Accuracy of IOS in Full-Arch Dentate Patients Compared to CBCT Cast-Scanning. An In-Vivo Study

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Accuracy of IOS in Full-Arch Dentate Patients Compared to CBCT Cast-Scanning. An *In-Vivo* Study

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ABSTRACT

Twenty fully-dentate patients were enrolled in the study.Full-arch maxillary and mandibular PVS impressions were acquired using stock metal trays and the dual mix technique. A full-arch maxillary and mandibular intraoral scanner (IOS) was also obtained using the Trios IOS. The impressions were cast and subsequently scanned using a Planmeca Promax cone beam computed tomography (CBCT) scanner. The casts were also scanned in a Desktop Scanner for reference(7series Dental Wings). DICOM files from the CBCT device were converted into stl files. The.stl files from the CBCT and IOS devices were compared for accuracy against the reference files from the Desktop Scanner using a 3D surface measurement software. Statistical analysis was carried out using SPSS software. Trios had a smaller error (median = 39μm) than CBCT (median = 62μm),a statistically significant difference between the 2 modalities (z=-4.6, p<0.005).Concerning the IOS, the anterior teeth presented with a smaller error (42±16μm) as opposed to the posterior teeth (47±16μm), a significant difference (t(39)=-2.4, p=0,019). There were no significant differences in IOS mean accuracy between maxilla and mandible or between left and right quadrants. Full-arch digitization using the Trios IOS is significantly more accurate compared to CBCT scanning of the relevant plaster models. Anterior teeth Trios IOS is statistically more accurate compared to posterior teeth IOS.

INTRODUCTION

Intraoral digital scanning (IOS) was introduced in Dentistry in the mid 1980's but it is in the recent years that it has gained momentum due to the developments in the fields of digital scanning technologies and 3d printing. IOS is the direct way of digitizing a dental arch and it comprises of an intraoral camera (hardware) that projects light that it is then recorded as individual images or video and compiled by proprietary software.[1] Confocal microscopy and active triangulation are the two most widely used image acquisition technologies in IOS today.[1-3] The main advantages of IOS include reduced diagnosis and treatment time, increased patient comfort, no physical storage room required and increased accuracy of prosthesis's fit.[4]

Opposed to IOS, indirect dental digitization requires taking a conventional impression and digitizing it with the use of either a desktop scanner or a cone beam computed tomography (CBCT) device. Alternatively, the impression can be poured and the resulting stone cast can be digitized in the same manner. Digitizing the stone model with a high precision lab scanner and then proceeding to digital designing and manufacturing the prosthesis (CAD/CAM process) is still the recommended method of choice for the production of the vast majority of prosthetic work worldwide.[5–7] Nevertheless, in the relevant literature, the high accuracy of indirect digitization by means of cast scanning is matched by that of direct IOS especially for the single and short-spanned fixed prostheses[8–12] although controversy still exists regarding full arch accuracy of the IOS process and how it compares to that of a laboratory scanner. There is recent available literature suggesting that, for the fully dentate arch, IOS is equally accurate compared to indirect digitizing by means of a laboratory desktop scanner [13–17] but there is also evidence suggesting the contrary.[18–23] The same controversy is observed in fully edentulous arches with multiple implants where IOS is shown to be equally accurate compared to laboratory bench scanning in some studies[24–26] whereas the opposite is reported in other studies.[5]

Similarly, the available literature on dental impression scanning accuracy with either a lab scanner or a CBCT device does not appear to be conclusive. There is available data indicating the superiority of IOS against impression scanning in terms of accuracy[5,27,28] but there is also available research postulating the opposite.[13,29]

The relevant literature on the comparison of accuracy between IOS and CBCT scanning of stone casts is scarce. In the only *in-vitro* study available, Wesemann *et al.* report that bench scanning of a resin cast using the Trios (3shape) scanner is statistically more accurate than CBCT scanning of the stone cast produced from the same resin cast following an impression taking and stone pouring procedure.[5]

Trueness and precision are two terms often quoted in the literature on direct and indirect dental digitization. According to the ISO international standard number 5725, trueness is the ability of a measurement or measuring device to match the actual value of the quantity being measured whereas precision is the ability of a measurement or measuring device to consistently repeat a particular measurement.[30] Trueness and precision are both a measure of accuracy.

The majority of the existing studies on full arch IOS accuracy in either dentate or edentulous patients rehabilitated with multiple implants are *in vitro* as opposed to the available *in vivo* studies.[31] The main reason for this is the cohort of patient and operator related confounding factors that play a crucial role in the determination of accuracy of an intraoral scanner *in vivo* such as, light scattering from metallic restorations, saliva, blood or crevicular fluids, patient mobility, tongue mobility, posterior areas accessibility. Other factors that may play a role in determination of accuracy are mainly technical ones such as, IOS scanner resolution, scanning protocol, image stitching and post processing algorithms but also study design and data interpretation.[32,33] Controlling these confounding factors is easier in an *in-vitro* study design setting and this may explain the plethora of laboratory studies, although the results may not always be directly applicable to the clinical situation.

The purpose of the present *in-vivo* study was to measure the full arch trueness of a direct digitization process by means of IOS (Trios) and the trueness of an indirect digitization method by means of scanning the stone casts from the same cohort of patients by a CBCT device (Promax 3D Mid) and, ultimately, to compare the two methods together.

Therefore, one main hypothesis was formulated concerning the difference between the IOS and the CBCT device followed by 3 secondary hypotheses concerning solely the meshes derived from the IOS device. The main null hypothesis was that there was no statistically significant difference in the full arch trueness of the IOS as compared to that of the CBCT device when the resulting stone casts are scanned by the latter. The second null hypothesis was that there was no statistically significant difference in the IOS trueness between anterior and posterior teeth. The third null hypothesis was that there was no statistically significant difference in the IOS trueness between maxillary and mandibular teeth. Finally, the fourth hypothesis was that there was no statistically significant difference in the IOS trueness between left and right quadrants.

MATERIALS AND METHODS

The present *in vivo* study was conducted in a private practice setting and followed the Helsinki Declaration. Written informed consent was acquired from each volunteer. A sample size calculation based on an estimated effect size (difference in trueness) between the IOS and the CBCT of 125μm (SD = 200μm, α=0.05, β=0.8) was initially performed. Inclusion criteria were fully dentate condition up to second maxillary and mandibular molars with no mouth opening restriction, no TMJ disorders and no gag reflex.

Twenty consecutive patients satisfying the inclusion criteria with a mean age of 40 years were enrolled in the study. The design is depicted schematically *(Figure 1*).

CLINICAL PROTOCOL

For every patient, an analogue and a digital full arch impression procedure was carried out in the same appointment using a randomization process with the use of the spinning wheel of a roulette. For the analogue procedure, a dual mix impression technique was utilized using appropriate size perforated stock metal trays and putty and wash addition-cured silicone materials without tray adhesive. For the digital impression, a Trios color Pod with a specific software version was employed *(Table 1*).

Extraoral mixing time for the putty silicone was 20 seconds. After mixing, the putty silicone was applied uniformly on the tray, the light body silicone was injected onto the putty, the teeth were lightly air-dried and the tray was inserted in the mouth. Intraoral setting time was 4 minutes according to the manufacturer. Upon setting, the tray was removed from the mouth with a single vertical move. Both a single maxillary and mandibular impression were obtained from each patient. All impression procedures were completed by the same operator (GM). Each impression was disinfected using an aldehyde free spray (TGspray) and send to the lab for pouring.

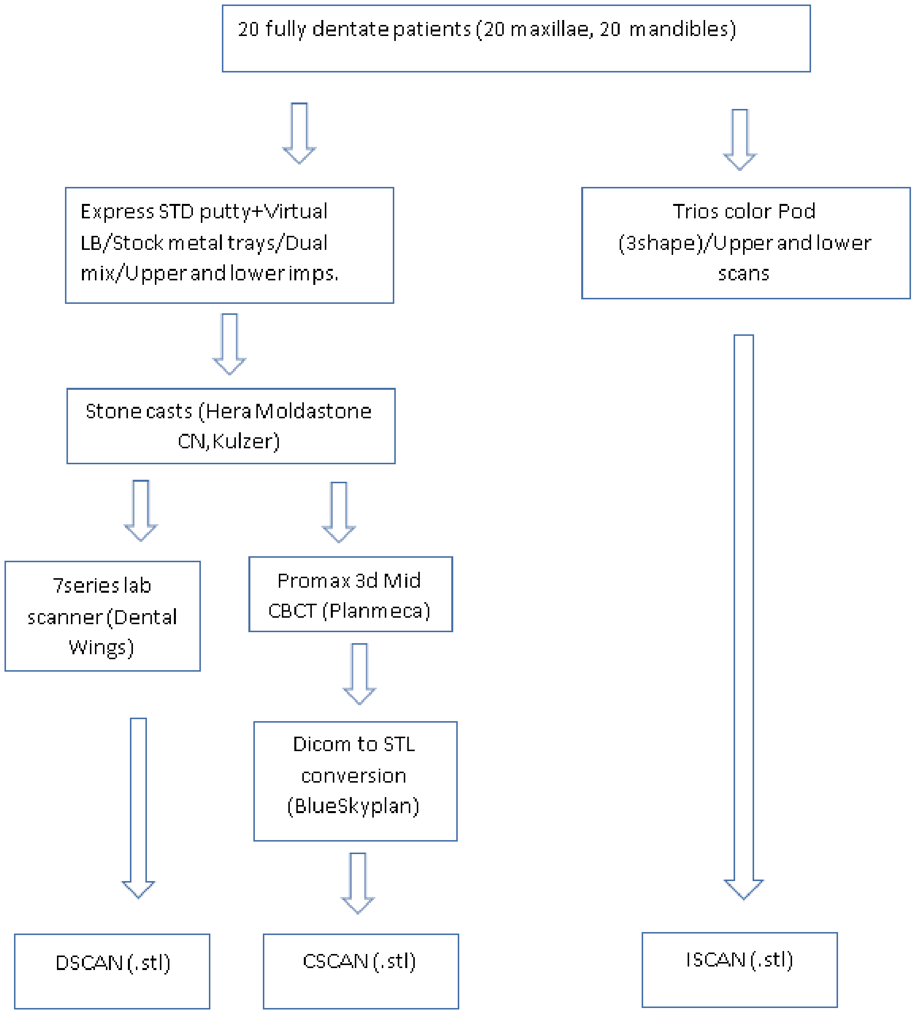

Figure 1: Schematic representation of study protocol

Table 1. Impression procedures

Impression method	Technique	Materials
Analogue impression	Dual mix with perforated stock metal trays. No tray adhesive used.	Putty silicone (Express STD, 3M ESPE) Light body silicone (Virtual Light Body, Ivoclar Vivadent)
Digital Impression	Official scan strategy[34]	Trios color Pod (Dental Desktop v.1.4.7.4, 3shape)

For the digital impression, the official scan strategy was employed as suggested by the manufacturer to ensure optimal accuracy.[34] For the maxilla, scanning initiated from the upper left posterior area and proceeded occlusally towards the right posterior area, then turned buccally towards the contralateral side and the scan was completed on the palatal side with a left to right direction of scan. For the mandible, scanning initiated from the posterior left quadrant and proceeded occlusally towards the contralateral side, then turned lingually towards the left quadrant and was completed on the buccal side with a left to right movement according to the official scan strategy. Digital scanning was performed by the same operator (GM). Each patient received a single maxillary and mandibular scan. All digital impressions were automatically post-processed by the software before been exported and saved as .STL files (ISCAN).

LABORATORY PROTOCOL

Within 1 hour of obtaining each conventional intraoral impression, it was poured with a Type IV dental stone (Hera Moldastone CN) using dose determination and vacuum mixing with distilled water. The gypsum was allowed to set for 24 hours before the impression was removed and the stone cast trimmed and prepared for scanning. A total of 20 maxillary and 20 mandibular stone models were produced. Each stone model was scanned once by a laboratory desktop scanner (7series, Dental Wings). This scanner has a large scanning volume (140mmx140mmx140mm), five axis of freedom, 2 high-speed cameras and an accuracy of 15μm as reported by the manufacturer. The .STL scans from this lab scanner served as the reference (DSCAN).

In order to estimate the repeatability of our reference scanner, the stone model of the first case (case 1, maxilla) was scanned with the laser scanner (gold standard) 10 times. The 10 meshes were simultaneously cropped and were finely registered with each other, following the same procedure as later described for the main study. This resulted in 90 pairs of meshes where each of the meshes acquired, was sequentially used as reference. The average standard deviation of the differences of the meshes was used as a measure of repeatability for the desktop scanner.

The stone models were consequently scanned by a CBCT device (Promax 3D Mid) using the exposure parameters shown in table 2. Each model was scanned once. The resulting DICOM files from the CBCT cast scanning were inserted into the BlueSkyPlan software and converted into .STL files. The segmentation value for the conversion of the DICOM files to triangular meshes was set to 2155 Hounsfield units, since this value has been found to provide the most accurate representation of the stone model when the particular combination of software, CBCT device and exposure parameters is used.[35]

Three sets of triangular meshes were therefore available for comparison for each stone model totaling 120 .STL files. Those produced by the intraoral digital scanning process (ISCAN), those produced and converted by the CBCT scanning process (CSCAN) and those produced by the desktop lab scanning process (DSCAN) which served as reference.

For every stone model, three (3) meshes (ISCAN, DSCAN and CSCAN) were imported for computational manipulation in a dedicated mesh and point cloud handling software (CloudCompare, v2.10 alpha). The triangular mesh which was derived from the laser scanning was used as a reference and no other manipulation was permitted. The IOS and CBCT originating meshes were then initially roughly registered together using a minimum (3-5) number of points and then were again finely registered with each other using the iterative closest point (ICP) algorithm, calculated on a sample of 50000 pairs of points. This resulted in the 2 meshes for each stone model overlapping one another. The meshes were then simultaneously cropped thus leaving only the teeth and 3-5 mm of the gingiva. The end result was 2 triangular meshes representing the same model, with clinically relevant remaining anatomy. Finally, each of these meshes was again separately, roughly and finely registered to the DSCAN (gold standard). This resulted in 2 registered to the gold standard different meshes for each model *(Figure 2)*.

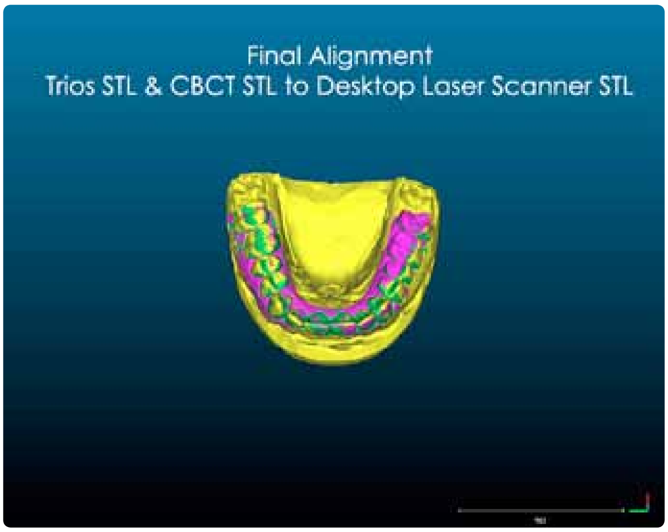

Figure 2: Final alignment of .STL files

For each registered to the gold standard mesh, IOS and CBCT derived, the absolute distance of each and every face of the mesh to a point on the surface of the reference (gold) standard was computed indicating the difference that exists between this mesh and the gold standard. The median value of the differences and the interquartile range (IQR) for each pair, was noted. Qualitative representations of these differences were depicted in color maps *(Figure 3)*.

Finally, the IOS originating meshes were divided by 1) separating the anterior part of the dentition (distal side of canine to distal side of canine) from the posterior part and 2) separating the dentition into left and right segments with a line crossing the area between the incisors. Again, for each IOS mesh the absolute distance of each and every face of the mesh to a point on the surface of the reference standard was computed. The median value of the differences and the interquartile range (IQR) for each pair, was noted.

STATISTICAL ANALYSIS

Determination of data outliers was conducted by inspection of Boxplots of the difference scores between the various groups (IOS vs CBCT, IOSMaxilla vs IOSMandible, IOSAnterior vs IOSPosterior, IOSLeft vs IOSRight), whilst tests of normality were accomplished with the help of Shapiro -Wilk test.

Descriptive statistics were calculated and inferences were drawn using Wilcoxon Signed-Rank test where the normality did not hold and paired t- test, otherwise. Results were considered significant for $p<0.05$. SPSS version 20 was used for the analysis.

Table 2. CBCT device exposure parameters

	KV	mA	Time (sec)	Voxel size (μm)
Exposure parameters	80	12,5	15	150

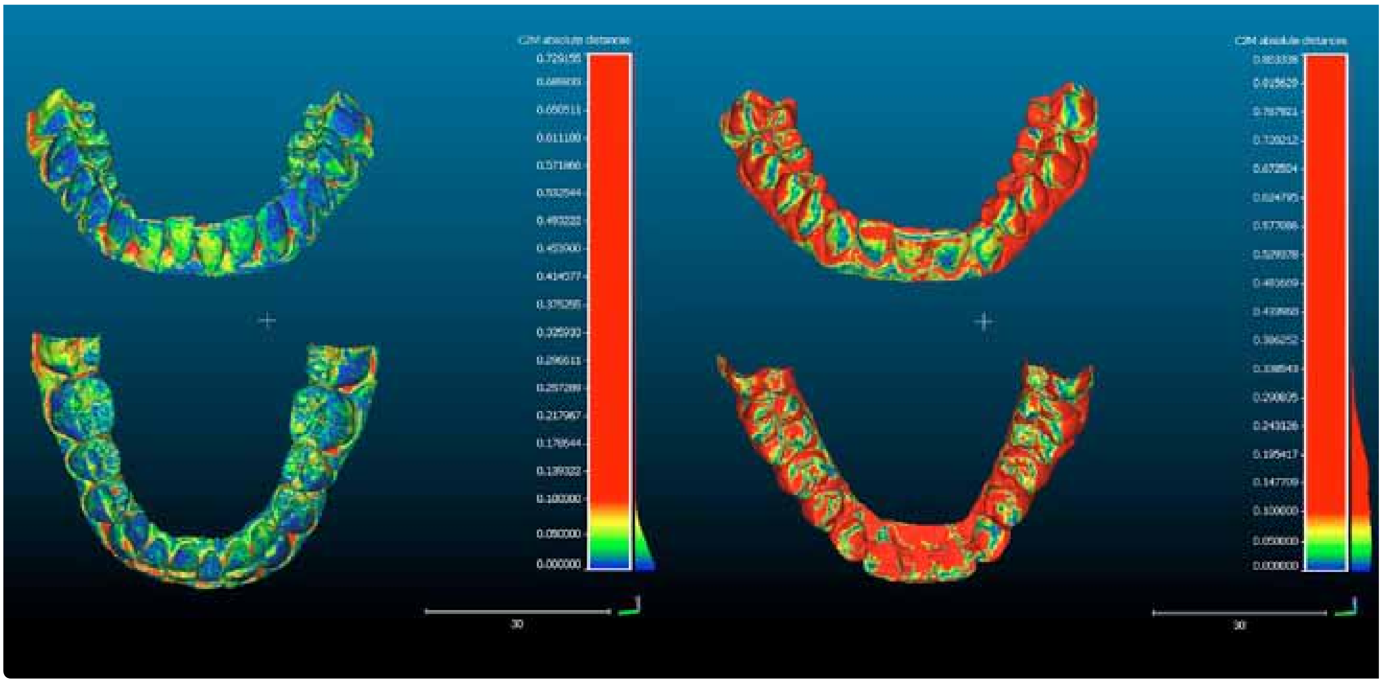

Figure 3: Colour maps indicating low (left) and high (right) deviations between compared .STL files

RESULTS

On the dataset of cases estimating the difference between the IOS and the CBCT, one extreme outlier was detected that were more than 3 box-lengths from the edge of the box in the boxplot and the case was removed from the analysis, resulting in the final analysis of 19 cases for this comparison. For the rest of the datasets, no extreme outliers were revealed.

Tests of normality determined that normality did not hold for all tested parameters with the exception of the difference scores of anterior/posterior IOS meshes comparison. Therefore, the Wilcoxon signed-rank test was used for all tests except the comparison of differences of the anterior and posterior parts of the IOS meshes which was conducted with the help of the paired t – test.

Regarding the comparison between IOS and CBCT scanning, the results indicated a statistically significant difference in trueness between the two methods of digitization (z =4.36, p <0,005). Median (IQR) ISCAN full arch trueness was 38, 6μm (10) whereas median CSCAN was 61,7μm (10) *(Table 3).* Therefore, the first null hypothesis was rejected.

Box plot of median, IQR and 1.5IQR values for ISCAN and CSCAN measurements are depicted in figure 4.

Regarding TRIOS trueness in anterior and posterior segments, results indicated a higher trueness for the anterior teeth (41,8μm, SD 16,2) compared to the posterior (47,0μm, SD 16,3). This difference was statistically significant (t(39)=-2.4, p=0,019). The second null hypothesis was therefore rejected. Results are shown in table 4. Box plot of median, IQR and 1.5IQR values are shown in figure 5.

Regarding TRIOS IOS trueness between maxillary and mandibular teeth, the results did not show any statistically significant difference, as did the results between left and right quadrants *(Table 5)*. Therefore, the third and fourth null hypotheses were not rejected.

Regarding the desktop laboratory scanner, our mean standard deviation between the 90 pairs of meshes tested was.[4] 1 μm, therefore the repeatability of the scanner could be considered excellent. A mean value of 16μm for the differences between the meshes was found and being the average deviation from truth (0 mm) it can be considered a measure of accuracy; it is similar to the value provided by the manufacturer of the laser scanner (15μm).

Table 3. ISCAN vs CSCAN full-arch accuracy values

TOTAL	TRIOS (μm)	CBCT (μm)	Significance
Median	38,6	61,7	
IQR	10	10	
			Wilcoxon Signed-Rank test, p=0,005

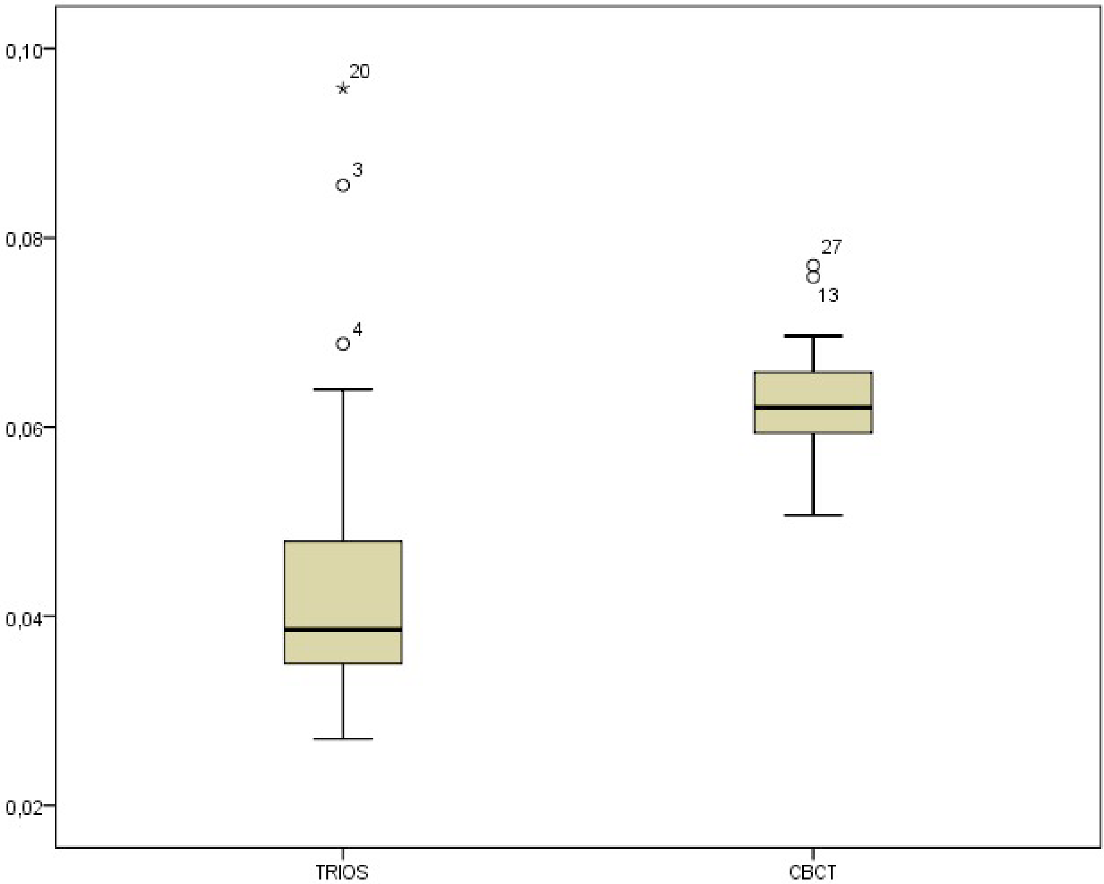

Figure 4: Box plot for TRIOS and CBCT trueness values (μm)

Table 4. Mean and SD trueness of TRIOS IOS in anterior and posterior segments

TRIOS IOS	Anterior (μm)	Posterior (μm)	Significance
Mean	41,86	47,07	
SD	16,24	16,34	
			t-test, p=0,019

DISCUSSION

The results of our study indicate an average full arch trueness of 38,6μm for the Trios IOS procedure. This is in agreement with previous *in vivo* studies that have reported a mean Trios IOS full arch accuracy for dentate patients ranging between 37-52μm.[13,22,36,37] Intraoral scanning accuracy has been shown to be affected by various clinical and technical parameters such as presence of saliva or blood, patient movement, metallic restorations, scanner resolution, scanning protocol and predominantly operator's learning curve.[36,38-40] Controlling these factors *in vivo* is extremely difficult and this may, partly, be responsible for the range in full arch accuracy measurements in identical IOS devices between studies. In our study, one experienced operator performed all digital and conventional impression steps with strict adherence to moisture control and scanning protocols in order to eliminate operator-specific and procedural variations. Nevertheless, there was no standardisation regarding presence of metallic restorations on teeth and their effect on trueness was not studied in the present report.

Our results on higher full arch trueness of the Trios IOS compared to CBCT cast scanning are in agreement with the only available study in the relevant literature. Wesemann and coworkers compared full-arch Trios IOS accuracy to Promax 3D Mid cast scanning full-arch accuracy and concluded that direct digitization with the Trios IOS (mean accuracy 27-50μm) is statistically more accurate compared to indirect digitization using cast scanning by the aforementioned CBCT device (mean 63-236μm), although they measured distances and not 3D spatial deviations. The method of distance measurements between predetermined points has also been employed in another study on the accuracy of the Promax 3D Mid device in stone cast scanning, making direct comparisons with our 3D spatial deviation measurements impossible.[41] Additionally, the CBCT exposure parameters for the

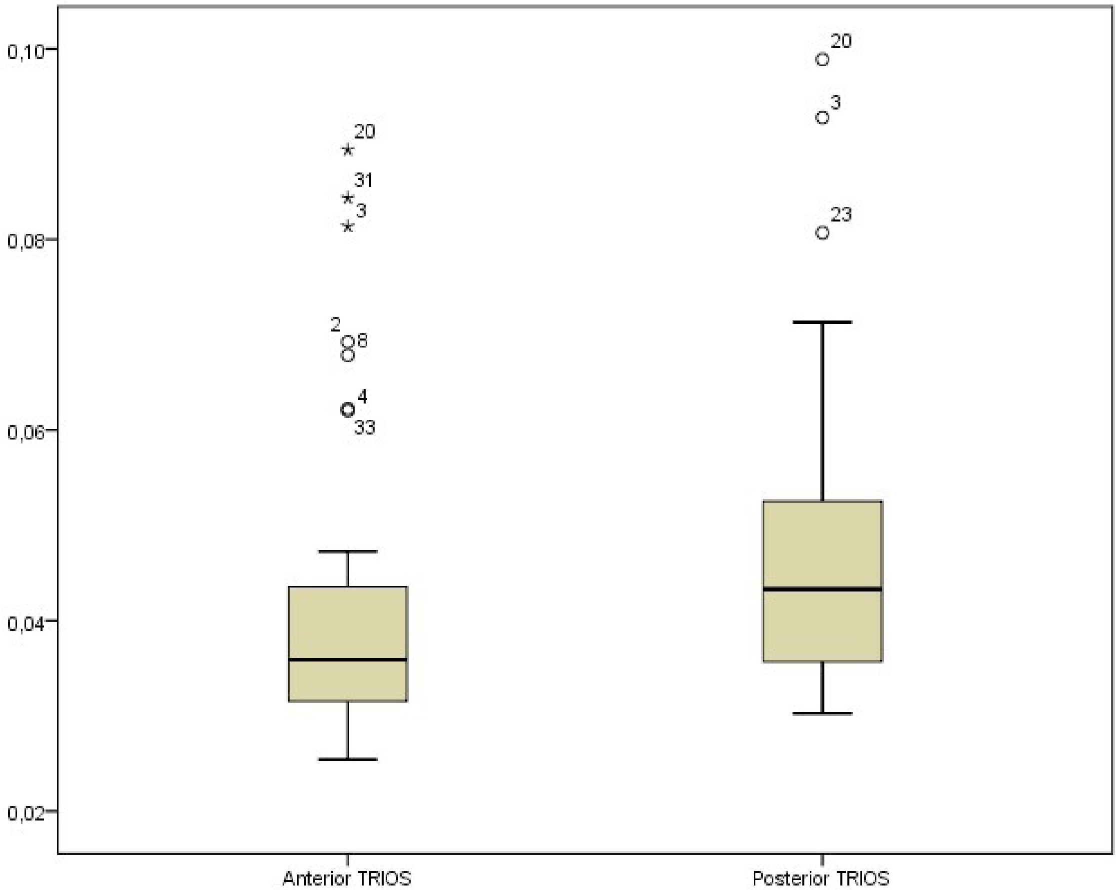

Figure 5: Box plot for TRIOS anterior and posterior trueness values (μm)

Table 5. Median and IQR trueness of TRIOS IOS in Maxilla/Mandible and Left/Right quadrant

TRIOS IOS	Maxilla (μm)	Mandible (μm)	Left (μm)	Right (μm)
Median	40	40	41,34	39,8
IQR	20	10	10	20
Significance	Wilcoxon Signed- Rank test, z = 0.478, p =0,633		Wilcoxon Signed- Rank test z = 0.054, p= 0.957	

aforementioned studies are not the same as the ones used in the present study, therefore direct comparisons on accuracy values are again not valid.

The results of the present study on the trueness of Trios IOS on anterior and posterior teeth are in full agreement with the existing *in-vivo* literature.[13,34,37,42] The anterior teeth are generally easier to capture and clinical confounding factors such as metallic restorations, accessibility of the scanner tip, moisture control and tongue and cheek displacement can be readily controlled by the operator or are non-existent. Deviation of full arch intraoral scanning towards the posterior quadrants has also been described in *in-vitro* studies with other IOS systems, indicating that this maybe a non device-specific error. [29, 43-45]

In the present study, there was no statistically significant difference in IOS trueness between the left and right quadrants both in the maxilla and the mandible *(Table 5*). Previous *in-vitro* studies however[5,46] have reported a build-up in the image stitching error during full-arch scanning, especially when the midline is crossed, that accumulates in the contralateral side. Wesemann and coworkers[5] reported that the last 3 teeth of the contralateral side are responsible for 46,6% of the total deviation observed.The authors attributed this effect to the scanning scope used and the image stitching algorithms within the software but do not provide any information regarding the scanning strategy they used. In our study, we employed the official scan strategy for the particular IOS device which is reported to produce the most accurate results.[34] Also, Wesemann *et al.*[5] and Anh and coworkers[46] used single resin casts in bench studies with well-controlled confounding factors whereas we performed *in-vivo* scanning prone to errors. Technical factors aside, further investigation is needed into the effect of various clinical confounding factors (saliva, blood, metallic restorations, patient movement) onto scanning accuracy between left and right quadrant.

At present, the conventional workflow in prosthodontics includes an elastomeric impression taking stage and a stone cast pouring laboratory stage followed by digitization of the stone model by a laboratory desktop scanner. This workflow is not free of inaccuracies. Dimensional changes of the impression material and the gypsum have been proven to produce deviations as high as 97μm.[47] Also, the inherent inaccuracy of the lab scanner as purported by the manufacturer (15μm) has to be calculated into the equation. These factors have to be taken into account when the results of this study are interpreted. In an effort to reduce dimensional error, we employed the one stage dual mix technique using putty and wash addition cured silicone. This intraoral impression procedure is very often used in the conventional prosthodontic workflow and has been proven to be very accurate.[48] To further adhere to the analogue workflow with reduced errors, we poured the impressions with a high accuracy low expansion type IV dental stone following a strict laboratory protocol.

The limitations of our study include the use of only one IOS device, only one CBCT device and only one set of impression materials due to financial restrictions. We also did not have access to an industrial high accuracy reference scanner so a laboratory desktop scanner was used for reference. Nevertheless, every effort was made to replicate the actual clinical and laboratory conditions of the digital and conventional prosthodontic workflows, in an attempt to maximize clinical relevance of our results. More well-controlled *in vivo* studies are needed to investigate the accuracy of the full arch digital cast compared to the conventional stone cast as dentists shift their attention towards the digital workflow and its merits.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be made:

1. Direct digitization of dental arches using the TRIOS IOS has statistically significant higher trueness compared to ProMax 3D Mid CBCT scanning of the resulting stone casts.
2. TRIOS IOS *in vivo* has statistically significant higher trueness in anterior as compared to posterior teeth in full arch scans.
3. TRIOS IOS *in vivo* has clinically relevant high trueness in full arch dentate digital impressions.

MANUFACTURERS' DETAILS

- Trios Pod, 3shape, Denmark
- Planmeca 3D Mid, Planmeca, Finland
- Express STD, 3MESPE, USA
- Virtual Light Body, Ivoclar Vivadent AG, Liechtenstein
- TG spray, Technical & General, United Kingdom
- Hera Moldastone CN, Heraus Kulzer, Germany
- 7series , Dental Wings, Canada
- Blueskyplan, BlueSkyBio, USA
- Cloudcompare, Cloudcompare.org, USA
- SPSS, IBM, USA.

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