for assessing marginal fit ranged from 5 to 10 per group (11). Groten et al (17) conducted a study to determine the lowest number of points for gap measuring on the margins of single crowns required to generate relevant gap analysis results. They concluded that a minimum of 50 measuring points is required regardless of the gap definition, cementation condition.

Using CBCT software tools, the locations of the measured sites were standardized across all specimens using a sample size of twenty (n = 20). In accordance with Gonzalo et al (18) and Lee et al (19) used a small sample size and compensated for it by taking a significant number of measurements per specimen.

According to manufacturer claims for zirconia crowns, a chamfer finish line was chosen for the current study's finish line design. As the master die was placed in a rigid acrylic typodont that did not permit gum retraction, a supragingival finish line was created.

The total occlusal convergence (TOC) utilized in this investigation was 10–12 o, as recommended by Mormann et al (20) for CEREC restorations.

The die spacer was set to 50 µm Nakamura et al (21) suggested a die spacer between 30 and 50 mm and a total occlusal convergence between 4 and 12 degrees for CEREC-fabricated crowns.

The die spacer is a semi-quantitative tool that balances errors within the process steps, such as powdering, manufacturing, or sintering shrinkage, as well as errors when scanning which create areas of premature contact between the abutment and axial walls (22).

All specimens were designed with the same software (CEREC 3D, V4.2 Sirona, Germany) and machined using a single milling machine (CEREC inLab MC X5). Using a new set of burs reduce the impact of the milling on the crowns' precision.

In this study, twenty 3D-printed master resin dies were divided into two groups (n = 10 for each group) in order to compare the marginal fit accuracy of direct and indirect digital scanning based on their average measurements.

Using digital scanners and the active triangulation method, all of the specimens were created. Triangulation is a non-contact method for digitally capturing data on the shape of a three-dimensional object and creating three-dimensional digital models. A light source emits an illumination beam that is focused on the target object's surface. The beam penetrates to the maximum depth possible based on the material's translucency, and is then reflected back to the camera sensor, which employs an algorithm to compute the object's third dimension. A crucial aspect of such a scanning system is that the triangulation technique necessitates a uniformly reflective surface with a moderate degree of translucency and reflectivity for accurate scanning (23).

Cone beam computed tomography permits proper 3D imaging of hard tissues and was used to take the measurements. This imaging modality is capable of producing sub-millimetre-high resolution images in a brief amount of time with reduced amount of radiation (24).

In addition, CBCT is a non-destructive technique that allows 3D assessment of marginal fit sectioning of the specimens. In this study, the limited field of view (FOV) configuration of CBCT was chosen which was (50*50 mm) with (85 µm) voxel resolution to reduce radiation dose while increasing image resolution (25,26).

In this study, a statistically significant difference was found for the marginal gap, with the mean value of Group 1 being 119.5 ± 27.0µm and the mean value of Group II being 144.8 ± 25.23 µm. The mean values for the two groups fall within the clinically acceptable ranges of 150 m and 120 m, according to Fransson et al (27) and Mclean and von Fraunhofer (28), respectively.

Group 1 had a mean value of 107.5 ± 36.36µm, whereas **Group 2** had a mean value of 154.3 ± 49.53 µm, indicating a statistically significant difference between the two tested groups.

Previous research has demonstrated that the use of direct optical scanning results in substantially lower level of marginal gaps than the use of the traditional methods (30). The current study supports this conclusion, as the direct scanning group had the lowest value of marginal gap when compared to the indirect digital scanning group. In comparison to direct digital scanning, these conventional impression materials may endure a degree of dimension changes which is marginally detrimental (30).

Utilized in this study were direct intraoral scanning and indirect scanning for impressions. The data was collected from surfaces with various optical properties, such as translucency, reflection, and uniformity. It is possible that getting the data with different levels of precision (31).

There is agreement with the conclusion by Pedroche LO et al 2016 that intraoral digital scanning (3Shape) provided a lower level of gap value when compared to traditional impressions and gypsum casts scanned with a benchtop extraoral scanner and evaluated using the silicone replica technique (32).

In accordance with the conclusion reached by Malaguti G. et al (33), the intraoral scanner produced the best results for marginal and internal gaps when compared to the extraoral scanner, and the results of the current study support this conclusion.

Contrary to the findings of DAcry et al (34) and Das Neves et al (35), who discovered no statistically significant difference between the marginal accuracy of direct and indirect scanners.

Moreover, Luthardt et al (36) found that indirect scanning enhanced the fit of glass ceramic crowns significantly more than direct scanning.

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. Direct digital scanning significantly enhances the fit accuracy of the CAD/CAM crowns compared to extraoral scanner.
3. Direct digital scanning facilitates the clinical procedures of the optical impression for both dentist and patient.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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