ORIGINAL ARTICLE

Fit of monolithic multilayer zirconia fixed partial dentures fabricated by conventional versus digital impression: a clinical and laboratory investigations

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Abstract

Objectives This study aimed to compare the accuracy of conventional and digital impressions based on the fit of produced three-unit fixed partial dentures (FPDs) in vivo and the trueness and precision of both impression techniques.

Materials and methods Twelve patients received a conventional polyether impression (group C, control, $n=12$) and a digital impression with CS3500 (group D, test, $n=12$) for each participant. Monolithic multilayer zirconia FPDs were fabricated, and the internal and marginal fit were assessed using the replica technique. Trueness and precision of both impression methods were assessed in vitro. A master model was used to create a reference scan. The master model received conventional impressions (group C, control, $n=5$) and digital impressions (group D, test, $n=5$). The virtual models of both groups were superimposed over the reference scan (5 superimpositions) using a three-dimensional (3D) processing software, and the 3D deviations were measured and averaged to obtain trueness value. For precision, the virtual models of each group were superimposed over each other (10 superimpositions) and the average deviation value was calculated. The data were analyzed using one-tailed Mann–Whitney U test at $P \leq 0.05$.

Results Group D resulted in a significantly better marginal and internal fit (30.91 ± 15.15 and 30.86 ± 13.57 μm for group D and 40.02 ± 19.50 and 41.86 ± 18.94 μm for group C). The mean values of trueness and precision for conventional and digital techniques were comparable (trueness: 62.8 ± 5.45 and 62.72 ± 12.01 μm and precision: 56.47 ± 27 and 60.9 ± 14.5 μm, respectively).

Conclusions No significant difference was found between conventional and digital impressions in 3D datasets accuracy. In addition, both techniques resulted in FPDs with an acceptable clinical fit. However, the FPDs fabricated using the digital technique displayed better internal and marginal fit.

Clinical relevance The applied impression technique as well as the computer-aided processing of the produced virtual models can significantly affect the fit of the final restoration. Direct digital impression is recommended over conventional impression for fabricating accurate monolithic zirconia 3-unit FPDs.

Trial registration This clinical trial was retrospectively registered on August 11, 2020, in the Pan African Clinical Trial Registry database, and the number for the registry is PACTR202008685699453.

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Introduction

Monolithic translucent and multilayer zirconia FPDs are a relatively new treatment modality that became only possible because of the ongoing evolution of the dental digital workflow. Such ceramic material while exhibiting a modified microstructure necessary to optimize esthetics, the effect of such modification on the fit of the restoration and the clinical success still requires to be studied [1]. In addition to the type of the ceramic material, the accuracy of the adopted

impression technique is paramount for a precise fixed restoration. In the direct or indirect digital impressions, merging multiple images during the scanning process can be associated with distortion and inaccuracies especially when scanning large areas or the whole dental arch. Other factors can further affect the impression accuracy, including clinical factors as bleeding, saliva, patient compliance, operator experience, and the impression material properties and manipulation if a conventional impression was required for indirect digital workflow [2].

In 2002, Brosky et al. [3] introduced a computer-aided 3D assessment method for accuracy of conventional impression based on the ISO concepts of trueness and precision where trueness is the deviation of a measurement from a reference, while precision is the deviation between multiple measurements of the same reference. The lower deviation values represent greater trueness and precision [4].

Trueness and precision mainly depend on scanner acquisition and processing software reflecting the complex 3D deviations that occurred during scanning, which is more expressive for the impression technique accuracy. Evaluating the accuracy of an impression technique through the fit of the produced restoration is considered more clinically relevant as it is the summation of multiple production steps, including impression as a significant factor [5, 6].

Previous studies have compared the accuracy of conventional and digital impressions based on the fit of the final restorations. Digital impression displayed comparable or higher accuracy than conventional for single-unit restorations and FPDs up to 4 units [7–9]. In addition, various studies demonstrated the high variability in trueness and precision according to the impression method used [10–12]. However, no consensus in the literature exists about the value of permissible deviation in the virtual models, and the clinical significance of these deviations still requires further research [6].

The current research aimed to compare the fit of monolithic multilayer zirconia FPDs produced using conventional and digital impressions and to assess the trueness and precision of both techniques and their significance on the fit results. The first null hypothesis of the current research was that no significant difference between the clinical fit of FPDs produced using conventional and digital impressions. The second null hypothesis was that no significant difference between both impression techniques in trueness and precision.

Materials and Methods

Study design, sample size, and patient selection

This study included a parallel controlled prospective in vitro investigation and a randomized examiner-blinded controlled cross over clinical trial with intra-subject comparison. The clinical trial was conducted following the CONSORT guidelines [13] after the approval of the Ethical Review Board of Faculty of Dentistry, Alexandria University, Egypt (IRB NO 00010556-IORG 0008839), and per The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans. The trial was registered in the Pan African Clinical Trial Registry (ID: PACTR202008685699453). Informed consent was obtained from all patients. The minimal sample size was calculated based on similar studies [9, 11] to detect a standardized effect size of 1.245 change in the primary outcome, as statistically significant with 90% power and at a significance level of 95% (accepted alpha error of 0.05). Twelve patients were included in the study, aged between 18 and 45 years with a missing upper first premolar, good oral hygiene, and with no need for additional extended treatment as endodontic and orthodontic treatment. Patients with bad oral hygiene, advanced periodontitis, subgingival restorations or root caries, short abutments, obvious malalignment, or parafunctional habits were excluded [9].

Prosthetic procedures

The abutments were prepared with 1–1.5 mm axial reduction, 1.5–2 mm occlusal/incisal reduction, and 1mm heavy chamfer finish line located not more than 0.5 mm subgingivally, and the retentive surface of the prepared teeth had to be at least 3 mm high with 6–10° axial taper [14]. One week after teeth preparation, each participant received a conventional and a digital impression according to a randomly allocated sequence using closed envelopes. The tissue retraction was performed using the double-cord technique (Ultrapak #000 and Ultrapak #00, Ultradent Products, Utah, USA). Only the larger retraction cord was removed before the first impression. The small cord was left in place to keep the gingival retraction and removed immediately before taking the second impression. For group D (n=12), digital impressions were taken with CS3500 intraoral scanner (Carestream Dental LLC, USA) according to the manufacturer's recommendations after calibration of the scanner. The scanning protocol comprised a full arch scanning of both arches and buccal aspect of teeth at the preparation side in intercuspation position. The occlusal surfaces were scanned at 90° from the second molar tooth, proceeding toward the second molar of the other side of the arch. The lingual and buccal surfaces were subsequently scanned at an angle of 45° to the long axis of teeth [15]. The scanning protocol used was recommended by the manufacturer and advocated by Desoutter et al. [15] to provide the least noise when CS3500 is used for scanning. All scans were performed by an experienced user who received training sessions. The 3D models were formulated with the CS IO 3D acquisition software, version 3.1.0 (Carestream Dental LLC, USA), and exported to the lab for the CAD/CAM process.

For group C (*n*=12), conventional impressions were taken with monophase polyether impression material (3M Monophase, 3M Deutschland GmbH, Neuss, Germany) using a one-step technique according to the manufacturer's instructions. Custom trays from cold-cure PMMA with a uniform material thickness of 2 mm were used after painting tray adhesive (Polyether Adhesive, 3M Deutschland GmbH, Neuss, Germany), and the impression material was mixed by an automix system (Pentamix 3 Automatic Mixing Unit, 3M ESPE, Minneapolis, USA). The impressions were poured after 2 hours with resin-reinforced low expansion type IV dental stone (Elite Rock, Zhermack, Badia Polesine, Italy) according to the manufacturer's recommendations. After the stone set, pins were placed to fabricate saw-cut models. The antagonist arch impression was taken with alginate (Chromaclone, Ultradent Products, Utah, USA), and maximal intercuspation was recorded using an auto-cure PVS material (Futar D, Kettenbach GmbH, Eschenburg, Germany). The models were sent for extraoral scanning (Ceramill map 400, Amann Girrbach AG, Koblach, Austria) and CAD/CAM fabrication of FPDs. Monolithic zirconia FPDs for both groups were designed by a single experienced dental technician using the Ceramill mind CAD software, version 2.2.5 (Amann Girrbach AG, Koblach, Austria) with 50 μm cement space starting 1 mm above the margins, a minimum wall thickness of 0.5mm, and a minimal connector dimension of 9 mm^2. A five-axis milling machine (Ceramill Motion 2, Amann Girrbach AG, Koblach, Austria) was used to mill the FPDs from multilayer zirconia (Ceramill zolid fx multilayer, Amann Girrbach AG, Koblach, Austria) under dry conditions using carbide burs with 2.5, 1.0, and 0.6 mm diameter in regular sequence followed by sintering at 1450°C for 10 hours in zirconia furnace (Ceramill Therm furnace, Amann Girrbach AG, Koblach, Austria). No external or internal manual adjustments were performed on the FPDs [16].

Clinical fit assessment using the replica technique

The FPDs were checked only for occlusal and proximal contacts intraorally, and necessary adjustments were performed. The sequence of the FPDs assessment was randomly allocated according to a computer-generated list. To obtain the silicone replicas, the retainers of each FPD were filled with light body silicone (3M Express VPS light body fast set, 3M ESPE, Minneapolis, USA), placed onto the abutment teeth, and axially loaded with a force of 20 N, controlled by a modified tension gauge for 6 minutes (Fig. 1) [17]. After setting of the light body silicone film, it was subsequently stabilized by injecting a different color light body silicone (3M Express VPS light body regular set, 3M ESPE, Minneapolis, USA). After setting, both silicone layers were removed together from the fitting surface of the retainers. Two replicas per FPD were made, one segmented buccolingually, and the other was


Fig. 1 Axial loading of the silicone light body with a modified tension gauge

segmented mesiodistally. To standardize the sectioning planes between the replicas of the two study groups, two templates of putty condensation silicone (Zetaplus, Zhermack, Badia Polesine, Italy) were fabricated for each patient: one for buccolingual sectioning and the other for mesiodistal sectioning (Fig. 2). The sectioned replicas were examined within 24 hours by a single blinded examiner under a stereomicroscope (Olympus SZ-1145TR Stereo Zoom Microscope, OLYMPUS Co., Tokyo, Japan) at ×18 and ×45 magnification integrated with a digital camera (Topcam XCAM1080PHB, ToupTek Photonics, Zhejiang, China) with a resolution of 0.16 μm per pixel and a special measuring software (ToupView software, version 3.7, ToupTek Photonics, Zhejiang, China) after calibration. The marginal gap, mid-axial (MA), axio-occlusal (AO), and mid-occlusal landmarks were measured [18]. Each point was measured three times, and the average value was recorded.

Evaluation of trueness and precision

A typodont (KaVo Basic study model; KaVo Dental GmbH, Biberach, Germany) with prepared upper central, upper canine, upper second premolars, and upper second molar was used as a template to fabricate the master model. The

Fig. 2 **a** Putty index adapted on the replica. **b** First replica sectioning. **c** Putty template. **d** Second replica inside the template for sectioning
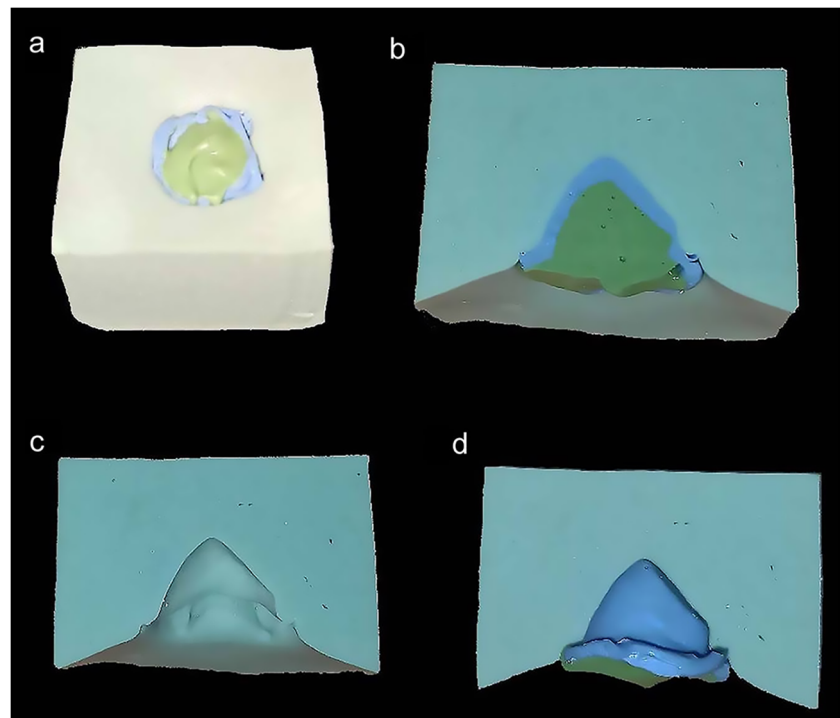

abutments were prepared for zirconia crowns and FPDs according to the guidelines followed in this clinical trial. The preparations were surveyed for an undercut-free path of insertion with a surveyor (Bio-art Surveyor B2, Bio-Art Dental Equipment, Sao Paulo, Brazil). The typodont was powdered and scanned with Ceramill map 400, and the 3D model was exported to a 3D printer (2 DENT 2 3D print, Mogassam, Delaware). The master model was additively manufactured from opaque resin with good mechanical and chemical resistance to avoid any disturbance of teeth during impressions [6]. The master model was scanned with Ceramill map 400 as a reference scanner to obtain a CAD reference model (CRM) for the assessment trueness and precision of both study groups.

For group D, five digital impressions were obtained from the master model with CS3500 intraoral scanner following the recommended protocol by the manufacturer by one trained operator at an ambient temperature of 22° C in a black scan box. The scan box was supposed to prevent the sensor from being saturated with ambient illuminance, which may cause a defect or a delay in capturing the data, and the LED light of the dental chair was used for the scanning oriented 45 degrees at 58 cm from the box [19, 20]. A holder was designed and used to hold the scanner head during scanning of the master model to eliminate the noise that might result from the scanner motion and to fix the distance and the angulation of successive scans (Fig. 3a) [20]. The resulting digital files were saved as an STL file format. For group C, five conventional impressions of the master model were taken with a one-step technique using monophase polyether impression material following the manufacturer's recommendations in a single custom

tray providing a uniform space of 2 mm after painting tray adhesive. The loaded tray was seated on the master model under a static load of 1.2 kg using a specially designed device for the study (Fig. 3b) [21]. Casts were poured and scanned with Ceramill map 400, and data were saved into an STL file format.

The reference scanner was calibrated to prove the manufacturer's claims about the scanner accuracy using the protocol adopted by Ender and Mehl [22]. The master model was scanned five times using a highly accurate laboratory scanner of ±20 μm accuracy (Ceramill map 400). The 3D models were imported into a reverse engineering software (MeshLab, version 2016.12, National Research Council, Pisa, Italy) and superimposed against each other (10 superimpositions in total) using the software's best fit matching algorithm tool, and 3D spatial divergences were calculated as root mean square (RMS) error using Hausdorff distance equation [23]. Mean absolute RMS error was calculated to obtain the mean value of the precision of the reference scanner. The manufacturer's claims about the scanner precision were validated as the mean value obtained was within the recommended tolerance levels. To assess the trueness, each of the 3D models of both groups was matched to the CRM (5 superimpositions in total); the virtual casts were trimmed to obtain the teeth and 2 mm of attached gingiva. This would ensure that the comparison is restricted to the critical area that can be influenced by impression accuracy. Another best-fit alignment was performed, and the mean absolute RMS value representing the trueness was calculated. Congruency to CRM was assessed qualitatively through a color-coded map and quality histogram showing

Fig. 3 **a** Scan box and intraoral camera holder. **b** Static load device for polyether impressions
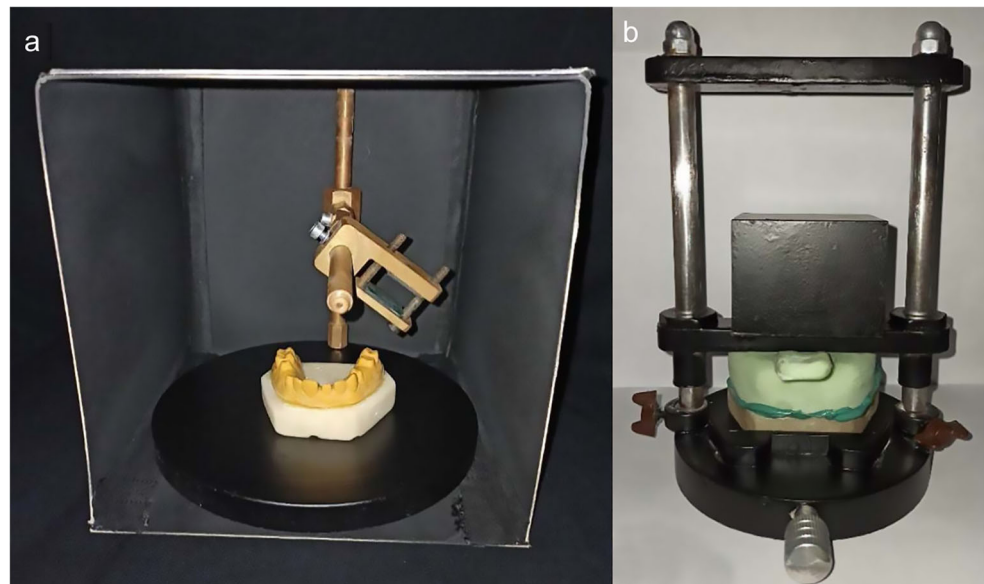
the distribution and magnitude of negative and positive deviations (Fig. 4). The precision of each group was calculated through a pairwise superimposition of the virtual models, the duplicate superimpositions were deleted so that 10 superimpositions in total were obtained, and the mean absolute RMS was calculated.

Statistical analysis

For statistical analysis, values were exported to a spreadsheet (Microsoft Excel 2019 VL 16.44, Microsoft Corp., WA, USA). The mean, median, minimum, maximum, standard deviation, and 0.25–0.75 quartile range of internal and marginal gap values were calculated for both groups and displayed in (Table 1). Regarding trueness and precision, the absolute RMS mean, median, minimum, maximum, standard deviation, and 95% confidence interval were calculated for both groups (Tables 2 and 3). One-tailed Mann–Whitney U test was used to evaluate the significant difference between both study groups, and the significance level was set $P \le 0.05$.

Results

In vivo part

Group D showed significantly less mean marginal gap value of 30.91±15.15 μm compared to 40.02±19.50 μm for group C ($P=0.00126$) and significantly lower internal gap mean value of 30.86±13.57 μm compared to 41.86±18.94 μm for group C ($P=0.00001$). In both group C and group D, no significant difference was found between the fit of the abutments, and the highest mean gap values were recorded at occlusal and axio-occlusal locations, while the mid-axial and marginal measuring points showed lower mean values. For group C, a significant difference was found between mean marginal gap values at mesial and distal surfaces of canine ($P=0.01876$) with the mesial surface exhibiting the highest gap value and between buccal and lingual surfaces of both canine ($P=0.00009$) and premolar ($P=0.01578$) with the lingual surface exhibiting the highest gap value. Besides, a significant difference ($P=0.00205$) was found between mean mid-axial gap values at mesial and distal surfaces of premolar with the mesial surface exhibiting the highest gap value (Fig. 5). For group D, a significant difference was found between mean marginal gap values at mesial and distal surfaces of canine with the mesial surface exhibiting the highest gap value ($P=0.00776$). Moreover, a significant difference was found between mesial and distal surfaces for mean mid-axial and axio-occlusal gap values in premolar with the mesial surface exhibiting the highest gap value with $P=0.00009$ and $P=0.02275$, respectively (Fig. 6).

In vitro part

Regarding the accuracy of 3D models, a quantitative analysis of absolute values of RMS error revealed that no significant difference was found between the control group and the test group in trueness or precision ($P=0.5$). Both tested impression techniques showed average and maximum deviation values below 100 μm. However, local significant deviations above 300 μm were found in both study groups. In the digital group, negative values ranged between 0 and 640 μm, and the positive values ranged between 0 and 680 μm, while in group C, the positive values ranged between 0 and 470 μm, and negative values ranged between 0 and 380 μm.

Fig. 4 **a**, **b** Deviations in group
D. **c**, **d** Deviations in group C. **e**
Color-coded histogram
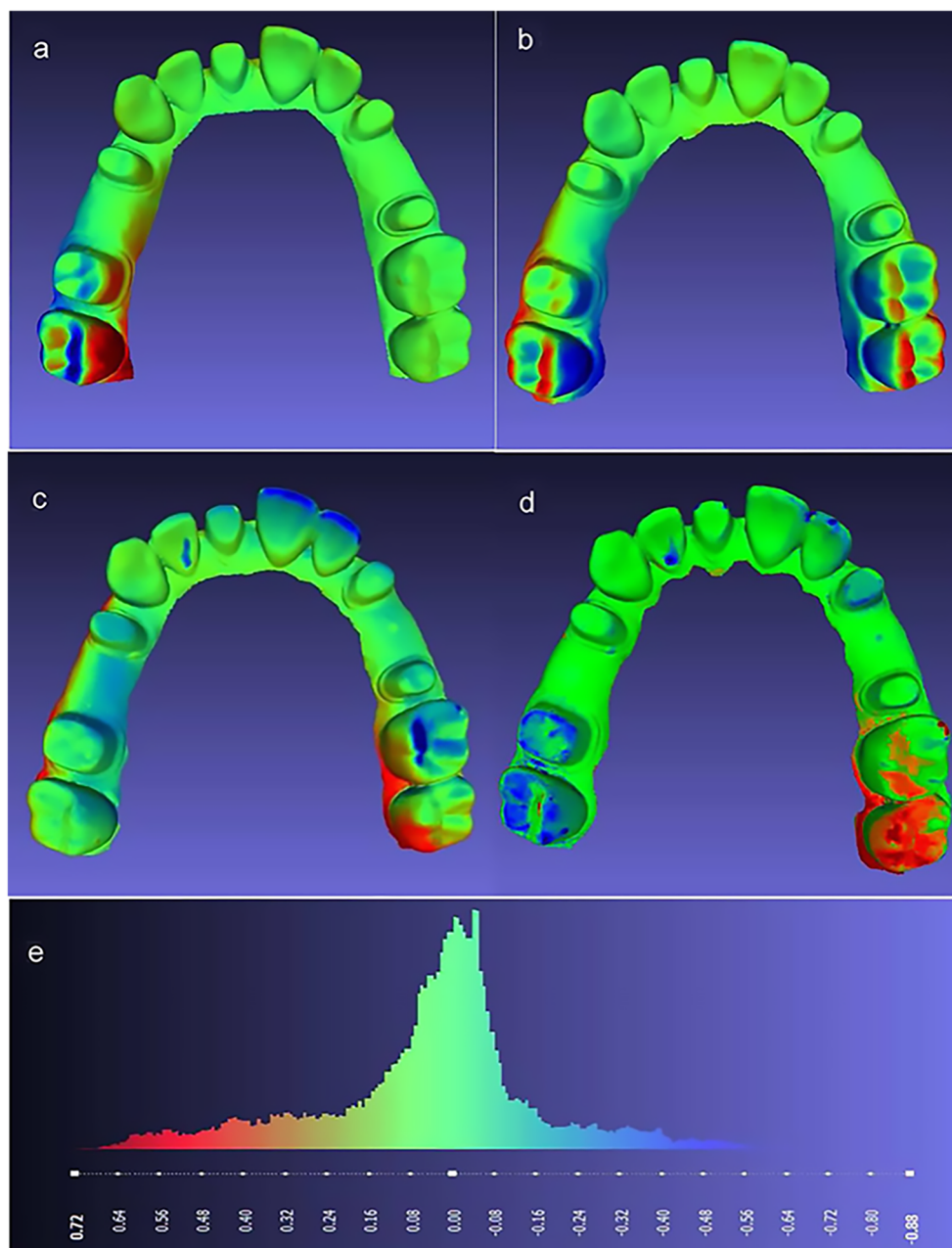
Discussion

In the clinical part of the study, the accuracy of the final res-
toration was regarded as the measuring target, so the influence
of the impression method cannot be separated from other fac-
tors of the production chain as well as clinical factors, which
may lead to an assessment closer to reality [6].

The in vitro part of this research primarily focused on the
best possible accuracy that can be obtained from the tested
impression techniques under ideal conditions eliminating the
influence of clinical error sources. In addition, this in vitro
setup was necessary because trueness is difficult to be mea-
sured in vivo as the CRM must be obtained from the true

dental geometry using high-accuracy scanners, and this is
not applicable intraoral [24]. However, the ideal conditions
for intraoral scanning in the in vitro setup cannot be used in
a clinical situation, and this is considered as a limitation of the
current research.

This study evaluated trueness and precision based on both
the signed and unsigned differences. Only absolute values
were used to assess the 3D deviations for obtaining more
feasible results. The signed values were used to disclose
whether the scanners tended to overestimate or underestimate
the reference [6].

The first null hypothesis of the study was rejected as group
D displayed significantly better marginal and internal fit

Table 1 Marginal and internal gap values in both study groups in (μm)

Point	Group C						Group D					
	Min	Mean	Max	SD	Quartile 0.25/0.75	Median	Min	Mean	Max	SD	Quartile 0.25/0.75	Median
Mid-axial												
Canine	15.49	33.73	63.53	11.66	24.51/40.59	31.17	6.51	23.57	42.88	8.84	18.51/29.66	22.62
Premolar	9.19	25.27	58.61	11.70	15.31/32.04	24.40	4.84	20.46	55.27	11.44	12.20/23.98	17.32
Group total	9.19	29.50	63.53	12.42	21.27/35.90	27.27	4.48	22.01	55.27	10.34	15.31/27.00	20.38
Axio-occlusal												
Canine	23.02	45.39	67.26	13.67	34.67/60.78	42.15	9.13	32.14	46.51	10.01	26.21/40.76	32.42
Premolar	13.69	46.03	79.15	17.87	32.59/61.50	41.19	10.96	35.17	63.36	13.09	23.40/45.92	35.50
Group total	13.69	46.56	79.15	15.51	34.04/60.78	42.64	9.13	33.65	63.36	11.75	24.73/43.52	34.20
Occlusal												
Canine	31.95	56.72	86.23	15.52	39.95/68.43	60.18	24.21	39.15	49.47	6.06	35.35/42.98	41.64
Premolar	33.89	61.06	96.87	21.36	46.06/77.75	49.91	29.05	46.79	76.51	12.52	39.89/52.32	41.74
Group total	31.95	58.89	96.87	18.80	44.04/74.20	52.45	24.21	42.97	76.51	10.55	38.81/44.55	41.74
Total internal fit												
Canine	15.49	42.99	86.23	15.86	31.56/58.44	39.67	6.51	30.11	49.47	10.67	21.78/39.72	30.20
Premolar	9.19	40.73	96.87	21.52	26.11/50.92	35.67	4.84	31.61	76.51	15.91	18.49/42.19	30.05
P value	0. 06944						0.41683					
Group total	9.19	41.86	96.87	18.94	27.50/52.83	37.71	4.84	30.86	76.51	13.57	20.41/41.64	30.20
P value	P=0.00001*											
Total marginal gap												
Canine	10.96	39.97	90.09	19.30	25.56/50.64	34.92	3.49	29.91	77.28	17.36	15.52/39.78	27.27
Premolar	8.27	40.08	98.77	19.70	25.07/49.28	37.24	9.13	31.91	60.81	12.46	22.20/41.66	30.80
P value	0.46414						0.15151					
Group total	8.27	40.02	98.77	19.50	25.48/50.05	37.06	3.49	30.91	77.28	15.15	19.96/41.27	29.19
P value	P=0.00126*											

*Significant difference at P value ≤ 0.05

values, while the second null hypothesis was accepted as no significant difference was found between the trueness and precision of both groups. For both tested impression techniques, the mean and maximum values of 3D deviations were below 100 μm, associated with a clinically acceptable marginal and internal gap values. The digital group displayed better congruency to the master model over the prepared teeth in all examined 3D models (based on qualitative analysis of color map); this finding was supported by a significantly better fit of FPDs in the digital group. How the software is handling the 3D model is more crucial for the final fit of the produced restoration. During intraoral scanning, errors resulting from patient or dentist movement, camera fogging, or moisture can be noticed by the software to a certain degree,

Table 2 Comparison between RMS values for trueness in both study groups in (μm)

RMS	Group C	Group D
Minimum	56.9	49.1
Mean	62.8	62.72
Maximum	69.5	82.2
Median	60.5	61.1
SD	5.45	12.01
95% confidence level	6.770	14.924
95% confidence interval	56.03–69.57	47.8–77.64

Table 3 Comparison between RMS values for precision in both study groups in (μm)

RMS	Group C	Group D
Minimum	17.2	35.7
Mean	56.47	60.9
Maximum	80.1	78.4
Median	73.85	57.6
SD	27	14.5
95% confidence level	19.317	10.397
95% confidence interval	37.15–75.79	50.5–71.3

Fig. 5 Group C intra-abutment comparison between different surfaces: buccal (BU), lingual (LI), mesial (M), and distal (D)
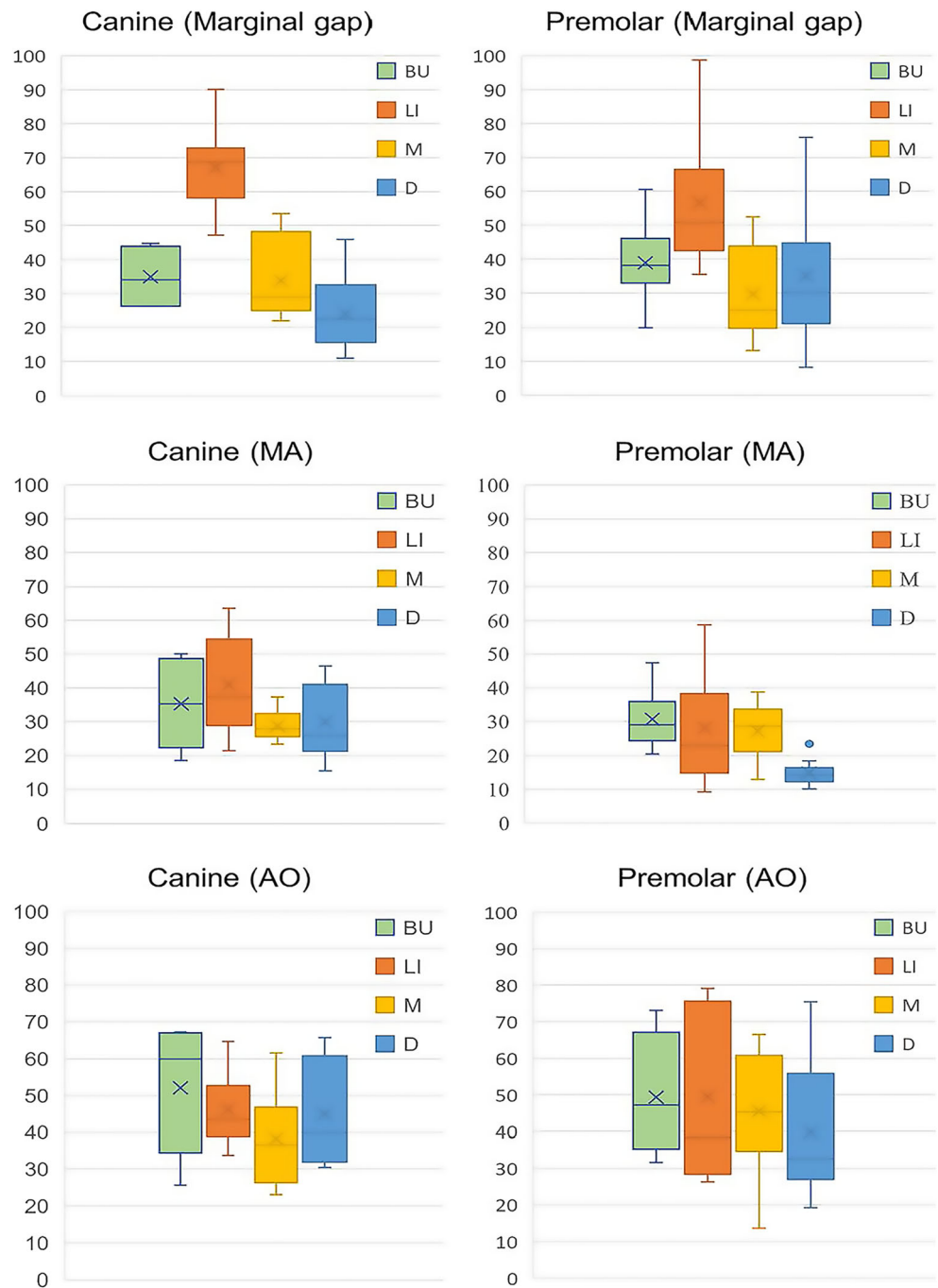

rejected, and recaptured. Artifacts resulting from conventional impression including voids, tearing, improper wetting, permanent deformation or stone abrasion, or expansion, despite having a negligible effect on the accuracy of the 3D model, such artifacts cannot be corrected in the model and are assumed to be the source of greater misfit of the restorations in group C of this study [24].

In group C, a higher marginal gap was measured at the mesial surface of the canine and distal surface of the premolar, while the same surfaces of abutments displayed less gap values at the mid-axial and axio-occlusal points. This might be due to the bending during zirconia shrinkage in a concave direction [25]. This finding concurs with e Silva et al. [25] and Su and Sun [26]. Another significantly high marginal gap in group C was noticed at the palatal surface of both abutments compared to the buccal surface; this might be attributed to premature contact which affected the complete seating of the FPD as a result of artifacts in the impression or stone. In group D, a significantly greater marginal gap was found at the mesial surface of the canine; this might be due to the difficulty in

Fig. 6 Group D intra-abutment comparison between different surfaces: buccal (BU), lingual (LI), mesial (M), and distal (D)
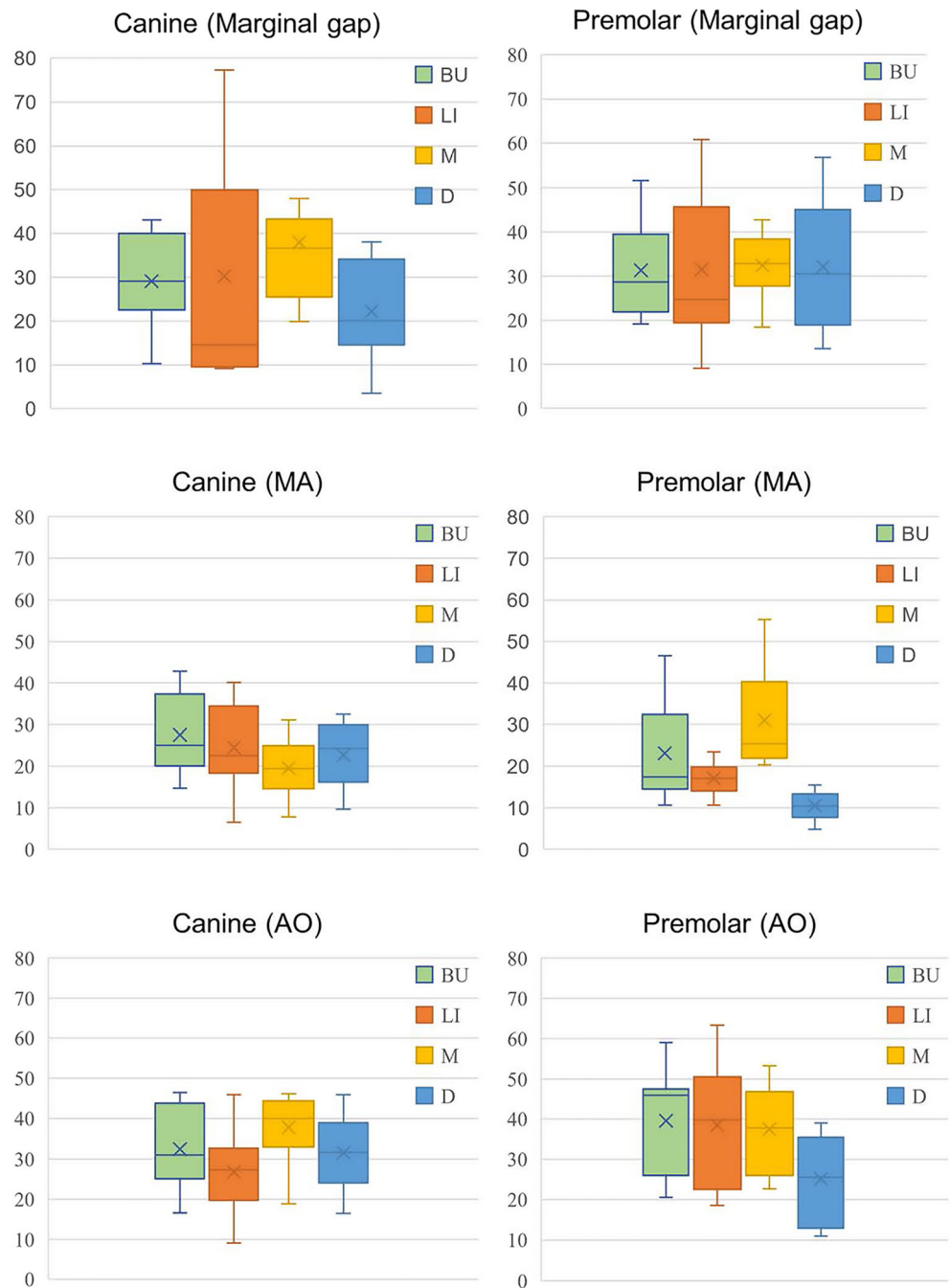
scanning this surface intraorally due to the presence of the neighboring teeth [26]. In both study groups, the highest gap values were detected at occlusal and axio-occlusal locations, while mid-axial and marginal points displayed the least values. These differences in the adaptation level could be related to the software manipulation of virtual models. A physical phenomenon called "Overshooters" most commonly appears at occlusal or incisal areas in the form of peaks or edges that would be rounded by the CAD software. In addition, any defects in the preparation are also rounded, which can lead to fit inaccuracies. Moreover, in geometrical areas smaller than

the narrowest bur diameter, more internal substance may be extensively removed, resulting in larger internal gaps [27, 28].

In the view of 3D qualitative analysis, significant local deviations above 100 μm were found in both study groups; such deviations were reported in previous studies as well [9, 29, 30]. In accordance with Zimmerman et al. [31] and Treesh et al. [6], the error extremities were more localized in group D than group C, mainly at the distal end in all test models. This may be explained by the fact that the posterior teeth have a large volume and complex geometry, which makes this area more prone to error during formulating the 3D image, the so-

called "Chord error." This is also supported by Rudolph et al. [32] who stated that tooth shape was a dominating factor for scanning precision. Also, the worst deviations were clustered at one side of the arch in four of the examined models; this observation was consistently reported by earlier papers on IOS accuracy [6, 29]. An explanation for such error is the "Error propagation." As a result of the scanning path which starts from one molar side toward the molar of the other side of the arch, the software may lose the tracking ability during stitching images, and errors accumulate from the starting point throughout the scan. A clinical finding that could be related to that finding in group D is that FPDs required more chairside adjustments for occlusal contacts, as the errors at the distal ends of the arch might negatively affect the virtual articulation. On the contrary, such error was not noticed in group C as the laboratory scanner takes multiple large field images of the whole arch and combines them into a single 3D image in an automated process [28]. Following Treesh et al. [6], CS3500 did not predictably underestimate or overestimate the reference file, while in group C, there was a greater tendency toward overestimation. Substantial positive deviations were located at the gingival areas of all teeth in four of group C models, and at natural undercuts of unprepared teeth, this can be attributed to stone expansion or permanent distortion of the impression during withdrawal from the model [33]. The measured internal and marginal gap values in group C were significantly higher than group D, which confirms that the virtual models were overestimated. The major negative discrepancies in group C were distributed over the teeth and ridge in all models, but without a specific distribution pattern; these deviations might be a result of the shrinkage of the impression material, stone abrasion, or improper pouring of impression [34]. It was also noticeable that the best reproducibility was seen in the canine replicas. Hypothetically, this is due to the favorable shape of the preparation, a uniform cone shape, which is uncomplicated to digitize [35]. This finding contradicts the study by Rudolph et al. [32] who stated that the steep mantle surface of the canine influences the scanning and milling precision negatively. The advantageous precision of canine could not be transferred to FPDs as no significant difference in fit accuracy was found between the canine and premolar in both groups C and D.

As in accordance with this study, Su and Sun [26] and Shembesh et al. [36] concluded that translucent zirconia FPDs fabricated with digital impressions resulted in significantly better accuracy than the conventional impression. On the other hand, the mean gap values of this clinical trial are lower compared to both studies as Su and Sun [26] detected a mean marginal fit value of 64 ±16 μm and a mean internal fit value of group 111 ±34 μm, and a mean marginal gap value of 62.4±5 μm was found in the study by Shembesh et al. [36]. The differences in the results may be attributed to the settings of the experiments. On the other hand, the marginal gap

median value of translucent zirconia FPDs obtained in this research was higher than a similar study by Schonberger et al. [8] using the Ceramill CAD/CAM system (37.06 μm compared to 22 μm). This difference might be attributed to the clinical conditions of this research compared to the standardized laboratory environment in the study by Schonberger et al. [8]. With regard to trueness and precision, as in agreement with our findings, Treesh et al. [6] reported an acceptable level of accuracy for the full arch scan with CS3500 (median value of 84.6 μm as trueness and 90.4 μm as precision). Moreover, the conclusion of the current research concurs with the studies by Ender and Mehl [10] and Tomita et al. [12]. In disagreement with this study, Renne et al. [37] stated that CS3500 produced less accuracy than indirect digitalization; this difference could be attributed to the master model and alignment software used. In another study by Park et al. [38], CS3500 presented an RMS mean value of 209.9 ±53.7 μm which was significantly higher than extraoral scanner error; this difference from our findings might be due to the best-fit protocol followed in the study by Park et al. [38]; the alignment was performed at one tooth only, and the deviation of the whole virtual model was measured.

Conclusion

Within the limitations of this study, it was concluded that digital impression produced 3-unit FPDs with a better fit than conventional impression technique. However, further clinical trials are recommended to compare the accuracy of both impression methods in case of long-span FPDs.

Declarations

Ethics approval This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Faculty of Dentistry, Alexandria University, Egypt (IRB NO 00010556-IORG 0008839), on 20th July 2019.

Informed consent Informed consent was obtained from all individual participants included in the study.

Conflict of interest The authors declare no competing interests.

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