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ORIGINAL ARTICLE

Marginal and internal fit of five-unit zirconia-based fixed dental prostheses fabricated with digital scans and conventional impressions: A comparative in vitro study

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Abstract

Purpose: This study aimed to compare the marginal and internal fit of five-unit zirconia-based fixed dental prostheses (FDPs) fabricated using digital scans and conventional impressions.

Materials and methods: Nine master models with three zirconia abutments were scanned with an intraoral scanner (test group), and nine conventional impressions (control group) of these same models were also made. The stone casts from these impressions were scanned with a laboratory extraoral scanner (D700, 3Shape, Copenhagen, Denmark). A total of 18 five-unit zirconia-based FDP frameworks (test group, $n = 9$; control group, $n = 9$) were manufactured. Marginal and internal fit (in μm) were evaluated using the replica method under micro-computed tomography. Analysis of variance (one-way ANOVA) and Kruskal–Wallis tests were used to compare continuous variables across two groups. A level of $p < 0.05$ was accepted as statistically significant.

Results: The mean \pm standard deviation of the marginal fit was $95.03 \pm 12.74 \mu\text{m}$ in the test group and $106.02 \pm 14.51 \mu\text{m}$ in the control group. The lowest marginal mean value was observed in the test group, with a statistically significant difference compared to the control group ($F = 14.56$, $p < 0.05$). The mean \pm standard deviation of the internal fit was 103.61 ± 9.32 and $106.38 \pm 7.64 \mu\text{m}$, respectively, in the test and control groups, with no statistically significant difference ($F = 1.56$, $p > 0.05$). The mean values of both groups were clinically acceptable.

Conclusions: The five-unit zirconia-based FDPs fabricated with digital scans showed better fit than those in the conventional impression group. Within the limitations of this study, these results are encouraging, and continued progress in the digital field should allow for more accurate long-span restorations.

KEYWORDS

accuracy, CAD-CAM, digital impression, high resolution, intraoral scanners, micro-CT

The accuracy of marginal and internal adaptation of prosthetic restorations on their respective abutments is one of the factors guaranteeing the durability of the treatment. This adaptation is a major objective that has led to periodontal integration of restorations and is necessary for predicting the prognosis of periodontal tissues adjacent to crowns or

fixed dental prostheses (FDPs).^{1,2} Indeed, Knoernschild et al showed in their review that biological complications, such as advanced gingival inflammation, deep pockets, attachment, and alveolar bone loss occurring on crown-supporting teeth, are most often due to the poor fit of restorations.² These results have been confirmed in other studies highlighting

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periodontal and caries complications on crowned teeth.^{3–5} Thus, in the study by Sailer et al, secondary caries were found in 21.7% of the three- or four-unit posterior FDPs.³ In their meta-analysis, Pjetursson et al reported that for different types of FDPs the annual rate of secondary caries ranged from 0.11% to 0.65%.⁴ Moreover, according to Goodacre et al,⁵ there is a 10% risk of failure of prosthetic rehabilitation on a crowned tooth in the case of a poor fit; this risk increases to 27% when several teeth are prepared for medium or large FDPs.⁵ Therefore, even though the proper fit of the reconstructions depends on several parameters, such as the type of cement⁶ and the quality of the cementation, only the most accurate impression technique (digital or conventional) can ultimately achieve a small thickness of the marginal joint or internal space.

Over the years, digital scan (DS) techniques using intraoral scanners have developed considerably and are now reliable, reproducible, and more comfortable for the patient.^{7–9} Digital scans can be used to design inlays, onlays, single crowns, or short-span prostheses.^{10,11} However, several disadvantages, such as deformations when recording the full arch, difficulties in recording coronal–radicular reconstructions, or the limits of intrasulcular preparations, are still encountered.¹ Conventional impressions (CIs) continue to be widely used and are implemented daily in many dental practices. Accurate reconstructions in many clinical situations can be obtained with CIs.¹² However, CIs have many limitations reported in various studies.^{13,14}

Few systematic reviews and meta-analyses have compared the accuracy of DS methods with CI techniques by evaluating the marginal and internal fit of zirconia-based FDP restorations.^{7,15–23} Some authors concluded that digital scanning provides significantly better marginal and internal fit than CI.^{15,23} Other authors have argued that the two impression techniques are comparable, and both achieve clinically acceptable marginal and internal thicknesses (39–120 μm).^{7,16–22} However, the *in vitro* and *in vivo* studies included in these reviews are only for single crowns or three-unit FDPs.¹⁵ The accuracy of these two impression techniques beyond three prosthetic abutments remains largely unstudied.²¹ Therefore, there is a lack of scientific evidence on the accuracy of intraoral scanners used for the fabrication of FDPs with more than three abutment teeth. To our knowledge, only one *in vitro* study to date has assessed the accuracy of the marginal and internal fit of five-unit zirconia-based FDPs fabricated with computer-aided design and computer-aided manufacturing (CAD-CAM) technology using direct digitalization and conventional methods.²⁴ The authors reported that the marginal and internal fit were similar between the two methods.²⁴ However, further studies are needed to confirm the results of this investigation. Therefore, the objective of the present comparative *in vitro* study was to evaluate and compare the mean values of the marginal and internal fit of three-abutment–five-unit zirconia-based FDP frameworks designed from direct scanning and CI using micro-CT. The null hypothesis states that there is no significant difference between the two impres-

sion techniques with respect to marginal and internal fit ($p > 0.05$).

MATERIALS AND METHODS

This comparative *in vitro* study included a test (DS) and control groups (CI), as shown in Figure 1. Nine pedagogical models (Frasaco, Tettngang, Germany) were used to make full-contour preparations for a five-unit zirconia-based FDP with three abutment teeth (the right maxillary canine, second premolar, and second molar). A single operator (O.N.B.) made these preparations. The occlusal reduction was 2 mm, and the axial reduction was 1.5 mm.²⁵ The finishing line located at the juxta-gingival level was a 1-mm-wide fillet. On each model, a DS and a CI were taken by a single operator (O.N.B.).

Nine DSs were taken using an intraoral scanner (TRIOS 3, Copenhagen, Denmark) according to the manufacturer's instructions. The maxillary and mandibular arches were scanned, and the occlusion was digitized. All standard tessellation language (STL) files were checked and transferred to the laboratory via a secure platform.²⁶ For the control group (CI), nine CIs were made with polyvinyl siloxane (PVS) (Extrude Xtra, Kerr) using a one-step two-viscosity technique, and their quality was evaluated using the form proposed by Haddadi et al.²⁷ The antagonist arch impression was taken with alginate, and the occlusion registration was made with occlusion silicone. The CIs were disinfected by glutaraldehyde-based disinfectant as described by Demajo et al.²⁸ It has been shown by these authors that chemical disinfection with this product eliminates all microbial forms of silicone without changing the dimensional stability.²⁸ Each of the nine CIs was cast with type IV gypsum (Fuji-Rock, Tokyo, Japan). This gypsum has excellent characteristics, and it is also ideal for all types of prostheses. The models obtained were scanned with an extraoral scanner (D700, 3Shape, Copenhagen, Denmark).

Based on the STL files from the DSs ($n = 9$) and CIs ($n = 9$), 18 zirconia-based FDP frameworks (IPS e.max ZirCAD, A3 shade, Ivoclar Vivadent, Schaan, Liechtenstein) were fabricated. The space required for the luting cement was set at 50 μm for the internal space.²³ The five-unit zirconia-based FDPs were milled from presintered zirconia blocks with a five-axis milling machine (DWX-52D, DGShape, Hamamatsu, Japan). A single technician (Y.G.) performed all of the laboratory steps.

The silicone replica technique combined with micro-CT was used to determine the mean values of marginal and internal fit.^{29–31} To do so, the underside of the framework was loaded with low-viscosity PVS (Hydrorise Light Body, Zhermack, Badia Polesine, Italy), and then the framework was placed and held on the abutment teeth of the initial Frasaco model (Fig 2a).²² Indeed, the excess PVS was gently removed with a #15 scalpel blade. This was done while keeping the bridge in place. After 5 min, the framework was removed, leaving the thin PVS layer attached to the surface of the

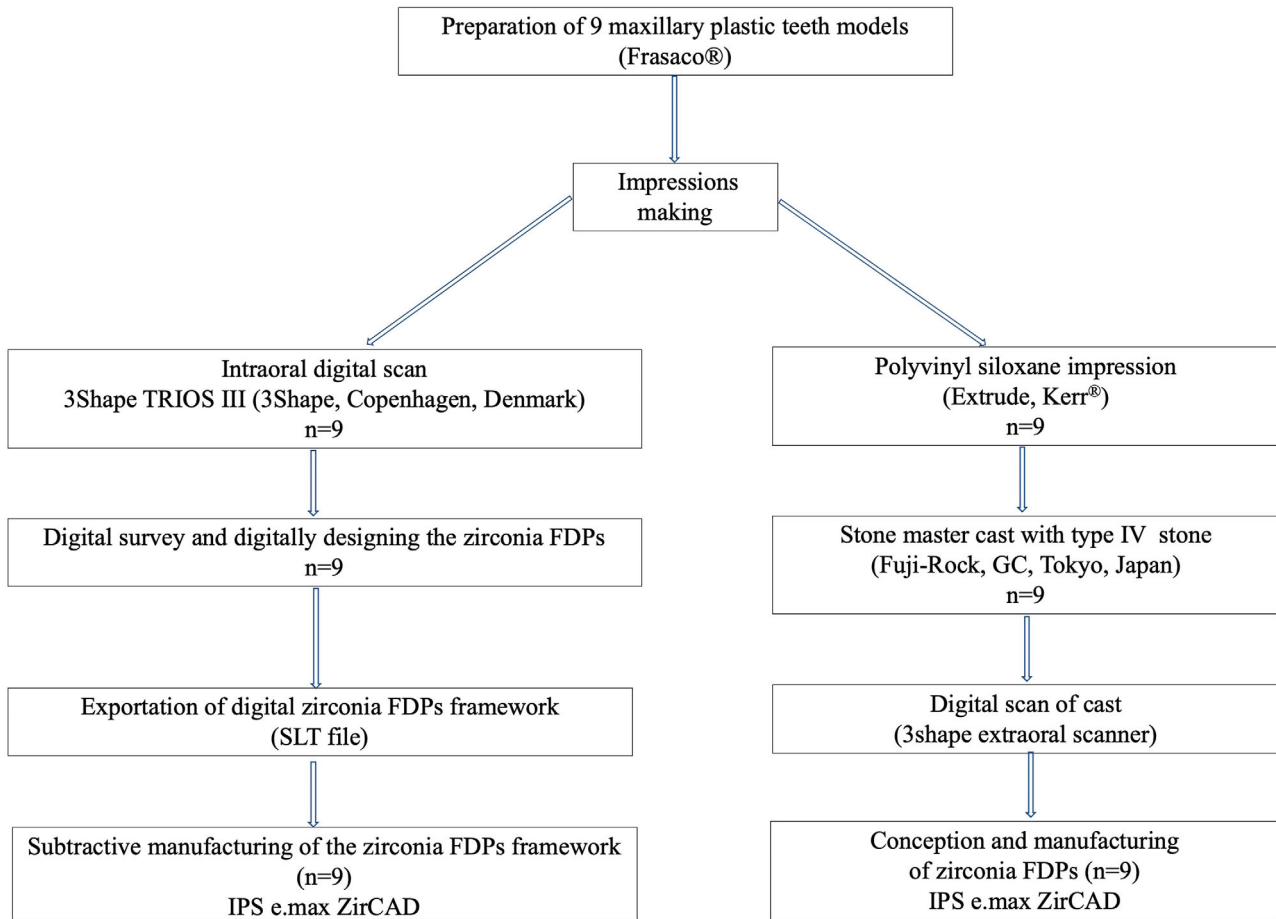


FIGURE 1 Experimental design with two workflows compared in flowchart form

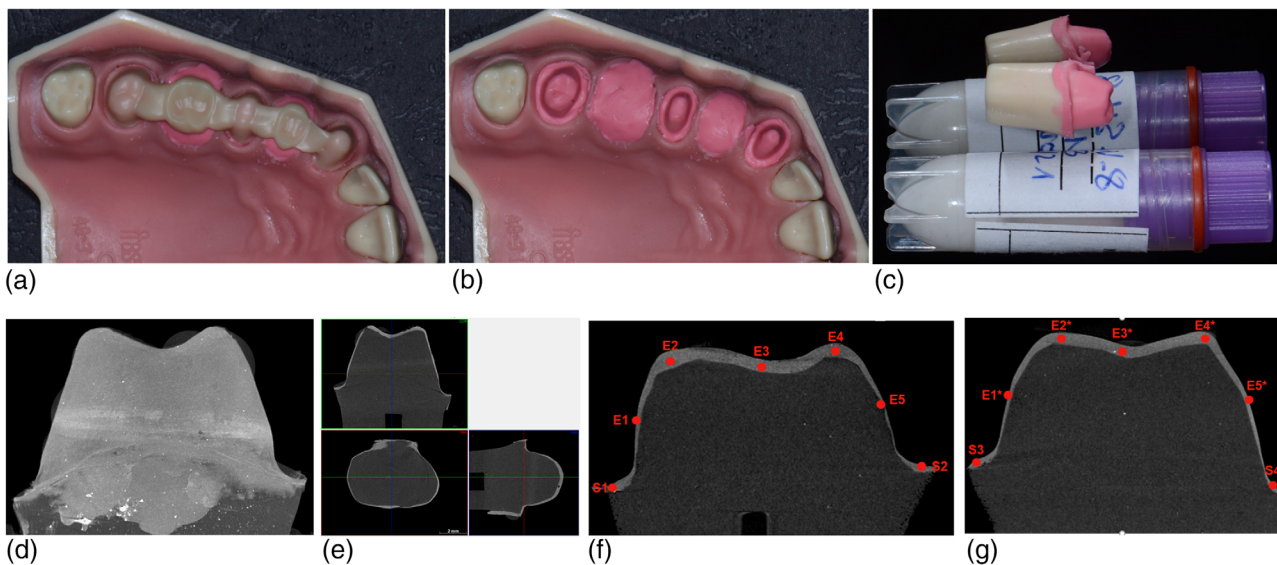


FIGURE 2 Full-contour preparation of zirconia abutment teeth (the right maxillary canine, second premolar, and second molar) on the nine master models. (a) Five-unit zirconia-based fixed dental prostheses (FDPs) framework loaded with low-viscosity polyvinyl siloxane and repositioned on the abutment teeth. (b) Release of the five-unit zirconia-based FDPs after the material has set leaving the film stuck to the tooth. (c) Abutment–film assembly unscrewed and put in a tube. (d) Micro-scanning of abutment tooth–film assembly (Skyscan 1272 Bruker—Source: 20–100 kV to 10 W, spot size < 5 μm). (e) Image cutting (CTVox v3.3.1; Bruker) and visualization of the elastomer film materializing the marginal and internal fit. (f) Sagittal section abutment 17 (mesiodistal axis), site measurements S1, S2, E1, E2, E3, E4, and E5. (g) coronal section abutment 17 (vestibulo-lingual axis), site measurements S3, S4; E1*, E2* E3*; and E4*, E5*

abutments (Fig 2b).^{22,32} After this step, each abutment tooth with the elastomer film in place was gently removed from the study model and placed in a tube for scanning in the laboratory by a single technician (J.V.) (Fig 2c,d). The PVS-coated abutment was checked before being sent to the laboratory. The tubes were previously identified (vestibular, palatal, mesial, and distal sides) to ensure proper repositioning of the abutments. Micro-CT is a high-resolution imaging technique capable of providing lower marginal and internal gap values.³³

Each tooth abutment was previously assigned a unique code to ensure blind evaluation of the results and to limit the risk of measurement bias. The images were acquired at 60 kV and 166 μ A with a rotation step of 0.4° using a microtome densitometer (Skyscan 1272 Bruker—source: 20–100 kV to 10 W, spot size < 5 μ m) using an 11-MP camera and 14- μ m resolution. The 3-D reconstruction of the tooth–abutment–elastomer film assembly was performed with NRecon v1.7.3.0 software (Bruker). The images of the samples were then cleaned using a macro in the software CTan v1.20.8 (Bruker) and then spatially oriented with DataViewer v1.5.6.2 (Bruker). Virtual visualization of the abutment–film teeth was performed in CTVox v3.3.1 (Bruker), a software program that enables slices to be made in the three views (coronal, sagittal, and transverse) (Fig 2e). These slices passed through various previously identified sites (S1, S2, S3, and S4; E1/E5/E1*/E5*; E2/E4/E2*/E4*; and E3/E3*). The choice of these sites was based on previous studies.^{25,29–31} For the marginal fit, S1 corresponds to the distance between the cervical margin and the FDP margin mesially, S2 distally, S3 on the vestibular side, and S4 on the palatal side. With respect to the internal space, three sites—E1/E5/E1*/E5*; E2/E4/E2*/E4*; and E3/E3*—were selected to determine the thickness between the prosthetic abutment and the underside of the FDP at the mid-axial, (E1/E5/E1*/E5*), axio-occlusal (E2/E4/E2*/E4*), and centro-occlusal (E3/E3*) sites (Fig 2f,g). Figure 2a–g shows the steps implemented in this study.

Each of the image slices was inserted into another image-processing software (ImageJ, Fiji) to automatically extract the values of the thickness of the marginal and internal fit using the methods proposed by Maragos et al³⁴ and Kimmel et al.³⁵ The average marginal fit was obtained by averaging the values of S1, S2, S3, and S4 of all of the abutment teeth, whereas the average internal fit was the average value of E1/E5/E1*/E5*, E2/E4/E2*/E4*, and E3/E3*. A total of 756 measurements were performed by a single operator (O.N.B.) for both groups (4 sites \times 3 abutments \times 9 FDPs \times 2 groups + 10 sites \times 3 abutment teeth \times 9 FDPs \times 2 groups).

The number of FDPs or abutments was calculated based on the study by Varol et al,³⁶ who determined the number of film sections necessary to obtain a mean difference of 20 μ m between the two groups.³⁶ This difference in mean was related to the marginal joint thickness, which was the primary endpoint. With a statistical power of 80%, a *p*-value of 0.05, and a common standard deviation of \pm 14 μ m, the number of FDPs per group was 8, that is, 24 abutments.

Because of the risk of abutment damage during preparation, one additional FDP per group was retained to constitute the sample size. Analysis of variance (one-way ANOVA) and Kruskal–Wallis tests were used to compare continuous variables across two groups. A level of *p* < 0.05 was accepted as significant.

RESULTS

The mean values of marginal and internal fit were obtained from 756 microscan measurements on 54 abutments. The values of marginal and internal fit according to the two study groups (DSs and CIs) are shown in Tables 1, S1, S2. The lowest marginal fit was observed in the DS group (95.03 \pm 12.74 μ m), which was significantly different from that of the CI group (106.2 \pm 14.51 μ m; *F* = 14.56, *p* < 0.05). In the DS group, the marginal discrepancy values ranged from 91.21 to 97.61 μ m, and for the CI group, these values ranged between 96.53 and 109.12 μ m. When the internal fit values were examined, there was no significant difference between the two impression techniques (DS: 103.61 \pm 9.32 μ m; CI: 106.38 \pm 7.64 μ m; *F* = 1.56, *p* > 0.05). The lowest mean values of the marginal fit were obtained at sites S3 and S4 for the DSs and at sites S1 and S4 for the CIs, with a significant difference between the two techniques for sites S2, S3, and S4 (*F* = 6.56, *p* < 0.05) (Table 2). Concerning the internal fit of the five-unit zirconia-based FDPs fabricated with CAD/CAM technology and CIs, low mean values were observed at the E1/E5/E1*/E5* (mid-axial) site for the DI method and at the E2/E4/E2*/E4* (axio-occlusal) site for the CI method, where the corresponding values were significantly different at the E1/E5/E1*/E5* areas (*F* = 3.68, *p* < 0.05) (Table 3). However, the marginal and internal adaptation of all five-unit zirconia-based FDP frameworks fabricated with the two tested techniques was within a clinically acceptable range.

DISCUSSION

The accuracy of impressions in fixed prosthetics plays a crucial role in the periodontal integration of reconstructions.^{1,2} This comparative in vitro study investigated the marginal and internal adaptation of five-unit zirconia-based FDP frameworks produced with intraoral scan methods and CI techniques. The null hypothesis—that a significant difference would not be found in marginal and internal fit between the two workflows—was rejected for marginal fit and accepted for internal fit. Low mean values of marginal and internal fit were obtained with the DS methods, with a significant difference for the marginal fit. However, these values remain clinically acceptable. In previous studies,^{26,37,38} acceptable values ranged from 34 to 120 μ m. The standard deviations of this study (Tables 2 and 3) ranged from 6.63 to 35.27 μ m. Although these values are high, they are consistent with those of other studies.^{32,39} The results of the present study

TABLE 1 Mean measurement values and standard deviations (SD) in micrometers (μm) for marginal and internal fit in two study groups: digital scans (DSs) and conventional impressions (CIs)

Areas	DS ($n = 27$)		CI ($n = 27$)		<i>p</i> -Values
	Mean \pm SD	Min-max	Mean \pm SD	Min-max	
Marginal fit	95.03 \pm 12.74	91.21–97.61	106.02 \pm 14.51	96.53–109.12	<0.05*
Internal fit	103.61 \pm 9.32	100.46–115.92	106.38 \pm 7.64	105.87–125.74	>0.05

*Significant differences indicated by $P < .05$.

TABLE 2 Average values of marginal fit in micrometers (μm) at the different sites of interest (S1, S2, S3, and S4)

Interest's areas	DS ($n = 108$)		CI ($n = 108$)		<i>p</i> -Values
	Mean \pm SD	Min-max	Mean \pm SD	Min-max	
S1	96.89 \pm 7.53	89.05–101.02	100.01 \pm 11.73	93.02–114.03	>0.05
S2	96.04 \pm 10.22	85.89–100.07	110.22 \pm 9.45	99.52–117.56	<0.05*
S3	94.67 \pm 8.64	90.22–97.71	101.13 \pm 13.54	88.83–105.02	<0.05*
S4	93.03 \pm 6.63	87.36–95.89	99.70 \pm 8.80	92.44–106.75	<0.05*

Abbreviations: CI, conventional impression; DS, digital scan; SD, standard deviations.

*Significant differences indicated by $P < .05$.

TABLE 3 Average values (μm) for internal fit at sites of interest between two impression techniques

Surveyed sites	DS ($n = 324$)		CI ($n = 324$)		<i>p</i> -Values
	Mean \pm SD	Min-max	Mean \pm SD	Min-max	
E1/E5/E1*/E5* (mid-axial)	99.23 \pm 9.58	94.32–108.67	120.58 \pm 29.53	103.32–137.55	<0.05*
E2/E4/E2*/E4* (axio-occlusal)	107.45 \pm 15.66	99.78–116.67	109.19 \pm 19.48	98.75–123.05	>0.05
E3/E3* (centro-occlusal)	105.33 \pm 32.37	98.25–117.26	112.49 \pm 35.27	104.03–126.81	>0.05

Abbreviations: CI, conventional impression; DS, digital scan; SD, standard deviations.

*Significant differences indicated by $P < .05$.

corroborate those of previous studies that reported that DS provides better marginal and internal fit than CI for fabricating zirconia single crowns or FDPs.^{11,15,23,25,40–44} In the literature, there was a lack of scientific data on the accuracy of DSs for long-span reconstructions, especially as Kim and Kim argued in their investigation that the length of the edentulous area can influence the extent of the marginal and internal gap with the use of direct or indirect digitalization.⁴⁵ Recently, Uluc et al compared the marginal and internal fit of 60 five-unit monolithic zirconia-based FDPs fabricated with CAD-CAM technology using direct and indirect digitalization methods.²⁴ The results of this study grouped according to workflow showed that the mean marginal gap values were 78.2 \pm 9 μm in the IOS group (intraoral scanner group), 82.6 \pm 9 μm in the IMP group (CI scanning group), and 82.6 \pm 9 μm in the STN group (stone cast scanning group), with no significant differences among groups ($p > 0.05$). Although our study is similar to that of Uluc et al in terms of the length of the restoration (five-unit zirconia-based FDPs in full contours),²⁴ our results indicate differences in the parameters evaluated. Indeed, lower average values of marginal and internal fit were obtained in the study by Uluc et al.²⁴ This could be explained by the differences in the study design and measurement method. In the present study, low marginal fit

values were obtained at sites S3 and S4 for the DS methods. These sites are located on the vestibular and palatal surfaces and appear to be easier to scan than the sites located on the mesial and distal surfaces. Indeed, Kim et al demonstrated that the adjacent tooth can be a confounding factor for accurate DSs.⁴⁶ The results of the study by Huang et al also appeared to show that the distance between the abutment teeth and adjacent teeth affects the accuracy of the abutment scan.⁴⁷ In intraoral scanning, when the distance between the abutment teeth and the adjacent teeth is more than 1.5 mm, the scan error does not increase, and more accurate scan data can be obtained.

In the present study, the plaster models were scanned with an extraoral scanner. This process does not alter the accuracy of the restorations²⁴ but instead improves the marginal and internal adaptation of the reconstructions.²³ Kernen et al reported that the precision and trueness were higher for extraoral scans than for intraoral scans.⁴⁸ These results agree with those reported by many other authors.^{40,49,50} According to these authors,^{26,51} scanning of the stone cast or impression is the most accurate method and the best fabrication technique with the lowest marginal gaps. However, the results of these different studies contradict those reported by some authors.^{52,53}

Some factors, such as the length of the restoration, can affect the accuracy of fit regardless of the impression technique used.^{45,54–56} Thus, in their *in vitro* study, Kim and Kim investigated the accuracy of monolithic FDPs with different numbers of pontics (no pontic, NP; 1 pontic, 1P; and 2 pontics, 2P) fabricated with different impression methods (direct and indirect digitalization).⁴⁵ The results of this study show that the length of the reconstruction can indeed alter the accuracy of the impressions. This was also demonstrated by other authors,^{1,48,57–59} who showed that the median precision of short-span scans was higher than that of complete-arch scans. The maximum accuracy values increased from 43 to 198 μm when using partial-to-complete-arch scans; thus, the accuracy decreased as the scanning scope increased.⁴⁸ Authors such as Park et al agree that intraoral scanners are useful for short scans.⁶⁰ However, recent advances in 3D technology and intraoral scanning systems enable the fabrication of large-span fixed prostheses by fully digital flows. This was demonstrated in the present study and in the study by Uluc et al.²⁴ The performance of intraoral scanning systems has been improved over the past few decades by limiting the distortion in STL files during full-arch scanning.⁶¹ This offers new perspectives in the design and fabrication of long-range reconstructions.

In previous studies,^{24,25,62–67} the measurement of marginal and internal fit was performed with the silicone replica technique. This process has many limitations related to the deterioration of the material and the lack of precision in the measurements made. To limit these errors, other evaluation methods such as 3D superimposition analysis (3DSA),⁶⁸ direct viewing techniques, or the use of micro-CT have been reported in the literature. The micro-CT method is a relatively expensive but nondestructive method of investigating marginal and internal fit. This 3D, high-resolution imaging system provides detailed information concerning the FDP-to-die fit without damaging the specimen.^{33,69–72} Nevertheless, our study has many limitations, especially because of its *in vitro* aspect. Indeed, the applicability of our results at the clinical level remains limited by the fact that many parameters specific to the patient, oral environment, situation of the cervical limit, and characteristics of the teeth are likely to alter the precision of the optical impressions.⁷³ Therefore, clinical studies evaluating the marginal and internal adaptation of large-area restorations fabricated by direct and indirect scanning are needed to confirm our results.

CONCLUSION

Based on the results of this study, the five-unit zirconia-based FDPs fabricated with digital scans showed a better fit. This offers new perspectives in the design and fabrication of long-range reconstructions. Within the limitations of this study, these results are encouraging, and continued progress in the digital field should allow for more accurate long-span restorations. Additional *in vivo* studies in a large population are needed to confirm these results.


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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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