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RESEARCH ARTICLE

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Evaluation of the effect scan pattern has on the trueness and precision of six intraoral digital impression systems

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Abstract

Objective: Clinicians have been slow to adopt digital impression technologies due possibly to perceived technique sensitivities involved in data acquisition. This research has two aims: determine whether scan pattern and sequence affects the accuracy of the three-dimensional (3D) model created from this digital impression and to compare the 5 imaging systems with regards to their scanning accuracy for sextant impressions.

Materials and Methods: Six digital intraoral impression systems were used to scan a typodont sextant with optical properties similar to natural teeth. The impressions were taken using five different scan patterns and the resulting digital models were overlayed on a master digital model to determine the accuracy of each scanner performing each scan pattern. Furthermore, regardless of scan pattern, each digital impression system was evaluated for accuracy to the other systems in this same manner.

Results: No differences of significance were noted in the accuracy of 3D models created using six distinct scan patterns with one exception involving the CEREC Omnicam. Planmeca Planscan was determined to be the truest scanner while 3Shape Trios was determined to be the most precise for sextant impression making.

Conclusions: Scan pattern does not significantly affect the accuracy of the resulting digital model for sextant scanning.

Clinical Significance

Companies who make digital impression systems often recommend a scan pattern specific for their system. However, every clinical scanning scenario is different and may require a different approach. Knowing how important scan pattern is with regards to accuracy would be helpful for guiding a growing number of practitioners who are utilizing this technology.

KEYWORDS
CAD/CAM dentistry, digital dentistry, digital impression, prosthodontics

1 | INTRODUCTION

Digital impression technology is improving at an extraordinary rate with indications expanding to include full arch prosthetic cases, large full arch implant cases, removable prosthetics, and orthodontic aligners.[1–5] Digital models are as reliable as plaster cast models, with an accuracy range between 6.9 and 45.2 μm.[6,7] Patients and clinicians benefit from quicker treatment times using a digital workflow, while maintaining or exceeding the quality of conventional workflows.[8–10] From a patient's standpoint, digital impressions produce less anxiety, are more comfortable, and elicit less nausea.[11]

Despite technological advancements, expanded indications, and supporting scientific evidence, there remain barriers to clinical adoption. In some areas of the country, for single unit crown impressions only 9% of clinicians use digital technology.[12] Recently, McCraken et al. surveyed 1777 dentists what their preferred impression technique was for single unit crowns, 77% used poly(vinyl siloxane), 12% used polyether, and only 9% used optical/digital impressions.[12] They found that the majority of physical impressions were sextant dual arch impressions made with plastic trays. According to Glidewell Lab, in 2016, 85% of the restorative impressions they received were triple tray impressions, including 47% of full arch impressions.[13] This type of impression is one of the least accurate impressions techniques with flexure of the plastic tray causing distortion of the impression typically causing it to be wide buccal lingual and short mesial distal.[14] One study found that when impression material was used in a plastic dual arch tray, gypsum dies were nearly 30 μm smaller in the mesio-distal dimension compared with other techniques.[15] Based on this evidence, we can conclude that ease of use is the most important factor that clinicians consider when picking an impression technique.

One potential reason clinicians remain reluctant to adopt digital impressions for a single unit crown, seemingly the simplest impression workflow, is the perceived technique sensitivity involved in the process. It may be overwhelming for clinicians to remember each complicated scan pattern recommended by manufactures of the digital impression systems. However, there are measured correlations between scan pattern and accuracy. For full-arch scans, the scan pattern has a significant effect on trueness and precision, and certain scan patterns may affect the fit of appliances made with those digital models.[16] For full-arch digital impressions, even small levels of inaccuracy can lead to ill-fitting appliances. However, no evidence in the literature exists, showing whether scan pattern has an effect on accuracy of sextant scans. Therefore, scan patterns that may overwhelm new or potential users may be completely unnecessary in these scanning scenarios. In addition, concerns for accuracy may influence the patterns adopted by existing users, regardless of evidence to support their strategy. Thus, the aim of this in-vitro study was to determine if scan pattern affects the accuracy of the resulting digital model when scanning sextants, the typical scan size for single unit crowns; and/or whether or not there are differences between existing scanning system platforms, with regards to accuracy. The null hypothesis was that no differences in the accuracy would occur between any of the five scan patterns for any of the six scanners tested.

Per ISO standard 5725-1, the accuracy of a measurement method consists of a combination of trueness and precision.[17] Trueness is defined as deviation from the actual dimensions of a measured object. In this case, trueness is how close the virtual models created using each scanner compared with the master model. A "true" scanner produces a model that is very close to the dimensions of the object scanned. Precision is defined as how close measurements are to each other for the same measuring device, or whether scanners are able to create reproducible models. All six scanners were evaluated for accuracy by measuring their trueness and precision when utilizing five different scanning patterns.

2 | MATERIALS AND METHODS

Six digital impression systems were evaluated: CEREC Omnicam (CO; Dentsply Sirona, York, PA), Planmeca Emerald (PE; Planmeca USA, Roselle, IL), Planscan (PS; Planmeca USA), TRIOS 3 (3S) (3Shape North America, Warren, NJ), Itero Element (IE; Align Technology, San Jose, CA), and True Definition (TD; 3M North America, St. Paul, MN).

A custom model was created by preparing 14 maxillary typodont teeth (Model D85SDP-200; Nissin Dental Products, Kyoto, Japan) for complete ceramic crowns in accordance with Rosenstiel's parameters for these preparations; a 1 mm modified shoulder finish line that is

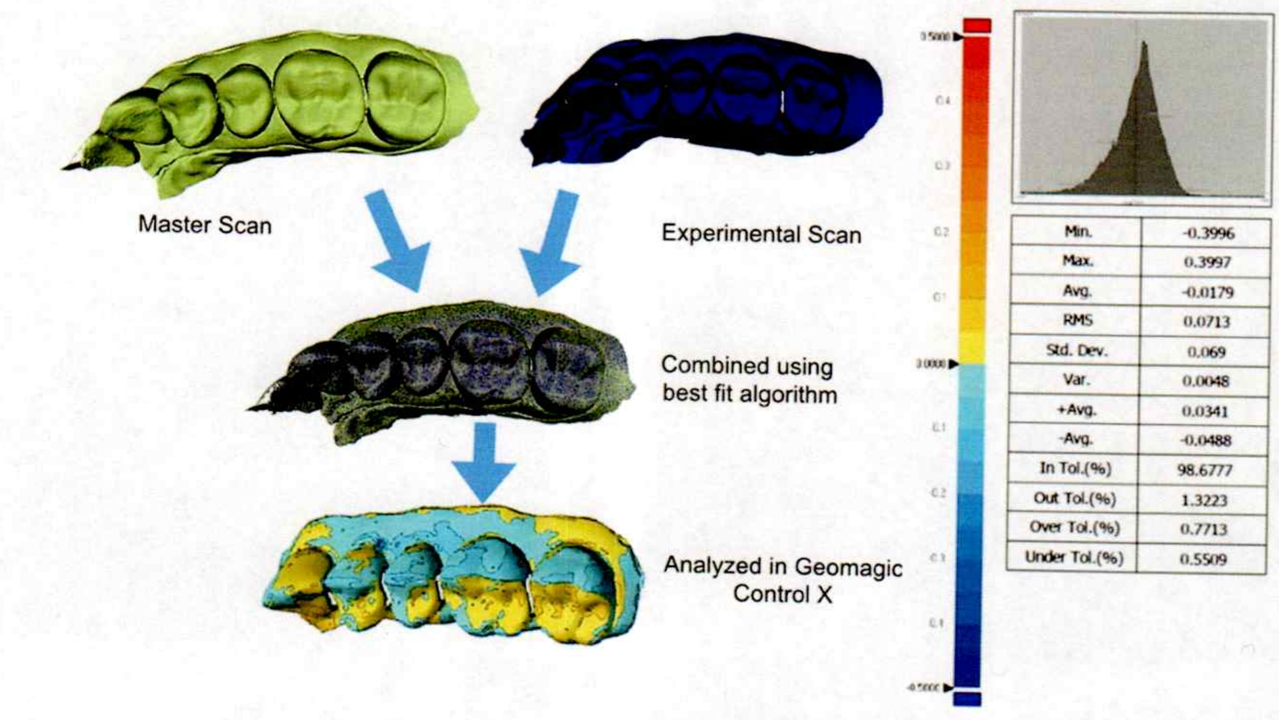

FIGURE 1 Displays the overlaying process in Geomagic that allows for graphical analysis of differences in 3-dimensional models

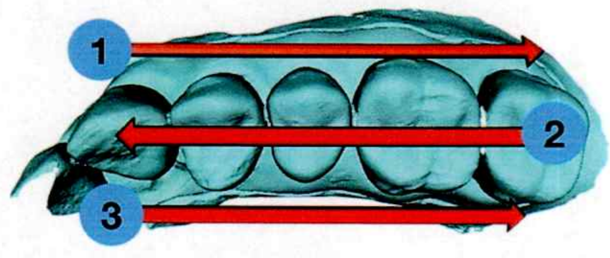

FIGURE 2 Shows SP1 (buccal first)

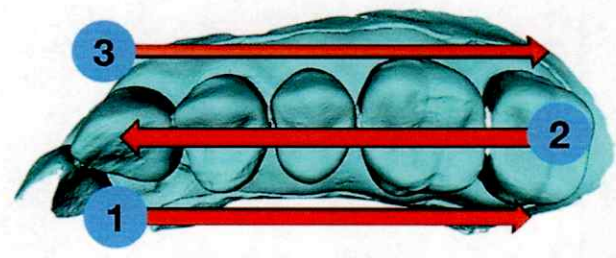

FIGURE 3 Shows SP2 (lingual first)

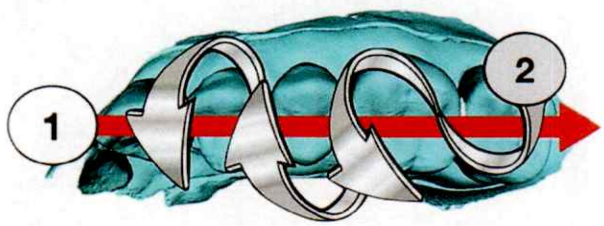

FIGURE 4 Shows SP3

smooth and continuous and follows the rise and fall of the gingival tissues, 6°–10° of taper, 1.5–2 mm of occlusal reduction, 1–1.5 mm of axial reduction, a functional cusp bevel and a general roundness and smoothness to the preparation.[18] Restorations were fabricated from Vita shade A3 Telio CAD (TC) (Ivoclar Vivadent AG, Amherst, NY) polymethyl methacrylate and bonded onto the typodont preparations using Rely-X Unicem (3M ESPE) self-etching, self-adhesive cement. Prior to cementation, the intaglio surfaces of the crowns were microetched using 40 μm coJet sand (3M ESPE). TelioCAD was selected for these restorations due to its ability to mimic the reflectivity of natural tooth structures as outlined by Renne et al.[19]

A master scan of this model was made to fabricate the master digital model, against which the different scan patterns would be compared for trueness and precision. This scan was taken using ATOS Triple Scan (GOM technologies, Santa Ana, CA), an industrial grade, blue-light 3D scanner that has been shown to be accurate to 3 μm.[20] This produced a master stereolithography (.stl) file that, when imported into a three-dimensional (3D) analysis software Geomagic Control (3D Systems, Rock Hill, SC), allowed for alignment of experimental and control .stl files by highest average nodal data-point overlay; and graphic comparison of the separate scan patterns (Figure 1).

Experimental scans were taken with each of the six digital impression systems, of each of the scan patterns. The scan patterns selected were those recommended by the manufacturers for each digital impression system. Scan pattern one (SP1, Figure 2) began at the second molar and scanned the occlusal surfaces of the sextant, followed by the buccal surfaces from anterior to posterior and concluded with the lingual surfaces from posterior to anterior. Scan pattern two (SP2, Figure 3) began at the cuspid and scanned the lingual surfaces first, followed by the occlusal surfaces from posterior to anterior and concluded with the buccal surfaces from anterior to posterior. Scan pattern three (SP3, Figure 4) began at the cuspid and scanned the occlusal surfaces first from anterior to posterior and then concluded by alternately rolling from buccal to lingual to buccal from posterior to anterior. Scan pattern four (SP4, Figure 5) began at the second molar and scanned the buccal surfaces first from posterior to anterior, then the occlusal surfaces from posterior to anterior, then the lingual surfaces from posterior to anterior and concluded with a wave scan beginning at the buccal of the second molar and terminating at the lingual surface of the cuspid. Scan pattern five (SP5, Figure 6) begins at the cuspid and involves alternately rolling from buccal to lingual to buccal from anterior to posterior. Each scan pattern was repeated five times ($n = 5$) to create the .stl files that were compared with the master model using Geomagic. These values were then averaged to determine trueness and precision.

3 | STATISTICS SECTION

3.1 | Scan pattern

Looking to see if any difference in scan pattern exists relative to each scanner, a repeated measures generalized linear model was used with averages as the outcome and pattern in the model. Six models were run, one for each scanner. A random intercept was in

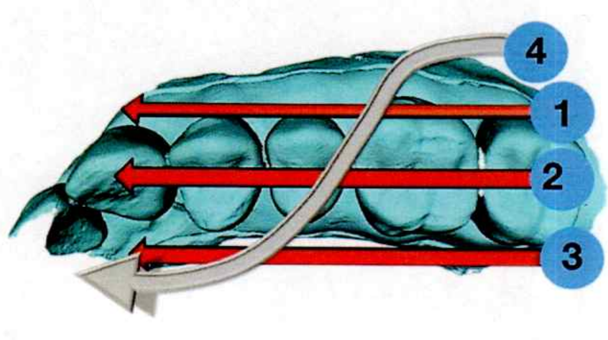

FIGURE 5 Shows SP4

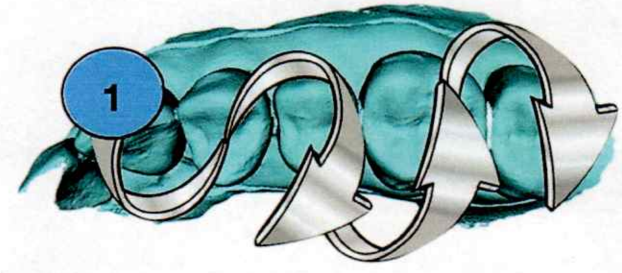

FIGURE 6 Shows SP5

the model to account for replicates. Post hoc comparisons for pattern with a Scheffe adjustment were looked at if the main effect was significant.

To determine scanner trueness, a repeated measures generalized linear model was used with trueness as the outcome and scanner in the model. A random intercept was in the model to account for replicates. Post hoc pairwise comparisons were looked at with a Scheffe adjustment.

To determine scanner precision, a repeated measures generalized linear model was used with precision as the outcome and scanner in the model. A random intercept was in the model to account for replicates. Post hoc pairwise comparisons were looked at with a Scheffe adjustment.

4 | RESULTS

Scan pattern did not affect the trueness or precision of any of the six scanners tested except for the CO where SP2 was significantly better than SP3 ($P = .0360$). For all other impression systems, the scan pattern did not affect trueness or precision (Table 1).

Summary statistics for trueness and precision are listed in Tables 2 and 3, respectively, and categorized based on mean, median, standard deviation, minimum and maximum, and ranking.

The rankings for trueness, from most true to least for sextant scans are as follows: PS > PE > TD > IE > 3S > CO. Statistical differences are highlighted in Table 2.

TABLE 1 Data for the effect of scan pattern on trueness and precision

Scanner	Pattern	N	Mean	Median	Std. Dev.	Minimum	Maximum
Emerald	1	3	−0.77	−0.60	0.57	−1.40	−0.30
	2	3	−0.90	0.90	4.11	−5.60	2.00
	3	3	−7.87	−9.90	3.87	−10.30	−3.40
	4	3	−9.60	−8.20	2.87	−12.90	−7.70
	5	3	−3.03	−3.20	3.45	−6.40	0.50
Omnicam	1	3	−27.00	−30.80	9.40	−33.90	−16.30
	2	3	−28.40	−33.20	10.28	−35.40	−16.60
	3	3	−20.80	−26.90	11.27	−27.70	−7.80
	4	3	−25.47	−26.60	8.26	−33.10	−16.70
	5	3	−25.03	−28.00	8.16	−31.30	−15.80
Planscan	1	3	7.60	7.80	8.10	−0.60	15.60
	2	3	6.20	7.10	7.59	−1.80	13.30
	3	3	1.63	2.00	2.57	−1.10	4.00
	4	3	−3.33	−5.00	7.83	−10.20	5.20
	5	3	2.57	4.10	4.69	−2.70	6.30
Trios	1	3	−18.63	−18.60	0.65	−19.30	−18.00
	2	3	−18.60	−18.00	1.13	−19.90	−17.90
	3	3	−21.03	−21.50	1.36	−22.10	−19.50
	4	3	−19.10	−18.30	1.65	−21.00	−18.00
	5	3	−19.93	−20.00	1.10	−21.00	−18.80
True Definition	1	3	−11.70	−12.60	2.19	−13.30	−9.20
	2	3	−12.20	−13.60	2.78	−14.00	−9.00
	3	3	−14.27	−14.60	0.58	−14.60	−13.60
	4	3	−12.40	−13.20	3.67	−15.60	−8.40
	5	3	−12.37	−11.80	0.98	−13.50	−11.80
iTero	1	3	−14.73	−14.20	0.92	−15.80	−14.20
	2	3	−13.77	−12.00	3.59	−17.90	−11.40
	3	3	−14.53	−14.30	2.46	−17.10	−12.20
	4	3	−15.27	−13.90	2.63	−18.30	−13.60
	5	3	−18.60	−19.00	2.23	−20.60	−16.20

TABLE 2 Summary statistics comparing trueness of intraoral scanners

Scanner	Scanner	Adj P
Emerald	Omnicam	<.0001
Emerald	Planscan	1
Emerald	Trios	<.0001
Emerald	True Definition	.0026
Emerald	iTero	<.0001
Omnicam	Planscan	<.0001
Omnicam	Trios	.0436
Omnicam	True Definition	<.0001
Omnicam	iTero	.0003
Planscan	Trios	<.0001
Planscan	True Definition	.0021
Planscan	iTero	<.0001
Trios	True Definition	.0131
Trios	iTero	.2811
True Definition	iTero	.674

The rankings for precision, from most precise to least for sextant scans are as follows: 3S > TD > IE > PE > PS > CO. Statistical differences are highlighted in Table 2.

5 | DISCUSSION

The aim of this in-vitro study was to determine what impact scan sequence and pathway had on the trueness and precision of digital models created from these impression techniques. Basic principles of dentistry dictate that dental prostheses are only as accurate and well-fitting as the model off of which they were fabricated. This is true despite whether a traditional impression or digital impression was used to capture the form of the dentition and surrounding support structure. Therefore, it is paramount to determine how variations in impression technique, in this case scan pattern, might affect the overall accuracy of the model.

The null hypothesis was in part rejected in this case. For sextant scanning, only one statistically significant variant was found for one of the six scanners in which a difference in scan pattern affected accuracy. This is important because it verifies that scan pattern or sequence will not affect the trueness and precision of the subsequently generated model with this one exception. SP3 was found to be the significantly less accurate than SP2 when using the CO.

This study examined five distinct scan patterns using six commonly used digital impression systems to determine their impact on accuracy of the digital model created. It is important to note that several studies have been done on these scanners in the past looking at the accuracy of the impressions.[16,19,21] While the hardware that is examined, that is the scanner itself, is essentially the same across these studies, the software algorithms that enable stitching of the separate images into a 3D model are constantly being improved. A study that showed certain levels of accuracy for a certain scanner two years ago may give very different results should it be repeated today. This presents a challenge when comparing similar research studies because different software versions may yield different results, much as you would expect from different hardware versions. This also means that these studies should be repeated periodically to determine if accuracies have changed as a function of software updates.

This study represents the results of scanning in an ideal situation; that is extraorally without the presence of saliva or the movement associated with the presence of the tongue and other soft tissues. This is a limitation of this study as intraoral scanning presents a separate set of challenges that that may affect scanning accuracy. The aforementioned challenges, saliva, and soft tissue movement, coupled with the presence of metallic, reflective restorations can make capturing intraoral surfaces more difficult. These difficulties can lead to altering the scan pattern to try to capture missed surfaces. Additional studies should be undertaken to determine how factors associated with intraoral scanning can affect accuracy of the digital model. However, we are convinced by the data measured in this study that scan pattern, with one minor exception, has no effect on scan accuracy. Therefore, clinicians can scan in whatever pattern they are most comfortable with to allow for clinical success with little or no loss in accuracy. These results may help dispel some preconceived notions regarding the technique sensitivity associated with intraoral scanning and allow for more widespread adoption of the technology.

TABLE 3 Summary statistics comparing precision of intraoral scanners

Scanner	Scanner	Estimate	Adj P
Emerald	Omnicam	−6.4982	<.0001
Emerald	Planscan	−3.1833	.0617
Emerald	Trios	1.7957	.5571
Emerald	True Definition	0.9349	.9501
Emerald	iTero	0.6077	.9924
Omnicam	Planscan	3.3149	.0473
Omnicam	Trios	8.2939	<.0001
Omnicam	True Definition	7.4331	<.0001
Omnicam	iTero	7.1059	<.0001
Planscan	Trios	4.9790	.0012
Planscan	True Definition	4.1182	.0085
Planscan	iTero	3.7910	.0174
Trios	True Definition	−0.8608	.9646
Trios	iTero	−1.1880	.8737
True Definition	iTero	−0.3272	.9996

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