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Original Article

Comparison of marginal and internal fit of 5-unit zirconia fixed dental prostheses fabricated with CAD/CAM technology using direct and indirect digital scans

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Background/purpose: Advancements in digital dentistry and the development of intraoral scanners (IOS) have provided clinicians with an accurate and efficient alternative to analog impressions. The aim of this study was to assess the accuracy of the marginal and internal fit of 5-unit monolithic zirconia fixed dental prostheses (FDPs) fabricated with CAD/CAM technology using direct and indirect digitalization methods.

Material and methods: Three teeth in a maxillary typodont model were prepared to receive a 5-unit zirconia FDP. Six different groups were created according to the type of scanner (intraoral and extraoral) and the type of workflow. For direct workflow, the typodont was scanned with two different IOS (3Shape Trios 3 [3S-IOS] and Cerec Omnicam [C-IOS]). For indirect workflow, after conventional impressions were obtained, the impressions (IMP) were scanned with two different laboratory scanners (3S-IMP and C-IMP). After the impressions were poured, the stone (STN) casts were scanned with the same laboratory scanners (3S-STN and C-STN). Sixty 5-unit monolithic zirconia FDPs (10 in each group) were designed and milled. The marginal and internal fit was assessed.

Results: The mean marginal gap values were $78.2 \pm 9 \mu\text{m}$ in the IOS group, $82.6 \pm 9 \mu\text{m}$ in the IMP group, and $82.6 \pm 9 \mu\text{m}$ in the STN group, indicating no statistically significant differences among groups ($p > 0.05$). The mean axial gap values were $77.7 \pm 10 \mu\text{m}$ in IOS group, $83.61 \pm 15 \mu\text{m}$ in the IMP group, and $84.5 \pm 9 \mu\text{m}$ in the STN group, indicating no statistically significant differences among groups ($p > 0.05$).

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Conclusion: The marginal and internal fit of 5-unit monolithic zirconia FDPs fabricated with direct and indirect digital scans were similar. The smallest gap values were observed at the marginal region while the greatest gap values were detected at the occlusal region.

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1. Introduction

In dentistry, treatment options have significantly changed due to rapidly evolving technological developments such as Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM). CAD/CAM technology has gained popularity in dental clinics exponentially over the past 30 years.^{1–3} To fabricate restorations with CAD/CAM technology, the accurate conversion of teeth, gingiva and other dental tissues into a 3-dimensional (3-D) digital data set is paramount. Digital data is acquired either “directly” by scanning the surface of the oral environment with an intraoral optical scanner (IOS) or “indirectly” by using an extraoral scanner to digitally recreate the oral environment based on scan data acquired from conventional impressions or stone cast models.⁴

Today, there are many IOS with different workflows.^{5,6} All cameras used for IOS require the projection of light. This projection is then recorded as either individual images or a video stream, which is then compiled by the software after recognition of the points of interest. The first two coordinates (x and y) of each point are evaluated on the image. Then, the third coordinate (z) is calculated depending on the distance to object technologies of each camera. These calculation systems vary according to the brand of the intraoral scanner used; triangulation, confocal imaging, Active Wavefront Sampling (AWS), and stereophotogrammetry.⁷

Direct digitalization provides predictable and accurate outcomes in the fabrication of single-unit restorations and short-span fixed dental prostheses.^{8–15} However, it has been reported that precision may decrease as the scanning area increases. Ender et al., reported that conventional impression methods were more successful than digital impressions.^{16,17} Su et al.,¹⁸ also reported that the conventional impression methods showed more successful results than full arch digital scans for five different clinical scenarios. Similarly, Malik et al.,¹⁹ found that conventional impression methods demonstrated more success than digital impressions, however they did not report any difference between IOSs.

Both marginal and internal fits of the prosthetic restorations have an important role in long-term clinical success.²⁰ Although various authors suggested different clinically acceptable values for the marginal gap, a marginal gap of 120 μm has widely been considered to be clinically acceptable.^{21–23}

Many factors such as impression technique can influence the marginal and internal fit of the restoration.²² Marginal and internal fits are used to assess the precision of impression and fabrication methods. Different measurement methods were used to evaluate marginal and/or internal fit;

microscopic measurement of cross-sectioned cemented specimens, direct microscopic observation of the marginal area, silicone replica techniques and micro-computed tomography (micro-CT).²³ Recently, in order to overcome the limitations of existing methods and allow 3-D evaluation instead of cross-sectional evaluation, a 3-D inspection and metrology (superimposing) and optical digitalization method was introduced.²⁴ The advantages of this method were reported to be the non-invasive nature of the technique, three-dimensional evaluation, and the number of points evaluated (>20,000 points).^{25,26}

The purpose of this in vitro study was to evaluate the marginal and internal fit of 5-unit monolithic zirconia fixed dental prostheses (FDPs) fabricated with CAD/CAM technology using direct and indirect digitalization and 3-D deviation analysis. The null hypothesis was that the marginal and internal fit of 5-unit FDPs fabricated by direct and indirect digitalization methods would not show statistically significant differences.

2. Materials and methods

In a maxillary typodont model (analog model), the right lateral incisor and right first premolar teeth were removed. Then the maxillary right central incisor, canine and second premolar teeth were prepared to receive 5-unit zirconia fixed dental prosthesis. All teeth were prepared by a single operator. A chamfer diamond rotary cutting instrument was utilized to prepare the 1 mm-wide chamfer margin. The preparation depth was 1.5 mm axially and 2 mm occlusally measured using a silicone index. Then, the left central incisor and right first molar tooth were removed to accurately capture proximal chamfer margins during digital scanning procedures.

Data was categorized into one of six groups according to the type of scanner used and the type digital workflow utilized (Fig. 1);

- 3S-IOS, scanning the reference model with Trios 3 intraoral scanner,
- 3S-IMP, scanning the conventional impression with E3 extraoral scanner,
- 3S-STN, scanning the stone cast with E3 extraoral scanner,
- C-IOS, scanning the reference model with Omnicam intraoral scanner,
- C-IMP, scanning the conventional impression with InEosX5 extraoral scanner,
- C-STN, scanning the stone cast with InEosX5 extraoral scanner.

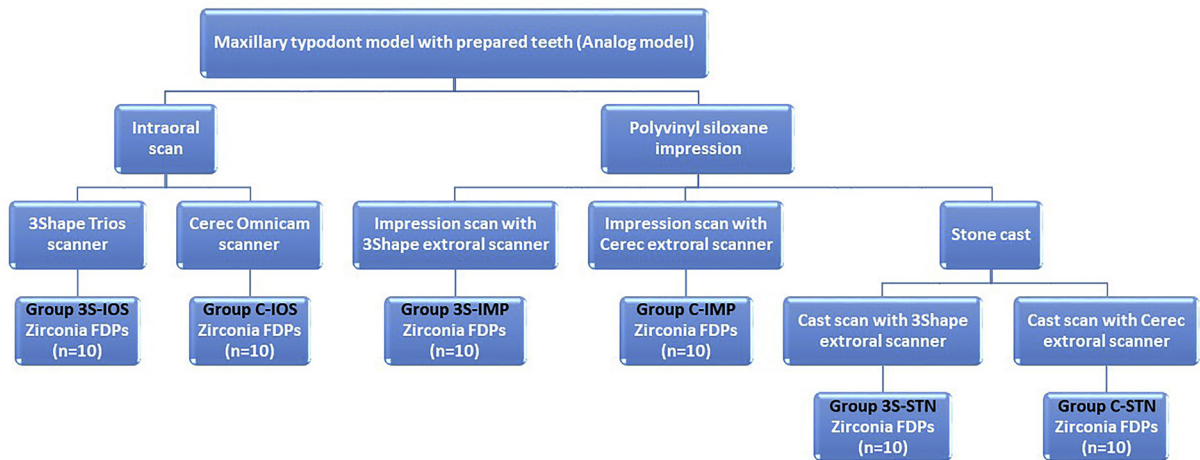


Figure 1 Study design showing six groups according to the type of scanner used and the type digital workflow utilized.

For the direct digitalization, two different intraoral scanners were used; Trios 3 (3Shape, Copenhagen, Denmark) and Cerec Omnicam (Sirona Dental System, Bensheim, Germany). The scanning procedures were performed by a single operator, who strictly followed the manufacturer's instructions.

For indirect digitalization, the conventional impressions were made from the analog model by using a scannable polyvinyl siloxane (PVS) impression material (Hydrorise Implant Heavy/Light Body, Zhermack, Badia Polesine, Italy) and a custom tray. The conventional impressions were scanned with two different extraoral scanners (E3, 3Shape, Copenhagen, Denmark and Cerec, InEosX5, Sirona Dental System, Bensheim, Germany). Immediately after the scanning of impressions, a scannable Type IV dental stone (Klasse 4 Dental, Augsburg, Germany) was vacuum mixed and poured into the impressions according to the manufacturer's instructions. The definitive casts were scanned with two different extraoral laboratory scanners (E3, 3Shape, Copenhagen, Denmark and Cerec, InEosX5, Sirona Dental System, Bensheim, Germany).

After all of the direct and indirect digital impressions were acquired, 6 different virtual (Reference) models (one for each group) were obtained in STL (Standard Tessellation Language) file format. The STL file format is the most dominant and extensively used file format generated by IOS. It is utilized by nearly all CAD/CAM software, 3-D milling machines, and 3-D printers. The STL format encodes the surface geometry of a 3-D object into a tessellated "triangular mesh": a meshwork pattern including small non-overlapping adjoining triangles.

A total of 60 (10 for each group) 5-unit monolithic zirconia FDPs in full contours were digitally designed from the virtual models by the same dental technician. A gap of 50 μm was integrated in the design as a cement space for the axial and occlusal regions but not for the marginal areas.²⁷ The restorations were designed by using their associated design software (3Shape Dental System and Cerec inLab SW). Subsequently, all FDPs were milled from presintered zirconia blocks (ZOLID-HT, Straumann AG,

Basel, Switzerland) with a 5-axis milling machine (Redon Hybrid Technology, Istanbul, Turkey). The sinterization process was performed at 1450 °C for 9 h 40 min. Then, the restorations were glazed at 830 °C for 40 min (Programat P510, Ivoclar Vivadent, Liechtenstein). No adjustments using high-speed or slow-speed handpieces were performed to enhance the marginal adaptation of the FDPs.

For 3-D discrepancy (superimposing) analysis, both the marginal integrity and internal fit were determined by using a 3-D industrial scanner (ATOS Triple Scan, GOM, Braunschweig, Germany) and also an inspection and metrology software (GOM Inspect Professional, Braunschweig Germany). The internal surface of each retainer was coated with a thin layer of silicone oil, which was dried with a cotton swab and high-pressure air. Then, all retainers of each FDP were filled with PVS light-body impression material (Hydrorise Implant Light Body, Zhermack, Badia Polesine, Italy) and seated on the analog model. A 1-kg load was uniformly applied on the occlusal surface of FDP for 5 min. After complete polymerization of the light-body silicone, the excess silicone was carefully removed with a scalpel. The FDP was gently removed, and a thin-layer of PVS impression material (silicone replica), which represents the gap between the surface of abutment teeth and internal surface of the FDP remained on the analog model. The analog model covered with the silicone replica was digitized by using the same industrial scanner, and the data was exported and named "Test model". Both the reference and test models in STL format were imported into the software program (GOM Inspect Professional, Braunschweig Germany). The reference and test models were accurately aligned and superimposed by using specific markers and the Relative Point System (RPS) incorporated in the software program (Fig. 2).

Measurement points were presented in Fig. 3. These points separate the abutment surface into 3 regions as follows: a) marginal area between points 1 and 2, b) axial area between points 2 and 3, c) incisal/occlusal area between points 3. The software automatically registered and measured 1900 points on each prepared tooth to assess the

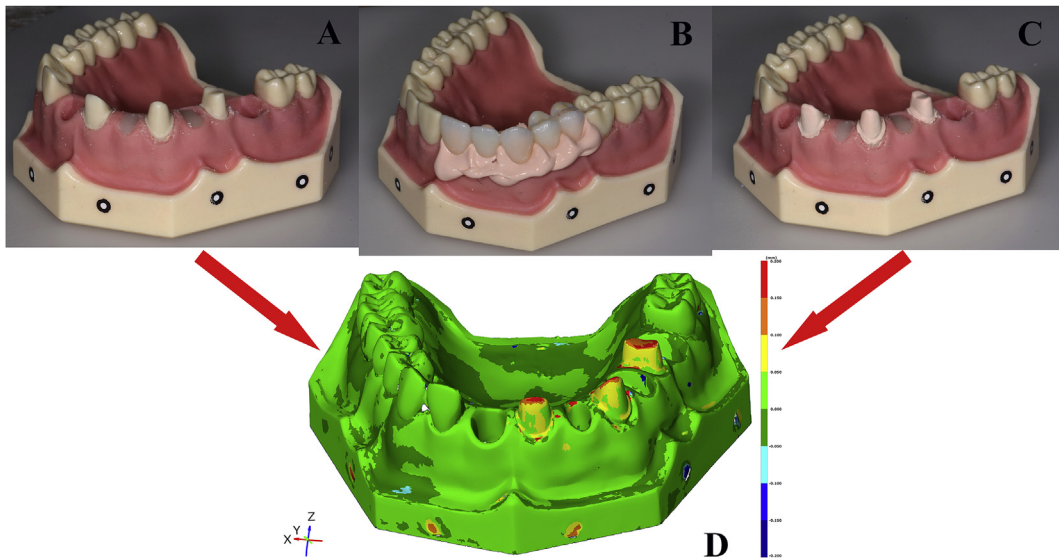


Figure 2 Steps used in this study. (A) Typodont with the prepared teeth, (B) zirconia FDP seated using silicone material, and (C) silicone replica on the prepared teeth. (D) The reference and test models were accurately aligned and superimposed by using specific markers to determine the discrepancy.

marginal and internal fit. A mean measurement value for each region was calculated and used for statistical analysis.

2.1. Statistical analysis

To test the normality and equality of variables before testing statistical differences between study groups, a Shapiro–Wilk normality test was performed. To evaluate the results, a Kruskal–Wallis non-parametric analysis was

performed. To test the differences between the groups, a Conover test was then conducted. Statistical significance would be indicated if $p < 0.05$.

3. Results

The discrepancy values derived from a total of 342,000 measurement points as 60 FDPs with 3 prepared teeth utilized in this study. A mean measurement value for each region (marginal, axial and occlusal) was calculated and used for statistical analysis.

In the direct digitalization workflow (60 prepared teeth), the mean marginal discrepancy values ranged from 62.7 μm (Group 3S-IOS) to 88.3 μm (Group C-IOS). The mean axial discrepancy values ranged from 62.7 μm (Group 3S-IOS) to 94.3 μm (Group C-IOS). The mean occlusal discrepancy values ranged from 132.7 μm (Group C-IOS) to 180.7 μm (Group 3S-IOS).

In the indirect digitalization workflow (120 prepared teeth), the mean marginal discrepancy values ranged between 74 μm (Group 3S-IMP) and 91.7 μm (Group C-STN). The mean axial discrepancy values ranged between 65.7 μm (Group C-IMP) and 102 μm (Group C-IMP). The mean occlusal discrepancy values ranged between 122 μm (Group C-STN) and 200.3 μm (Group 3S-IMP).

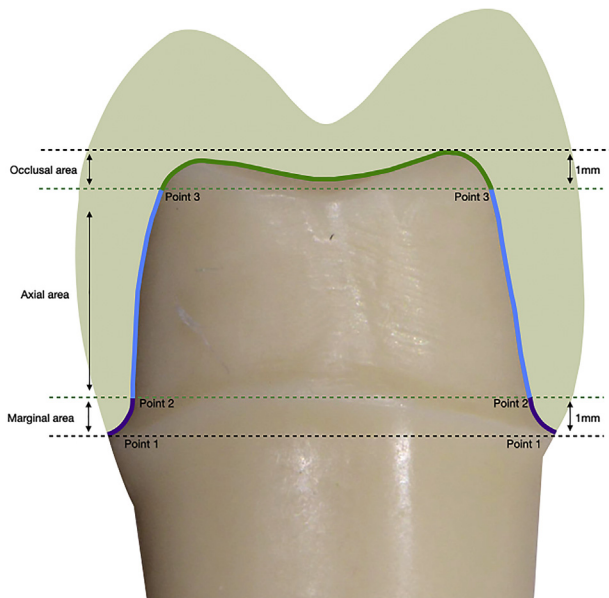


Figure 3 Measurement regions and points for marginal and internal fit evaluations: a) marginal area between points 1 and 2, b) axial area between points 2 and 3, c) occlusal area between points 3.

Table 1 Mean measurement values and standard deviations in micrometer (μm) for all three regions by two different scanners.

Areas	3Shape	Cerec	p-values
Marginal	81.2 \pm 9	82.2 \pm 8	>0.05
Axial	86.3 \pm 11	80.8 \pm 11	<0.05
Occlusal	151.3 \pm 19	141.8 \pm 21	<0.05

When the impact of the type of scanners (3Shape versus Cerec) on the discrepancy (gap) values was evaluated, the mean discrepancy values at the marginal area were not significantly different ($p > 0.05$) between 2 groups but the corresponding values were significantly different at the axial and occlusal areas ($p < 0.05$) (Table 1).

When 3 different workflows (IOS, IMP and STN) were considered, the mean discrepancy values at the marginal, axial and occlusal areas are presented in Table 2. No statistically significant differences were noted among the 3 groups at any regions ($p > 0.05$). For each workflow, the smallest mean gap values were observed at the marginal regions and the highest corresponding values were recorded at the occlusal region; the only exception to this was found in the IOS group.

Table 2 Mean measurement values and standard deviations in micrometer (μm) for all three regions by three different workflows. IOS: intraoral scanner, IMP: impression, STN: stone cast.

Areas	IOS	IMP	STN	p-values
Marginal	78.2 \pm 9	82.6 \pm 9	82.6 \pm 9	>0.05
Axial	77.7 \pm 10	83.6 \pm 15	84.5 \pm 9	>0.05
Occlusal	151.2 \pm 19	150.8 \pm 23	142.8 \pm 19	>0.05

Table 3 Mean measurement values and standard deviations in micrometer (μm) for three areas by six different workflows. * indicates $p < 0.05$. 3S-IOS: scanning the reference model with Trios 3 intraoral scanner. 3S-IMP: scanning the conventional impression with E3 extraoral scanner. 3S-STN: scanning the stone cast with E3 extraoral scanner. C-IOS: scanning the reference model with Omnicam intraoral scanner. C-IMP: scanning the conventional impression with InEosX5 extraoral scanner. C-STN: scanning the stone cast with InEosX5 extraoral scanner.

	Marginal	Axial	Occlusal
3S-IOS	76.2 \pm 10	80.1 \pm 10	156.3 \pm 18
3S-IMP	81.7 \pm 8	86.9 \pm 13*	154.6 \pm 22
3S-STN	82.6 \pm 8	86.6 \pm 10	143.9 \pm 18
C-IOS	80.3 \pm 6	75.3 \pm 10*	146.1 \pm 18
C-IMP	83.5 \pm 9	80.3 \pm 15	147 \pm 24
C-STN	82.5 \pm 10	82.4 \pm 7	141.7 \pm 20

Table 4 Mean measurement values and standard deviations in micrometer (μm) for 3 areas by 6 different workflows. Identical letters in each column (vertically) indicated no statistically significant differences ($p > 0.05$), while non-identical letters in each column indicated statistically significant differences ($p < 0.001$). 3S-IOS: scanning the reference model with Trios 3 intraoral scanner. 3S-IMP: scanning the conventional impression with E3 extraoral scanner. 3S-STN: scanning the stone cast with E3 extraoral scanner. C-IOS: scanning the reference model with Omnicam intraoral scanner. C-IMP: scanning the conventional impression with InEosX5 extraoral scanner. C-STN: scanning the stone cast with InEosX5 extraoral scanner.

	3S-IOS	3S-IMP	3S-STN	C-IOS	C-IMP	C-STN
Marginal	76.2 \pm 10 ^a	81.7 \pm 8 ^c	82.6 \pm 8 ^e	80.3 \pm 6 ^g	83.5 \pm 9 ^k	82.5 \pm 10 ⁿ
Axial	80.1 \pm 10 ^a	86.9 \pm 13 ^c	86.6 \pm 10 ^e	75.3 \pm 10 ^h	80.3 \pm 15 ^k	82.4 \pm 7 ⁿ
Occlusal	156.3 \pm 18 ^b	154.6 \pm 22 ^d	143.9 \pm 18 ^f	146.1 \pm 18 ⁱ	147 \pm 24 ^m	141.7 \pm 20 ^r

In this study, a total of 6 different workflows (2 direct digitalization and 4 indirect digitalization) were designed and tested. The mean discrepancy values at the marginal, axial and occlusal areas were given in Table 3. No statistically significant differences were observed at any regions among the 6 groups ($p > 0.05$), except two groups (axial region between 3S-IMP and C-IOS groups). For each workflow, the greatest mean gap values were observed at the occlusal area and the smallest corresponding values were noted at the marginal area; except one intraoral scanner (Cerec) group which deferred from this trend at the marginal and axial regions (Tables 4 and 5).

4. Discussion

In this study, the marginal integrity and internal fit of 5-unit monolithic zirconia FDPs fabricated by direct and indirect digitalization were investigated. No statistically significant differences were noted among the groups based on the mean discrepancy (gap) values at three different designated regions. As a result, the null hypothesis was accepted based on the data sets collected in this study.

Some other studies regarding the marginal and internal fit of restorations using CAD/CAM technology are available in the literature. However, a direct comparison between the present study and other studies cannot be made, as different types of scanners, software, inspection and metrology methods were utilized on those studies.

Arezoobakhsh et al.,¹⁵ compared the marginal and internal fit of forty 3-unit zirconia frameworks which were fabricated using direct and indirect digital scans. Two different intraoral scanners [(3Shape Trios 2 (TRI) and Cerec Omnicam (CSI))] were

Table 5 Mean measurement values and standard deviations in micrometer (μm) for 3 areas by 3 different workflows. Identical letters in each column (vertically) indicated no statistically significant differences ($p > 0.05$), while non-identical letters in each column indicated statistically significant differences ($p < 0.001$). IOS: intraoral scanner, IMP: impression, STN: stone cast.

	IOS	IMP	STN
Marginal	78.2 \pm 9 ^a	82.6 \pm 9 ^c	82.6 \pm 9 ^e
Axial	77.7 \pm 10 ^a	83.6 \pm 15 ^c	84.5 \pm 9 ^e
Occlusal	151.2 \pm 19 ^b	150.8 \pm 23 ^d	142.8 \pm 19 ^f

used in this study, and three different workflows were compared; the workflows under investigation were similar to the workflows presented in this study. The Arezoobakhsh study measured discrepancies at 4 different regions (marginal, mid-axial, axio-occlusal, and mid-occlusal).¹⁵ They detected no significant differences in marginal gap between the TRI ($60 \pm 15 \mu\text{m}$) and CSI ($55 \pm 13 \mu\text{m}$) groups. They observed that the internal discrepancies in the mid-axial position were similar between the TRI ($70 \pm 15 \mu\text{m}$) and CSI ($72 \pm 23 \mu\text{m}$) groups. They also reported that the internal gap in the mid-occlusal regions were significantly higher in the CIL ($238 \pm 92 \mu\text{m}$) and DCL ($248 \pm 71 \mu\text{m}$) groups when compared with the TRI ($104 \pm 27 \mu\text{m}$) and CSI ($128 \pm 16 \mu\text{m}$) groups.

The actual gap measurement numbers were comparable between the present study and the study by Arezoobakhsh et al.,¹⁵ and the finding that the gap measurement values were smaller with direct digital scans than indirect digital scans is also a consistent finding in both studies. Additionally, the smallest gap measurement values were observed in the marginal regions while the largest gap measurement values were observed in the occlusal regions; a consistent finding with the present study. The main differences in the present study and the study by Arezoobakhsh et al., was the length of the restoration under investigation: 3-unit zirconia copings versus 5-unit zirconia FDPs in full contours. Additionally there were differences in the number of measurement points per tooth (4 in the Arezoobakhsh et al. study versus 1900 in the present study). Internal and marginal gap measurement methods also differed between the Arezoobakhsh et al. study and the present study; a stereomicroscope at $\times 50$ magnification versus inspection and metrology (overlapping) method were utilized in each study respectively.

Kim et al.,²⁸ sought to uncover whether the number of pontics and impression technique effected the accuracy of 4-unit monolithic zirconia FDPs. Master models were fabricated and then scanned using direct digitization (DD) and indirect digitalization (ID) methods. Then 4-unit monolithic zirconia FDPs were fabricated and divided into 3 groups based on the number of pontics. Marginal, axial, and occlusal gaps were measured using 10 measurement points per abutment tooth, and a reflected light microscope technique at $\times 50$ magnification. It was concluded that for the 2-pontic groups, using the direct digitalization method, the marginal, axial, and occlusal gaps were 69.4 μm , 127 μm , and 188.5 μm respectively, while the indirect digitalization method yielded 75.2 μm , 124.7 μm , and 189.5 μm gaps for the same respective marginal, axial and occlusal categories. It was concluded that direct digitalization resulted in smaller gap values in all measurement areas when compared with the indirect digitalization method; a finding consistent with those noted in the present study.

Ahrberg et al.,¹⁴ assessed the marginal and internal fit of both single unit zirconia crowns and 3-unit FPD's using two different impression methods; a computer-aided (digital) impression (CAI) and a conventional impression (CI). A total of 17 single zirconia crowns and 8 three-unit zirconia FDPs were fabricated using CAD/CAM technology. Both types of impressions (CAI and CI) were captured for each patient. A silicone replica technique was then used to determine the marginal and internal fit of each framework. Each sample

was cut into four sections and then evaluated with a microscope at four different sites: marginal gap, mid-axial wall, axio-occlusal transition, and centro-occlusal. The mean marginal gap values demonstrated statistically significant differences: 61.08 μm for CAI group and 70.4 μm for CI group. The difference in mean gap values at the centro-occlusal site were also determined to be statistically significant: 155.5 μm for CAI and 171.5 μm for CI group. The authors in this study concluded that the digital impression technique was more accurate than the conventional impression technique in fabricating single unit crowns as well as three-unit FDPs. These findings were consistent with the findings reported in the present study.

One of the strengths of the present study, when compared with previous studies conducted, is the total number of measurement points recorded. Most studies evaluating the marginal and internal fit of single crowns and FDPs use fewer than 50 measurement points per tooth for overlapping procedures while the present study uses 1900 points per tooth. Therefore, it can be speculated that the gap values presented in this study are credible.

The silicone replica method was used in the present study, as well as several previous studies mentioned.^{12,14,29,30} This method is an easy, cost-effective and non-invasive way to evaluate the marginal and internal fit of crowns/FDPs. However, the authors of the present study believe that silicone replica method has certain limitations due to the elastic nature of the silicone light-body impression material. A 1-kg load was uniformly applied on the FDP for 5 min to allow for complete polymerization of the light-body silicone material. After each FDP was removed, a thin-layer of PVS impression material (silicone replica) representing the gap between the surface of abutment teeth and internal surface of the FDP remained on the analog model. After the occlusal load was removed, the silicone replica demonstrated resilience or "bounced back" which might have resulted in a greater thickness of material being recorded, than space which it was intended to measure, due to decompression. Therefore, one can speculate that the gap values might have been smaller than those reported in the present study.

Another limitation of the present study is in the nature of the in vitro study itself; several factors such as humidity, saliva, proximities to an adjacent tooth, and the translucency parameter of the abutment teeth are not the same as one would find in the intraoral environment of a human. The above mentioned factors might limit the applicability of this study to direct digitalization in a human model. Therefore, further clinical studies that evaluate the marginal and internal fit of long-span FDPs fabricated by direct digitalization are needed.

Based on the data collected in this vitro study, it was concluded that the marginal and internal fit of 5-unit monolithic zirconia FDPs fabricated by using direct and indirect digitalization techniques were similar. It was noted that direct digitization yielded smaller gaps at the marginal and axial regions when compared to indirect digitalization; however these findings were not of statistical significance. Additionally, the smallest gap values were consistently observed at the marginal region and the greatest gap values were detected at the occlusal region; these findings were consistent for both the direct and indirect digitalization groups. It was also noted that the

marginal and axial gap values in all groups were within the clinically acceptable range.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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