Original Article

Comparison of Restoration Fit and Operation Time between Clinical Conventional and Digital Impression Methods in Fabricating Fixed Dental Prostheses

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Abstract

Aim: *Dental treatment services have entered the era of digitalization. Relatedly, the operation time required for the digital fabrication and fit of fixed partial prostheses is an important issue. The purpose of this study was to compare the accuracy and time required for fixed partial prosthesis fabrication between a digital fabrication system and conventional fabrication methods.*

Materials and Methods: *The study was conducted at Kaohsiung Municipal Cijin Hospital in Kaohsiung City and included 20 patients for whom a total of 37 prostheses were made. Both digital scanning and conventional operations were performed for the same dental positions by the same senior dentist. Polyvinyl siloxane (Aquasil, Dentsply Caulk, Milford, DE, USA) was the material of choice used in the conventional impression process, while CS3500 (Carestream, USA) was the digital image acquisition machine used in this study. The design software used was Exocad (GmbH, Germany), and the milling machine used was an ARDENTA CNC mill (DT100-4A, Tainan, Taiwan). The composite material used in milling that did not require thermal sintering was crea.lign (Bredent, Germany). The restoration fit was measured by using Fit Checker (GC, Japan) silicone material intra-orally, and each result was assessed using a three-dimensional coordinate measuring instrument (3D CMM , Jingstone Metrology, Taiwan). The operation time and restoration fit data were analyzed by using paired two-sample t-tests ($p < .05$).*

Results: *This study included 20 patients for whom 37 abutments were made. We measured the operation time and marginal discrepancy of those abutments. On average, the time required for the clinician to obtain dental data using the digital device was 12.73 minutes (standard deviation, SD ± 5.34), while it took 41.81 minutes (±8.50) when performed with the conventional process. In this respect, the data showed a statistically significant difference between the two methods ($P<0.001$). The total time used in the digital operation was 48.16 minutes (±11.67), while that for the conventional operation was 76.99 minutes (±13.70), which was also a statistically significant difference ($p<0.001$). A comparison of the marginal discrepancies for the prostheses made by the conventional and digital processes was also performed. The average marginal discrepancy of four buccal, lingual, distal, and mesial points for the digital process was 77.67μm (± 47.88), while that for the conventional process was 111.25 μm (± 52.02), which was also a statistically significant difference ($p < 0.001$).*

Conclusion: *The analysis showed that the operation time required for the digital process was shorter than that for the conventional one, while the digital process also provided better precision.*

Key words: Digitalization, Conventional, Accuracy, Time, Remote service

Introduction

Digitalization has shown tremendous promise in the dental industry. It is expected to shorten operation times and reduce the number of clinical visits required of patients. The conventional method used in fabricating fixed prostheses uses impression material to obtain a negative imprint of the given patient's abutment teeth. The impression is then sent to a dental laboratory for prosthesis fabrication. Similar to clinical setting, the conventional laboratory procedure also includes multiple time-consuming steps, including die trimming, articulator mounting, etc. Meanwhile, computer-assisted design and computer-assisted manufacturing (CAD-CAM) techniques have been used to produce ceramic restorations since the 1980s.[1] The digital prosthetic treatment process can be divided into two workflows, one of which is performed by the dentist and the other of which is performed by the technician.[2] The advantages of digital optical oral scans include shortened clinical steps and easy data modification. The digitalization process can be used to convert conventional impression models into digital data by using a reference scanner or using the data from an oral scanner directly. Using design software, technicians can remove the need to perform multiple conventional steps, such as die trimming, articulator mounting, and manufacturing of the prosthesis by a milling machine. It is thus anticipated that digitalization will save considerable amounts of human resources and time.

In recent years, the use of elastic impression materials in combination with conventional single- or 2-step impression techniques has remained the mainstream approach; however, digital oral scanners are gaining in popularity for the 3-dimensional (3D) capturing and digitization of prepared teeth, and various digital impression systems are now available.[2] Each of these systems operates according to different principles,[3] including the use of the active triangulation technique in combination with optical microscopy [Carestream (CS) 3500], optical triangulation in combination with confocal microscopy (Cerec Omnicam), confocal microscopy in combination with ultrafast optical scanning (Trios 3, Planmeca Planscan), active speed 3D video (CS 3600), the parallel confocal imaging technique (iTero), active wavefront sampling in combination with structured light projection (Lava COS) and "3D-in-motion" video technology (3M True Definition), and video in combination with artificial intelligence (Cerec primescan). Intra-oral scanning machine technology has been greatly improved in recent years while the size of such equipment size has also been reduced, giving dentists more flexibility to scan intra-orally under different circumstances. With the digitization of the design and production process, all data is transmitted over a network, bypassing the distance between a clinic and laboratory office and decreasing the time required for the overall process compared to the conventional workflow.

To fabricate a single crown or fixed partial denture, an accurate cast can be obtained with either digital scanning or a conventional impression. The marginal fit is an important clinical factor used for the quality assessment of fixed partial prostheses. In previous studies, an acceptable crown margin-tooth finishing line discrepancy ranged from 34 to 119 um,[4] and fixed partial prostheses with marginal discrepancies of less than 120 um were considered more likely to be successful.[5] Tsirogiannis et al.[6] conducted a review and meta-analysis and found that no significant differences were observed in the marginal discrepancies of single-unit restorations fabricated using digital or conventional impressions. However, Imburgia et al.[7] found that the precision was higher in a partial edentulous model than in a full arch when using a digital workflow. Lee and Gallucci[8] evaluated the time efficiency of the dental prosthesis impression process in an *in vitro* experiment and found that digital scanning required less time than the conventional technique. Ahrberg et al.[9] compared the time efficiency of digital scan and conventional impressions for the fabrication of tooth-supported restorations in a clinical study and found that optical scanning is significantly less time consuming than making conventional impressions.

Using digital scans for fixed prosthodontics has several advantages compared with using conventional impressions, according to *in vitro* studies.[10 11] However, Benic et al.[12] conducted a clinical *in vivo* study comparing these 2 different techniques and found that conventional impressions were more time-efficient than digital impressions. Given these conflicting findings of past studies, the purpose of the present study was to verify whether a remote process could be used to effectively provide digital prosthetic services. We also sought to compare the time required by digital devices versus conventional procedures, as well as the marginal discrepancies on the same abutments of prostheses made using the digital process versus the conventional process. The null hypothesis was that there would be no statistically significant difference in the operation times and marginal discrepancies for the conventional and the digital workflows.

Materials and Methods

Study setting and participants

This study was approved by the Human Research Ethics Committee of Kaohsiung Medical University Chung-Ho Memorial Hospital IRB, Kaohsiung ROC. (IRB code: KMUHIRB-F(II)-20160090). Informed consent was acquired from all the participating patients. The study followed the CONSORT guidelines for reporting clinical trials.

This research was conducted at Kaohsiung Municipal Cijin Hospital (which is entrusted to Kaohsiung Medical University for its operation) between August 2016 and September 2018 (as approved by the institutional review board). The potential participants were screened and selected by a prosthodontist. Each participant had to be 20~90 years old. The exclusion criteria included any cases that required removable partial denture or complete denture fabrication, as well as any patients with a mouth opening limitation (< 38 mm). In this study, the clinical operator was a senior prosthodontic specialist, and the same laboratory technician was chosen to perform each conventional prosthesis fabrication process. Both the dentist and the laboratory technician achieved the plateau of the learning curve for the optical impression systems and the CAD-CAM training before starting the study. For obtaining acceptable, good results with reduced delivery time, the authors and the technician used the best crown parameters for each patient, which were determined before the study.

Conventional and digital impression (Fig. 1)

After tooth preparation and gingival retraction, the production process after the conventional impression method was as follows:

1. Polyvinyl siloxane (Aquasil, Dentsply) impression material was used to obtain the participant's negative imprint.
2. The negative imprint was sent to the dental technician's office.
3. Gypsum was used to obtain the tooth positive model.
4. The positive model was scanned with a reference scanner (Activity 880 scanner; Smart Optics, Bochum, Germany) to obtain the digitization data for the target tooth [stereolithography(STL) file].
5. Prosthesis design was performed using the CAD software Exocad (GmbH, Germany), and the crown parameters were set using conventional pathway records.
6. An ARDENTA CNC mill (DT100-4A, Tainan, Taiwan) was used in the laboratory office to make the prosthesis.
7. Adjustments to the output tooth were made on the articulator.
8. The prosthesis was sent to the clinical department for delivery by the dentist.

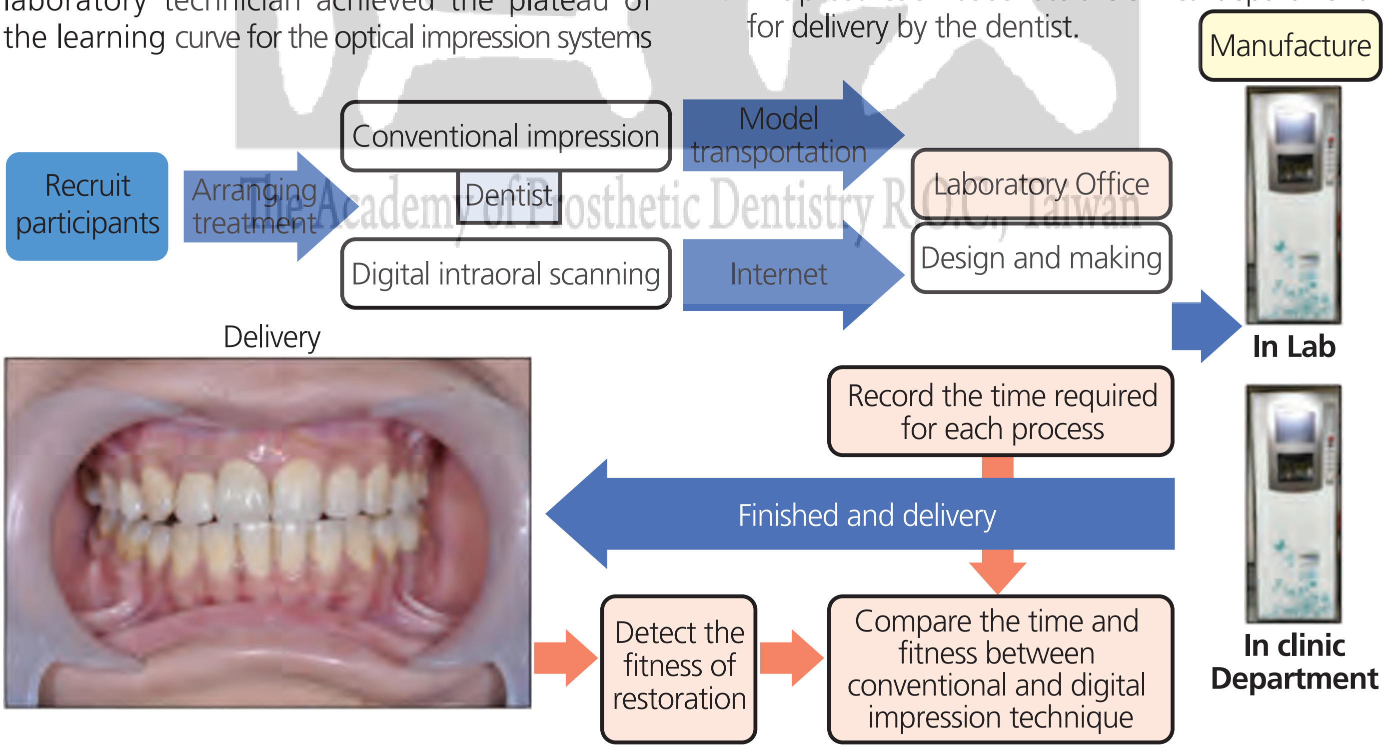

Figure 1. Flowchart of the conventional process and the digital process.

After the tooth preparation and gingival retraction, the production process after the digital optical intra-oral scan was as follows:

1. A photo-type optical digital dental scanner CS3500 (Carestream, USA) was used to obtain the target tooth data (STL file).
2. The dental data was transferred to the laboratory via the Internet.
3. Prosthesis design was performed using the CAD software Exocad (GmbH, Germany), and the crown parameters were set using intraoral scanner pathway records.
4. The data was transferred to the clinical department and an ARDENTA CNC mill (DT100-4A, Tainan, Taiwan) was used to make the prosthesis.
5. The prosthesis was sent to the clinical department for delivery by the dentist.

Critical operation time calculation (Fig. 2)

To determine the time required for the conventional process for each patient, we started the timer after placing the gingival retraction cord in the abutment sulcus and stopped the timer upon completion of the upper and lower occlusion recording.

The laboratory operation time began after the hardening of the working cast, including die preparation with a Di-Lok tray (San Xing, Taiwan), and ended when the cast and tray were mounted on the articulator. After the articulator setting was completed, the second period began with the model being placed in the reference scanner and ended when the storage of the data was completed. After the output was completed, the finishing and polishing of the prosthesis were performed by the same senior dental technician on the articulator.

The starting time for the digital scanning process began with the gingival retraction and ended when the storage of the scan data was completed. The laboratory design time began with the extraction of the data and ended when the design was completed and the data was stored. The 3D tooth milling machine's output time started with the data being transferred to the machine and ended with the machine notification of the completed output. The material used in this study was crea.lign ® (Bredent, Germany), which does not require thermal sintering.

The delivery time began after the patient had been seated in the chair and the relevant pre-delivery preparation had been completed and ended when the patient indicated that there was no problem with occlusion.

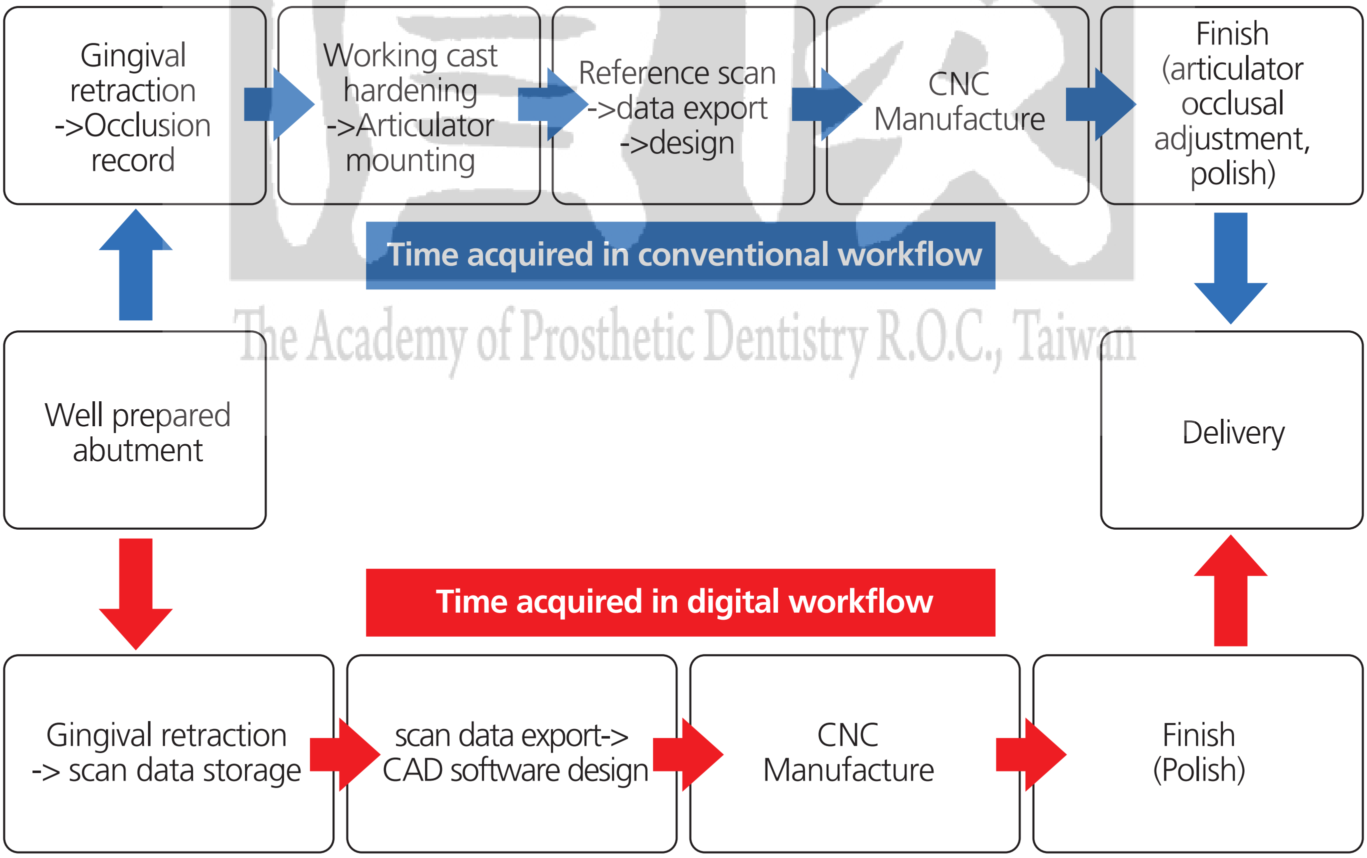

Figure 2 Time required for the conventional workflow and the digital workflow.

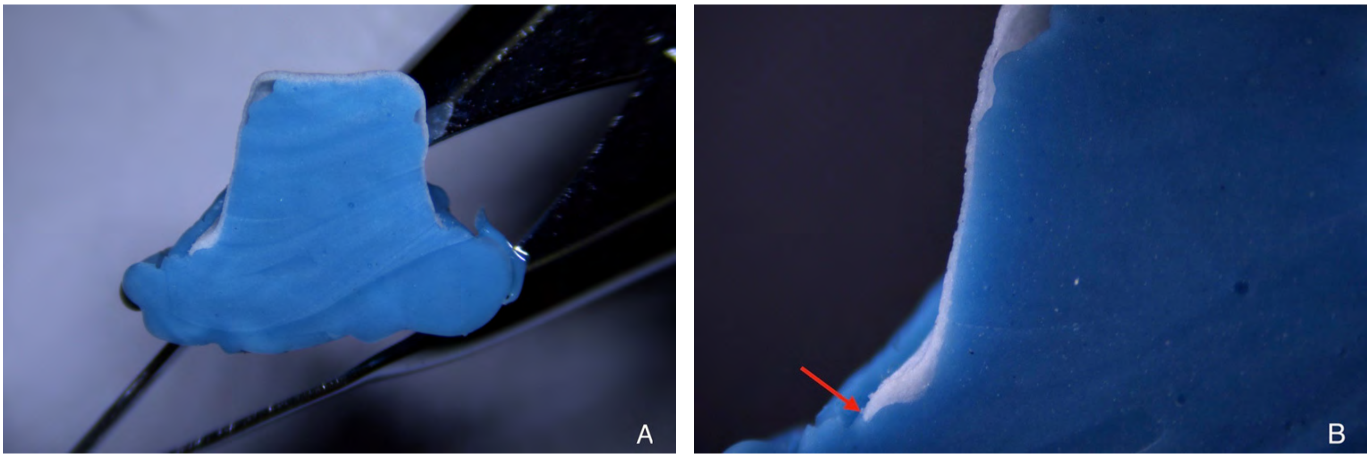

Figure 3. Representative replica cross-section with locations of the measurement points. A, the cross-section of the abutment (original magnification, x0.67). B, the arrow shows the marginal discrepancy from the specimen cross-section (original magnification, x3).

Fit comparison

After the prosthesis delivery-time calculation for the two methods was finished, a replica method was used to evaluate the marginal space between the prostheses and abutment teeth. The intaglio surface of each of the prostheses was filled with Fit Checker (GC, Japan) silicone material. The prosthesis was then placed on the abutment teeth and the patient was asked to bite with normal force for 30 seconds with gauze in between the opposite dentition. Upon removing each prosthesis from the mouth, we injected low-viscosity light-body PVS (Aquasil, Dentsply) into the intaglio surface of the prosthesis to replicate the abutments. Figure 3A shows a layer of the Fit Checker material attached to the surface of the abutment teeth that surrounded by the PVS silicone to fix the Fit Checker layer, which was sectioned mesiodistally and buccolingually with a razor blade. Four points (buccal, lingual, distal, and mesial) for each specimen were then measured one time by the same laboratory staff using a three-dimensional coordinate measuring instrument (3D CMM, Jingstone Metrology, Taiwan) at 0.67X~3X magnification. We selected four reference points, one point per side (mesial, distal, buccal, and lingual), and measured the thickness of the Fit Checker layer to determine the value of the marginal discrepancy (Fig. 3B).

Statistical Analysis

The operation time and fit data obtained as described in the preceding section were analyzed by using paired two-sample t-tests. The statistical significance level was set to P < 0.05.

Results

A total of 20 patients participated in the study. There were 15 female and 5 male participants, and they received a total of 8 anterior prostheses and 29 posterior prostheses. There were 29 prostheses placed in their upper jaws and 8 prostheses placed in their lower jaws. A total of 43 abutments was analyzed, including 31 single crowns and 6 crown-and-bridge prostheses. Details of the participants' data and dental condition distribution can be found in Table 1.

Table 1. Participants' basic data and dental condition distribution

Item	n	%
Sex		
Male	5	15.0
Female	15	75.0
Tooth position		
Anterior	8	21.6
Posterior	29	78.4
Jaw		
Maxilla	29	78.4
Mandible	8	21.6
Prosthetic		
Single	31	83.8
Bridge	6	16.2

Total 20 participants, 37 prostheses.

Comparison of key operation time between the conventional and digital processes

In the comparison of operation time, the average time required to complete the digital process was 12.73 minutes (standard deviation, SD ± 5.34), while that required for the conventional process was 41.81 minutes (±8.50). The time spent obtaining dental data showed a statistically significant difference (P<.001)

Table 2. Comparison of the time (min) required to fabricate a tooth using the conventional and digital acquisition of dental data

	Conventional		Digital					
Item	M	± SD	M	± SD	Diff.	± SD	95%CI	*P*
Time for obtaining dental data (min)	41.81	± 8.50	12.73	± 5.34	29.08	± 10.88	**(25.28 , 32.87)**	**<0.001**
Clinically acquired dental model	15.99	± 6.95						
Laboratory operation	18.74	± 4.32						
Reference scan	7.07	± 1.09						
Design	3.55	± 1.37	4.11	± 2.21	-0.55	± 1.56	**(-1.10 , -0.00)**	**0.047**
Manufacture	20.30	± 7.07	19.99	± 7.48	0.31	± 3.09	(-0.76 , 1.39)	0.559
Polish	4.40	± 1.74	0.5	± 0.02				
Delivery	6.91	± 3.53	6.32	± 3.44	0.59	± 4.25	(-0.89 , 2.07)	0.422
Total	76.99	± 13.70	43.16	± 11.65	33.83	± 11.84	**(29.69 , 37.96)**	**<0.001**

Paired two-sample t test

Diff. is difference mean

Time unit is minute

Total sample size was 37 prostheses

Table 3. Comparison of the marginal fits of the conventional and digital dental prostheses

	Conventional		Digital					
	M	± SD	M	± SD	Diff.	± SD	95%CI	*P*
Buccal	100.37	± 65.19	64.48	± 47.49	35.88	± 65.84	**(12.26 , 58.50)**	**0.003**
Lingual	111.25	± 55.87	79.31	± 65.63	31.94	± 57.20	**(12.29 , 51.59)**	**0.002**
Mesial	121.37	± 112.07	90.62	± 96.63	30.74	± 138.41	(-16.80 , 78.28)	0.197
Distal	108.00	± 72.42	76.28	± 62.72	31.71	± 78.02	**(4.91 , 58.51)**	**0.022**
Mean	110.25	± 52.02	77.67	± 47.88	32.57	± 46.86	**(16.47 , 48.67)**	**<0.001**

Paired two-sample t test

Diff. is difference mean

Unit of distance [μm]

between the conventional process and the digital process. The average time required for the digital design process was 4.11 minutes (±2.21), while the average time for the conventional design process was 3.55 minutes (±1.37). The time required for the digital design process was thus longer than that required for the conventional design process by 0.55 minutes (±1.56), which was a statistically significant difference ($p=.047$). The average polish time for the digital group was 0.5±0.02 minutes, while that for the conventional group was 4.4±1.74 minutes, which was much longer than the time required for the digital group. The reason for this difference may have been that the conventional method required the technician to put the specimen back on the gypsum model to make contact area adjustments. From the time when the dental data was obtained to the delivery of the prosthesis, the total time of the digital process was 43.16 minutes on average (±11.65), and the average key operation time for the conventional process was 76.99 minutes (±13.70), which was significantly longer than the total time for the digital process ($p<.001$). Meanwhile, there was no statistically significant difference between the two methods of modulo in the time used for delivery and milling in the milling machine ($p>0.5$). For detailed time comparison values, please see Table 2.

Comparison of fit for the conventional and digital prosthesis fabrication processes

Table 3 shows a comparison of the marginal discrepancies for the prostheses made using, respectively, the conventional process and the digital process. For the digital workflow, the mean value obtained for the buccal side of the specimens was 64.48μm (±47.49), while at the same location, the mean value for the conventional workflow was 100.37μm (±65.19), which was a statistically significant difference ($p = .003$). The mean marginal discrepancy was 79.31μm (±65.63) for the lingual side of the specimens made using the digital workflow, while that for the specimens made using the conventional process was 111.25μm (±55.87), which was also a statistically significant difference ($p = .002$). For the distal surface, the mean marginal discrepancy for the digital workflow was 76.28μm

(±62.72), while that for the conventional process was 108.00μm (±72.42), which was a statistically significant difference (p =.022). However, there was no statistically significant difference between the two workflows in the measurements for the mesial side of the specimens.

The average marginal discrepancy values of all four points obtained for the digital workflow and the conventional workflow were 77.67μm (± 47.88) and 110.25μm (±52.02), respectively, which were significantly different (p <.001).

Discussion

In recent years, scholars and dentists all over the world have begun to explore the differences between intra-oral digital scanning and conventional impressions. Chochlidakis et al. reviewed and compared *in vitro* studies that measured the marginal fits or internal fits of prostheses made by digital scans and conventional impressions. Carbajal Mejia et al. [13] compared the accuracy of conventional impression and digital scanning methods with a direct intraoral scanner and reference scanner, and the results showed that the highest degree of reproducibility was achieved by intra-oral direct scanning. Park and his coworkers[14] presented a dental technique in which digital data pertaining to a patient's lateral occlusion relationship could be adjusted using software, such that the chair time could be reduced and the anatomic form conserved with the help of CAD software. In this study, the total time required for the digital process significantly differed from the total time required for the conventional process; however, the working time (12.73±5.34 minutes) required to acquire dental data from the images captured by the intraoral scanner (CS 3500) was still longer than the clinician had expected. The benefits provided by other new scanners (Trios, Cerec primescan) might yield better results, and exploring that possibility would be an interesting direction for a future study. However, we strongly recommend that a clinician first achieve the relevant learning curve plateau before using such new cutting-edge devices in order to fully maximize the benefits of their use. Lim et al. [15] investigated the effect of the experience curve on changes in the trueness of full arch scans and mentioned that easy-to-use scanning systems and acceptance training were relevant to such scan results. Relatedly, the present study was performed by a senior prosthodontic specialist who has been well trained and reached the plateau of the learning curve.

Our results showed that the conventional and digital processes did not differ significantly in terms of the time required for obtaining a dental impression (15.99 vs. 12.73 min), designing a prosthesis (3.55 vs. 4.11 min), manufacturing it (20.30 vs. 19.99 min), and delivering it (6.91 vs. 6.32 min). Rather, the excess time required for the conventional process was spent on completing the associated laboratory work. The laboratory procedure involves multiple time-consuming steps, including die trimming, articulator mounting, etc., and any error may necessitate repeating the steps from the start. Therefore, the use of digital impressions can help to reduce the amount of dental material used and lessen the environmental pollution caused by such material.

Matta et al.[16] showed that impression scanning generated more precise models than conventional impression methods. However, impression scanning relies on the use of a special reference scanner such as the NobelProcera 2G scanner (Nobel Biocare), a scanner that can scan the negative imprint, to reduce laboratory working time. In this study, the reference scanner used was the Activity 880, a scanner that can only scan positive models, which resulted in more laboratory time.

Su and Sun[17] compared the internal fits and marginal fits of CAD-CAM, 3-unit ceramic fixed partial dentures and found that the marginal discrepancies of such prostheses made using a digital impression system were smaller than those of such prostheses made using a conventional system. The six fixed partial dentures produced in this *in vivo* study exhibited similar results. Marghalani et al. [18] compared the accuracy of conventional impression and digital scanning systems for partial edentulous arches and reported that the results for all of the investigated impression techniques were within clinically acceptable levels and that there was no statistically significant differences in the results for the different intra-oral scanners used (namely, Omnicam and True Definition scanners). In the present study, a photo-type optical digital dental scanner CS3500 (Carestream, USA) was used to obtain the oral data (STL file). The accuracy of this scanner was similar to that of the True Definition scanner, which allowed for the easy and convenient transfer of data to the CAD-CAM system for further prosthesis fabrication. Tsirogiannis et al. [6] conducted a review and meta-analysis of various *in vitro* studies, finding that the mean marginal discrepancy of a restoration made using a digital impression was 56.1 um (95% CI: 46.3-65.8 um), whereas that of restoration made using a conventional impression was 79.2 μm (95% CU: 59.6-98.9 um). The marginal discrepancy obtained in this paper is 110.25 μm. It is a little bit larger than the Tsirogiannis's review (56.1 μm)[6] or Su's results (71 μm).[17] The main difference was that our study was an *in vivo* study and thus had greater variability in the prostheses produces, in addition to being impacted by the reality of various clinical factors. Moreover, Su's study used the same model with two kinds of polyvinylsiloxane (PVS) used as the replica material, whereas our study used Fit Checker silicone material combined with PVS. The associated binding ability thus might also have been a factor underlying the higher marginal discrepancy value we obtained.

Although no data regarding patient satisfaction was collected in this study, Gallardo and coworkers[11] reviewed the patient outcomes and procedure working times for digital versus conventional impressions and reported that patients are more likely to prefer the digital workflow than the conventional workflow. In a time-comparison study, Benic et al. [12] showed that conventional impressions required less time to produce than digital impressions for single posterior teeth. However, they only calculated the impression/scanning time of the given impression procedure, while the benefits from digital fabrication would also include benefits pertaining to the model pouring, die trimming, and digital occlusal adjustment. Relatedly, Sailer et al. [19] reported that the laboratory working time for a digital workflow was significantly shorter than the laboratory working time for a conventional workflow.

There were only 20 participants for whom 37 prostheses were produced in this *in vivo* study, and the marginal discrepancy and time required were calculated for both the digital and conventional workflows. The limitations of the current study were that the same cement space would possibly not have been created for two groups of FPDs made through two processes of fabrication, the lab technician and dentist were not blind to the study purpose, and the mean marginal gap for the conventional FPD group was slightly bigger than the sizes of such gaps reported in previous studies. To improve upon the present study then, it is expected that larger sample sizes, different scanners, and data regarding patient satisfaction and chewing efficiency can be incorporated in future studies.

Conclusion

Compared with the conventional impression process, the digital scanning process requires fewer operation steps. The results of the analysis showed that photo-based optical digital scanning required less time to obtain dental data than the conventional impression method. Furthermore, digital scanning yielded prostheses with a lower mean marginal discrepancy than that for prostheses produced using conventional impressions, which was consistent with the results of previous studies. For dentists and dental technicians, even those separated by long distances, the digital process can shorten the operation time required, and the precision of the restorations produced by the digital process is not inferior to that of restorations produced using the conventional process.

Acknowledgments

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Conflicts of Interest

The authors declare no conflicts of interest.

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