The effect of scanning strategy on intraoral scanner's accuracy.

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Abstract

Background

The purpose of the present study was to examine the impact of scanning strategy on trueness and precision of the impression acquired from an intraoral scanner.

Materials and methods

Fifteen complete-arch, mandibular, post orthodontic treatment casts were scanned with a laboratory scanner (Identica SE 3D, Medit) as the gold standard, and with an intraoral scanner (i500 Medit) following 3 different paths of the scanning head over the arch (scanning strategies A, B, C). The hand scans were performed twice by one examiner and repeated by a second examiner, resulting in 180 triangular mesh surfaces (digital casts). The meshes were superimposed on the gold standards using the Viewbox 4 software. The closest distances between the meshes were computed and trueness and precision were evaluated using a General Linear Model.

Results

Scanning strategy A was statistically significantly better ($p < 0.05$) and differed from B and C, which were similar. A positive correlation was found among examiner and strategy.

Conclusions

The accuracy of complete-arch impressions is affected by the scanning strategy. The manufacturer's recommended strategy was statistically significantly better ($p < 0.05$). Average accuracy below 50 μm, which is clinically acceptable in most orthodontic procedures, was achieved with all the examined scanning strategies.

Introduction

Digital scanning has been applied in Orthodontics to simplify the diagnostic and treatment procedures. Digital impressions are more accurate compared to conventional methods, achieving accuracy of 100 μm. [1–3]The use of an intraoral scanner (IOS) leads to optimized results and better time management[4,5] while patients are highly satisfied.[5–7] In addition, the IOS systems require a smaller learning curve for the clinician.[8,9]

In order to scan the area correctly, the clinician moves the head of the IOS following a specific path positioning the scanned object at the center of the viewfinder.[9] This path constitutes the scanning strategy. The impact of scanning strategy on the accuracy of the impression is not yet fully determined.

In 2013, Ender and Melh[10] indicated that scanning strategies, different than the suggested by the IOS manufacturer, lead to significantly lower accuracy. Muller et al.[11] indicated that the scan strategy has an impact on trueness and precision of the digital impression but only the precision differs in a statistically significant level. In addition, Anh et al.[12] demonstrated that the precision of the digital model depends on the starting point of the scan. Oh et al.[13] further deduced that vertical rotation of IOS should be avoided. Medina et al. [14] and Passos et al. [15]tested multiple IOS systems, operating using different data capturing principles, and both found that scan strategy affects the accuracy of IOSs differently, depending on the IOS type. There are scarce data regarding the accuracy of IOS systems using active triangulation technology, depending on scanning strategy. Active triangulation is a promising IOS technology. It requires less bulky hardware and can therefore improve patient comfort and decrease the price of the device. [16]

All scanning systems aim to create a three-dimensional (3D) model by merging several images taken under different angles using an algorithm.[17] The scan strategy of IOS is highly correlated with the image stitching software, which uses areas of common coverage in consecutive images to create the digital model.[18] Therefore, if scanner movement is too fast or has extreme changes in orientation, the stitching process may be inhibited.[16] It was recently reported that scanning software significantly affects the precision of complete-arch scans.[18,19]

The aim of this study was to examine the effect of scanning strategy on trueness and precision of the impression, using an IOS based on active triangulation technology. The manufacturer’s recommended strategy was compared with two alternatives: one without extreme changes in IOS head direction and one with continuous changes. The null hypothesis was that scanning strategies do not affect the accuracy of the impressions.

Materials And Methods

Our sample consisted of 15 complete-arch mandibular post-treatment dental casts, acquired from patients with permanent dentition of the Department of Orthodontics of the School of Dentistry, National and Kapodistrian University of Athens.

The casts were scanned with the laboratory scanner Identica SE 3D (Medit, Seoul, Korea), which was considered the Gold Standard, and with the IOS i500 (version 1.1.1, Medit, Seoul, Korea) following three different scanning strategies (A, B, C). The scans, following all strategies, were performed twice by examiner 1 and were repeated twice by examiner 2, totaling 180 meshes. Examiner 1, during his first session, was aiming to a detailed scan without time limit, while a time limit of 60 secs (recommended scanning time by Medit) was set for the remaining scans. Additionally, 5 casts were scanned twice with the laboratory scanner in order to evaluate its precision. As defined by the International Organization for Standardization (ISO) 5725-1, accuracy consists of trueness and precision of the used method.[20] Trueness describes systematic error, while precision describes random error.

The Medit Link software (version 2.2) was used for intraoral scanning. The settings were set to ‘mandible scanning’, 16 mm scanning depth and filtering level of 1. The high-resolution option was deactivated. The IOS was calibrated before each scan session, according to manufacturer’s instructions.

In scanning strategy A, which is recommended by the manufacturer, the scan was continuous. It started from the occlusal surface of the lower left posterior teeth followed by the anterior teeth with an alternating labio-lingual movement. Then, the occlusal surface of the lower right posterior teeth was scanned. The scan was completed with the impression of the lingual and labial surface of the arch (Fig. 1a).

In scanning strategy B, the scan was performed in a single uninterrupted motion. It started from the buccal surface with a left-to-right direction, then captured the occlusal surface and finally the lingual (Fig. 1b).

In scanning strategy C, the scan was performed in a continuous labial-lingual motion, with a left-to-right direction (Fig. 1c).

At the end of each scan, scanning time was recorded and the files were post-processed by Medit Link. The options of not filling holes and excluding unreliable data were selected and then files were exported in object file (obj) format.

To compare the impressions acquired with IOS to the reference casts from the laboratory scanner, we used the Viewbox 4 software (version 4.1.0.10 BETA, dHAL software, Kifissia, Greece). The meshes were input into Viewbox 4, without further processing. Each mesh acquired from the Medit Identica consisted of approximately 1.000.000 vertices and 2.000.000 triangles. The corresponding meshes from the Medit i500 consisted of around 140.000 vertices and 280.000 triangles. Each impression acquired from the laboratory scanner (reference impression) was superimposed to the corresponding one from the IOS i500. The superimpositions involved only the crowns of the teeth and not the whole cast and were performed through the iterative closest point algorithm (ICP). The basic settings were: 99% estimated overlap of meshes, matching point to plane, exact nearest neighbor search, 100% point sampling, 50 iterations. Afterwards, the distances between the closest pair of points of the superimposed meshes were computed (around 75.000 distances per cast). The same procedure was followed for each mesh acquired twice from the laboratory scanner.

For the statistical analysis, SPSS statistics (version 26.0 IBM Corp. Armonk, NY, USA) was used. The data were normally distributed. Descriptive statistics were calculated for each superimposition. A General Linear Model was created for the processing of the data acquired from the superimpositions between meshes from IOS and the laboratory scanner. The dependent variable was the mean value of absolute distances between casts and the fixed factors were: examiner, strategy and repeat. Finally, post hoc analysis (Tukey, Scheffe) was conducted to assess which strategy was statistically significantly different. The level of significance was set at $a = 0.05$.

Results

The results regarding the precision of the laboratory scanner are presented in Table 1.

Table 1
Descriptive statistics for evaluating the precision of the laboratory scanner.

Mesh	Mean (± SD)	Median
1	5.1 (± 16.8)	2.8
2	10.0 (± 31.4)	4.7
3	6.6 (± 33.5)	3.3
4	7.5 (± 28.6)	3.7
5	9.6 (± 37.7)	4.0
Values in µm.		

Figure 2 shows the superimposition between two meshes scanned with Identica SE 3D (Medit).

The mean accuracy values of the intraoral scanner were 37.5 (± 12.5) µm, 44.8 (± 17.3) µm and 43.9 (± 20.0) µm, for scanning strategies A, B and C, respectively (Table 2).

Table 2
Mean and Standard Deviation for each scanning strategy, examiner and session.

Scanning strategy	A		B		C	
	E1	E2	E1	E2	E1	E2
S1	26.8 (± 6.5)	39.6 (± 14.3)	29.3 (± 6.1)	47.2 (± 15.7)	27.4 (± 8.6)	48.4 (± 17.5)
S2	35.5 (± 7.6)	48.1 (± 10.2)	45.1 (± 12.1)	57.5 (± 19.8)	34.5 (± 12.5)	65.1 (± 16.3)
Overall	37.5 (± 12.5)		44.8 (± 17.3)		43.9 (± 20.0)	
E1, examiner 1. E2, examiner 2. S1, session 1. S2, session 2.						
Values in µm.						

Examiner 1 got better results than examiner 2 on all strategies. However, there was an interaction between examiner and strategy, since examiner 1 was equally better in strategies A and B but much better in strategy C than examiner 2, who had the worst performance using this strategy (higher error). This fact implies that strategy C might be examiner-sensitive (Fig. 3).

Both examiners achieved less accurate results during the second scan session. Additionally, the second scan session results were similarly less accurate for all scanning strategies. No interaction between examiner and repeat or between strategy and repeat was detected. Strategy A was the most accurate in both sessions.

The General Linear Model demonstrated that the mean value of the absolute distances depends on three factors: examiner, strategy and repeat. In addition, there was a positive correlation between examiner and strategy (Tables 3 and 4).

Table 3
Parameter estimates of the General Linear Model.

Parameter	Coefficient estimate	95% Confidence Interval	p-value
Intercept	36.5	31.5–41.6	0.000
Examiner 2	25.8	19.2–32.4	0.000
Strategy A	0.1	-6.5-6.8	0.965
Strategy B	6.3	-0.4-12.9	0.063
Session 1	-11.2	-15.0 to -7.4	0.000
Examiner 2 * strategy A	-13.0	-22.4 to -3.7	0.006
Examiner 2 * strategy B	-10.7	-20.0 to -1.3	0.026
Values in µm.			
Reference levels: Examiner = 1 Strategy = C, Session = 2.			

Table 4
Tests of Between-Subjects Effects of General Linear Model.

Source	Type III Sum of Squares	df	Mean Square	F	p-value
Corrected Model	23355.3[a]	6	3892.6	23.2	0.000
Intercept	318109.7	1	318109.7	1893.3	0.000
Examiner	14398.6	1	14398.6	85.7	0.000
Strategy	1896.7	2	948.4	5.6	0.004
Session	5611.2	1	5611.2	33.4	0.000
Examiner*strategy	1448.8	2	724.4	4.3	0.015
a. R Squared = .446 (Adjusted R Squared = .426).					
Values in µm.					

Post-hoc analysis demonstrated that strategy A was statistically significantly better and differed from B, C, which were similar (Fig. 4).

Scanning strategy C was faster than A and B (Table 5). The 1st scan session lasted 69 seconds while the 2nd 47 seconds, on average.

Table 5
Average scanning time (± Standard Deviation) for each scanning strategy.

Scanning strategy	**A**		**B**		**C**	
	E1	E2	E1	E2	E1	E2
Session 1	93 (± 16)	53 (± 5)	84 (± 14)	51 (± 5)	80 (± 12)	49 (± 6)
Session 2	48 (± 7)	52 (± 6)	47 (± 6)	47 (± 4)	42 (± 8)	46 (± 6)
Overall	62 (± 21)		57 (± 18)		54 (± 17)	
E1, examiner 1. E2, examiner 2.						
Values in seconds.						

Discussion

In recent years, IOS are considered as a paradigm shift in everyday Orthodontic practice. The main considerations about these systems, besides the high cost, are the accuracy and the required chair time.[21] The accuracy of the impression is regarded as the most important step in digital workflow and thus it should be maximized.[11] Manufactures and researchers aim to increase IOS accuracy in full arch scans, which are essential for the fabrication of clinically acceptable removable or fixed orthodontic appliances. Different scan strategies and extensive scanning software development are investigated to achieve this ambition.[15,18,19] Hence, this study was conducted to examine if different scan strategies, can improve active triangulation IOS systems' accuracy and if so, which strategy is dominant. The null hypothesis that scan strategy does not affect the accuracy of the impression was rejected, since scanning strategy A provided statistically significantly better results. The secondary aim of the current study was to determine if scan strategy can affect IOS performance. A numerical benefit was observed in scanning strategy C, which was 8 seconds quicker per arch than the dominant strategy, but this difference is clinically negligible.

The in vitro design of the current study ensured that scanning conditions were similar for all the scans performed. Since the number of scans performed is high (N = 180), it would have been difficult to maintain the same scanning conditions in an in vivo design with many different patients. In addition, with the in vitro design a high precision reference scan (with trueness of 5.1–10.0 μm), from a laboratory scanner, was acquired. The reference scanner could not be used for scanning the mandibular arch in a clinical environment. Therefore, the same surfaces were scanned with both scanner systems, ensuring that the observed differences in accuracy was attributed only to IOS hardware and software.

We used mandibular casts, without edentulous regions, derived from patients after orthodontic treatment. This may pose limitations in the clinical application of our results. In the oral environment, the clinician is confronted with saliva, blood, patient's movement, limited work field, moving soft tissues, pharyngeal reflexes etc. during scanning.[13,22,23] Undoubtedly, oral mucosa is not an ideal surface since its translucency hinders image-stitching process.[24] Additionally, in clinical practice, ambient lighting can vary and thus interfere with the accuracy of the scan.[25] Moreover, in orthodontic patients, whose dentitions are often malaligned or crowded and have appliances such as brackets which create deep undercuts, scanning might be inaccurate[12,26,27], adding an extra limitation to our study.

Another aspect of the in vitro design worthy of discussion was the casts' construction material. Specifically, casts of type III orthodontic stone (Spyrman, Oinofyta, Greece) were scanned. The physical properties of the scanned substrate impact on the way in which the light is reflected back to the scanner. Trueness and precision of the scanner are significantly affected by reflection, refractive index and translucency of the substrate.[28] IOSs display lower accuracy during the scan of materials with higher translucency.[29] According to Dutton et al.[28], the i500 (Medit) exhibited higher scan trueness, at a statistically significant level, when scanning opaque dentin composite than translucent enamel composite. This was observed only when the high-resolution option was activated. Moreover, stone casts have a rough surface, which increases scanning accuracy, due to minimized light scattering.[30]

Another subject that has not been extensively investigated is the interaction between the examiner and the scanning strategy. In the current study all scans were performed by two examiners. Examiner 1 achieved better accuracy results than examiner 2 on all strategies. This can be explained since examiner 1 was highly experienced and had performed a higher number of scans using this specific IOS, than examiner 2, who was considered less experienced. Previous studies have indicated that examiner experience is associated with digital model accuracy.[31,32]

This study is one of the few to investigate the effect of scan strategy on the accuracy of active triangulation IOS. Active triangulation is a contactless method for acquiring the shape of a 3D object. A light beam is reflected on the oral elements, by a prism in the scanner head. A photo-detector in the IOS's camera calculates the position and orientation of the illuminated element knowing the coordinates (X, Y, Z) of the other two points of view.[16] The measuring accuracy of this method depends on the surface reflectivity of the substrate as well as laser and/or camera occlusion.[33,34] In addition, according to Waldecker et al.[35] small reflection angles are difficult to scan. Active triangulation scanners are also affected by different substrates more than those using confocal microscopy.[28]

Previous studies regarding active triangulation IOSs have reached different conclusions. In 2018, Medina et al.[14] investigated the impact of scanning strategy on the accuracy of four IOS systems using confocal microscopy (iTero, Align Technology Inc., San Jose, CA, USA; and Trios, 3Shape Dental Systems, Copenhagen, Denmark), active wavefront sampling (True Definition, 3M ESPE Dental Products, Seefeld, Germany) and active triangulation technology (Cerec Omnicam, Sirona, Bensheim, Germany). Only a confocal IOS (iTero) was depended on the strategy used. It attained better results, in terms of both trueness and precision, when a sequential strategy (similar to the strategy C of the current study) was followed. In contrast to these results, the active triangulation IOS we examined, was affected by scanning strategy at a significant level and the sequential strategy led to inferior accuracy results. This could be attributed to the different IOS system used, regarding both hardware and software.

All scanning systems use “image stitching” algorithms to create the 3D model. Details of the algorithms are not revealed by the companies, but systematic errors have been reported.[17] In addition, quadrant scans are more accurate than full-arch scans[36,37], implying that extended image stitching affects mesh accuracy. In the current study, we investigated the importance of the starting position on the different scanning strategies. In scanning strategy A, which was statistically significantly better than the other strategies examined, the scan started from the occlusal surface of the posterior teeth. This area is easy to scan and provides enough data if tracking is lost. In scanning strategies B and C the scan started from the buccal surface of the posterior teeth, a region with fewer data due to its simpler morphology. Thus, errors may have been introduced in the image stitching process leading to lower accuracy in these strategies. A previous study[12] has also indicated a relation between the starting point and the accuracy of the IOS, but the different starting points examined were only diametrically opposed in the arch and did not include different tooth surfaces. Furthermore, the scanners used were based on the principle of confocal microscopy. In contrast, Oh et al.[13] noted that the starting position of the scan does not impact on the accuracy of the 3D model. This result was obtained using the same IOS and software as with the current paper but different scanning strategies. One strategy was continuous and the scan started from the occlusal surface of the posterior teeth while the other was segmental and the scan started from the anterior tooth region. Thus, the difference in our results can be attributed to the unsimilar strategies examined.

The accuracy of IOS regarding the individual axes (x, y, z) has not been fully determined.[38] A recent study[13] emphasized that rotations and vertical movements of scanner head should be minimized, since change of direction results in lower values of accuracy owing to disruption of the image-stitching process. In the current study, we also observed significantly lower accuracy in strategy C, in which rotations dominate. Therefore, tilting might be one the reasons leading to the observed difference in accuracy. Interestingly, strategy B, in which the IOS was held mostly horizontally, led to similarly inferior accuracy. This is in agreement with the outcomes of Passos et al.[15], who also validated the dependence of IOS accuracy on scanning strategy, using an active triangulation IOS. They observed that the sequential strategy led to significantly lower results that the dominant strategy, which was mainly linear. However, the accuracy results of the sequential strategy were similar with many other linear strategies. Further studies are required on this subject due to the scarcity of data concerning how IOS software works.

In the current study, the i500 (Medit) reached error below 50 μm (37.5–44.8 μm), using any of the three scanning strategies. Other in-vitro studies that investigated the error of complete arch scans, using this IOS, obtained similar accuracy results (52.3–66.3 μm).[39,40] This error is clinically acceptable in the field of Orthodontics since it does not affect diagnosis and treatment planning. Intra-arch linear measurements, such as intercanine width and Bolton analysis, may be reliably achieved using an IOS. [41][42]Considering that the average adult male mandibular arch's inercanine width is 24.8 mm[43], any IOS error would be less than 0.2% and thus clinically insignificant. Regarding the overall Bolton ratio, the possible bias of 0.05 mm is not clinically significant since it is lower than the observed difference of 1.5–2.2 mm often noted when the Bolton ratio is traditionally calculated in a plaster model.[44,45] These observations are consistent with previous studies examining the reliability of IOS on linear measurements necessary for orthodontic diagnosis.[26,42,46,47] Additionally, with the achieved accuracy the clinician can use IOS to monitor tooth movement during and post-treatment.

As far as other orthodontic procedures are concerned, the achieved accuracy of 50 μm may be considered important. In procedures such as interproximal enamel reduction (IPR), 50 μm are considerable compared to the average planned IPR (100–500 μm per tooth)[48] and may affect the treatment result. In addition, concerning the inter-arch measurements, 50–100 μm are considered as a contact[49], while the traditional articulating paper has a thickness of 80 μm. Thus, the recording of occlusal contacts could be inaccurate.[50, 51] However, conclusions cannot be drawn since bite registration constitutes a complex procedure not examined in this study. Further research is needed to verify the accuracy of these measurements.

As to 3D printing and fabrication of orthodontic appliances, the accuracy of 50 μm is also important but clinically acceptable. Numerous studies have proved that digital workflow can manufacture single unit fixed dental prostheses within the 120 μm maximum marginal misfit.[52–55] The error of 50 μm observed in the current study accounts for approximately 42% of the acceptable misfit. Hence, the importance of IOS accuracy and all factors affecting it, is emphasized. It would be reasonable to presume that since digital workflow permits the fabrication of accurate single unit dental prostheses, this technology may be widely used for the fabrication of clinically acceptable -and in terms of accuracy- orthodontic molar bands. In addition, 50 μm are insignificant for 3D printing dental casts suitable for diagnosis and manufacturing of orthodontic appliances.[56, 57] Accuracy of orthodontic casts should be within 500 μm clinically relevant limit.[58, 59] The achieved accuracy also permits the direct 3D printing of retainers, within the 500 μm clinically acceptable discrepancy[58, 60], comparable to the traditional vacuum-formed.[61] Furthermore, 3D printed transfer trays for indirect bracket bonding can be produced, thus enabling accurate bracket placement with error bellow 500 μm.[62] A previous study has demonstrated that error < 250 μm in the positioning of brackets in incisors and < 500 μm in the other teeth is clinically acceptable. [63]According to the American Board of Orthodontics' Objective Grading System, differences bellow 500 μm in teeth alignment and leveling of marginal ridges, do not change the grade. [59]

Based on the results of our study, we may elicit the following clinical recommendations. The i500 (Medit) can acquire clinically acceptable scans, using any of the three strategies. However, the manufacturer's recommended scanning strategy is the most preferable since it attained significantly better accuracy in comparison to the other strategies performed. This is clinically important as intraoral scanning is one of the first steps of the digital workflow and inaccuracies in this step can lead to summation of errors in the following steps. Additionally, scanning strategies that include the rotation of IOS head, should be followed with caution since they might be examiner-sensitive. Scanning the anterior region of the arch proved to be challenging in many casts and thus repeated scanning could be necessary. This may be associated with factors, such as the labial inclination of the anterior teeth and the presence of undercuts from the occlusal view which lead to inferior scanning accuracy, mostly in the interproximal surfaces. This was noticed on the superimpositions of all scanning strategies (Fig. 4) and confirms previous results.[9,12] For instance, this can be more evident in patients with severe crowding and can possibly introduce errors in appliance manufacturing.[12] Furthermore, a detailed scan without time limit is suggested, as we observed more accurate results during the first scan session similarly for all strategies. (1st session: 69 s, 2nd session: 47 s).

In vivo studies designed to examine the impact of scanning strategy on the accuracy of active triangulation IOS are required for the application of our results in clinical practice. In addition, future in vivo studies on IOS scanning strategy should include IOSs based on all image acquisition principles, such as confocal microscopy and active wavefront sampling to further understand the interaction between scanning strategy and scanner technology. Future research may concentrate on the IOS software, especially the image-stitching algorithm and the guided scanning strategies, that could lead to improvements in accuracy. Certainly, studies with more and differently experienced examiners should further investigate the interaction between the examiner and the scanning strategy.

Conclusions

Considering the in vitro limitations of the current study, the following results were obtained:

1. IOS i500 (Medit) produces digital complete-arch impressions with an average accuracy below 50 μm, using any of the examined scanning strategies.
2. The accuracy of the specific IOS is affected by the scanning strategy. The manufacturer's recommended scanning strategy is more accurate in a statistically significant level. Definitely, the observed difference of 6–7 μm, between the recommended and the alternative strategies, is negligible and does not seem to affect clinical practice.

Declarations

Authors' contributions: NG conceived the theme, designed the study, performed literature search, acquired the data, drafted the manuscript and created figures. CG performed literature search, acquired the data, drafted the manuscript and created figures. DH performed literature search and statistical analysis, supervised, edited and reviewed the manuscript. All authors read and approved the final manuscript.

Additional Information:

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Tables

Mesh	Mean (±SD)	Median
1	5.1 (±16.8)	2.8
2	10.0 (±31.4)	4.7
3	6.6 (±33.5)	3.3
4	7.5 (±28.6)	3.7
5	9.6 (±37.7)	4.0

Table 1: Descriptive statistics for evaluating the precision of the laboratory scanner.

Values in µm.

Scanning strategy	A		B		C	
	E1	E2	E1	E2	E1	E2
S1	26.8 (±6.5)	39.6 (±14.3)	29.3 (±6.1)	47.2 (±15.7)	27.4 (±8.6)	48.4 (±17.5)
S2	35.5 (±7.6)	48.1 (±10.2)	45.1 (±12.1)	57.5 (±19.8)	34.5 (±12.5)	65.1 (±16.3)
Overall	37.5 (±12.5)		44.8 (±17.3)		43.9 (±20.0)	

Table 2: Mean and Standard Deviation for each scanning strategy, examiner and session.

E1, examiner 1. E2, examiner 2. S1, session 1. S2, session 2.

Values in µm.

Parameter	Coefficient estimate	95% Confidence Interval	p-value
Intercept	36.5	31.5-41.6	0.000
Examiner 2	25.8	19.2-32.4	0.000
Strategy A	0.1	-6.5-6.8	0.965
Strategy B	6.3	-0.4-12.9	0.063
Session 1	-11.2	-15.0 to -7.4	0.000
Examiner 2 * strategy A	-13.0	-22.4 to -3.7	0.006
Examiner 2 * strategy B	-10.7	-20.0 to -1.3	0.026

Table 3: Parameter estimates of the General Linear Model.

Values in μm.

Reference levels: Examiner=1 Strategy=C, Session=2.

Source	Type III Sum of Squares	df	Mean Square	F	p-value
Corrected Model	23355.3[a]	6	3892.6	23.2	0.000
Intercept	318109.7	1	318109.7	1893.3	0.000
Examiner	14398.6	1	14398.6	85.7	0.000
Strategy	1896.7	2	948.4	5.6	0.004
Session	5611.2	1	5611.2	33.4	0.000
Examiner*strategy	1448.8	2	724.4	4.3	0.015

Table 4: Tests of Between-Subjects Effects of General Linear Model.

1. R Squared = .446 (Adjusted R Squared = .426).

Values in μm.

Scanning strategy	A		B		C	
	E1	E2	E1	E2	E1	E2
Session 1	93 (±16)	53 (±5)	84 (±14)	51 (±5)	80 (±12)	49 (±6)
Session 2	48 (±7)	52 (±6)	47 (±6)	47 (±4)	42 (±8)	46 (±6)
Overall	62 (±21)		57 (±18)		54 (±17)	

Table 5: Average scanning time (±Standard Deviation) for each scanning strategy.

E1, examiner 1. E2, examiner 2.

Values in seconds.

Figures

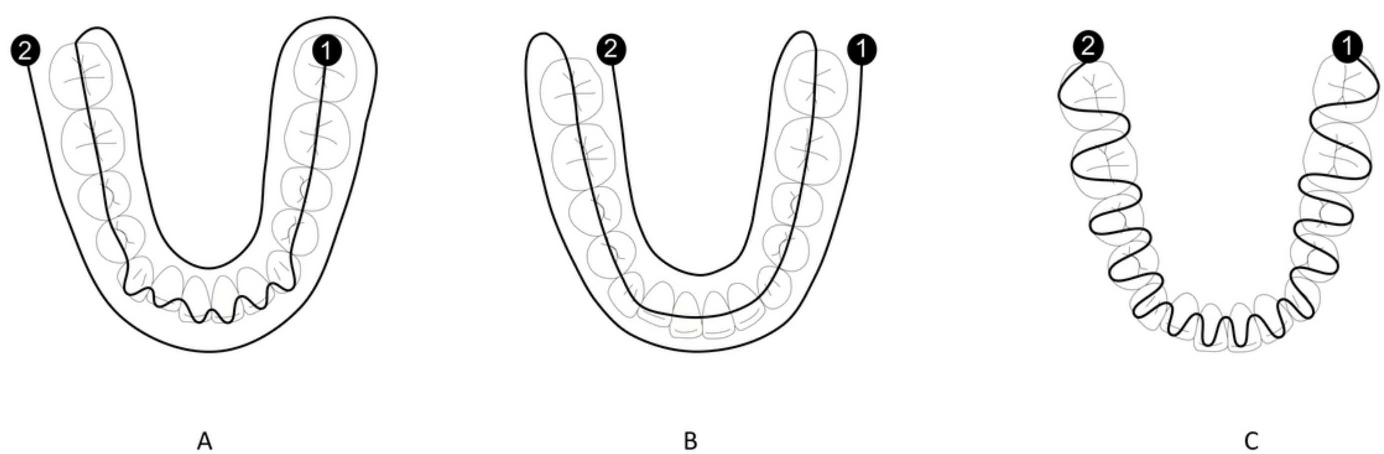

Figure 1

(a) Scanning strategy A. (b) Scanning strategy B. (c) Scanning strategy C. The scan starts at point 1 and proceeds with a continuous movement to point 2.

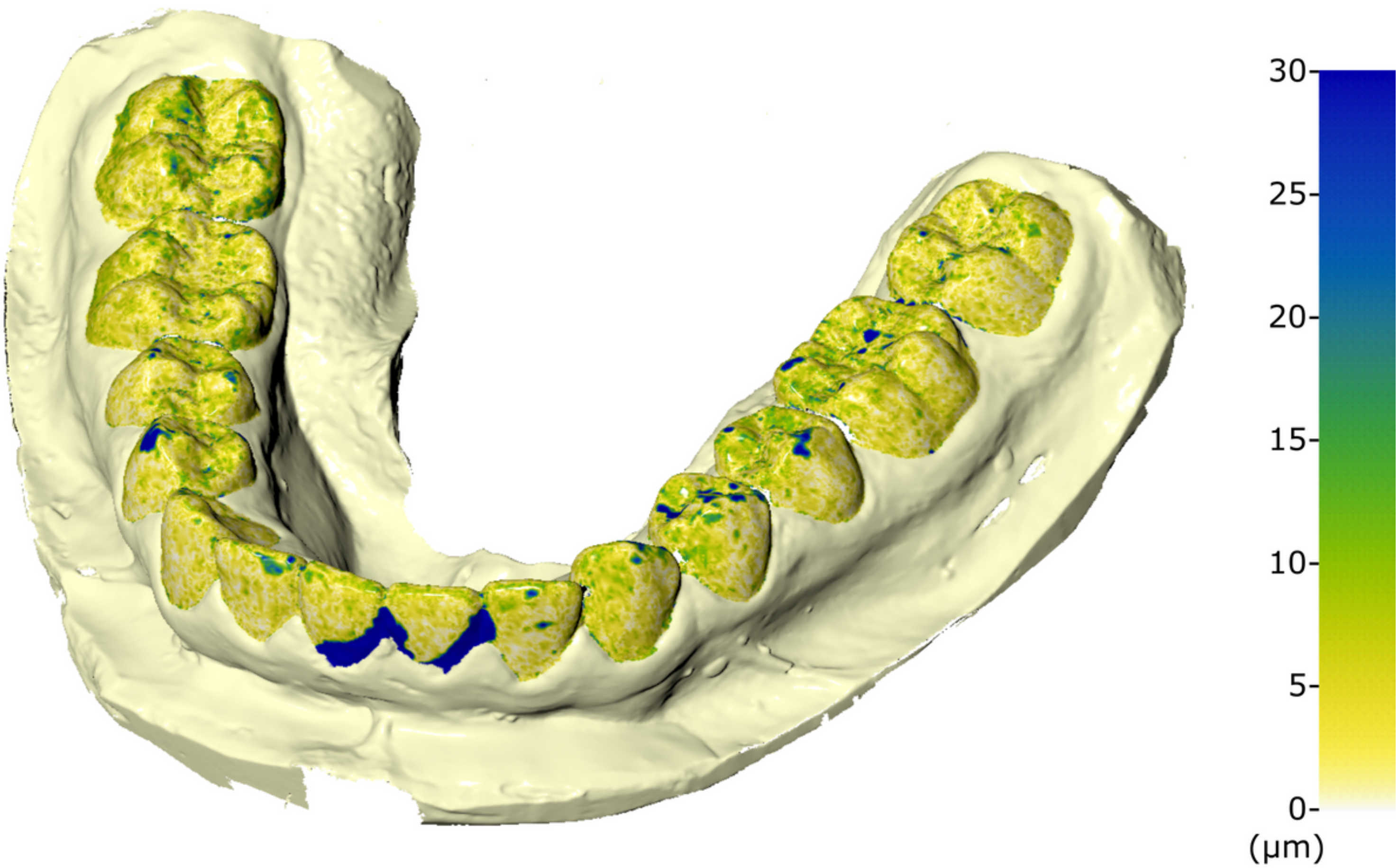

Figure 2

Superimposition of 2 impressions of the same cast, both acquired with the laboratory scanner. The color-map indicates its precision. Values in µm.

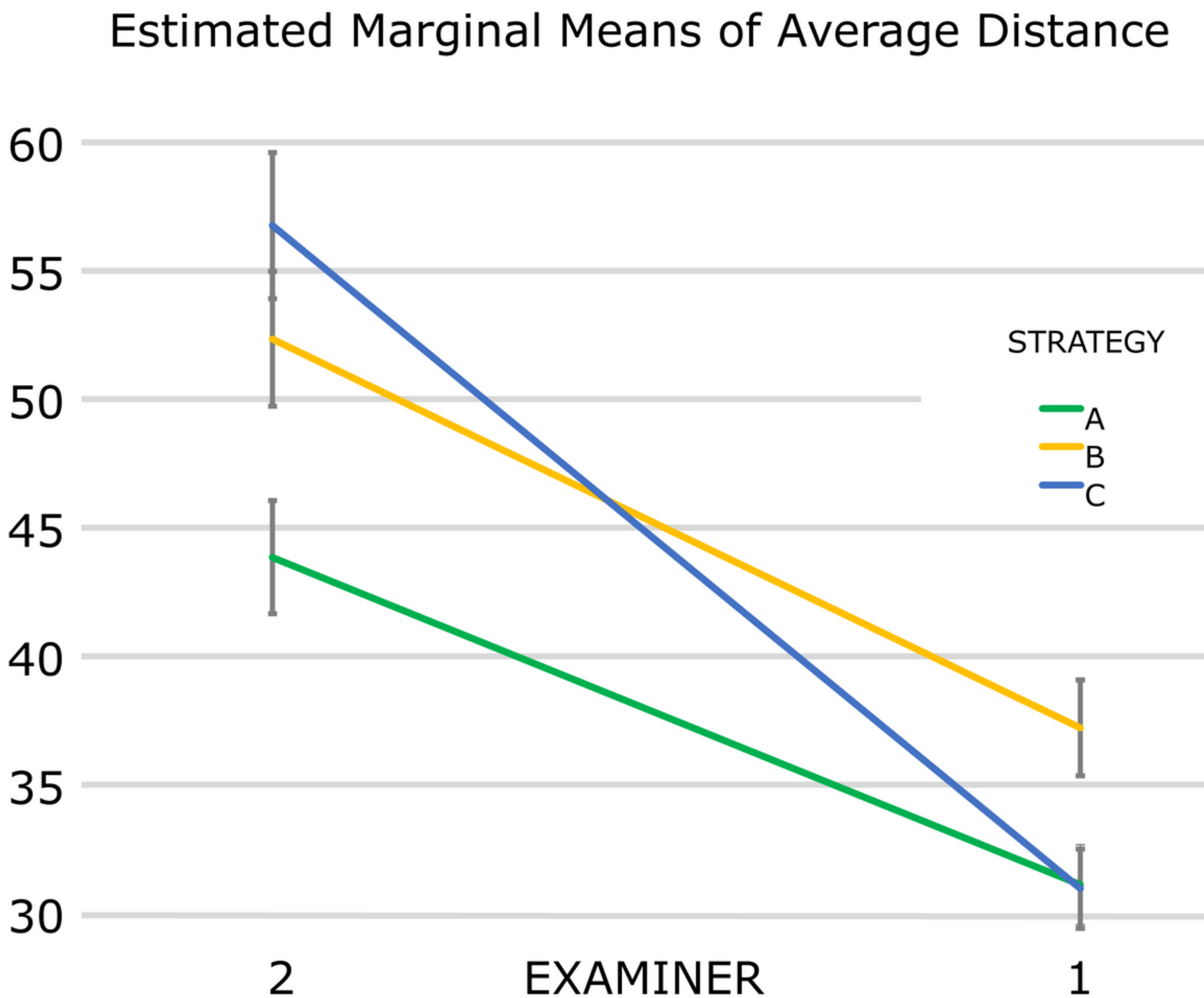

Figure 3

Comparison of the achieved accuracy between the examiners for each scanning strategy. Error bars: 95% confidence interval. Values in µm.

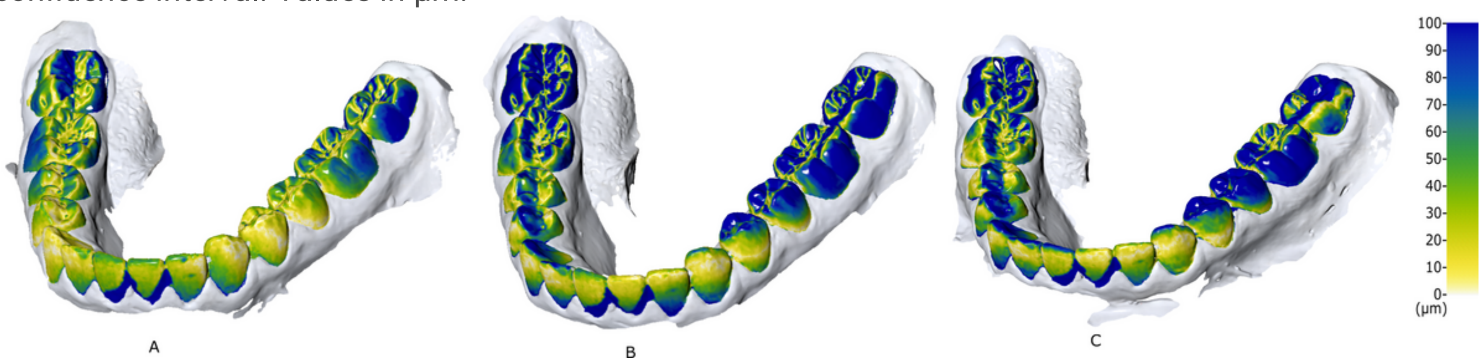

Figure 4

Representative superimpositions for each scanning strategy (A, B, C). The color-map indicates the trueness of Medit i500. Premolars and molars of the lower left quadrant presented inferior trueness, probably because this region was the scan's starting point for all strategies. Values in μm.