

Comparison of the Time and Accuracy of Intraoral Scans Performed by Dentists, Nurses, Postgraduates, and Undergraduates

M Gao • X Guo • Y Fu • M Li • X Ma • Z Chen

Clinical Relevance

Scanning time and accuracy are crucial for intraoral scanning. By comparing the time consumption and accuracy of intraoral scans among operators with different professional backgrounds, theoretical guidance can be offered to improve the efficiency of clinical application.

SUMMARY

Objective: This study aimed to assess the scanning time (ST) and accuracy of 10 repeated upper and lower dentition scans by four groups of operators with different professional backgrounds.

Methods: There were a total of 32 participants, including dentists, nurses, postgraduates, and undergraduates (n=8). They received the same training about intraoral scanning and then performed 10 repeat scans on the

plaster maxillary and mandibular dentition models in a manikin head, with the first five scans being the T1 phase and the last five scans being the T2 phase. Each ST was recorded. Trueness and precision were evaluated by root mean square (RMS) value gained from alignments of corresponding virtual models. For statistical analysis, the paired-sample t-tests, one-way ANOVA, and Pearson correlation tests were employed ($\alpha=0.05$).

Results: Limiting the comparison in scan phase and scan target the sequence of STs for the four groups was the same ($p<0.05$), by which undergraduates, postgraduates,

Maomao Gao, MS, Department of Prosthodontics, Hospital of Stomatology Hebei Medical University, Shijiazhuang City, Hebei, China

Xiaoyang Guo, MS, Department of Prosthodontics, Hospital of Stomatology, Hebei Medical University, Shijiazhuang City, Hebei, China

Yixuan Fu, MS, Department of Prosthodontics, Hospital of Stomatology Hebei Medical University, Shijiazhuang City, Hebei, China

Meng Li, Hospital of Stomatology Hebei Medical University, Shijiazhuang City, Hebei, China

Xiaoping Ma, Restoration Technician's Studio of Hospital of Stomatology Hebei Medical University, Shijiazhuang City, Hebei, China

*Zhiyu Chen, DDS, Department of Prosthodontics, Hospital of Stomatology Hebei Medical University, Shijiazhuang City, Hebei, China

*Corresponding author: #383 Zhongshan Dong Lu, Chang'an District, Shijiazhuang City, 050017 Hebei Province, China; e-mail: kqxfchen@163.com

<http://doi.org/10.2341/23-013-C>

nurses, and dentists were in descending order. Undergraduates gained the best precision, followed by postgraduates, dentists, and nurses, in both maxillary and mandibular scanning ($p < 0.05$). Compared with corresponding items of the T1 phase, the trueness of the T2 phase was much higher ($p < 0.05$), while the ST of the T2 phase was much shorter ($p < 0.05$).

Conclusions: The operator's professional background affects the precision and scanning time but not the trueness. Most dental personnel have good access to the intraoral scanner. As the number of scans increased, the accuracy and scanning efficiency also improved.

INTRODUCTION

The accuracy of intraoral scanners (IOSs) has substantially improved with advancements in digital technology in recent decades, offering dental practices improved comfort, efficiency, and material savings.¹⁻³ On this basis, IOSs are already applied to in-office digital restorations (crowns, veneers, inlays, and other restorations), orthodontic model analysis, and digital implantology (design and fabrication of implant guides, implant abutments, and crowns).⁴⁻⁷

The accuracy of IOSs was assessed according to "trueness" and "precision" as stated in ISO 5725-1.⁸ Trueness is defined as the degree of agreement between the measurement data and the reference data. The higher the trueness, the closer it is to the actual dimensions of the object being scanned. Precision is defined as the consistency of repeated measurement data, the higher the precision the better the stability of the scanner.

Given the differences in the users' innate abilities, occupational backgrounds, and interests, it is challenging to systematically analyze the reasons for scanning differences among populations. While conventional dental impression-making techniques depend on well-trained procedures and the considerable experience of dentists, the intraoral scanning technique for making digital models is much less technically sensitive and requires less professional experience of the operator. There have been successive studies focusing on the performance of intraoral scanner operators from different professional backgrounds. Zarauz and others proposed that students without experience in intraoral scanning take more time to perform intraoral scans than doctors without experience in intraoral scanning, but the participant's backgrounds included in their study were relatively lacking in diversity.⁹ Ahmed and others found different scanning times (STs) for dental prosthodontic students, dentists, and postgraduate students.¹⁰ Their study recruited participants from

diversified backgrounds but did not analyze the scanning accuracy. Lim and others stated that the dentist's level of clinical experience affects the accuracy of intraoral scanning, but only dentists were included in the study.¹¹ There are few studies on the effect of participants with different professional backgrounds on the accuracy and ST of intraoral scanning.

It would take time for people to master new techniques introduced into the medical field. As experience increases over time, the learning behavior demonstrates a pattern, called the learning curve.¹² By analyzing the learning curve of different intraoral scanner operators, the training quality and the application effectiveness of the intraoral scanning technique can be captured, leading to targeted improvements in clinical efficiency. Kim and others compared the ST learning curves of iTero and Trios IOSs among dental hygienists and found that iTero had a faster learning rate but longer scanning times.¹³ Lim and others evaluated the trueness learning curves of the iTero and Trios IOSs between practitioners with 3-5 years of clinical experience and those with more than six years of clinical experience.¹¹ They concluded that the length of clinical experience affected the trueness of the repeated scanning data. Previous studies confirmed that the learning curve of IOSs is influenced by the scanner and the operator's clinical experience. However, it is unknown about the performance of operators with different professional backgrounds learning to use new intraoral scanners.

In this study, four groups of operators with different professional backgrounds were recruited to take repeated scans of the maxillary and mandibular dentition in a manikin head, to investigate the differences in the accuracy and ST among the four groups during the T1 (the first five scans) and T2 (the last five scans) phases. The null hypothesis was that there are no differences in accuracy or ST between the four groups and the T1 and T2 phases.

METHODS AND MATERIALS

Research Subjects

There were four groups of participants in this study: dentists, nurses, postgraduates, and undergraduates, with eight individuals in each group. None of the participants had any experience with intraoral scanning. The dentists had three years of postgraduate education experience and more than three years of experience in the Department of Prosthodontics. The nurses had at least two years of clinical experience in dentistry. The postgraduates in prosthodontics had one year of clinical experience. Undergraduates were

sophomore students without clinical experience. All participants included 8 males and 24 females.

Acquiring Scan Data

A reference model fabricated of dental stone (Hera Moldastone, Kulzer GmbH, Germany) was selected. Maxillary and mandibular stone models were attached to a manikin head (model NT1CM-1000, Nissan Dental Products Inc, Japan), which was fixed on a dental chair in the supine position to simulate a real patient (Figure 1). The same reference model was scanned by a desktop scanner (D700, 3 Shape) extra-orally to create the reference data, while scanned by an IOS (Trios 3, 3Shape) in a simulation of clinical conditions to create intraoral scan data. Both scanners had been calibrated following the guidelines of the manufacturer before image acquisition.

Having no experience in intraoral scanning, all participants were given theoretical and practical training on the first day. The theoretical training focused on imaging principles and technical details of the IOS through slide presentations and videos. The practical training began with an introduction to the full-arch scanning method and then allowed participants to perform 1-2 scans under the supervision of the trainer (Figure 2). The criterion of qualification was to obtain the whole maxillary and mandibular dentition scanning data (beyond 2-3 mm apical of the gingival margin), without defects, overlaps, or distortions by relatively less repetition of scans. After passing the training, participants began the procedure of exercise repetition. The procedure of exercise was implemented in another two days to avoid the possibility of learner fatigue.¹⁴ On the second day, each participant completed five repeated scans of the plaster maxillary and mandibular dentition, and the scan data was saved as the T1 phase.

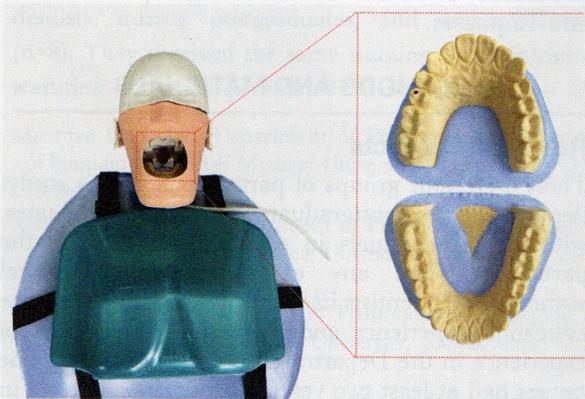


Figure 1. Maxillary and mandibular reference models were attached to the manikin head to simulate clinical scanning.

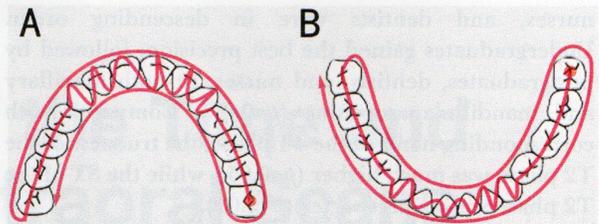


Figure 2. Schematic diagram of the scanning method. A. Maxillary scanning method. Began at the left second molar, following the occlusal-buccal-palatal sequence. Buccolingual rotation is performed in the anterior region. B. Mandibular scanning method. Began at the left second molar, following the occlusal-lingual-buccal sequence. Buccolingual rotation is performed in the anterior region.

On the third day, each participant completed another five repeated scans and the scan data was saved as the T2 phase. During each scanning, the Trios 3 scanner recorded the ST for the maxillary and mandibular jaws.

Processing Scan Data

All data obtained were exported in standard tessellation language (STL) file format and saved in sequence numbers. The STL file was imported into 3D analysis software (Geomagic Studio 2013, 3D Systems, Germany). For each set of maxillary or mandibular data obtained by one operator, the data outside the dentition was trimmed out first, which was conducted by connecting the line of the buccal gingival apex to the line of the palatal gingival apex through the “trim with curve” operation, the remaining data was saved as a fixed model. Subsequently, uncropped data (floating model) were imported, and two-by-two alignment was performed by a series of operations such as N-point alignment, best-fit alignment, trim with curve, and best-fit alignment again (Figure 3). In N-point alignment, nine distributed anatomical marker points, which were prominent on the crown surface such as the incisal edge, dental cusp, fossa, groove, pit, etcetera were selected to bring the two virtual models into the same coordinate system.¹⁵ The initial alignment was achieved by the first best-fit alignment (sample size 5000). A second best-fit alignment (sample size 10,000) was performed after cropping the two digital models to the same range, to achieve an accurate alignment.

Analyzing Scan Data

Following the completion of the alignment, a 3D deviation analysis was performed to yield RMS estimate values. The formula used in RMS was:

$$\text{RMS} = \sqrt{\frac{\sum_{i=1}^n (X_{1,i} - X_{2,i})^2}{n}}$$

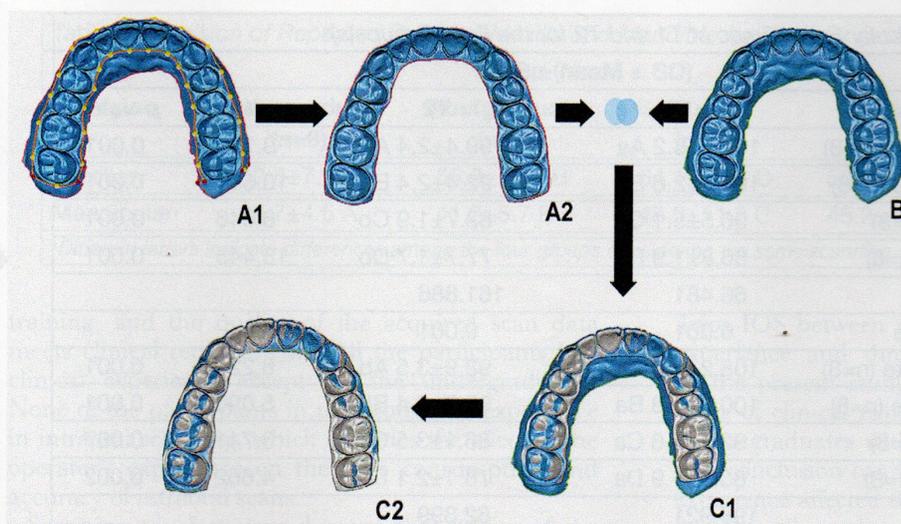


Figure 3. 3D alignment in Geomagic software. A1, reference data (fixed model). A2, trimming of reference data. B, uncropped scan data (floating model). C1, initial alignment of two scan data. C2, accurate alignment after trimming was repeated.

where " $X_{1,i} - X_{2,i}$ " is the distance between the nearest corresponding pair of points on the fixed model and the floating model, and " n " is the total number of point pairs tested, which shows the degree of the 3D discrepancies between the two digital models, the greater the variance, the lower the accuracy. Hamad and others suggested that operators can achieve 80% of their best performance after five repetitions of intraoral scans, so precision was assessed with the mean value of the RMS acquired by aligning the intraoral scan data at the T2 phase from each participant.¹⁶ Trueness was assessed with the mean value of the RMS acquired by aligning the reference data with ten sets of intraoral scan data for each participant.

Statistical Analysis

All data were analyzed by using a statistical software program (IBM SPSS Statistics, v23.0, IBM Corp, Armonk, NY, USA). A Shapiro-Wilk test was applied to test the normal distribution of data, and the Levene test was applied to evaluate the homogeneity of variances. Differences among the four groups of participants in terms of trueness, precision, and ST were assessed by one-way ANOVA. A paired-sample t-test was conducted to detect significant differences between T1 and T2 phases. The Pearson correlation test was applied to evaluate the correlation between ST and trueness ($\alpha=0.05$ for all tests).

RESULTS

The maxillary and mandibular STs of the four groups at T1 and T2 are shown in Table 1. Considering the same scan phase and scan region, the difference in ST among the four groups was statistically significant,

with undergraduates recording the highest STs, followed by postgraduates, nurses, and dentists ($p_{\max}=0.001$, $p_{\text{mand}}=0.001$). Regardless of maxillary and mandibular, the STs for the T2 phase were lower than the T1 phase for all four groups, and the change in ST showed a general decreasing trend throughout the four groups, with a greater fluctuation in the dentist group (Figure 4).

The precision of the maxillary and mandibular jaw repeat scans for the four groups is shown in Table 2. In the maxillary jaw, the difference in precision among the four groups was statistically significant, with undergraduates higher than postgraduates and dentists higher than nurses ($p=0.009$). There was also a statistically significant difference in precision for the mandibular jaw among the four groups: undergraduates were highest, followed by postgraduates, dentists, and nurses ($p=0.005$).

The maxillary and mandibular trueness of the four groups at T1 and T2 are shown in Table 3. There were no statistical differences among the four groups, considering the same scan phase and scan region ($p>0.05$). Regardless of maxillary and mandibular, trueness was lower in the T1 phase than in the T2 phase for all four groups ($p<0.05$) and trueness increased as the number of scans increased (Figure 5). There was a weak correlation between trueness and ST for both jaws (Maxillary: $r=0.316$, $p=0.078$; Mandibular: $r=0.110$, $p=0.550$).

DISCUSSION

Based on the results of this study, one part of the null hypothesis, that no differences in trueness among the four groups, was accepted while the other part

		Mean ± SD			
Region	Group	T1	T2	t	p-value
Maxillary	Undergraduate (n=8)	108.9±3.2 Aa	99.4±2.4 Ab	9.107	0.001
	Postgraduate (n=8)	104.2±2.6 Ba	92.4±2.4 Bb	10.691	0.001
	Nurse (n=8)	96.5±5.1 Ca	83.7±1.9 Cb	6.846	0.001
	Dentist (n=8)	86.8±1.9 Da	77.7±1.7 Db	13.448	0.001
	F	66.481	161.886		
	p-value	0.001	0.001		
Mandibular	Undergraduate (n=8)	108.2±1.9 Aa	98.9±3.5 Ab	6.220	0.001
	Postgraduate (n=8)	100.0±1.9 Ba	92.7±3.4 Bb	5.090	0.001
	Nurse (n=8)	92.1±2.6 Ca	86.1±3.5 Cb	3.741	0.007
	Dentist (n=8)	83.3±1.9 Da	78.1±2.1 Db	4.662	0.002
	F	198.921	62.399		
	p-value	0.001	0.001		

Abbreviations: SD, Standard deviation; T1, the first five scans; T2, the last five scans.
^aUppercase letters indicate differences among the four groups considering the same scanning phase. Lowercase letters indicate the difference between T1 and T2 considering the same group.

of the null hypothesis was rejected since there were significant differences in ST and precision among the four groups, as well as ST and trueness between T1 and T2 phases.

It is impractical to allow all operators to scan a single patient too many times in a short period. Therefore, this study used a manikin head and a pair of plaster dental casts to simulate the dental arch of real patients. This strategy has several advantages. First, the plaster models can be taken out for desktop scanning to get reference data with eminent accuracy, which rationalizes the virtual model alignments for trueness.

Second, the manikin head can keep stable during the whole scanning process, making the repeated scanning data more comparable. Third, scanning within a manikin head excluding the patient influence factors such as saliva, mouth opening, and tongue movement, makes the distinctions between the accuracy and efficiency of intraoral scans performed by different groups more prominent.

In this study, four groups of operators with different professional backgrounds were included. It was found that all operators can quickly master the techniques of complete dentition intraoral scanning after the same

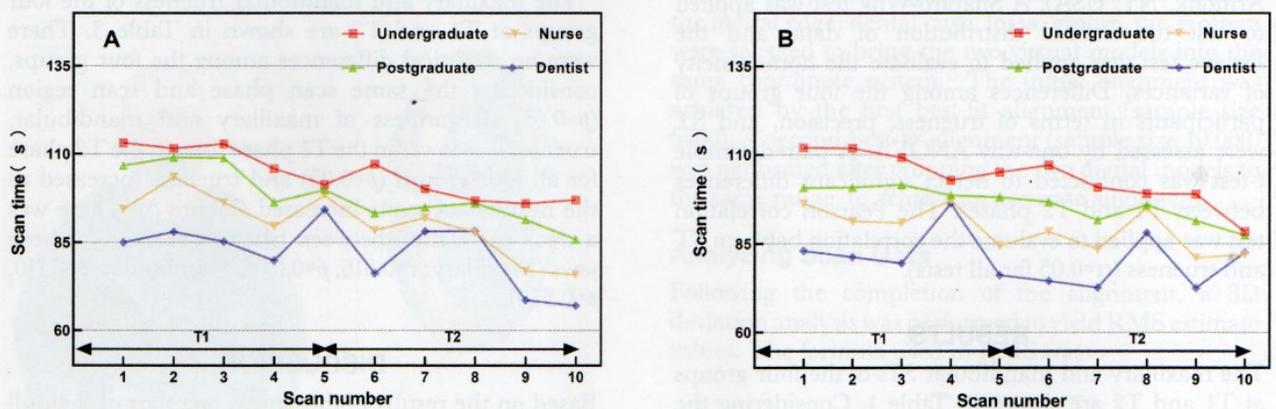


Figure 4. Graph of the change in scan time for the four groups. A. Scan time obtained from 10 repeated scans of the maxilla in four groups. B. Scan time was obtained from 10 repeated scans of the mandible in four groups.

Table 2: Precision of Repeated Scans of Maxilla and Mandible for the Four Groups (μm)^a

Region	Group (Mean \pm SD)				F	p-value
	Undergraduate (n=8)	Postgraduate (n=8)	Nurse (n=8)	Dentist (n=8)		
Maxillary	42.4 \pm 7.1 A	55.0 \pm 14.7 B	64.1 \pm 16.0 C	58.7 \pm 7.1 B	4.672	0.009
Mandibular	34.7 \pm 4.5 A	41.2 \pm 5.7 B	48.5 \pm 11.3 C	45.2 \pm 5.4 D	5.357	0.005

^aDifferent letters indicate differences among the four groups considering the same scanning region.

training, and the quality of the acquired scan data meets clinical requirements. All the participants had clinical experience except for the undergraduates. None of the participants in this study had experience in intraoral scanning, which excludes the effect of the operator's experience on the time consumption and accuracy of intraoral scans.

Scanning too fast may damage the quality of the acquired data, so accuracy is the primary concern, but once accuracy is assured, the ST should be reduced as much as possible. Shortening the ST is crucial for improving clinical efficiency and patient satisfaction. Several studies^{13,17,18} regarding the learning curve of IOSs have noted a steady decrease in ST and an improvement in operator competency as the number of scans increases, the present study also found that ST decreased with repeated intraoral scanning in all four groups. Among the four groups, undergraduates without clinical experience had the longest STs, in line with the findings of Ahmed's study that operators' clinical experience would affect ST.¹⁰ But Kim and others found that there was no ST difference for the

Trios IOS between dentists with 3-5 years of clinical experience and those with more than five years.¹³ In the present study, dentists with more than three years of clinical experience had lower STs compared to postgraduates with one year of clinical experience, so a conclusion can be drawn that the level of clinical experience affected the intraoral scan time. The ST in Al Hamad's study was much longer than that of the present study in both jaws, perhaps because of the difference in the IOS used, Al Hamad's study used the CEREC Omnicam while the present study used the TRIOS 3.¹⁶ Resende and others also proposed that the CEREC Omnicam IOS had a longer ST than the Trios 3 IOS, which further supports our speculation.¹⁹

The root mean square (RMS) algorithm is widely used in digital dentistry, especially in assessing the deviation between two corresponding 3D models.^{17,20,21} In the Park and Revilla-León studies,^{20,21} accuracy was assessed using the RMS values gained from the best fit of the reference data and scanning data. Therefore, the RMS values were also adopted in this study to assess precision and trueness. Precision refers to the

Table 3: Maxillary and Mandibular Trueness at T1 and T2 for the Four Groups (μm)

Region	Group	Mean \pm SD		t	p-value
		T1	T2		
Maxillary	Undergraduate (n=8) *	96.5 \pm 17.3	81.8 \pm 11.9	2.395	0.048
	Postgraduate (n=8)	115.0 \pm 18.9	84.4 \pm 12.2	5.349	0.001
	Nurse (n=8)	98.1 \pm 28.3	82.9 \pm 23.1	3.658	0.008
	Dentist (n=8)	110.9 \pm 26.9	84.6 \pm 16.5	4.198	0.004
	F	1.254	0.050		
	p-value	0.309	0.985		
Mandibular	Undergraduate (n=8)	82.5 \pm 10.8	71.6 \pm 5.7	3.320	0.013
	Postgraduate (n=8)	85.9 \pm 15.8	75.6 \pm 6.1	2.528	0.039
	Nurse (n=8)	85.6 \pm 9.5	69.9 \pm 4.7	5.068	0.001
	Dentist (n=8)	86.8 \pm 15.5	70.9 \pm 9.2	3.569	0.009
	F	0.164	1.103		
	p-value	0.920	0.364		

Abbreviations: T1, the first five scans; T2, the last five scans.

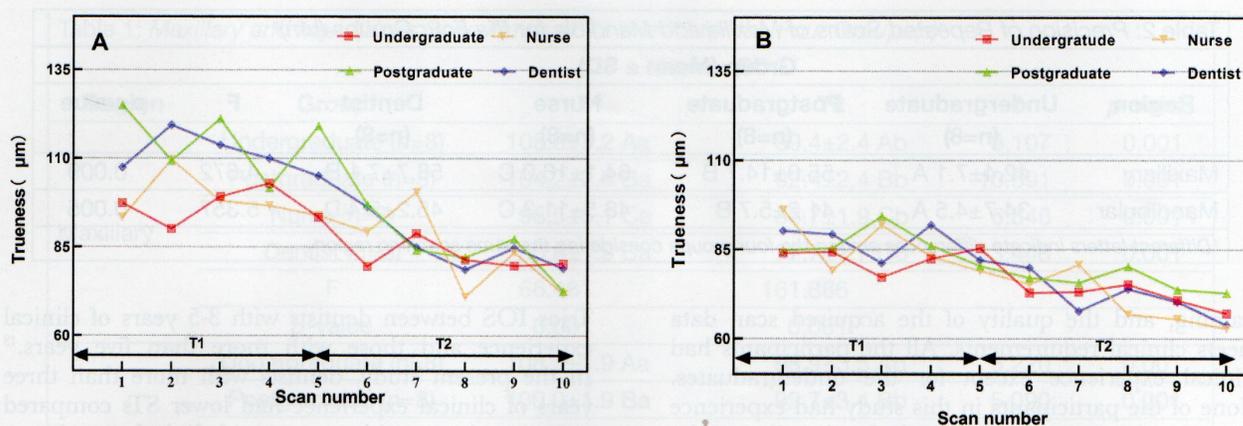


Figure 5. Graph of the change in trueness for the 4 groups. A. Trueness was obtained from 10 repeated scans of the maxilla in four groups. B. Trueness was obtained from 10 repeated scans of the mandible in four groups.

consistency of repeated measurement data. Recent studies have shown that precision may be affected by the operator's experience with intraoral scanning. Resende and others¹⁹ found that higher precision was achieved by operators with experience in intraoral scanning; however, in the study by Schimmel and others,²² operators without experience in intraoral scanning gained higher precision. How the experience in intraoral scanning has effects on precision is still not defined and requires further verification. All participants included in this study had no experience in intraoral scanning, especially the undergraduates who had no clinical experience but got the best precision, which might be a result of operational stability and longer scanning time. During the experiment, the supervisor observed an interesting detail: when operating scanning, the undergraduates' attention was primarily focused on the scanning tip movement in the manikin head rather than frequently shifting the eyes to the scanner screen, so the scanner tip moved more steadily in speed and direction and the data acquisition was more accurate. This technique feature also resulted in longer ST in the undergraduate group, which is consistent with Schimmel's conclusion that a longer ST would allow for greater precision.²²

An accurate digital impression is a prerequisite for the fabrication of the restoration. According to relevant investigations, many IOS devices have achieved *in vitro* full-arch scanning accuracy within 100 µm.²³⁻²⁵ All participants in this research fulfilled the accuracy request after six repeated scans. The results showed that the trueness of the T2 phase was better than that of the T1 phase in all four groups. Conversely, Lim and others concluded that there was no apparent change in trueness with repeated intraoral scanning.¹¹ The discrepancy between the two results is probably

attributed to Lim and others scanning the real dental arch in a patient's mouth, which may be disturbed by various patient factors, resulting in decreased trueness. There was no significant difference in trueness between all four groups in the present study, indicating that trueness was not influenced by the operator's professional background; this is consistent with Lim's findings.¹¹ Except for the maxillary jaw in the undergraduate group, the trueness values after ten repeated scans were about 70 µm. This result is comparable with Lim and others' investigation, which reported a trueness value of 79.8 µm after 10 repeat scans. This study revealed a weak correlation between ST and trueness, which is in line with the findings of Resende and others.¹⁹

Becker and others thought that it is important to analyze registration errors when two digital models are aligned.²⁶ The application of the 3D alignment technique to full arch scanning accuracy analysis has become widespread. It is proposed that cropping out the reference area before best-fit alignment can significantly reduce alignment errors.²⁷ Based on this point, Latham and others employed an alignment procedure that consisted of target region cropping, N-point alignment, and best-fit alignment in sequence.²⁸ The cropping of irregular areas outside the dentition also led to more accurate alignment results in the investigations by Resende and others¹⁹ and Lim and others.¹¹ The alignment process in this study was: cropping out the reference region, N-point alignment, initial alignment (best-fit alignment, sampling point 5000), second cropping, and exact alignment (best-fit alignment, sampling point 10,000), in this process, both models were cropped to improve alignment accuracy further.

This study had some potential limitations. First, it was *ex vivo* research with little influence of patient-related

variables; therefore, the experimental results may differ from those carried out *in vivo*. Second, the participants in this study were recruited from the same institution and there may have been selection bias. Finally, only one IOS was employed in this study while the learning curve may be different from other scanners; thus, the results may be not suitable for other IOSs.

CONCLUSIONS

Based on the findings of this study, the following conclusions were drawn:

- The operator's professional background affects the precision and scanning time of intraoral scanning but not the trueness. Most dental personnel have good access to the intraoral scanner.
- As the number of scans increased, the accuracy and scanning speed also improved. The targeted practice will improve the accuracy and efficiency of the intraoral scan.

Regulatory Statement

This study was conducted in accordance with all the provisions of the human subjects oversight committee guidelines and policies of Ethics Committee of Hospital of Stomatology Hebei Medical University. The approval code issued for this study is 2017007.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 17 June 2023)

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