Influence of Scanning Strategy on the Accuracy of Digital Full-Arch Partially Edentulous Models

Keywords

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ABSTRACT

Objective: To evaluate whether scanning strategies influence the accuracy of the full arch partially edentulous digital model in six intraoral scanner systems. Methods: Six intraoral scanner systems and four scanning strategies were tested. Results: For Scanner A, the deviations were significantly lower when strategy 3 (sextant) or 4 (sequential) were used than when strategy 2 was used (p<0.05). For scanner B, smaller deviations were observed in strategies 1 (interior/exterior) and 4 (sequential) than in strategy 2 (quadrant) (p<0.05). For scanner C, strategy 1 (interior/exterior) provided significantly smaller deviations than 3 (sextant) and 4 (sequential) (p<0.05). For the scanners D and E, there was no significant difference between the strategies regarding deviation (p>0.05). For the scanner F, the deviation was significantly lower with strategy 3 (sextant) than with strategies 1 (interior/exterior) and 4 (sequential) (p<0.05). Conclusions: The scanning strategy interferes with the accuracy of the scanner systems on full-arch partially edentulous models. No unanimous strategy in accuracy was observed, but rather strategies that best suit each scanner system. Clinical Relevance: This study highlights that no single strategy ensures optimal precision across all systems in partially edentulous patients, emphasizing the need for tailored scanning protocols to improve clinical outcomes in digital dentistry.

INTRODUCTION

The popularity and availability of virtual technology in dentistry for replacing paper records with electronic ones are growing rapidly, with a move towards a “digital” patient for diagnosis, planning and monitoring of treatment progress and results[1]. Digital scans reduce treatment time, simplify clinical procedures for the dentist, eliminate the plaster models, enable better communication[2] and result in greater patient comfort[3].

The available intraoral scanners, which utilize a freehand scanning strategy, differ in terms of accuracy[2]. Accuracy is the association between trueness and precision[4]. Trueness is defined as the amount of deviation of a test object from a reference object (“reference standard”)[5]. Precision represents the reproducibility of measurements, after consecutive scans[4]. Several factors influence the accuracy of intraoral scanning, including ambient lighting conditions[6], operator experience[1,7,8], the type of scanned substrate[7], and the scanning strategy employed[9].

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The scanning strategy can be performed from the buccal to the lingual/palatal surface, by quadrants, by sextants or sequentially[10]. Companies that develop digital printing systems usually recommend a specific scan pattern for their system[4]. However, evidence of superiority is lacking[5] and each clinical situation may require a different scanning pattern[4]. Knowing the influence of the scanning strategy on the accuracy of three-dimensional models would be useful to guide a growing number of professionals who are using this technology in creating reproducible models[4] and more closely related to clinical reality[5], thus avoiding prosthetic errors. Scientific evidence related to intraoral scanning still shows variable results. As scanner technology continues to evolve, both in hardware and software, it is essential to evaluate these systems to determine the scanning strategies that minimize errors as much as possible[11].

Thus, this study aims to determine whether four different scanning strategies[10] alter the accuracy of full-arch partially edentulous models on results in six different intraoral scanner systems. The null hypotheses evaluated were: H01: There is no difference between the type of scanner; H02: There is no difference between the scanning strategies. H03: There is no interaction between scanner type and scanning strategies.

METHODS

SAMPLE SELECTION

The scan of the upper arch of a rigid base model (ROIC - Odontological models, Três Corações, Brazil) was used *(Figure 1)*, simulating a partially edentulous patient. The study was conducted in a private radiological clinic in Goiania, Goias (Brazil).

Figure 1: A – Partially scanned rigid base model (ROIC – Odontological models, Três Corações, Brazil).

IMAGE ACQUISITION

The study model was scanned with an optical scanner (Smart small, Optical 3D Scanner, Open Technologies, Rezzato, Italy) with 5 μm precision (ISO 12836 certification) and served as a reference standard for intraoral scanners.

Six different intraoral scanner systems were selected for evaluation, namely:

A- Cs 3D 3600 Carestream (software version 2.0 updating feature HD 3d color Carestream CA, USA).

B- Cs 3D 3600 Carestream (software version 3.1 updating featuring hybrid workflow, scanning sounds and costumer driven features Carestream CA, USA).

C- Trios 3 (software version 1.4.5.3, 3 Shape Dental Systems, Copenhagen, Denmark).

D- iTero (software version OrthoCad 5.7.0.301 Cadent LTD, Align Technology, Inc. San Jose, CA, USA).

E- iTero Element 2 (software version 1.9.3.3, Align Technology, Inc. San Jose, CA, USA).

F- iTero Element 5D (iTero software v2.5.3, Align Technology, Inc. San Jose, CA, USA).

Four scanning strategies were tested, according to the study conducted by Medina-Sotomayor *et al.* (2018) (10) *(Figure 2)*.

1: Exterior/interior strategy: Begins with the occlusal surfaces, starting from the second left molar to the second right molar, returning by the buccal surface and finally the palatal surfaces.

2: Quadrant strategy: Begins with the occlusal side of the second right molar and continues up to the right central incisor, returning by the buccal and then the palatal sides. The second part is then scanned, starting from the second left molar to the left central incisor, returning by the buccal surfaces and finally the palatal surfaces.

3: Sextant strategy: Begins with the occlusal surfaces starting from the second right molar to the first right premolar, returns by the buccal and then the palatal sides. The incisal surfaces are then scanned starting from the right canine to the left canine, returning by the buccal and then the palatal sides. Finally, the occlusal surfaces from the first left premolar to the second molar are scanned, returning by the buccal and then the palatal sides.

4: Sequential strategy: Is based on a sequential scan of the three surfaces of each tooth (occlusal/incisal, buccal and palatal) making an “S”-shaped movement following the course of the second right molar in all directions and without returning to the starting point.

A final screening was performed in all scans to fill in the gaps that did not contain digital information.

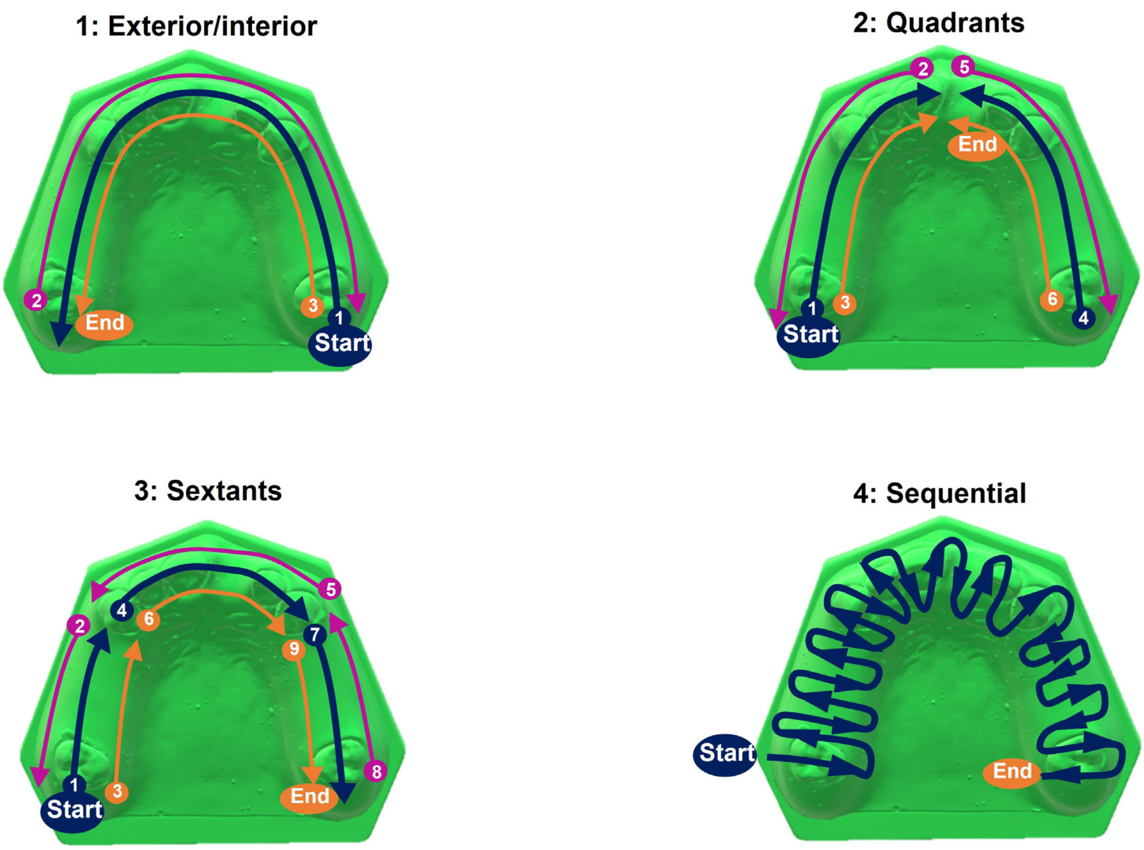

Figure 2: A - Digital models illustrating scanning strategies 1 (interior/exterior), 2 (quadrant), 3 (sextant) and 4 (sequential).

Each scanning strategy was repeated 10 times on each of the six scanner systems (n=240). This sample number was based on previous studies that used similar study methodology.[5,10] All scans were performed by a single operator with four years of experience in intraoral scanning in each piece of equipment to avoid errors and biases.

ANALYSIS OF THE SCANS

All files were exported in the standard tessellation language (STL) format. The STL files were imported into the GOM software (GOM Inspect 2019, Braunschweig, Germany) for the comparative tests according to the Best Fit Alignment method. This tool allows the alignment of the file considered “reference standard” obtained with the optical scanner (Smart small, Optical 3D Scanner, Open Technologies) with the test files.

The reference standard model was opened in the GOM software and compared with the 10 scans of each of the 4 strategies of each scanning system (scanner + software). The intraoral scans were assessed individually. An automatic overlay with the tools pre-alignment and best fit identified the overlay with the smallest possible deviation in micrometer units. The values of mean, median, standard deviation, minimum and maximum deviation were compiled in a spreadsheet (Excel; Microsoft Corp version 16.0.10392.20029).

STATISTICAL ANALYSIS

Initially descriptive and exploratory analyses of the variance data were carried out. These analyses indicated that the data do not meet the assumptions of an analysis of variance (ANOVA) and then a generalized linear model was estimated considering the scanner effects, strategy and the interaction between them. The model also considered that all scans were performed on the same model. The analyses were performed in the R program, with a significance level of 5% ($p<0.05$).

RESULTS

Analyzing Table 1 and Figure 3 show the results of the deviations (micrometers) of each scanner, in each strategy, in relation to the reference standard. The mean values obtained in this study present the trueness and the standard deviation values the precision. It was observed that there was a significant difference between the scanners, between scanning strategies and there was a significant interaction between the scanners and the strategies ($p<0.05$). This means that comparisons between scanners had to be made on each strategy and comparisons between the strategies had to be made for each scanner. The smallest average deviation observed was 47.82 micrometers when scanner C was used with strategy 1 (interior/exterior). The highest average deviation observed was 171.98 micrometers, which occurred in scanner A when strategy 2 (quadrant) was used.

Table 1. Mean (standard deviation) deviations (micrometers) in relation to the optical scanner (Smart small, Optical 3D Scanner, Open Technologies), of high accuracy (5 μm), depending on the intraoral scanner and scanning strategy.

1 Intraoral scanner	2 Scanning strategy			
	1 (Exterior/interior)	2 (Quadrants)	3 (Sextants)	4 (Sequential)
A-Cs 3D 3600 (software version 2.0)	152,02 (26,14) ABa	171,98 (25,02) Aa	139,09 (12,07) Ba	144,32 (29,80) Ba
B-Cs 3D 3600 (software version 3.1)	145,06 (17,53) Bab	170,00 (32,14) Aa	156,21 (15,48) ABa	140,11 (18,99) Ba
C-Trios 3	47,82 (4,86) Ce	49,83 (6,52) BCe	55,62 (7,24) ABd	57,80 (4,79) Ab
D-iTero	120,02 (19,88) Acd	122,71 (16,09) Ac	113,27 (16,91) Ab	127,63 (21,93) Aa
E-iTero Element 2	125,47 (16,34) Abc	142,40 (40,76) Ab	139,80 (32,99) Aa	133,82 (18,34) Aa
F-iTero Element 5D	105,95 (12,68) Bd	96,30 (25,37) BCd	87,64 (16,31) Cc	146,96 (55,28) Aa

Distinct letters (upper case on the horizontal and lower case on the vertical) indicate statistically significant differences (p≤0.05). p(scanner)=<0.0001; p(strategy)=0.0040; p(interaction)<0.0001.

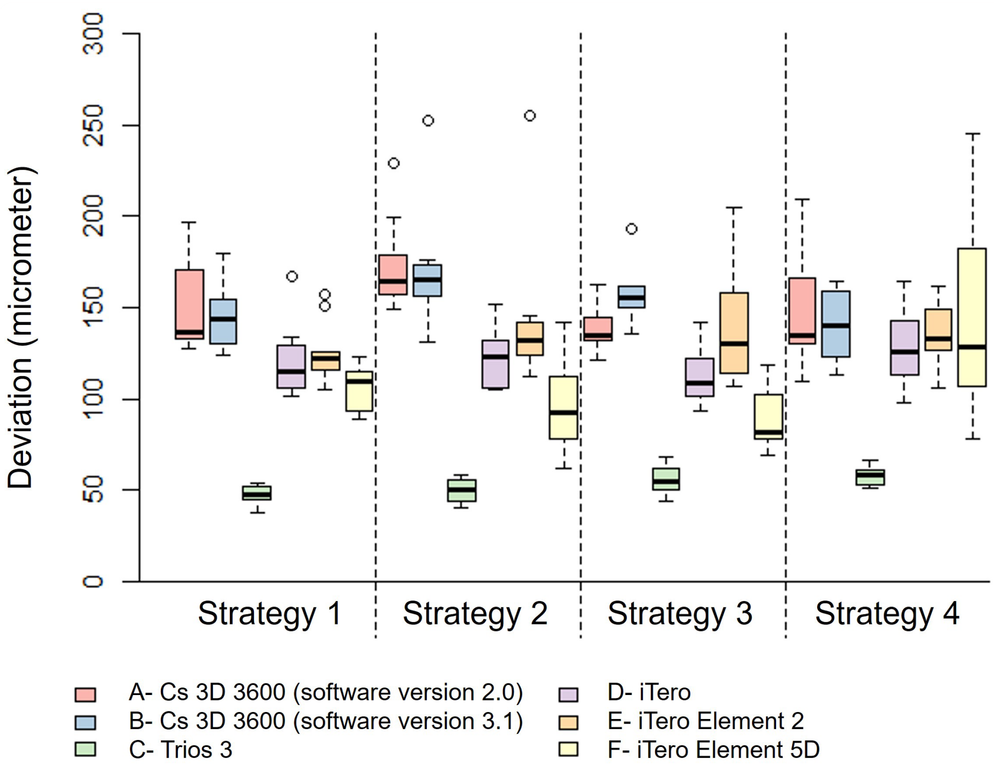

Figure 3: A – Box plot of the deviations (micrometers) in relation to the optical scanner (Smart small, Optical 3D Scanner, Open Technologies), of high accuracy (5 μm), depending on the scanner and scanning strategy.

For scanner A, the deviations were significantly smaller when strategies 3 or 4 were used than when strategy 2 (quadrant) was used ($p<0.05$). For scanner B, smaller deviations were observed in strategies 1 (interior/exterior) and 4 (sequential) than in strategy 2 (quadrant) ($p<0.05$). For scanner C, strategy 1 provided significantly lower deviations than strategy 3 (sextant) and 4 (sequential) ($p<0.05$). For scanners D and E there was no significant difference between the strategies regarding deviation ($p>0.05$). For scanner F, the deviation was significantly lower with strategy 3 (sextant) than with strategies 1 (interior/exterior) and 4 (sequential) ($p<0.05$). In the comparison between the scanners, it can be observed that for all the strategies, the smallest deviation was observed with scanner C ($p<0.05$). In addition, when strategy 1 (interior/exterior) was used, scanners D, E and F showed lower deviations than scanner A; and scanners D and F showed lower deviations than scanner B ($p<0.05$). When strategy 2 (quadrant) is used, scanners D, E and F showed lower deviations than scanners A and B ($p<0.05$). When strategy 3 (sextant) is used, scanners D and F showed lower deviations than scanners A and B ($p<0.05$). In strategy 4 (sequential) there was no significant difference between scanners A, B, D, E and F ($p>0.05$).

DISCUSSION

This study evaluated six intraoral scanner systems, regarding the accuracy of digital full-arch partially edentulous models, using four different scanning strategies proposed by a previous study[10]. Scanning strategy, scanner type, and patient-specific conditions are known factors that may influence the final accuracy of the scanned model[11,12]. In this study, variations in model accuracy were observed when different scanning strategies were applied to the partially edentulous arch.

In the present study, the Cs3600 intraoral scanner (A and B) demonstrated lower trueness when using scanning strategy 2 (quadrant) across both evaluated software versions. In contrast, higher trueness was observed with strategies 3 (sextants) and 4 (sequential) in version 2.0, and with strategies 1 (exterior/interior) and 4 (sequential) in version 3.1. A previous study[13], however, reported no difference between strategies 2 and 4 when scanning a fully dentate hemi-arch model using the Cs3600 scanner. It is noteworthy that the manufacturer's manual for Carestream does not specify a recommended scanning strategy[14]. Therefore, it can be inferred that strategy 4 (sequential) is the most suitable for partially edentulous patients, as it yielded favorable results with this scanner in both software versions. The reduced performance of strategy 2 may be attributed to the edentulous anterior region dividing the quadrants, which lacks sufficient anatomical reference points for accurate image stitching[12].

The Trios 3 intraoral scanner (C) demonstrated the highest trueness and precision when using scanning strategy 1 (interior/exterior), which may be attributed to the fact that this method is the manufacturer's recommended protocol[15]. This finding contrasts with a previous study[10], which reported the highest trueness with strategy 4 (sequential). However, in that same study, strategy 4 presented lower accuracy values. Similarly, another study[5] using a comparable sequential strategy, starting on the palatal surfaces, found the highest standard deviation. It is worth noting that each scanner in those studies was operated by a different clinician, which may have influenced the outcomes. In contrast, the study by Mennito *et al.* (2018)[4] reported that the scanning strategy did not significantly affect the accuracy of the digital models obtained with this scanner.

The iTero and the iTero Element 2 scanners were not influenced by the type of scanning strategy. The iTero Element 5D scanner showed higher accuracy with strategy 3 (sextant) and the smallest with strategy 4 (sequential). This study was the first to compare different scanning strategies using this system and may be used as a reference for future analyses. The only strategy recommended by the manufacturer used was the iTero device (D), corresponding to scanning strategy 4 (sequential). However, no significant differences were observed regardless of the strategy used.

Another important factor that may influence the trueness and precision of intraoral scanners, as well as the effectiveness of the scanning strategy, is the updating of software or system versions. In this study, a slight improvement in trueness was observed in most scanning strategies when comparing the updated software version of the CS 3600 intraoral scanner (version 3.1) to its previous version (version 2.0), as well as between the iTero Element 5D and its earlier model. These findings underscore the importance of utilizing the most current software and hardware to optimize the performance and accuracy of intraoral scanning procedures[16]. Furthermore, the most appropriate scanning strategies differed depending on the software version used.

When comparing the scanners, the Trios 3 showed the highest accuracy (trueness and precision) values in all scanning strategies, consistent with the findings of a previous study[14], who evaluated a single tooth. Therefore, the Trios 3 scanner can be considered the one that most closely replicates the 'real object' after consecutive scans.

Although differences in trueness and precision values were observed among scanning strategies and between scanners, it is important to emphasize that the clinical acceptability of scan deviations varies depending on their intended use. A previous study[17] determined that deviations of up to 150 µm between the implant and the fixed total prosthesis do not induce clinical complications, considering them clinically acceptable. A restoration would be successful if the marginal gaps and cement thickness were less than 120 µm[18]. Other clinicians[19] consider a marginal fit of 100 µm as clinically acceptable in relation to the longevity of restorations.

Regarding the measurement method of the analyzed data, it is important to highlight that the GOM software used includes all standard alignment functions. This includes: RPS alignment, hierarchical alignment based on geometric elements, alignment on a local coordinate system, alignment by reference points, as well as various best adjustment methods. The best fit tool makes it possible to align the digital models without altering the values found. The software reports deviation measurements to up to 20 decimal places, making micrometer measurements possible, which enables a three-dimensional analysis of the whole model. This methodology is superior to linear measurements based on single point analysis, as it considers the overall geometry of the model.

The present study has a limitation due to its *in vitro* design, as it used a partially edentulous arch model with resin teeth, which does not accurately replicate real oral conditions such as the presence of blood, saliva and soft tissue movement[20]. However, a rigid model was chosen for ethical reasons, given that 240 scans were required. Additionally, the intraoral scanner considered the gold standard in this study may show a distortion of 5 μm. For future research, it is suggested to explore different types of dental materials and compare full-arch versus partial-arch scans. Additionally, future studies should involve multiple users with varying levels of clinical experience and expertise.

CONCLUSIONS

Based on the data evaluated, we concluded that the scanning strategy affects the accuracy of the Cs3600 (A), Cs 3600 (B), Trios 3 (C) and iTero Element 5D (F) intraoral scanners when applied to digital full-arch partially edentulous models. In this study, no unanimous strategy for accuracy was observed, but rather strategies that best suit each scanner system. Among the scanners compared, the Trios 3 showed the highest accuracy.

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