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READER'S FORUM

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Full-arch accuracy of five intraoral scanners: *In vivo* analysis of trueness and precision.

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I appreciate the authors' work to investigate the full-arch accuracy of five intraoral scanners. For better understanding, I would like to ask some questions.

Q1. In this article, the main key issue was the concept of trueness and precision. Would you explain in more detail about the concept of trueness and precision in analysis of the scanners?

Q2. You compared five scanners in this article. In capturing data, were there any technical differences among them in terms of the possibility of errors?

Q3. I thankfully read your article for reference of each scanners. Did you have any comforts or disturbances in manipulating each scanner? If you experienced anything worthwhile, would you advise for readers.

Questioned by
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A1. The trueness and precision of the scanners were analyzed by measuring linear distances of the full-arch scan data acquired from the scanners. Four reference spheres were placed in the dental arch (two in the canines and two in the molars), and the distance between the spheres was analyzed (Figure 1). Using the distance between the spheres instead of the tooth's anatomic landmarks minimizes measurement errors because the Geomagic Control X software (version 2018.1.1; Evatronix SA, Bielsko-Biala, Poland) that was used in the study automatically detects the spheres and calculates the distance between the centers of the spheres; thus, minimizing the error from positioning the anatomic landmarks, such as the cusp tip. Trueness indicates the difference between the intra-arch linear measurements acquired from the intraoral scan data and those from the extraoral industrial-grade scanner, which was the reference scanner. The industrial scanner has an accuracy of 7 μm and served as the "truth."

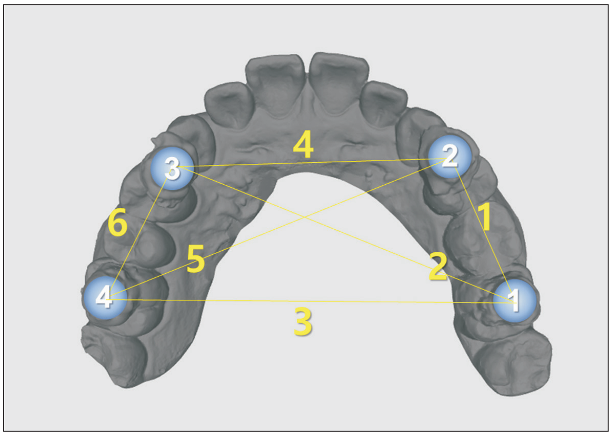

Figure 1. Measurement of linear distances. Linear distances between spheres are automatically calculated by matching with pre-imputed specification data. Distance 1, between reference spheres 1 and 2; Distance 2, between reference spheres 1 and 3; Distance 3, between reference spheres 1 and 4; Distance 4, between reference spheres 2 and 3; Distance 5, between reference spheres 2 and 4; Distance 6, between reference spheres 3 and 4.

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Precision was analyzed by calculating the mean pairwise difference from the five repeated scans per scanner. Tables 1 and 2 display the raw data for trueness and precision acquired from the scan data of a patient using an i500 scanner (Medit Corp., Seoul, Korea), respectively.

A2. There were statistically significant differences in trueness and precision among the five scanners for certain measured distances (Table 3). We believe that scanning technology, such as confocal microscopy (Trios; 3Shape A/S, Copenhagen, Denmark/iTero; Align Technology, Inc., San Jose, CA, USA) and optical triangulation (i500/Omnicam; Dentsply Sirona, York, PA, USA/CS3600; Carestream Health, Rochester, NY, USA), is a major factor associated with scanner accuracy. A systematic review of intraoral scanner accuracy has also shown that there is a difference in accuracy according to intraoral scanner technologies, and a meta-analysis showed that Trios is more accurate than Omnicam in both trueness and precision.[1] Moreover, the scan accuracy is also affected by the scan strategy.[2-4] Therefore, it is important to scan the arch according to the manufacturer's instructions. Other factors associated with the scan data accuracy are scanner software versions,[5,6] ambient lights,[7] and scanning skills.[8] In our study, an intraoral scan was performed following the manufacturer's instructions to minimize errors during data capturing.

A3. Regarding manipulations, the scanner head should be small, light-weight, and ergonomic in design. Personally, I prefer a pod-type scanner to a gun-type scanner. iTero has a heavy (approximately 500 g) and large scanner head that makes it difficult when scanning patients who have limited mouth opening or temporomandibular joint issues. However, it has advanced software features such as automated tooth setup and tooth movement tracking features. Medit's i500 also has an automated tooth setup function that may be used for patient consultations. i500 has the lightest scanner head (280 g). The Omnicam scanner has a solid build and the scanner head is small. The Trios scanner has the highest accuracy. The accuracy for a full arch scan of the studied intraoral scanners was clinically acceptable for orthodontic treatments, such as virtual setup and clear aligner therapy. However, for prosthodontic treatment, such as long-span fixed partial dentures, errors ranging from 200–300 μm can be problematic.[9]

Table 1. Sample raw data for trueness acquired from one patient (Pt) using an i500 scanner (mm)

Distance		1	2	3	4	5	6
Reference (A)*		15.750	39.762	45.200	29.449	39.146	14.322
Actual value (B)†	Pt1_i500 (1)	15.782	39.907	45.418	29.541	39.285	14.334
	Pt1_i500 (2)	15.763	39.800	45.245	29.481	39.193	14.348
	Pt1_i500 (3)	15.741	39.783	45.220	29.408	39.091	14.324
	Pt1_i500 (4)	15.773	39.829	45.132	29.471	39.076	14.355
	Pt1_i500 (5)	15.771	39.851	45.353	29.486	39.230	14.346
Deviation (B-A)‡	Pt1_i500 (1)	0.032	0.146	0.218	0.092	0.139	0.011
	Pt1_i500 (2)	0.013	0.038	0.045	0.032	0.047	0.026
	Pt1_i500 (3)	–0.009	0.022	0.019	–0.041	–0.055	0.002
	Pt1_i500 (4)	0.023	0.067	–0.068	0.022	–0.070	0.033
	Pt1_i500 (5)	0.021	0.089	0.152	0.037	0.084	0.024

For each patient, distances were measured for each of the five scans [(1)–(5)] performed per scanner. Then, the difference between the distance measured from the reference scan and the intraoral scan was calculated. Mean absolute distances were regarded as the trueness for the scanner.
1, distance between reference spheres 1 and 2; 2, distance between reference spheres 1 and 3; 3, distance between reference spheres 1 and 4; 4, distance between reference spheres 2 and 3; 5, distance between reference spheres 2 and 4; 6, distance between reference spheres 3 and 4.
*Indicates the distance measured from the scans taken with the industrial scanner (Solutionix C500; Medit Corp., Seoul, Korea).
†Indicates the distance measured from the intraoral scanner (i500; Medit Corp.).
‡Indicates the difference between the distance measured from the industrial scanner and the intraoral scanner.

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Table 2. Sample raw data for precision acquired from one patient using an i500 scanner (mm)

Distance	1	2	3	4	5	6
Difference between scans						
(1), (2)	–0.021	–0.091	–0.146	–0.062	–0.098	0.002
(1), (3)	–0.004	–0.070	–0.112	–0.024	–0.045	–0.007
(1), (4)	–0.005	–0.097	–0.168	–0.045	–0.082	0.004
(1), (5)	–0.089	0.018	0.018	0.004	–0.002	–0.002
(2), (3)	0.017	0.021	0.035	0.039	0.053	–0.009
(2), (4)	0.016	–0.006	–0.022	0.017	0.016	0.003
(2), (5)	0.020	0.109	0.165	0.066	0.096	–0.003
(3), (4)	–0.009	–0.027	–0.057	–0.022	–0.037	0.011
(3), (5)	0.003	0.089	0.130	0.027	0.043	0.006
(4), (5)	0.004	0.115	0.187	0.049	0.080	–0.006

Pairwise differences from the five repeated scans [(1)–(5)] were calculated and the mean was regarded as the precision of the scanner for the patient.
1, distance between reference spheres 1 and 2; 2, distance between reference spheres 1 and 3; 3, distance between reference spheres 1 and 4; 4, distance between reference spheres 2 and 3; 5, distance between reference spheres 2 and 4; 6, distance between reference spheres 3 and 4.

Table 3. Tests of fixed effects

Effect	Numerator DF	Denominator DF	F value	*p*-value
Distance	5	185	140.3	< 0.0001
Scanner type	4	37	1.13	0.357
Distance × Scanner type	20	185	1.66	0.044

DF, degrees of freedom.

Replied by
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