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Three-Dimensional Analysis of Dental Models Produced from Intraoral Scanning versus the Conventional Alginate Impression Method

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ABSTRACT

Impression-making plays an important role in dentistry, where records of the oral cavity are needed to provide an optimum treatment plan for the patient. In this study, we utilised both the conventional impression method and the intraoral scanner (IOS) to make a comparison on the accuracy of the resulting oral cavity imprint using three-dimensional (3D) superimposition. In this study, a total of 18 participants were involved. Alginate impressions were made in a stock maxillary tray and poured with type III dental stone. The models were then scanned using IOS to generate virtual dental models where digital analysis can be made. For the IOS method, the scanning was done directly on the patient's oral cavity by the same operator. Meshmixer software was utilised to convert the virtual models into a Standard Tessellation Language file, and then CloudCompare software program was selected to evaluate the volume, surface area, Dice similarity coefficient (DSC) and Hausdorff distance (HD) of the dental models produced from both methods. Statistical analyses were carried out using an independent *t*-test. It was revealed that the *p*-value of area and volume for both methods is > 0.05, which shows no significant differences. Besides, the mean and standard deviation for the HD were 0.02 and 0.01, respectively, which shows minimal differences between the two datasets. The mean DSC was also 0.9, which shows close to 100% overlap. These findings significantly indicate that conventional impression and IOS have comparable accuracy and are both reliable for impression-making.

Keywords: *3D superimposition; accuracy; conventional impression; intraoral scanning*

INTRODUCTION

Dental impression is defined as a negative imprint of the oral mucosa structures, including the teeth and soft tissues of the mouth (The Academy of Prosthodontics and The Academy of Prosthodontics Foundation, 2017). This process is typically performed to create prostheses, restorations, and study models for further evaluation and treatment planning. Traditionally, it involves placing semi-solid materials, such as alginate or polyvinyl siloxane, onto a dental impression tray, which is then fitted over the teeth and alveolar ridge to capture an impression. Due to its simplicity and sufficient diagnostic accuracy, this method remains the gold standard for impression-making and continues to be widely used by dentists worldwide (Roig *et al.*, 2020).

However, this method involves multiple steps in producing the final diagnostic model, increasing the risk of errors if not performed correctly, which can lead to a flawed impression. Producing a precise dental impression is crucial, as it directly affects the accuracy of the dental prosthesis. An inaccurate impression can lead to both mechanical and biological complications (Rhee *et al.*, 2015). This method has also been reported to cause discomfort for the patient and present challenges for the clinician (Schaefer *et al.*, 2012; Burzynski *et al.*, 2018; Serrano-Velasco *et al.*, 2024).

Nowadays, conventional impressions are no longer the only method available for capturing imprints of the oral cavity. With advancements in technology, digital dental impressions have been introduced through intraoral scanner (IOS) to address the challenges of conventional techniques and enhance the experience for both clinicians and patients.

IOS can directly capture digital impressions of the dental arches' shape and size through the emission of a light beam (Alassiry, 2023). IOS is designed to eliminate errors such as shrinkage and distortion, which are common in conventional impression techniques. Additionally, this method enhances the overall patient experience (Ender & Mehl, 2011; Schepke *et al.*, 2015; Burzynski *et al.*, 2018; Serrano-Velasco *et al.*, 2024) as well as reducing chair time (Kekez *et al.*, 2022). By integrating IOS with CAD/CAM processing within a comprehensive virtual environment, various clinical, technical, and economic advantages can be achieved for fixed implant restorations (Joda & Brägger, 2014, 2016). The use of the Standard Tessellation Language (STL) format in IOS reduces storage requirements, improves and accelerates communication with technicians or colleagues, and minimises the inconveniences of conventional impressions (Pellitteri *et al.*, 2022). IOS also delivers fast and accurate results with streamlined manufacturing (Joda *et al.*, 2017). The primary advantages of dental digitalisation include the implementation of standardised protocols, improved predictability through the ability to reproduce treatment outcomes, and reduced work time by simplifying manufacturing processes (Patzelt *et al.*, 2014; Joda & Brägger, 2016; Alassiry, 2023).

According to recent studies, the accuracy of digital impressions is comparable to that of conventional impressions (Ahlholm *et al.*, 2018; Kong *et al.*, 2022). However, few scientific in vivo studies have been conducted to confirm that intraoral impressions achieve the same level of accuracy as conventional impressions (Kong *et al.,* 2022; Pellitteri *et al.*, 2022). To date, only a limited number of in vivo studies have evaluated the accuracy of complete-arch scans obtained directly from patients' oral cavities (Lee & Park, 2020). Nevertheless, a study using a paediatric typodont model was conducted to evaluate the accuracy of the complete-arch digital impression method in comparison to a gold standard (Rolfsen *et al.*, 2023). However, this study does not fully represent a clinical setting, as it was performed on artificial models rather than real patients.

As recommended by a recent systematic review (Kong *et al.*, 2022), further research is needed to compare accuracy in three-dimensional (3D) using different software to validate the current evidence. To the best of the authors' knowledge, utilising CloudCompare software to assess 3D differences represents a novel approach that may help confirm the similarity in accuracy, as highlighted in Kong *et al.*'s (2022) review.

Therefore, this study aims to evaluate and compare the accuracy of conventional alginate impressions and digital impressions, using the conventional method as the reference (control) for comparison. The null hypothesis states that there is no statistically significant difference in the accuracy of IOS impressions compared to the conventional method.

MATERIAL AND METHODS

This clinical study involved a 3D digital comparison between conventional and digital impressions. To achieve a projected independent *t*-test of 0.8, with a lower confidence limit of 0.6 (*r*), an 80% power, and a 5% alpha level, the required sample size was calculated to be 16 participants using BioEstat software (version 5.3, Mamiraua Maintanable Development Institute, Brazil). With a dropout rate of approximately 10%, a total of 18 participants (2 men and 16 women; mean age, 23 years) from a Malaysian population (14 Malay, 3 Chinese, 1 Indian) were finally included in this clinical study. The inclusion criteria were as follows: (1) Individuals aged 18 to 25 who are fully dentate with normal crown morphology and maintain good oral hygiene, as indicated by a basic periodontal examination (BPE) score of less than 2; (2) Individuals with no intraoral or extraoral abnormalities. The exclusion criteria were those participants wearing orthodontic appliances, patients with periodontitis and patients with recently extracted teeth. The investigation was carried out between November 2022 and December 2022. One operator was responsible for managing the 18 participants. The ethical application was approved by the Ethics and Research Committee USM (Ref. no.: USM/JEPeM/22040214). Written informed consent was obtained from all participants.

Conventional Impression by Alginate Material

Alginate impression material (AIM) (Blueprint Xcreme, Dentsply, USA) was utilised for the conventional impressions in a metal maxillary perforated stock tray (Unident Gibling Dentate Tray, Australia). Before mixing the materials, the tray was coated with alginate tray adhesive (Fix Adhesive, Dentsply, USA). The manual mixing of the AIM was carried out according to the manufacturer's instructions. After completing the impression procedure, the AIM was promptly poured within 30 minutes using a vibrator and manually mixed type III dental stone (Unident Yellowstone, Australia), following the standard procedure for diagnostic models. Once the stone had set, the models were trimmed using a model trimmer, and a base was created with Plaster of Paris. Finally, the models underwent additional trimming and polishing to complete the process.

The manufacturers' recommendations were adhered to for all research materials (Fig. 1). The loaded trays were gently inserted into the patient's mouth with consistent finger pressure. All the teeth, gingivae and hard palate have been recorded in the impressions. A sole operator was responsible for all the impressions. The impressions were checked by a qualified dentist (MAR) to assess their acceptability and lack of errors. If it is not acceptable, then the impression will be repeated. These conventional impressions were used to make definitive models, which were then scanned by Medit i500 (Medit Corp., Seoul, Korea) IOS to generate virtual dental models.

(a) (b)

Fig. 1 Steps for conventional impression: (a) Alginate impression and type III dental stone; (b) Dental model scanned using Medit i500 IOS.

Digital Impression by Intraoral Scanning

The subject's maxillary arch was scanned using the Medit i500 (Medit Corp., Seoul, Korea) IOS (Fig. 2) by an operator who possessed appropriate training in the use of the IOS system. Prior to scanning, no scanning powder was applied. The scanning procedure commenced with placing the IOS camera on the posterior molar located on one side and concluded with the posterior molar located on the other side. The IOS camera underwent a zigzag motion as it traversed the arch, capturing the occlusal aspect initially, and then the palatal and buccal views of the teeth, followed by the rest of the maxillary arch. After processing the data in Medit processing software, the virtual models can be further viewed and checked. The scan taken was checked by a qualified dentist (MAR) to assess its acceptability, and an assessment was carried out to check whether there was a need to reperform the scanning process. During the scanning procedure, if overlapping data or scans occur in certain regions of the maxillary arch, the operator will delete the scan and repeat the entire process to prevent double scanning of specific areas, which could lead to additional errors during comparison. This is likely attributable to the old IOS model or the specifications of the utilised laptop. The resultant acceptable models were then exported for further actions.

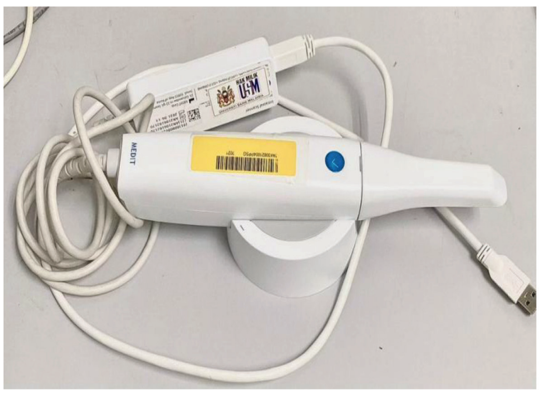

Fig. 2 IOS Medit i500.

Analysis of 3D Images

Meshmixer software (Autodesk, USA) was used to transform the resulting virtual models (Fig. 3) into an STL file. The STL file from the scanned conventional impression was set as reference and compared with the STL file from the digital impression taken using IOS. The palatal vault was selected and trimmed out following the gingival margin as shown in Figure 4 using 3-Matic Research 9.0 software (Materialise NV, Heverlee, Belgium) from the STL files so that the comparisons of the two superimposed objects can be measured more accurately. Using the CloudCompare software programme (CloudCompare v2.11.3 Anoia, France), the superimposition of the reference and target data was carried out. The Move Bounding-Box function was used to overlap the conventional impression virtual models with the digital impression virtual models, and the Fine Registration iterative closest point (ICP) function was used to align the two superimposed objects, holding the conventional impression model as a reference and root mean square (RMS) difference to 1.0e-5 with a 100% final overlap set.

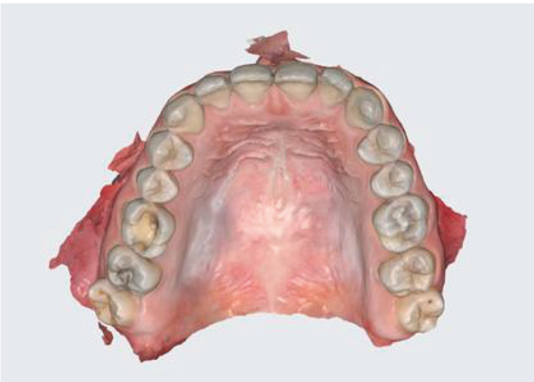

Fig. 3 Digitally scanned image of maxillary arch using IOS.

The comparison was carried out following the study by (Egger *et al*., 2013; Farook *et al.*, 2020; Farook *et al.*, 2022) in which authors compared the geometric interpoint mismatches between two superimposed objects using the Hausdorff distance (HD), while comparing the volumetric spatial overlap between similar objects using Dice similarity coefficient (DSC) by using an open-source CloudCompare software programme. After the fine registration with 100% overlap of the two objects was done, the Cloud-Mesh Distance function was applied to determine the HD. The aligned objects were processed through the Cork plug-in, and the intersection function was applied to obtain a singular object of the intersect. The volume of the intersect was measured, followed by the DSC measured using the formula: 1(DI ∩ CI)/ (DI + CI), where ∩ is the intersection, DI is the volume of digital impression virtual models and CI is the volume of conventional impression virtual models. The dental virtual models produced from both methods were assessed for their volume, surface area, intersection volume, DSC, and HD (Fig. 4).

The superimposition results were illustrated in a "difference" map, in which discrepancies (in mm) are represented through a colour-coded scale: The green meant perfectly matching surface, the red meant test model surface was positively positioned – relative to reference model – and the blue meant test model surface was negatively positioned, relative to reference model.

Statistical analyses were carried out by using a statistical software program (IBM SPSS Statistics, v26.0; IBM Corp). The parameters were tested for normality by using Kolmogorov-Smirnov test. Since the data is normal, the results of both methods were compared using an independent *t*-test. Comparison of the mean of the variables of 18 subjects for 2 different methods was done.

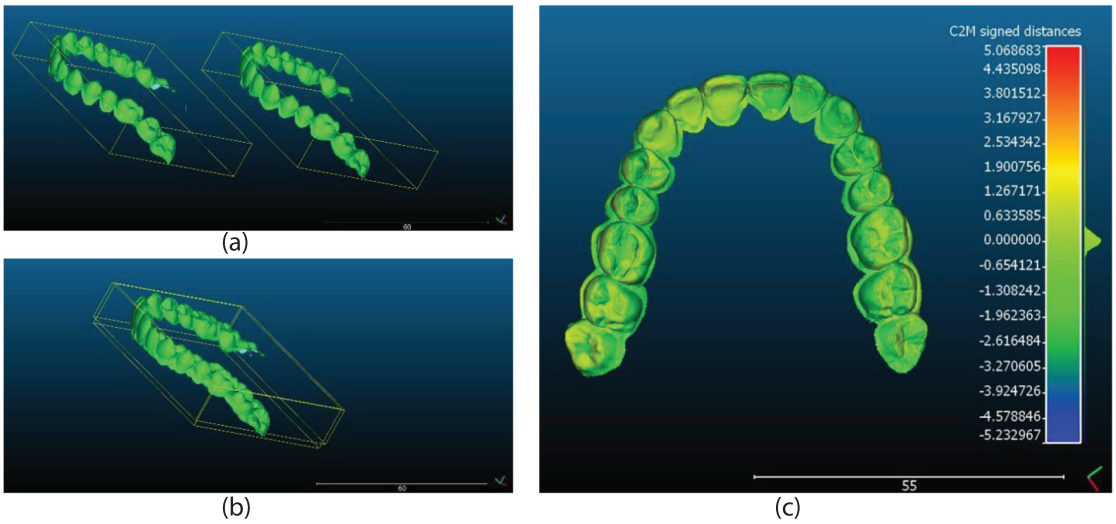

Fig. 4 3D superimposition: (a) The STL format for the scanned conventional impression and IOS; (b) Superimposition of the two datasets; (c) The overlapping of the two datasets showing the colour spectrum of yellow and green indicating minimal Hausdorff distance (HD).

RESULTS

Table 1 shows the data obtained from the two methods which includes the surface area, volume, DSC and HD. DSC represents the spatial overlap and reproducibility of the two intersected regions between data obtained from conventional impression and IOS of each subject. HD is the average maximum distance between the points of intersection of the conventional impression model and IOS. The DSC showed that the intersection region between conventional data and IOS was 0.9, which indicates 90% overlap. This shows excellent similarity between the two results.

Table 2 shows the descriptive statistics with mean, standard deviation (SD) and *p*-value of the data obtained from conventional impression and IOS. The *p*-value of both datasets was more than 0.05, indicating no significant differences between the two results.

Table 3 shows the mean and SD of DSC and HD for both the conventional method and IOS. The mean and SD for the HD were 0.02 and 0.01, respectively, which shows minimal differences between the two datasets. The mean DSC was also 0.9, which means that on average, the IOS was 90% overlap with conventional impression and considered as similar to the gold standard. DSC estimates the spatial overlap volume between the two objects to evaluate the amount of similar space between them; the acceptable threshold is generally set at 0.70 (Farook *et al.*, 2022).

Table 1 Surface area, volume, DSC and HD of the two methods

Case no.	Dental model (P) area (m^2)	IOS (Q) area (m^2)	Dental model (P) volume (m^3)	IOS (Q) volume (m^3)	Intersect volume (m^3)	DSC	HD (mm)
1	2448.41	2478.22	8162.13	11904.60	19973.05	0.995	0.038
2	2607.31	2421.11	6231.90	10263.90	15882.49	0.962	0.015
3	2545.58	2695.03	12310.80	13470.00	25412.31	0.985	0.025
4	2382.65	2545.66	15250.80	15538.80	29265.60	0.950	0.021
5	3249.59	3227.25	12120.80	11691.30	24228.35	0.871	0.031

(*continued on next page*)

Table 1 (*continued*)

Case no.	Dental model (P) area (m^2)	IOS (Q) area (m^2)	Dental model (P) volume (m^3)	IOS (Q) volume (m^3)	Intersect volume (m^3)	DSC	HD (mm)
6	2309.52	2304.29	8510.50	6489.15	18197.76	0.956	0.023
7	2447.80	2509.91	10220.00	11376.10	21835.38	0.980	0.003
8	2724.69	2688.36	10505.60	10025.70	23055.75	0.970	0.044
9	2385.37	2311.81	8307.23	7133.95	21093.23	0.898	0.016
10	2266.45	2250.64	14510.4	11709.50	21985.60	0.948	0.006
11	2374.30	2361.45	13996.20	10507.70	17979.30	0.775	0.015
12	2689.07	2713.42	9886.22	10764.20	19847.57	0.807	0.028
13	2690.80	2717.31	21250.80	15742.20	27602.00	0.819	0.014
14	2070.62	2352.68	16451.90	14537.90	24506.84	0.824	0.016
15	2410.82	2442.52	13531.10	10741.70	19914.72	0.795	0.020
16	2780.88	2738.38	14294.90	11740.70	26505.42	0.990	0.029
17	2515.47	2413.60	11250.10	10019.10	18413.78	0.834	0.024
18	2514.95	2488.70	14576.10	11052.90	25207.50	0.998	0.016

Table 2 The surface area and volume of the two methods (n = 18)

Parameters	Conventional impression		IOS		*p*-value
	Mean	SD	Mean	SD	
Area	2523.01	254.28	2536.69	233.18	0.867
Volume	12359.31	3423.63	10623.72	2389.89	0.087

Table 3 The HD and DSC of the two methods (n = 18)

Method	Mean	SD
HD	0.029	0.01
DSC	0.909	0.08

DISCUSSION

The primary objective of this study is to evaluate the accuracy of intraoral scanning compared to conventional alginate impression techniques using the 3D superimposition method in CloudCompare software. To achieve this, it is essential to determine the units and measurements to be analysed and compare the two datasets. During the superimposition process, the conventional impression is designated as the reference (control), as it is considered the gold standard, while the intraoral scan serves as the target data. This allows for an accurate comparison of IOS accuracy against the conventional method (Abduo, 2019), which acts as the benchmark for evaluation (Drancourt *et al.*, 2023). This study did not assess the precision of conventional and intraoral scans; it focused solely on evaluating accuracy (trueness).

This study demonstrated that IOS, when compared to the conventional technique, achieved a similarity of 90.9% with a small standard deviation, indicating its high trueness. Similarly, a study by Gavras *et al.* (2023) evaluated the trueness and precision of IOS (Planmeca Emerald S) in scanning a complete mandibular denture, comparing it to a desktop scanner (3Shape D2000 Laboratory Scanner) using 12 identical digital scans of the dentures. Their findings showed an exceptionally high trueness of the IOS, with a DSC of 0.98343 (98.34% similarity) and HD of 0.05103, as analysed using CloudCompare software. They concluded that the IOS used in their study demonstrated both high trueness and precision in digitally duplicating complete dentures.

In another study by Cao *et al*. (2023), the accuracy of digital dental impressions obtained using IOS for partially edentulous patients with maxillary defects was evaluated by comparing them to conventional impression techniques in 10 subjects. Instead of using DSC and HD, the authors analysed their data using linear distance and best-fit algorithm measurements. Their results indicated that the accuracy of IOS was comparable to that of conventional impression techniques, further supporting our findings.

Onbasi *et al*. (2022) compared the trueness of complete- and partial-arch impressions obtained using conventional impression materials and IOS in vivo. Full-arch impressions were taken using polyether and polyvinyl siloxane, while intraoral scanning was performed with the CEREC Omnicam and Trios 3 scanners. Surface matching software (Atos Professional) was used to determine mean deviations (mean distances) from the reference casts, similar to HD analysis. They reported mean trueness deviations ranging from 0.005 mm to 0.023 mm for Trios 3 and 0.001 mm to 0.068 mm for CEREC Omnicam. Our mean HD results were comparable to their findings.

Alginates are excellent materials for initial impressions, as they are minimally invasive for patients. They effectively produce plaster models for preliminary evaluations in prosthetic, surgical, and orthodontic treatments. Given their continuous development since the 1940s, these materials are expected to further evolve, leading to the creation of high-performance impression materials (Cervino *et al*., 2018).

The use of alginate impressions is recommended in specific clinical situations, particularly for the fabrication of orthodontic appliances such as dental aligners, removable retention devices, and study casts for orthodontic treatment planning (Schott *et al*., 2019). Alginate impressions play a crucial role in routine diagnostic and therapeutic dental procedures (Kekez *et al*., 2022).

Conventional impressions are highly technique-sensitive and can be easily distorted if the cheeks or lips are not properly retracted during the impression-making process (Lee & Gallucci, 2013; Kekez *et al*., 2022). Additionally, patient-related factors such as a strong gag reflex and limited mouth opening can create challenges, leading to discomfort for both the clinician and the patient (Kekez *et al*., 2022).

In this study, alginate was chosen as the impression material due to its ease of use, cost-effectiveness, simple mixing process, and easy removal from the patient's mouth. However, alginate has poor dimensional stability and can shrink if left exposed for too long (Aalaei *et al*., 2017). To mitigate this, type III dental stone was poured within an hour after the impression was made and covered with dampened gauze to prevent drying. A vibrator machine was used to minimise the formation of air bubbles in the model. Although dimensional changes, such as stone expansion, were challenging to avoid, the study's outcomes suggested that these changes were negligible, as the HD and DSC results showed minimal differences between data from conventional impressions and IOS.

That being said, the conventional method of creating a study model involves multiple steps, each of which directly impacts the final outcome, including the manipulation, storage, and application of impression materials (Giachetti *et al*., 2020). Errors can occur at various stages, such as shrinkage, distortion, detachment of the impression material, and the formation of air bubbles

(Rhee *et al.*, 2015; Kekez *et al.*, 2022). Additionally, capturing an accurate record of posterior teeth, particularly the second molars, can be challenging due to limited space. In this study, one participant had a strong gag reflex, which affected the impression-making process and increased the number of retakes required.

Digital impressions are more efficient and cost-effective than conventional impressions, with implementation costs potentially being offset within the first year (Resnick *et al.*, 2019). However, the high cost of adopting IOS remains a significant barrier for low-income countries, where the use of alginate material does not compromise accuracy or treatment outcomes. A cost analysis showed that the initial investment in digital procedures is 10.7 times higher than conventional methods, but the cost balances out after approximately 3.6 years of use (Serrano-Velasco *et al.*, 2024).

The scanning time and difficulty level decreased with repeated use of the IOS (Al Hamad, 2020). Digital impressions are preferred by children aged 6–11 years and offer significantly faster acquisition times compared to conventional alginate impressions (Bosoni *et al.*, 2023). In this study, intraoral scanning was performed in a separate session after the conventional impression. The procedure involved fewer steps, as scanning was done directly inside the patient's mouth. However, challenges arose when scanning the posterior dentition due to the relatively large tip of the scanner, particularly in the buccal area, which was confined by the cheeks. Although the Medit i500 software includes a delete function for parts of the scanned image, it does not overwrite errors but instead registers overlapping data when scanning resumes. In this study, when such errors occurred, the operator had to delete the entire dataset and restart the scan. This issue may have been related to the IOS model or laptop specifications. Additionally, scanning took longer than the conventional impression process at times, as the IOS occasionally failed to capture images when the scanning motion was too fast over a specific area.

The analysis method used in this study provides new insight into 3D assessment by utilising software, confirming the similarity between digital and conventional impression techniques. The findings align with those of Kong *et al.* (2022), who reported that both digital and alginate full-arch impressions demonstrated similar trueness and high precision. However, another group of researchers used a digital caliper to evaluate differences between impression techniques and concluded that digital scans produced models that were more accurate than those derived from alginate impressions (Rolfsen *et al.*, 2023).

On the other hand, another study assessed shell-to-shell deviation using the Rapidform 2006 (Inus) software and found that digital scans deviated by 0.10 mm from alginate impression models (Lee & Park, 2020). The authors emphasised that when performing in vivo full-arch scanning, factors that contribute to scanning errors—such as strong light, irregular scanner calibration, excessive saliva, and moisture in the patient's mouth—should be controlled beforehand to maintain scan quality (Lee & Park, 2020).

The IOS is highly reliable for in vivo use, as it directly transfers scan images from the oral cavity to the processing software without the need for intermediate laboratory procedures, unlike conventional impressions (Kong *et al.*, 2022). Additionally, a 3D model of the dental arch can be obtained through 3D printing and stored indefinitely without degradation (Pellitteri *et al.*, 2022). The digital format also facilitates faster and more efficient communication with dental technicians, as 3D images can be transferred online, eliminating the need for physical copies.

CONCLUSION

Based on the findings of this study and previous research, it can be concluded that 3D comparisons of models generated from IOS are comparable in accuracy to those obtained from conventional impressions. Therefore, clinicians can confidently utilise IOS, particularly for special needs patients who may have difficulty tolerating conventional alginate impression techniques, as part of routine diagnostic and early therapeutic dental management.

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