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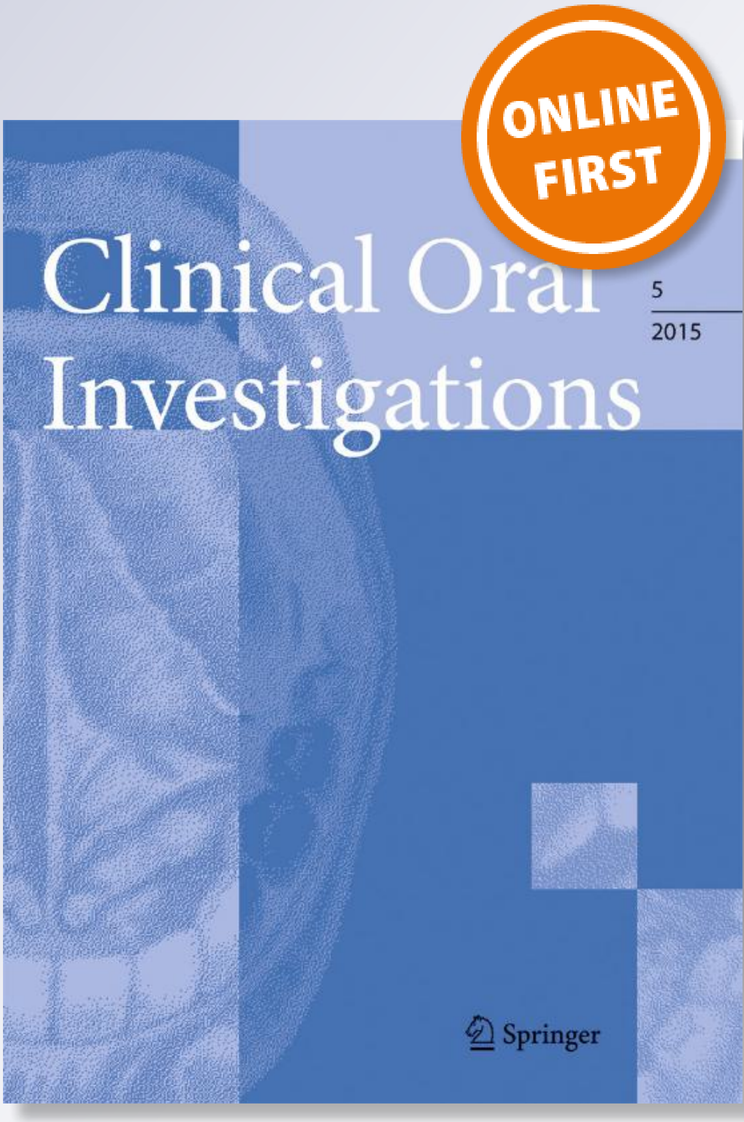

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ORIGINAL ARTICLE

Evaluation of fit and efficiency of CAD/CAM fabricated all-ceramic restorations based on direct and indirect digitalization: a double-blinded, randomized clinical trial

Danush Ahrberg[1,3] · Hans Christoph Lauer[1] · Martin Ahrberg[2] · Paul Weigl[1]

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Abstract
Objectives The aim of this clinical trial was to evaluate the marginal and internal fit of CAD/CAM fabricated zirconia crowns and three-unit fixed dental prostheses (FDPs) resulting from direct versus indirect digitalization. The efficiency of both methods was analyzed.
Materials and methods In 25 patients, 17 single crowns and eight three-unit FDPs were fabricated with all-ceramic zirconia using CAD/CAM technology. Each patient underwent two different impression methods; a computer-aided impression with Lava C.O.S. (CAI) and a conventional polyether impression with Impregum pent soft (CI). The working time for each group was recorded. Before insertion, the marginal and internal fit was recorded using silicone replicas of the frameworks. Each sample was cut into four sections and evaluated at four sites (marginal gap, mid-axial wall, axio-occlusal transition, centro-occlusal site) under ×64 magnification. The Mann–Whitney U test was used to detect significant differences between the two groups in terms of marginal and internal fit (α= 0.05).
Results The mean for the marginal gap was 61.08 μm (±24.77 μm) for CAI compared with 70.40 μm (±28.87 μm) for CI, which was a statistically significant difference. The other mean values for CAI and CI, respectively, were as follows in micrometers (± standard deviation): 88.27 (±41.49) and 92.13 (±49.87) at the mid-axial wall; 144.78 (±46.23) and 155.60 (±55.77) at the axio-occlusal transition; and 155.57 (49.85) and 171.51 (±60.98) at the centro-occlusal site. The CAI group showed significantly lower values of internal fit at the centro-occlusal site.

A quadrant scan with a computer-aided impression was 5 min 6 s more time efficient when compared with a conventional impression, and a full-arch scan was 1 min 34 s more efficient.
Conclusions Although both direct and indirect digitalization facilitate the fabrication of single crowns and three-unit FDPs with clinically acceptable marginal fit, a significantly better marginal fit was noted with direct digitalization. Digital impressions are also less time-consuming for the dental practitioner and the patient.
Clinical relevance The results show that a direct, intraoral, digitalized impression technique is more accurate and efficient when compared with conventional impressions in fabricating single crowns and three-unit FDPs.

Keywords Computer-aided design/computer-aided manufacturing (CAD/CAM) · Intraoral scanner · Digital impression · Conventional impression · Marginal gap · Zirconia ceramic

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Introduction

In computer-aided design and computer-aided manufacturing (CAD/CAM), the transformation of the clinical situation into a three-dimensional dataset in the production process of dental restorations can be achieved by direct or indirect digitalization [1]. Indirect, extraoral digitalization starts with a conventional impression that is processed to a gypsum cast and then

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digitalized in the dental laboratory. In recent years, many new systems for direct, intraoral digitalization have been introduced to dentistry with the aim of digitalizing the workflow [2]. It is claimed that these systems are more advantageous for the dental practitioner when compared with the conventional impression methods that have been present for more than 100 years [3]. This digital workflow does not require the use of an impression material and trays, leading to improved patient comfort [4] and reduced technique sensitivity. Using these scanners, an accurate representation of the soft and hard tissues is possible, and a virtual, three-dimensional model is directly produced. This three-dimensional stereolithography file can then be transferred to an automated production device.

Although there have been advances in impression material technology, and such materials exhibit adequate stability and precision, factors such as impression technique, impression material, transportation, impression trays, and mixing techniques significantly influence the accuracy of the impression [5–10]. Moreover, discomfort for the patient caused by gagging or an unpleasant taste remains associated with conventional impression techniques. Imprecision during impression-taking is difficult to correct in subsequent laboratory procedures, and this influences the internal and marginal fit of the prostheses [9]. To optimize the manufacturing process, the number of steps involved should be minimized [11]. This will improve the accuracy of the impression, and subsequently, the resulting restoration.

A consensus exists among various authors that marginal openings below 120 μm are clinically acceptable [12–14]. Poor marginal adaptation increases plaque retention and changes the distribution of the microflora, which can result in inflammation of the periodontal tissues [15, 16] and even to clinical failure of fixed prostheses [14]. Moreover, the internal adaptation also has a practical impact and plays an important role in the long-term stability of all-ceramic reconstructions [17]. A correlation between increased cement thickness and decreased flexural failure load of ceramics has previously been demonstrated [18].

CAD/CAM systems were introduced to dentistry with the aim of automating the production and standardizing the quality of dental restorations [1]. Moreover, CAD/CAM technology enables the use of new restorative materials, e.g., oxide ceramics such as yttria-stabilized zirconia [19], hybrid ceramics [20], resin nano-ceramics [21], zirconia reinforced lithium silicate [22, 23], and presintered cobalt-chrome alloys [24], and allows digital veneering workflow [25, 26] in the dental laboratory. Recently, three-dimensional monitoring and quality control using an intraoral optical camera system was discussed [27].

The first CAD/CAM system to provide a computer-aided impression was CEREC (Sirona Dental Systems, Bensheim, Germany) [28]. This system can be used with a chairside milling machine, enabling direct, chair-side production of CAD/CAM restorations from industrially manufactured ceramic blocks [29]. The working principle is based on the triangulation of light, with the need for an opaque titanium dioxide powder placed on the tooth surface. The accuracy of the Camera system has been documented [30].

The Lava Chairside Oral Scanner (Lava C.O.S.; 3M ESPE, Seefeld, Germany) was introduced in 2009 and works on the principle of active wavefront sampling, in which intraoral data is captured by three-dimensional imaging at a video rate (3D-in-Motion) [31, 32]. This system also comes with the need for powdering the tooth surface. This intraoral scanner can offer comparable results like conventional methods, regarding accuracy [33]. However, a number of computer-aided impression systems do not require the use of an opaque powder, such as iTero, cara Trios, and CEREC Omnicam [34].

One clinical investigation, which was similar to this study protocol, reported better marginal fit of all-ceramic crowns fabricated by direct digitalization when compared with indirect digitalization [35]. Another clinical trial, which used the same intraoral scanning system as this study, showed marginal gaps of 48.65 μm for all-ceramic crowns [36].

Various studies have examined the fit of fixed dental prostheses (FDPs) in indirect digitalization using different CAD/CAM systems [37–39], whereas some studies compared the fit of single crowns and FDPs fabricated using indirect and direct digitalization with intraoral scanners [25, 40–43]. Although three in vitro studies compared the internal and marginal fit of three-unit CoCr alloy [43], four-unit zirconia [40, 42], and four-unit CoCr alloy FDPs [42] using direct and indirect digitalization, no clinical data is present regarding computer-aided impressions fabricating three-unit FDPs, and it is unclear whether the digital impression contributes to a more time efficient workflow in the dental office. Only few studies validate and compare the required time for both impression methods [4, 44–46].

This study assesses the clinical fit of CAD/CAM-generated zirconia frameworks of single crowns and three-unit FDPs after indirect and direct digitalization, and compares the efficiency of both impression methods. Two null hypotheses were defined for this study. The first null hypothesis was that single crowns and three-unit FDPs with zirconia frameworks fabricated from direct (computer-aided impression group; CAI) and indirect digitalization (conventional polyether impression group; CI) would show equal values for marginal and internal fit. The second null hypothesis was that no difference in working time would be found between the two methods.

Materials and methods

This prospective, randomized clinical trial and its study protocol were approved by the ethics committee of the Johann Wolfgang Goethe University, Frankfurt (application no. EK 56/10).

All patients enrolled gave consent after being informed about the aims and study protocol. The exclusion criteria were as follows: a periodontal screening index >2, poor oral hygiene, bruxism, patients under the age of 18, and polyether or adrenaline intolerance. Two dentists with CAD/CAM experience in a private practice were assigned to treat the patients. Both examiners had undergone training in intraoral scanning; however, one dentist dropped out shortly after the study began because of a severe health condition. The dentist who dropped out was not replaced.

In 25 patients (15 females and 10 males) with indications for indirect restorations, 17 single all-ceramic zirconia crowns and eight three-unit all-ceramic zirconia FDPs were fabricated and selected for evaluation of the fit between the frameworks and the abutment teeth under clinical conditions.

Clinical procedures

Prior to preparation, all patients received local anesthesia. Preparation of the abutment teeth was performed with distinct chamfer finish lines, where the location of the finish lines was considered optimal at an equigingival or 0.5-mm subgingival level. Guidelines for abutment tooth preparation for all-ceramic reconstructions comprised a tapering of the axial walls by 6–10°, a circumferential reduction of the tooth between 1.2–1.5 mm, and an occlusal reduction of approximately 2 mm. All edges were rounded using Arkansas stones and polishers. Temporary restorations were fabricated using a Bis-GMA Composite (Protemp 4, 3 M ESPE, Seefeld, Germany) and seated with a non-eugenol temporary cement (RelyX Temp NE, 3M ESPE, Seefeld, Germany).

Approximately 1 week after preparation, the patients returned for a second appointment. The teeth were prepared for impression with two retraction cords, sizes #0 and #1 (Ultrapak, Ultradent Products, South Jordan, UT, USA), soaked in aluminum sulfate liquid (ORBAT Sensitive, lege artis, Dettenhausen, Germany). The retraction cords were placed in the sulcus; the size #0 cord remained in the sulcus during the entire impression-taking procedure, and the size #1 cord was removed prior to impression-taking to allow an accurate display of the preparation and surrounding soft tissues. The same retraction cord technique was used for both the CI and CAI groups.

For each patient, the impression method was randomly allocated with an envelope by the patient, with both the patient and examiner blinded to the group allocation (Fig. 1). To evaluate the efficiency of intraoral scanning versus the conventional impression technique, the total working time was recorded with a stopwatch, with each step involved in the impression procedure recorded individually. The working time was defined as the time required to achieve an impression meeting the acceptance criteria. Impression retakes and rescans of missing areas were recorded as additional time.

Direct digitalization (Lava C.O.S.)

For direct digitalization, a soft tissue retractor (OptraGate, Ivoclar Vivadent, Schaan, Liechtenstein) and Dry Tips (Mölnlycke, Erkrath, Germany) were used. To enable the scanner to detect intraoral surfaces, a thin layer of titanium dioxide powder (Lava Powder for Chairside Oral Scanner, 3M ESPE, Seefeld, Germany) was applied. Phase one of time recording began with powdering. The superiorly placed retraction cord was removed, and the abutment teeth were lightly powdered.

The scanning protocol, using the Lava C.O.S. intraoral scanner, for single crowns involved a quadrant scan capturing the prepared tooth, the opposing quadrant, and the buccal aspect of these quadrants in the intercuspal position. For three-unit FDPs, the scanning protocol consisted of a full-arch scan of the prepared teeth, the opposing quadrants, and the left and right buccal aspects with the teeth in the intercuspal position. The manufacturer's recommendations were followed for the scanning path, and this was the same for all intraoral scans. After powdering, phases two (computer aided-impression of the prepared teeth) and three (computer-aided impression of the opposing teeth) of time recording were initiated. Phase four of time recording began at the start of the bite registration procedure.

In total, the beginning sequence occurred 11 times with the computer-aided impression and 14 times with the conventional impression method (Fig. 1).

Real-time three-dimensional models were viewed on a flat screen monitor, and after approving the preparation, the data were sent electronically to the manufacturer in the USA via wireless internet connection for digital post-processing.

The scan data downloaded by the dental laboratory were used for virtual segmentation and ditching of the models, and this was done using Lava Laboratory software for Lava C.O.S. (3M ESPE, Seefeld, Germany). One stereolithographic model was produced by means of rapid prototyping at an external model fabrication center. At this point, the design (CAD) and production process (CAM) for the zirconia frameworks was equivalent to the indirect digitalization workflow.

Indirect digitalization (Lava Scan ST)

For all conventional impressions, the polyether material Impregum Penta Soft (3M ESPE, Seefeld, Germany) was used with a Pentamix machine and the monophase technique, making up phase two of time recording. Following phases three and four of time recording, opposing impressions were taken using the alginate material, Palgat Plus (3M ESPE, Seefeld, Germany), and a bite registration was taken in maximum intercuspation using Protemp 4 (3M ESPE, Seefeld, Germany). Prior to impression-taking, metal stock trays were selected and

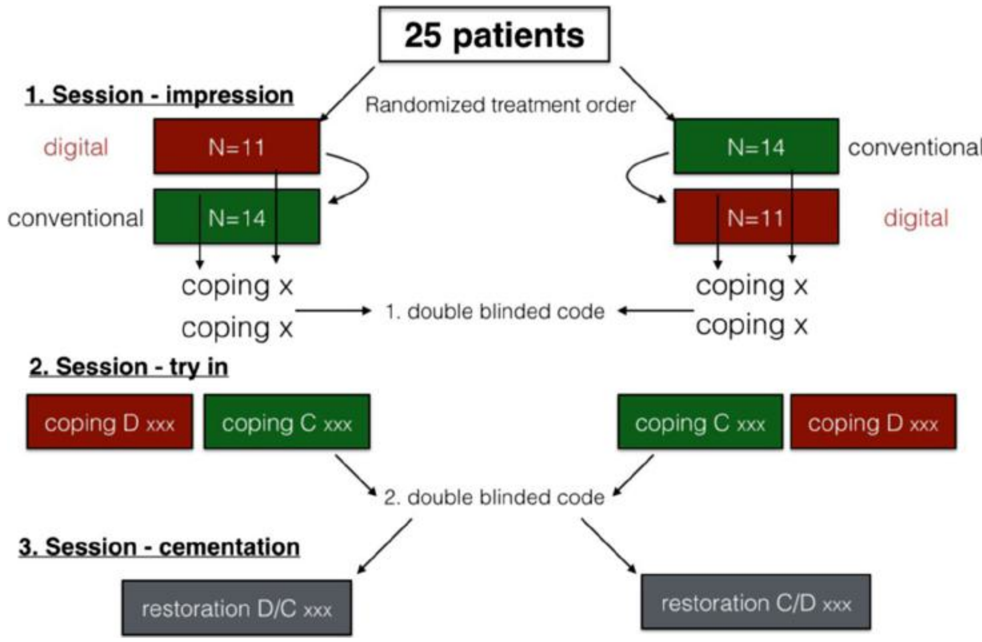


Fig 1 Randomization and blinding method flow chart

individualized with silicone stops and either alginate or polyether adhesive. Phase one of time recording for conventional impressions occurred up to the moment that the tray adhesive was applied.

The impressions were disinfected, and the models were poured with type IV plaster (Fujirock EP, GC, Tokyo, Japan). The stone models were digitalized indirectly with an extraoral scanner using active triangulation (Lava Scan ST, 3M ESPE, Seefeld, Germany) and zirconia copings were designed using Lava Design Software (CAD). The minimum wall thickness of the core material was 0.4 mm. A cement spacer setting of 50 μm, starting 0.8 mm above the margin, and a minimal connector dimension of 9 mm^2 were maintained. The same settings were used for both groups. Presintered zirconia blanks, which were colored with a coloring liquid according to each patient's tooth shade, were used in a 5-axis milling unit (Lava CNC 500, 3M ESPE, Seefeld, Germany) to produce the frameworks. Following the milling procedure, the frameworks were sintered to a full density and adapted onto the master casts. Two densely sintered frameworks were examiner-blinded with a three-digit code by an independent person who was not involved in the study. The frameworks were tried in and the fit was evaluated. If corrections were necessary, they were done with a red ring diamond bur under constant water-cooling. The frameworks were then veneered by one experienced dental technician with IPS e.max Ceram (Ivoclar Vivadent, Schaan, Liechtenstein). Then, two finished restorations were once again blinded with a three-digit code.

The third clinical appointment comprised a double-blinded try-in of the copings from both groups. Then, at the last clinical session, two restorations were tried in and assessed for clinical parameters including occlusion, proximal contact, and marginal contour. This stage was also double-blinded. Finally, the best fitting crown or FDP, produced either by digital or conventional workflow, was seated using RelyX Unicem (3M ESPE, Seefeld, Germany).

Evaluation of fit

To document the marginal and internal discrepancy between the inner surface of the restoration and the abutment tooth surface, a replica technique [47] was applied at the try-in appointment. Zirconia copings were filled with a light body silicone material (Express 2 Light Body Flow Quick, 3M ESPE, Seefeld, Germany), seated on the abutment teeth with finger pressure for 10 s, and then fixed with a cotton roll while the patient closed their mouth. After setting, the silicone material that adhered to the internal surface of the framework was removed together with the framework, and this was stabilized to the framework with a silicone material of a different color (Express 2 Ultra-Light Body Quick, 3M ESPE, Seefeld, Germany). After setting, both silicone materials were simultaneously removed from each framework. Because of differences in finger pressure, three replicas were made for each framework to obtain repeatability.

Measurement of the marginal and internal fit

The silicone replicas were cut with a sharp razor blade in both mesio-distal and bucco-lingual directions, resulting in four sections to be measured per abutment. All sample measurements were carried out by one examiner. Cross-sections were adjusted horizontally on modeling clay (Plasteline clay) to obtain a parallel orientation to the microscope's plate and to achieve a rectangular observation angle. Replica film thickness was examined at mesial, distal, buccal, and lingual locations using a light microscope (Wild M420, Leica Microsystems, Wetzlar, Germany) at ×66 optical magnification and a digital camera that was connected to computer software (IM 1000, Leica Microsystems, Wetzlar, Germany). For each cross-section, the following four landmarks were assessed (Fig. 2):

Marginal gap—measuring points VMR represented the marginal gap according to Holmes et al. [48]. The width was measured as the perpendicular distance from the internal surface at the margin of the restoration to the preparation.

Mid-axial wall—measuring points VMA represented the distance between the die and the inner surface of the crown at the middle of the axial wall.

Axio-occlusal site—the mean of three measuring points at the axio-occlusal site represented the axio-occlusal transition discrepancy (VMC).

Centro-occlusal site—measuring points VMO represented the centro-occlusal discrepancy.

Statistical analysis

The tabulated data were imported into a statistical program (SPSS 21.0, SPSS Inc., Chicago, USA). For each method, the mean, standard deviation (SD), median, minimum value, maximum value, and 95 % confidence interval of the marginal and internal gap (cement gap) width were calculated and shown graphically using box plot diagrams.

The Kolmogorov–Smirnov and Shapiro–Wilk tests were carried out to test normal distribution, and Levene's test was used to assess for homogeneity of variance. Then, for the comparison of continuous variables with two levels, the Mann–Whitney *U* test was applied. Results with p values< 0.05 were considered statistically significant.

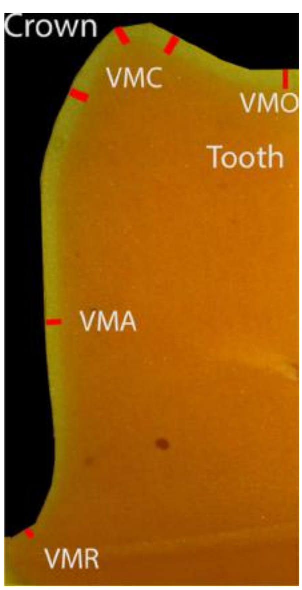


Fig 2 Example of a cross section of a replica. Locations of measurements at *VMR* marginal gap, *VMA* mid-axial wall, *VMC* axio-occlusal transition (defined by three points at the cusp), *VMO* centro-occlusal

Results

Levene's test displayed no significant difference between the two groups regarding equality of variances, and the Kolmogorov–Smirnov and Shapiro–Wilk tests showed a non-normal distribution.

The overall results for the mean, median, SD, minimum, maximum, and 95 % confidence interval for all landmarks for single crowns and three-unit FDPs are shown in Table 1 for CAI and CI. The mean marginal gap dimension at landmark VMR was 61.08 μm (SD 24.77 μm) for CAI and 70.40 μm (SD 28.87 μm) for CI. For landmark VMA, the mean values were 88.27 μm (SD 41.49 μm) for CAI and 92.13 μm (SD 49.87 μm) for CI. Landmark VMC had a mean of 144.78 μm (SD 46.23 μm) for CAI and 155.60 μm (SD 55.77 μm) for CI. VMO means were 155.57 μm (SD 49.85 μm) and 171.51 μm (SD 60.98 μm) for CAI and CI, respectively. The *box plot* diagrams are shown in Figs. 3 and 4.

Only the values for the marginal (VMR) and internal gap at the occlusal site (VMO) of CAI differed significantly from the measurements of CI (p<0.05) (Mann–Whitney *U* test). Landmarks VMA and VMC did not differ significantly. Time recording for a quadrant scan for single crowns with Lava C.O.S. (CAI) revealed a mean total time of 10 min 21 s, whereas for a full-arch scan for three-unit FDPs, a mean time of 15 min 27 s was required, compared with 15 min 33 s and 17 min 07 s, respectively, for an Impregum impression (CI) (Table 2). The individual phases for time recording are illustrated comparatively for both methods in Fig. 5 for quadrant scans and in Fig. 6 for full-arch scans. Therefore, the total working time for quadrant and full-arch scans was 5 min 6 s and 1 min 34 s less, respectively, when compared with conventional impressions.

Discussion

One major parameter for clinical success is the fit of a restoration. The larger the marginal discrepancy, the more rapid is the rate of cement dissolution and the higher is the risk of bacterial insult, causing pulpal inflammation and necrosis [49]. The precision of digital and conventional impressions was evaluated in this in vivo study by comparing the different

Table 1 Mean gap widths, medians, standard deviations, minimum, and maximum values of 17 fabricated crowns and 8 three-unit FDPs fabricated by CAI and CI at 4 different landmarks are displayed

	CAI							CI						
Landmark	Mean (μm)	Median (μm)	SD (μm)	Min (μm)	Max (μm)	95 % confidence interval		Mean (μm)	Median (μm)	SD (μm)	Min (μm)	Max (μm)	95 % confidence interval	
						lower	upper bound (μm)						lower	upper bound (μm)
VMR[a]	61.08	60.31	24.77	22.41	104.65	56.30	73.41	70.40	68.64	28.87	24.54	115.76	63.91	79.39
VMA	88.27	83.34	41.49	31.04	179.32	82.15	99.58	92.13	83.06	49.87	26.78	188.98	78.13	89.93
VMC	144.78	139.99	46.23	53.43	259.34	138.32	153.16	155.60	141.53	55.77	66.54	330.53	144.83	159.93
VMO[a]	155.57	145.37	49.85	73.20	297.98	154.6	177.39	171.51	168.67	60.98	87.85	377.43	168.50	188.61

VMR marginal gap, *VMA* mid-axial wall, *VMC* axio-occlusal transition, *VMO* centro-occlusal site

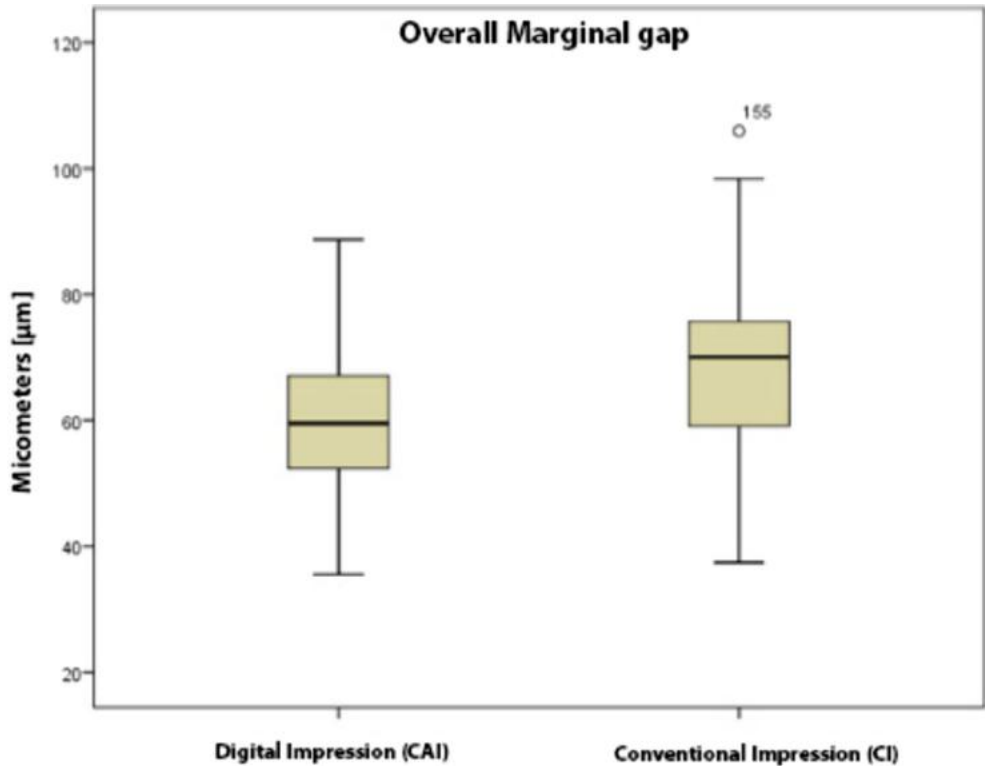
[a] Statistically difference was found at landmark VMR and VMO between CAI and CI (Mann–Whitney *U* test)

workflows, different indications for restoration, and measuring the marginal and internal fit of the fabricated zirconia frameworks. Both examiner and participants were blinded to prevent bias in the results and to obtain an objective assessment without influence by branding and other confounding variables. The first null hypothesis has to be rejected. The results showed significant differences between the types of methods being applied. The marginal values for both methods were within the range of clinical acceptance according to Mclean et al. [13]. Zirconia frameworks fabricated using direct digitalization exhibited significantly smaller values for marginal and internal fit at the occlusal site assessed, thereby indicating a more precise fit. Although the marginal gap values at VMR of CAI and CI differed significantly, the relevance of this difference is debatable because the mean, confidence interval, and maximum value are below the described threshold of 120 μm, indicating acceptable clinical fit. This can also be explained by the fact that no internal adjustments were necessary for any of the evaluated frameworks produced by digital or conventional impressions at the try-in session. The maxima of the gap values were nearly similar for digital and conventional impressions, with values of 104.65 and 115.76 μm, respectively. The internal fit revealed in the present study was smaller than that found in other studies [17, 36]. It is interesting to note that a statistically significant difference in the marginal and internal fit could be found at the occlusal landmark. Previous studies also found a correlation between the marginal and internal accuracy [17, 50].

CAD/CAM fabrication of zirconia substructures currently uses two methods of data acquisition. In indirect digitalization, the need for a conventional impression with elastomeric materials and the production of a plaster model, made out of gypsum, is essential. In contrast, direct intraoral digitalization merges these steps into a digital workflow. This digital workflow eliminates the need for a plaster model to fabricate the coping. The copings are constructed from a direct intraoral dataset, and a physical model is produced by rapid prototyping with stereolithography, allowing a layer thickness of 25 μm in the production process [51]. The higher inaccuracies in the conventional workflow can be explained by the potential sources of error and the long process chain [33].

The second null hypothesis also has to be rejected. The scanning protocol for Lava C.O.S. was conducted with either a quadrant or full-arch scan, and this was evaluated by measuring the total working time. This system produces video sequences that are assembled to a virtual model of the jaw. By using only one clinician with specific training in direct intraoral scanning, standardization of the time recording procedure was achieved. Aspects such as removal of the temporary restoration, cleaning of abutments, cord placement, and drying of the oral cavity were not included because durations were similar for both approaches. The present study showed that digital impressions were more efficient than conventional

Fig 3 Box plot diagram comparing overall mean marginal gap values at VMR and standard deviation (SD) in micrometers for CAI and CI



impressions for single crowns and three-unit FDPs. Direct digitalization demonstrated a mean time saving of 5 min 6 s and 1 min 34 s for quadrant and full-arch scans, respectively. This may be explained by the fact that the practitioner can view a real-time model on a computer display immediately after scanning. As such, errors during impression-taking can be corrected without repeating the entire process. Therefore, the rescan time for digital impressions was less than the time taken to retake conventional impressions. Furthermore, the use of impression materials and trays is not needed, thereby conserving the time normally used for preparation of stock trays, application of adhesive, and individualization with silicone. Moreover, it can be stated that stitching full-arch scans appears to be more time-consuming than stitching quadrant scans because of the greater amount of data and the ability of the computer hardware to manage this data.

Lee and Galluci [44] evaluated the efficiency of both impression methods for single implants, resulting in a significant difference of more than 12 min in favor of digital impressions. It is interesting to note that in this study, second year dental students with no experience in either conventional or digital implant impressions judged the level of difficulty to be

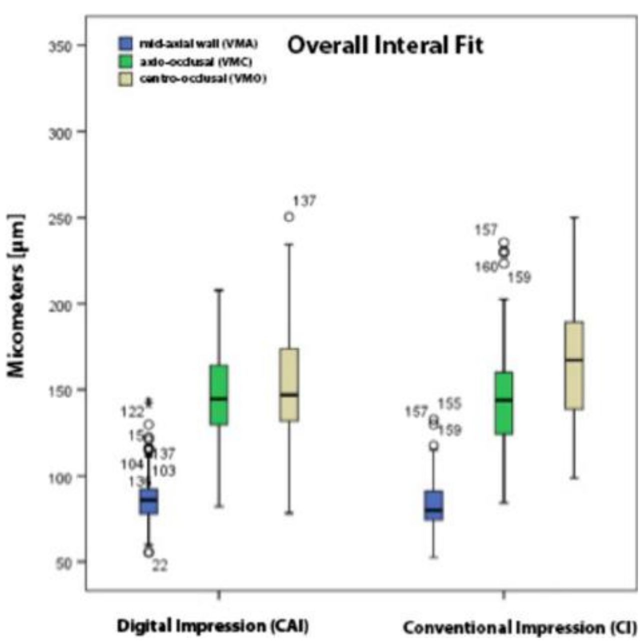


Fig 4 Box plot diagram comparing overall mean internal fit at values VMA, VMC, VMO, and standard deviation (SD) in micrometers for CAI and CI

Table 2 Mean time recording for quadrant (CAI-Q) and full arch (CAI-F) scanning with Lava C.O.S. and polyether impression (CI)

	Total	Step one	Step two	Step three	Step four
CAI-Q[a]	10 m 21 s	1 m 26 s	5 m 25 s	2 m 52 s	0 m 42 s
CI	15 m 33 s	4 m 25 s	7 m 1 s	2 m 48 s	1 m 33 s
CAI-F[a]	15 m 27 s	2 m 09 s	7 m 45 s	4 m 20 s	1 m 18 s
CI	17 m 07 s	4 m 38 s	8 m 9 s	3 m 29 s	1 m 20 s

Step one—powdering/stock tray individualization; step two—impression; step three—impression antagonist; step four—bite registration

[a] Quadrant (Q); full arch (F)

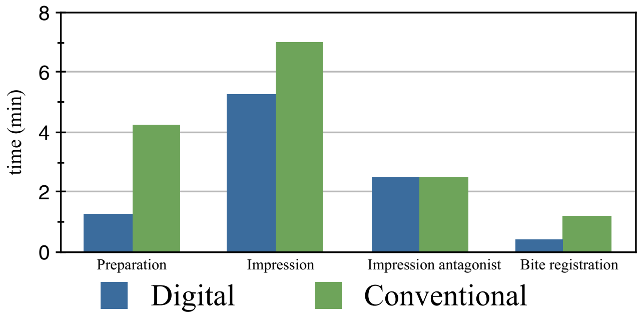


Fig 5 Bar diagram comparing mean time expense for quadrant scan (digital impression) and conventional impression for each step

significantly lower for the digital versus the conventional impressions. This suggests that the learning curve for this generation in taking digital impressions may be reduced when compared with conventional impressions. The results from the aforementioned study and the results of our study are also in accordance with those found by Patzelt et al. [46], who stated that a digital workflow might be beneficial in establishing a more time efficient workflow for the clinician, whereas it is still significantly dependent on the system used, the intraoral scanner technology, and whether a quadrant or a full-arch scan is being performed. Because of differences in time measurement methodologies and the variations that were present in these studies, a complete comparison cannot be made. However, another study comparing digital and conventional impression techniques showed that the participants significantly favored the digital impression because of its associated treatment comfort [4].

Inaccuracies of 14–17 µm may result during matching of different scans [52]. An in vitro study conducted by Ender et al. [53], which compared the precision of computer-aided impressions and the matching algorithm in full-arch scans for the CEREC Bluecam and the Lava C.O.S. systems, showed that the accuracy of digital impressions is similar to that of conventional impressions.

In this study, a coating powder was necessary because of the translucency of the tooth surface. Under optimal conditions, the thickness of the coating is 25–30 µm. The powdering technique has a significant influence on the coating

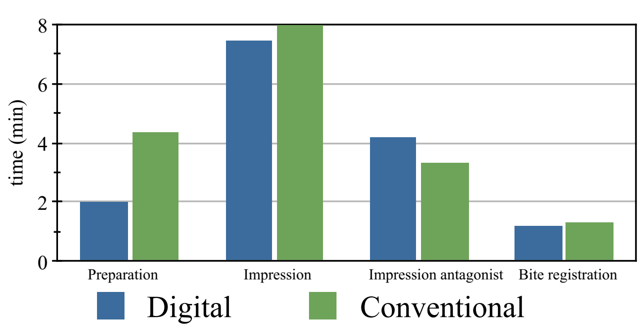


Fig 6 Bar diagram comparing mean time expense for full arch scan (digital impression) and conventional impression for each step

thickness [54], but further investigation is necessary on the influence of powder type and precision of application. The intraoral scanner can only display areas that can be viewed directly by the dental practitioner. Chamfer lines in this study were mainly at an equigingival or slightly subgingival level. Problems in preparation line detection using the intraoral scanner are more likely to occur when finish lines are placed deep subgingivally, as a greater effort is required for adequate soft tissue management. However, this issue was not tested in this study and further investigation on this topic is required. Moreover, accuracy in intraoral scanning is also highly dependent on the practitioner. It is important for the practitioner to obey the scanning protocol recommended by the manufacturer [55], and to maintain a steady learning curve in managing this new technology. Furthermore, the accuracy of intraoral scanning is affected negatively by patient-related factors such as intraoral space, saliva, and patient movement [56].

In this study, clinical fit was investigated using the silicone replica technique. Among the in-vivo techniques for measuring the fit of restorations, the replica technique is an accepted evaluation method [57]. This method has been used by numerous authors to investigate the accuracy of crowns and FDPs because of its reliable and non-invasive nature [25, 35–38, 40–42]. As opposed to the techniques used in the aforementioned studies, our zirconia frameworks were filled with light-bodied silicone during try-in, without ceramic veneering, to avoid incomplete seating due to proximal contacts. However, it must also be considered that significant changes may occur during the veneering [58] and sintering processes [42] of presintered zirconia, which can influence the density and final dimension of the restoration, possibly leading to higher values for marginal fit. For a precise analysis, it would have been more favorable to evaluate the clinical fit after veneering. Finger pressure was used to simulate clinical cementation. Additionally, three replicas were fabricated per abutment tooth, capturing 4608 values in total. This provided a reliable dataset for acquiring mean values for each measurement site. However, a disadvantage of this technique is its two-dimensional format. In our study protocol, four segments with six landmarks per abutment were obtained to measure marginal and internal accuracy, and this may not represent the complete circumferential fit [59]. Shortcomings of this technique may include the presence of defects in the silicone film, leading to inaccuracies in the microscopic measurements, especially if the finish line is located subgingivally [37, 38].

The results of this study are in agreement with the results of other clinical studies dealing with all-ceramic computer-designed zirconia restorations. In a similar comparative study protocol using the replica method for 20 single all-ceramic Lava crowns fabricated on the basis of direct digitalization, Syrek et al. [35] revealed a median marginal gap of 49 and 71 µm for the directly and indirectly digitalized test groups, respectively. The present study also affirms the results by

Scotti et al. [36], which showed a gap value of 48.65 μm for Lava C.O.S. and a similar internal fit. Furthermore, Brawek et al. showed clinical gap values of 51±38 μm for single crowns fabricated on the basis of direct digitalization using the Lava Digital Veneering System compared with 83± 51 μm for the Vita Rapid Layering technique [25]. In a comparable in vivo study using the replica method, Reich et al. identified a median marginal accuracy of 91 μm for veneered Lava four-unit FDPs [38] and 65–75 μm for veneered Lava three-unit FDPs [37]. In another investigation, the marginal and internal fit of four-unit zirconia frameworks fabricated using the same direct and indirect digitalization methods as in the present study were measured in vitro, resulting in no significant differences between the methods with both groups showing clinically acceptable fit of the restorations (Lava C.O.S.: 63.96±36.75 μm; Lava Scan ST: 65.33±37.27 μm) [40].

According to Seelbach et al. [41], marginal accuracies of 48±25 μm for Lava C.O.S., 48±25 μm for CEREC and 41±16 μm for iTero showed comparable results for single crowns and putty wash impressions, indicating that differences in the accuracies of intraoral scanning devices may be caused by their resolution and individual technology.

Furthermore, for the iTero scanner, data is available. Keul et al. conducted an in vitro study comparing the accuracy of datasets on the basis of direct and indirect digitalization, showing significantly lower deviations for iTero [42]. It also indicated that four-unit frameworks milled from base metal alloys after direct digitalization showed a significantly better fit than frameworks fabricated from cobalt-chrome alloy after indirect digitalization. Similarly, an improved fit has also been noted for three-unit frameworks generated from digital and conventional impressions that were milled from cobalt-chrome alloy [43]. However, because of differences in the measurement protocols and landmarks used, an accurate comparison between these studies is difficult. Moreover, long-term clinical observation of these restorations is required to demonstrate the true effect of marginal and internal discrepancies.

Conclusions

Zirconia frameworks of single crowns and three unit FDPs fabricated from computer-aided impressions demonstrated significantly better marginal fit than those fabricated from conventional impressions.

Zirconia frameworks of single crowns and three unit FDPs fabricated from computer-aided and conventional impressions showed clinically acceptable marginal fit.

Computer-aided impressions may be more time efficient for both quadrant scans and full-arch scans when compared with conventional impressions.

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