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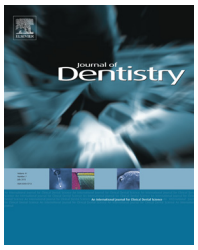

Clinical evaluation comparing the fit of all-ceramic crowns obtained from silicone and digital intraoral impressions based on wavefront sampling technology

Q1 *Guillermo Pradíes* *, *Cristina Zarauz*, *Arelhys Valverde*, *Alberto Ferreiroa*, *Francisco Martínez-Rus*

Q2 *Department of Buccofacial Prostheses, Faculty of Dentistry, Complutense University of Madrid, Pza. Ramón y Cajal, s/n Ciudad Universitaria 28040, Madrid, Spain*

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ABSTRACT

Objective: The aim of this study was to compare the fit of ceramic crowns fabricated from conventional silicone impressions with the fit of ceramic crowns fabricated from intraoral digital impressions.

Methods: Twenty-five participants with 30 posterior teeth with a prosthetic demand were selected for the study. Two crowns were made for each preparation. One crown was fabricated from an intraoral digital impression system (IDI group) and the other crown was fabricated from a conventional two-step silicone impression (CI group). To replicate the interface between the crown and the preparation, each crown was cemented on its corresponding clinical preparation with ultra-flow silicone. Each crown was embedded in acrylic resin to stabilise the registered interface and then cut in 2 mm thick slices in a buco-lingual orientation. The internal gap was determined as the vertical distance from the internal surface of the crown to the prepared tooth surface at four points (marginal gap, axial gap, crest gap, and occlusal fossa gap) using stereomicroscopy with a magnification of 40×. Data was analysed by using Wilcoxon signed rank test ($\alpha = 0.05$).

Results: Internal adaptation values were significantly affected by the impression technique ($p = 0.001$). Mean marginal gap was 76.33 ± 65.32 μm for the crowns of the IDI group and 91.46 ± 72.17 μm for the CI group.

Conclusion: All-ceramic crowns fabricated from intraoral digital impressions with wavefront sampling technology demonstrated better internal fit than crowns manufactured from silicone impressions.

Clinical significance: Impressions obtained from an intraoral digital scanner based on wavefront sampling technology can be used for manufacturing ceramic crowns in the normal clinical practice with better results than conventional impressions with elastomers.

* *Corresponding author*. Tel.: +34 91 394 20 29.
E-mail address: gpradies@odon.ucm.es (G. Pradíes).

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1. Introduction

Q3 Fixed dental prosthesis (FDP) is still mainly produced by casting techniques. The automation of the production process can be achieved by the use of computer-aided design (CAD)/computer-aided manufacturing (CAM) techniques. These techniques are recognised in general industry as a standard workflow in order to obtain high quality products in terms of accuracy and cost production efficiency.[1,2]

To start with the CAD/CAM workflow a digitalisation process is needed. An optical impression system is a device used to record relevant topographical intraoral surfaces, dental impressions, or stone cast for use in the computer assisted design and manufacturing of dental restorative prosthetics.[3] In recent years, various optical impression systems have been developed with which direct impressions could be made in the oral cavity. The most commonly used intraoral dental scanners among others are: Cerec AC (Sirona, Behnheim, Germany), Lava Chairside Oral Scanner (Lava COS, 3M ESPE, St Paul, MN, USA), E4D Dentist (D4D Technologies LLC, Richardson, TX, USA), and iTero (Cadent, Carlstadt, NJ, USA). Intraoral scanners play an important role in the development of digital dental technology because they are the first step towards a full digital workflow of prosthetic fabrication.[4] Intraoral digital impressions improve patient acceptance, reduce possible distortion of impression materials, allow for three-dimensionally (3D) previsualisation of the preparation, decrease potential cost, and increase efficacy.[5]

Also, one of the most significant advances in this field has been the production of high resistance all-ceramic restorations that until today can only be produced with CAD/CAM systems. The popularity of these materials, such as zirconia, has increased significantly in the last decade due to their esthetic, mechanical and biocompatibility properties.[6–8] In addition to the physical properties and biocompatibility, the predictable production of suitable marginal inter-phases is one of the most important factors for long-term success of restorations.[9–13] Poor marginal adaptation between the tooth and the restoration increases plaque retention and changes the distribution of the microflora, which can induce the onset of periodontal disease.[14,15] Poor marginal fit can also cause secondary caries and lead to clinical failure of fixed prosthodontics.[16] Microleakage from the oral cavity may cause endodontic inflammation.[17]

Although marginal adaptation is a fundamental factor in the clinical success of the FDPs, there is no consensus on what constitutes a clinically acceptable maximum marginal gap width. The values reported on the maximum acceptable gap in scientific literature range from 50 to 200 μm so, there does not seem to be an objective limit based on scientific evidence.[10,13,18] At present, many investigators still use the limit established by McLean and Von Fraunhofer of 120 μm.[18]

Lava Chairside Oral Scanner (3M ESPE) intraoral scanner is based on the principle of active (optical) wavefront sampling which obtains 3D information from a single lens imaging system by measuring depth based on the defocus of the primary optical system. This device has three sensors, which capture the surface to be scanned from different perspectives. With these three images captured at the same time, 3D surface patches are generated by proprietary image processing algorithms by using the in-focus and out-of-focus information.[19] With this technology, twenty 3D datasets per second can be captured with over 10,000 data points in each, resulting in over 24 million data points for obtaining an accurate scan of the dental preparation, soft tissues and hard tissues. According to the manufacturer specifications, the high data redundancy resulting from many overlapping pictures together with special image processing algorithms allows us to obtain optimal image quality and high accuracy.

At present, the number of clinical studies that evaluate the fit of the restorations manufactured with an intraoral scanner is still limited.[11,12,20] The aim of this in vivo prospective study was to evaluate the accuracy of a digital intraoral impression workflow based on the principle of active wavefront sampling technology and to compare it with a conventional silicone impressions workflow by measuring the marginal and internal misfits of the zirconia-ceramic crowns generated with both systems. The null hypothesis was that there is no difference in marginal and internal misfit between crowns obtained from digital and from silicone impressions.

2. Materials and methods

2.1. Study design

This in vivo prospective clinical trial was previously approved by the local ethical committee. The study was conducted in accordance with the Declaration of Helsinki and Good Clinical Practice (GCP). This study included participants aged between 16 and 65 needing a single crown in a posterior tooth, with acceptable standards of oral hygiene, not requiring additional extended treatment of endodontic or periodontics in the study tooth, and who gave informed consent. In contrast, participants with an advanced periodontal attachment loss affecting the mobility of the teeth (mobility degree 1 or higher), severe wear facets or marginal preparation located deeper than 1 mm subgingivally were excluded.

Thirty participants were enrolled into the study and were fitted with 34 zirconia-ceramic single crowns (Lava, 3M ESPE). For each of the 34 teeth in this study, three crowns were made: two crowns for the study, one made by each impression method (intraoral digital impression – IDI and conventional two-step silicone impression – CI); and one crown to be finally cemented produced exactly like the study crown for the CI group. 102 crowns were made in total.

2.2. Tooth preparation

Sixteen molars and eighteen premolars were treated, 15 in the maxilla and 19 in the mandible. All participants received local anesthesia prior to tooth preparation for a ceramic crown. Distinct chamfer finish lines were prepared and placed at gingival level, not exceeding a subgingival depth of 1 mm. The axial reduction of the tooth substance was between 1 and 1.5 mm, in accordance with the remaining hard tissue. Occlusal reduction was approximately 1.5 mm. All internal edges were rounded. The preparation had a divergence angle of around 6%.[21] After tooth preparation a provisional restoration was

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placed by using a temporary resin based material (Protemp Crown, 3M ESPE). The participants were then scheduled for refining of the preparation and polishing. A double-cord packing technique was used to allow a correct display of the finish line for the definitive impression (Ultrapak #000 and Ultrapak #00, Ultradent Products, South Jordan, UT, USA). The same retraction double-cord packing technique was used to make both the conventional and the digital impressions. A disposable soft tissue retractor (Optragate, Ivoclar Vivadent, Schaan, Liechtenstein) was placed to retract the cheeks and lips. The mouth was then rinsed with water and air-dried.

2.3. *Impression protocol*

One operator randomised the sequence of impression making (conventional versus digital) with a smart phone application (Undecided, Deadmans Production, Wilmington, NC, USA).

For the conventional impressions, a polyvinyl siloxane (PVS) material was used in a two-step impression technique (Express 2 Penta Putty as tray and Express 2 Light Body Quick as wash material, 3M ESPE), in rim-lock metal trays. After removal, a trained independent observer inspected the impressions by using 2.8× magnification (ExamVision HD, Akura Medical, Madrid, Spain), verifying that all impression surfaces of the abutments were free of pulls, voids, and air bubbles. The opposite dental arch impression was made with irreversible hydrocolloid impression material (GC Aroma Fine Plus, GC Corporation, Tokyo, Japan), and the occlusal registration with an elastomer material (Imprint 4 Bite, 3M ESPE). The impressions were disinfected and poured with type IV plaster (Fuji Rock, GC Corporation) one hour after mouth removal and sent to our paired laboratory, where the master cast was scanned by means of the extraoral scanner (Lava Scan ST, 3M ESPE).

Digital intraoral impressions were made by using an intraoral digital scanner based on wavefront sampling technology (Lava Chairside Oral Scanner, 3M ESPE) according to the manufacturer's scanning protocol: light dusting of the teeth surfaces to be scanned (titanium dioxide powder), scanning of prepared tooth, scanning of the remainder of the quadrant, scanning of the opposing quadrant, and finally scanning of the teeth in occlusion as an occlusal registration. After completing the scan sequence, the virtual casts were reviewed in the touch screen attached to the scanning wand, checked for completeness before acceptance, and sent to the certified laboratory paired for the study, for processing of the digital impression, digital die cutting, margin marking, coping design and production.

2.4. *Crown manufacturing workflow*

The digitised data from the conventional impression, as well as the captured impressions at intraoral level were transmitted to a CAD software program (Lava Design Module, 3M ESPE) in which the copings were designed. Previously, the finish line was marked by the lab technician on the preparation. When the preparation limit was not clear, the technician returned the cast (or the 3D virtual model) to the dentist for the completion of the finish line. This happened only three times. Stereolithographic (SLA) casts for IDI group were produced by rapid prototyping (Fig. 1). The copings for both groups were milled from pre-sintered zirconia blocks (Lava Zirconia Blocks Refill, 3M ESPE). After sintering, copings and SLA casts were sent to the laboratory, where compatible feldspathic porcelain was veneered on the copings on their corresponding cast.

2.5. *Fit recording*

Before definitive insertion, silicone replicas were produced for all 60 crowns that were made for the study. To register the space between the inner surface of the copings and the abutment, a modified replica technique was applied[11,12,22–26]:

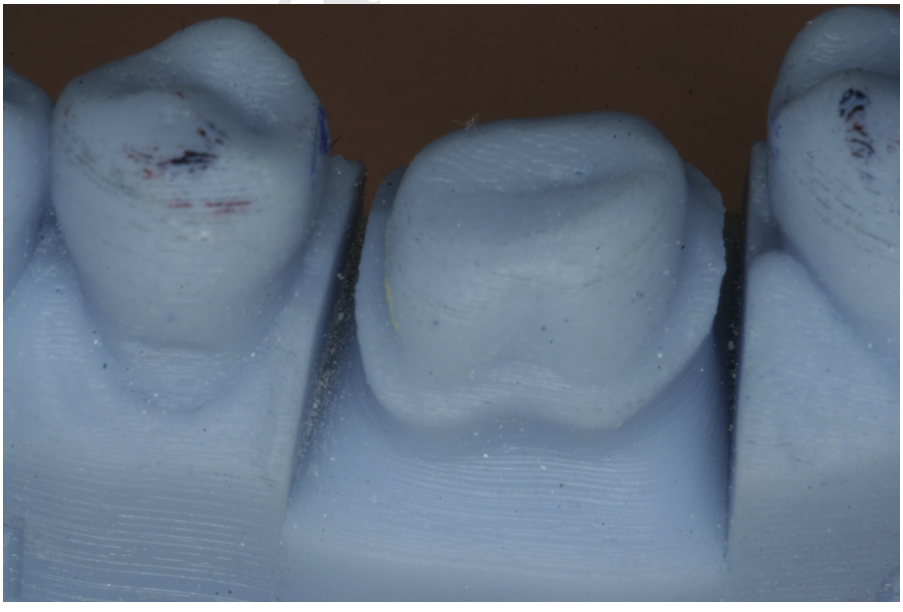

Fig. 1 – Stereolithographic cast produced by rapid prototyping.

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the crowns were filled with a low viscosity silicone (Express 2 Ultra-Light Body Quick, 3 M ESPE), seated on the preparation and held in place with maximum finger pressure to simulate clinical cementation of the crown. After two and a half minutes (intraoral setting time of the impression material), the crowns were dragged off the preparation with a conventional partial silicone impression (Express 2 Penta Putty as tray and Express 2 Light Body Quick as wash material, 3 M ESPE).

Once the replication process was completed with each patient, a third crown, originated from the conventional impression, which still remains the gold standard, was cemented on the prepared abutment by using a luting resin agent (RelyX Unicem, 3M ESPE).

As for the two crowns dragged off the tooth, their preparation continued in the lab. To stabilise the thin silicone film representing the cement space, the crowns were embedded in an acrylic resin (Pikuplast, Bredent, Senden, Germany) with good dimensional stability properties (lineal contraction $\leq$0.016%) that mimicked the abutment tooth. The crowns with the replicated interface, embedded in Pikuplast resin, were further embedded in a transparent resin (Epofix, Struers, Ballerup, Denmark), which facilitated the slicing of the created blocks into 2 mm thick specimens, with parallel walls to obtain a parallel orientation to the microscope plate and to achieve a vertical observation angle, in a bucco-lingual orientation with a precision cutter (Micromet-E, Remet, Bologna, Italy). The sections were polished on a metallurgical polishing wheel by using increasingly fine carbide papers (LS2, Remet). The same operator prepared all samples.

2.6. *Measurements*

Film thickness of the replica was captured by means of a stereomicroscope (M-80, Leica, Wetzlar, Germany) at magnification factor 40×, with a built-in charge-coupled camera (Hitachi CCTV HV-720E, Hitachi, Tokyo, Japan). Image analysis software (Leica Application Suite, Leica) was used to measure film thickness at the sites margin, axial, crest, and occlusal fossa (Fig. 2). Marginal gap (S1) was the shortest distance from the restoration to the abutment surface close to the preparation finish line.[27] Axial adaptation (S2) was the perpendicular measurement from the internal surface of the coping to the axial wall of the preparation, 2 mm coronal to the cavosurface line angle. Crest discrepancy (S3) was measured from the coping to the abutment at the highest point of the crest, or described as the bisector of the angle between the straight line attached to the incisal plateau and the straight line applied to the axial wall. Finally, occlusal fosse discrepancy (S4) was measured from the coping to the abutment at the lowest point of the fossa of the preparation.

At each site 10 measurements were taken, resulting in 40 measurements around each specimen. All measurements were recorded in microns (μm), and exported to a spreadsheet (Microsoft Excel 2007, Microsoft Corp, Redmond, WA, USA). The overall misfit discrepancy was also calculated so as to obtain a complete misfit comparison between both impression methods, conventional and digital intraoral. Two trained investigators, who were previously calibrated and who were not involved in the clinical treatment, carried out the measurement procedure of the samples in the stereomicroscope. Finally the average of the two measurements was calculated.

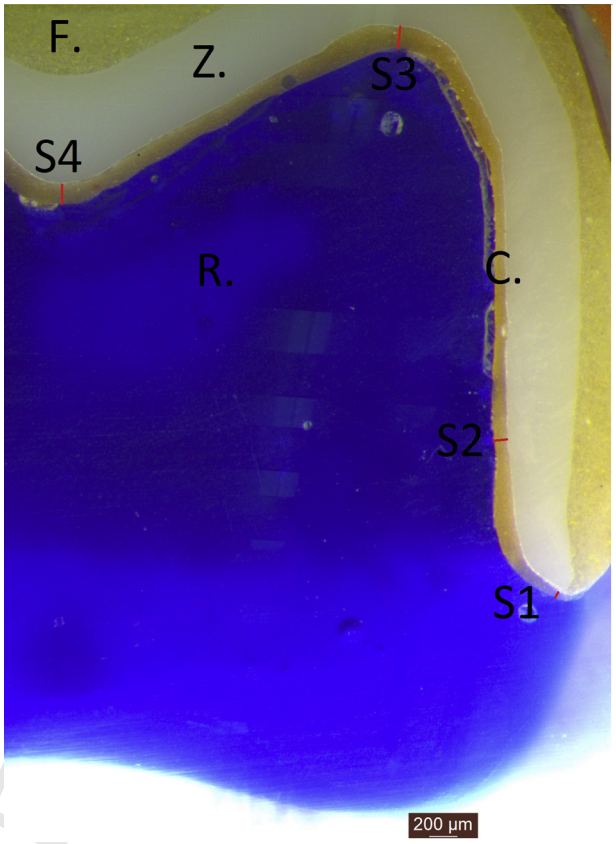

Fig. 2 – Sample with marked landmarks: (S1–4) margin, axial, crest and occlusal fossa gap; (R) acrylic resin (replicated abutment); (C) cement space (replicated misfit); (Z) zirconia core; and (F) feldspathic porcelain.

2.7. *Statistical procedure*

The sample size utilised was calculated for 80% power by specific software (G-Power version 3.1.9 for Mac OS (Heinrich Heine University, Dusseldorf, Germany). Statistical analysis was performed by software (SPSS 19.0, IBM Corporation, Armonk, NY, USA). Mean values and standard deviations per group were calculated. Normality distribution was checked by using Shapiro–Wilk test. Wilcoxon signed rank test for paired samples was used to assess the influence of the impression system on the internal discrepancy. The level of significance was established at $\alpha = 0.05$.

3. Results

Of the 34 teeth, one tooth was dropped out of the study because it developed irreversible pulpitis symptoms after preparation, and had to be referred to the Department of Endodontics for root canal treatment. An additional three teeth were dropped out of the study because of damage at sample slicing.

Table 1 – Mean, standard deviations, minimum, maximum values and significance results.

		Mean (microns)	Std. deviation (microns)	(Microns)		Wilcoxon signed rank test
			Min.	Max.	p (2-tailed)	
Margin gap	Conventional	91.46	72.17	6.62	378.30	0.001
	Lava COS	76.33	65.32	6.63	364.45	
Axial gap	Conventional	146.35	66.45	16.98	398.71	0.000
	Lava COS	128.96	62.80	5.72	393.14	
Crest gap	Conventional	200.40	72.42	14.96	393.14	0.403
	Lava COS	195.21	67.44	30.00	394.85	
Occlusal fossa gap	Conventional	224.89	67.52	86.37	391.66	0.008
	Lava COS	198.96	67.81	73.21	398.64	
Overall gap	Conventional	165.77	69.64	6.62	398.71	0.000
	Lava COS	149.86	65.84	5.78	398.64	

The means, standard deviations and inferior/superior confidence intervals for the internal misfit values (in microns) of the remaining 30 teeth are shown in Table 1. The distribution of the results for both groups can be seen in the boxplot graphs shown in Figs. 3 and 4.

Shapiro–Wilk test detected that the samples did not have a normal distribution, hence the need to perform a non-parametric test. Wilcoxon signed ranked test showed that the IDI restorations had a significantly better fit than the CI group at every site analysed (Table 1) ($p < 0.05$), with the exception of the crest gap. The global comparison also showed significant better fit for the IDI group (Table 1). The lowest misfit was registered at marginal level in both groups, 76.33 ± 65.32 μm for IDI group and 91.46 ± 72.17 μm for CI group. Thus, the null hypothesis was rejected.

4. Discussion

This in vivo study was designed to compare the performance of two different impression systems, a conventional two-step impression technique and a digital intraoral impression technique. CAD-CAM technology has been introduced in the dental field to improve conventional workflows like impression making procedures and design of dental prosthesis. Another purpose of this technology is to allow the fabrication of, between others, high strength ceramic restorations like partially stabilised zirconia frameworks, for which milling is the only approach available nowadays.

There are also many clinical factors, besides impression material and technique, which can influence the quality of an

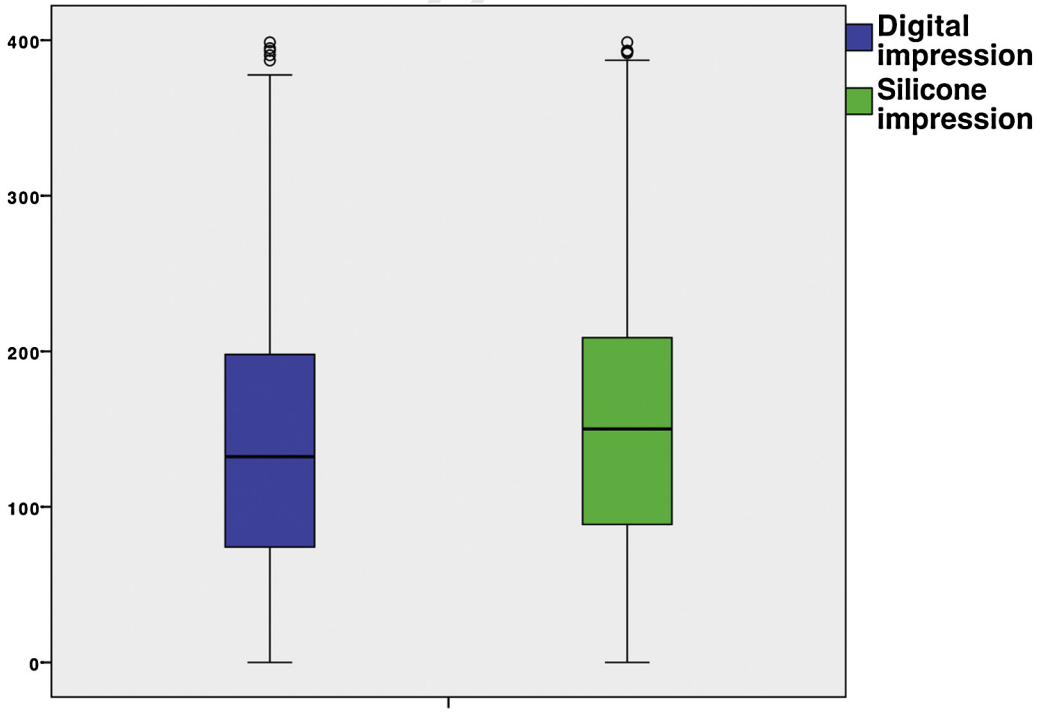

Fig. 3 – Box plot general comparison of impression systems.

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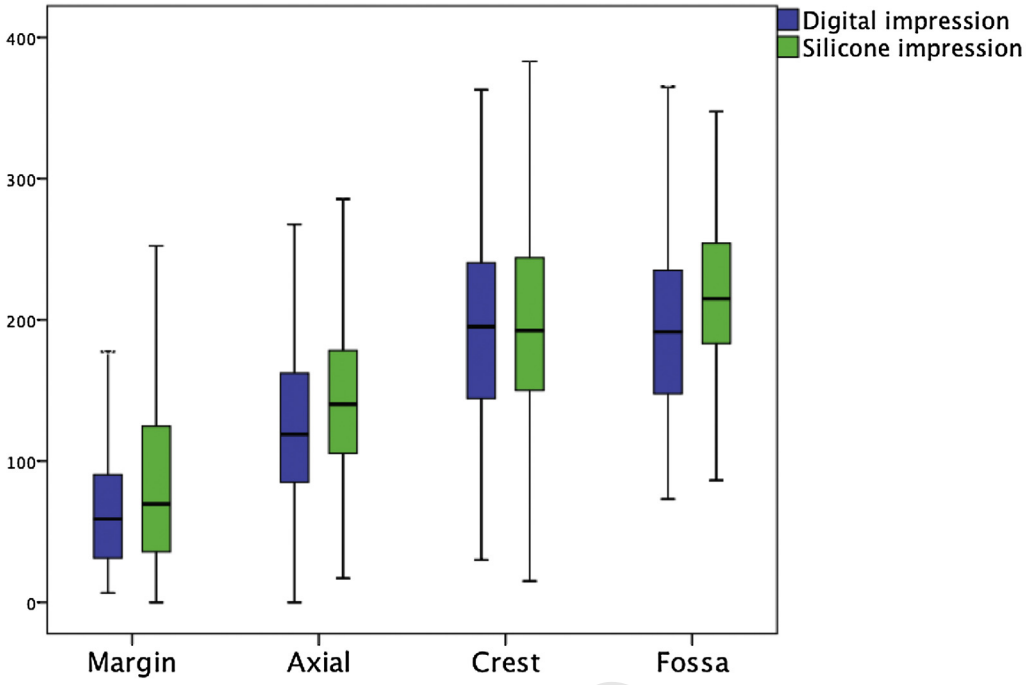

Fig. 4 – Box plot representing comparison of impression systems by site in microns.

impression, including: location of the finish line, periodontal health, sulcus bleeding during impression making, saliva flow rate, or patient compliance. In addition, if the impression is made by means of an intraoral scanner, the accessibility of the preparation for the scanner wand becomes critical for the success of the impression. Accessibility can be limited especially in the retro molar region of patients with limited opening or an ascending ramus of the mandible situated close to the buccal surface of the last molar.[11] For this reason, we decided to analyse the internal and marginal fit with a clinical approach, which had the disadvantage that the evaluation of crown fit was more difficult compared to an in-vitro study where for instance, direct measurement of marginal discrepancies by means of microscopy would have been possible. To overcome this, a replica technique for determining the marginal gap size was adopted. The replica technique is accepted as a reliable and non-invasive means to determine the in vivo adaptation of crown-to-tooth surfaces.[20,23–26] A modification of the previously described technique in the handling and stabilisation of the replicated silicone layer was used. The misfit replicated space is thin and fragile, with a thickness ranging from 20 to 150 μm. It is a very delicate layer of silicone, to just elevate it from the abutment tooth, embed it in a heavier silicone, and slice it with a blade. This procedure to stabilise the cement space has the benefit of being a simple procedure, but it means also less control over the dimensional stability of the sample, introducing more variables and confounding errors to the results, bearing them less credibility. As described in the material and methods, the cement space replication was dragged out stabilised in the crown and putty/wash partial silicone impression, to proceed with acrylic resin embedding and cutting with a precision cutter.[6,13]

In the present study, a definition of the marginal accuracy. according to Holmes et al.[27] was used. The internal gap was defined as the perpendicular distance between the framework and the abutment teeth and it was the misfit of the coping at the axial, crest, and occlusal fossa surfaces. The same measurement at the margin was called the marginal gap. The internal fit is an important factor for the marginal accuracy, since a uniform internal gap width avoids compromising either the retention or the resistance of the restoration and provides an appropriate space to accommodate for the cement.[28] On the other hand, the internal fit also has a practical aspect. If too much space is lost as a result of large occlusal discrepancies, the intercuspal clearance available for veneering is reduced.

The data obtained in this study support rejection of the null hypothesis that no differences would be found in fit discrepancy among the crowns fabricated by the two different impression techniques. The mean marginal gap size was 76.33 μm for the digital impression and 91.46 μm for the PVS impression. There are two commonly used impression techniques for PVS: the dual-viscosity one-step impression technique, and the putty-wash two-step impression technique. Several studies have shown that the two-step technique is more accurate than the one-step technique, since it is characterised by uncontrolled wash bulk and a high risk of capturing portions of the prepared margin in the putty material rather than the wash material.[29–31] Therefore, in the present investigation, the putty-wash two-step impression technique was used.

Currently, there are only a few studies available that measured the fit of crowns produced by means of intraoral scanning with a replica technique in vivo. Syrek et al.[11] found a

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median marginal gap size of 49 μm for the digital impression and 71 μm for the conventional impression; while Scotti et al.[12] did not have a conventional impression control group, but on the other hand measured different landmarks of the preparation: 48.65 μm for the marginal gap, 112.25 μm at the mid-axial wall, 137.81 μm at the axio-occlusal edge of the abutments, and 157.25 μm at the centro-occlusal location. Brawek et al.[20] had no control group with a conventional impression either, as they meant to compare the misfit found with two different digital intraoral scanners, and their results were for Lava COS and Cerec AC respectively: at the marginal gap, 51 μm and 83 μm; mid-axial, 130 μm and 128 μm; axio-occlusal, 178 μm and 230 μm; and centro-occlusal, 181 μm and 297 μm.

The mean marginal gap widths of CAD/CAM-fabricated zirconia restorations in this study were slightly higher than the reported literature results at the marginal site. This could be due to our specimens being finished crowns with veneered porcelain, whereas Syrek et al.[11] and Scotti et al.[12] only used the copings to measure the fit. Adding porcelain to copings can cause distortion and lead to an inadequate fit according to Pak et al., [9] whose results of two different zirconia systems with a presintered milling and totally sintered milling showed significant differences when analyzing the marginal gaps before and after porcelain veneering within each group. However, it remains unclear whether a difference in mean marginal gap between 40 μm and 80 μm is a clinically relevant difference. As shown in Fig. 4, the mean marginal fit of both IDI and CI groups are within the 100 μm acceptable marginal discrepancy threshold established for this study. Although the IDI group has a lower mean, this is not as relevant as the fact that the 3rd quartile of the boxplot graph for the IDI group is below this threshold, whereas the 3rd quartile on the CI group is above it.

There were some limitations in the present study. The measurements were performed without cementing the crowns, so the increase in marginal gap width caused by cementation was not included. More clinical studies are needed to establish digital impressions as a gold standard for impression making in more extensive treatments in fixed prosthodontics, as well as for implant impressions.

5. Conclusions

Within the conditions and limitations of this study, the following conclusions were drawn:

The zirconia-based ceramic crowns fabricated using digital impression obtained better marginal and internal fit than the crowns fabricated from the conventional impression.

The mean marginal discrepancy in both groups was within the limits of clinical acceptability.

Conflict of interest

This work has been partially supported by 3M ESPE, but its contents are solely the responsibility of the authors and do not necessarily represent the official views of 3M ESPE.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jdent.2014.12.007.

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