Metrol. Meas. Syst., Vol. 31 (2024) No. 1, pp. 73–83
DOI: 10.24425/ mms.2023.148541

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POLSKA AKADEMIA NAUK

METROLOGY AND MEASUREMENT SYSTEMS
Index 330930, ISSN 0860-8229
www.metrology.wat.edu.pl

UNIFIED PROTOCOL TO EVALUATE INTRAORAL SCANNER RESOLUTION, TRUENESS AND PRECISION: THE RTP-PROTOCOL

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Abstract

Over the past decade, studies published on the evaluation of *intraoral scanners* (IOSs) have mainly considered two parameters, precision and trueness, to determine accuracy. The third parameter, resolution, not much studied, seems essential for an application in dentistry.

Objective: The objective of this preliminary study is to create an original method – a *Resolution-Trueness-Precision* (RTP) protocol to evaluate these three main parameters – resolution trueness and precision – at the same time.

Material and Method: A ceramic tip with particular and calibrated dimensions is determined as the reference object and its mesh recorded with a scanning microtomograph, and compared with the one extracted to the IOS. It is the particular geometric shape of the object that will make it possible to simultaneously assess: resolution, trueness and precision.

Results: The results have shown a mean resolution of 79.2 µm, a mean for trueness of 17.5 and a mean for precision of 12.3 µm. These values are close to previous results published for this camera. So, the RTP protocol is the first including the three parameters at the same time. Simple, fast and precise, its application can be useful for comparisons between IOSs within research laboratories or test organizations. Finally, this study could be a first step to create a reference kit for practitioners allowing them to control the quality of their IOS over time.

Keywords: resolution, accuracy, trueness, precision, intra oral scanner, Micro CT.

1. Introduction

In the 1970s François Duret proposed the use of *intra oral scanners* (IOSs) as an alternative to conventional dental impressions [1]. An IOS device measures the positions of many points in 3D while taking an optical image. Then, it is possible to build a 3D mesh, i.e., a set of faces whose

Article history: received July 11, 2023; revised August 28, 2023; accepted October 24, 2023; available online February 14, 2024.

vertices are the measured points and to project on it the image in order to get a three-dimensional representation of the teeth structure. Over the years, various applications of this data acquisition system have been developed in different aspects of dentistry, such as orthodontics or prosthodontics treatments [2–6]. The performance of an IOS for optical impressions in fixed prostheses has been widely studied in recent years. A systematic review has concluded that digital IOS impressions have a better accuracy when compared to conventional impressions and are acceptable for clinical practice [7–11].

Following the international standard (ISO 5725-1), accuracy is defined by trueness and precision [12]. Trueness is the deviation of the object scanned with an IOS from its real geometry and precision represents the deviation between the repeated scans of the same object performed with the same IOS in the same conditions (see Fig. 1). The camera technology, the scanning conditions and the software properties have an influence on those two parameters.

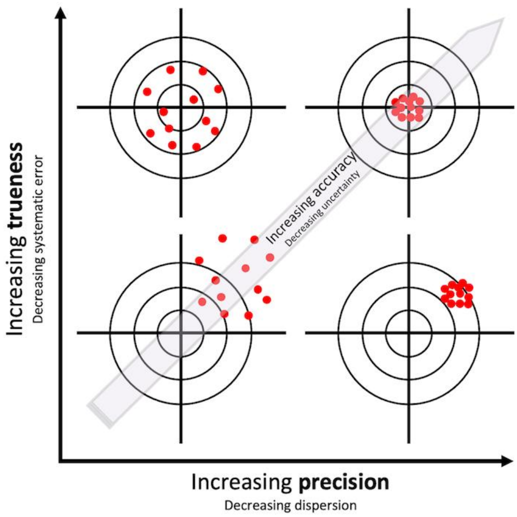

Fig. 1. Representation of precision, trueness and the resulting accuracy. Each red point represents a measure.

Precision and trueness are considered by most authors as the main criteria of IOS quality and are generally studied individually [13–17].

However, in clinical practice, some areas of interest, such as preparation ridges, are difficult to scan. This problem is related to the resolution of the IOS, which is defined by the smallest change in the quantity being measured that causes a detectable change in the corresponding indication [18]. Singularly, resolution is rarely provided by the manufacturers or is substituted by an indirect indicator based on the number of vertices of the image acquired by the IOS device [19]. Notice that the number of vertices of the 3D mesh cannot be directly related to the resolution, as it depends mainly of the algorithm which reconstructs the mesh software. Actually, only very few publications precisely evaluate the resolution, whereas it is an important element to assess IOS quality [20].

In fact, the most adapted way to perform an IOS assessment would be to evaluate from a single manipulation the resolution, the precision and the trueness in a unified protocol. It is the aim of this preliminary study in which we describe what we named the *Resolution-Trueness-Precision* (RTP) protocol.

For this, there was created a reference object with a particular geometry, which makes it possible to evaluate the minimum distance between points that an IOS can acquire. At first, the reference object is scanned by both a micro-CT to obtain a reference mesh and the IOS being evaluated [15, 21]. Next, meshes obtained with the evaluated IOS mesh and the reference ones are compared to assess Resolution, Trueness and Precision. To validate the potential of this protocol, we performed experiments with a Primescan camera (Dentsply Sirona®, Charlotte, USA) which is a reference for many practitioners [22–26]. All scans were performed by the same experienced operator following the scanning path reco mmended by the manufacturer in order to limit inter-operator variability.

2. Material and methods

2.1. Reference object preparation

The reference object is a ceramic tip. It is a point-shaped object with a thin tip at the extremity (See Fig. 2A).

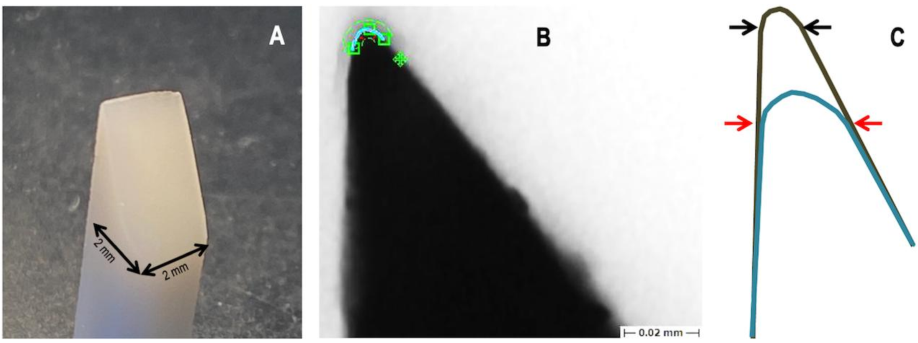

Fig. 2. a) Ceramic tip. b) Tip profile recorded with an optical measuring machine. c) Scheme of resolution in IOS; in our study: the black arrows indicate the actual shape of the tip, whereas red arrows show the shape recorded with the IOS due to the resolution limit.

The tip was prepared by longitudinally sectioning a Vita Mark II feldspathic ceramic blocks (Vita Zahnfabrik) for CAD-CAM systems, with a high-speed diamond saw (Isomet 2000). The 2 mm × 2 mm × 4 mm match like sample was then obliquely cut to create the pointed tip. The cut face was polished with abrasive discs with up to 1200 grit followed by polishing with diamond pastes of 0.25 and 0.1 μm particle sizes using a polishing machine (Escil). Our sample was ultrasonically cleaned in a distilled water bath. Verification of sharpness was performed with an Excel 502 Multisensor Measuring machine (Windsor). See Fig. 2B. The tip was made of a material chosen to be as close as possible to the appearance of tooth enamel. CAD/CAM ceramic materials are similar to the enamel and are used for their aesthetic properties in dentistry. Ceramics for restorative dentistry also permit to mill the reference object quite easily, with optical properties close to the tooth which also makes them suitable for our RTP protocol. Moreover, the dimensions were selected to obtain a macroscopic and recordable object similar to a tooth, while being not too large to be easily and quickly scanned.

2.2. Reference mesh

Our reference mesh was performed with micro-CT tomography of the tip. The system used was EasyTom 150 kV (RX Solution, Chavanod, France). Resolution (voxel size) was set to 5,4 micrometres with an error of the measure lower than 0.5 micrometre. The X ray source had a voltage of 70 kV, an intensity of 66 mA and, additionally, an aluminium filter was placed in front of the X ray generator.

2.3. Micro CT mesh construction

16-bit tiff microtomography slice images (1,315 files) were processed by Fiji software (v1.51, National Institutes of Health). The threshold value, corresponding to distinction between air and ceramic, was determined using the grey shade mean value of the internal material of the tip. Then, 16-bit images were transformed into the 8-bit format to permit thresholding and binarization. Plugin 3DViewer in Fiji software was used as it allows reconstructing the 3D mesh, visualization of 3D surface, and exportation of such mesh in an STL binary file. The reconstruction algorithm provides a mesh resolution in the range of the voxel size.

2.4. IOS mesh extraction and comparison

IOS meshes were obtained from the Primescan software 5.0. Then, they were exported to MeshLab v2022.02 (Istituto di Scienza e Tecnologie dell'Informazione (ISTI), Italian National Research Council, Italia), to compute the RTP parameters.

2.5. Resolution

In this study, we assumed that the smallest detail recorded by IOS was the smallest distance of two points of the mesh belonging to the two faces of the tip (see Fig. 4C). Such distances were measured several times, and their mean was considered as the Resolution. IOS meshes were opened with MeshLab, and the distance tool of this software permits manual selection of the points of interest. For each mesh recorded with IOS or micro CT, 40 measurements were collected and averaged.

2.6. Trueness

Trueness was studied through point to point registration between the mesh recorded with IOS and the reference mesh recorded by the reference high-resolution micro-CT system (see Fig. 4B). To align similar meshes, each time a *region of interest* (ROI) was selected.

The registration was performed with MeshLab, by fixing one mesh and defining manually some point landmarks on each part of the two meshes. Then, the MeshLab algorithm automatically computed the optimal position of the other in order to minimize the distances. This algorithm converges with 3 or 4 iterations. The CloudCompare software measures, for a given mesh, the projected distance of every vertex on each triangle face of the other mesh. The micro CT mesh is then projected on the IOS mesh. Thus, the points of one mesh are projected on the other mesh and all the projection distances are averaged; the distances are exported in a file and measurements were extracted with excel.

2.7. Precision

Precision was measured by registration between IOS meshes and then, projection of the vertex on the face. The variability of measurements was evaluated with four meshes of the tip (Fig. 4A). We superimposed them, two at a time, with the same method as for trueness, i.e., the registration was done in the MeshLab Software and the cartography of distances was performed in the CloudCompare software (Version 2.10-alpha, EDF R&D, France). We extracted 6 lists of values for each comparison.

3. Results

3.1. Mesh

Scans of the tips, based on microtomography or directly recorded with the IOS, exported in STL files, were visualized, processed and measured with MeshLab, as explained above. The numbers of vertices and faces depends on the ROI chosen for registration. For the IOS, the number of vertices is in the range of 3000 and 6000, and from2.5 to 3.8 million for the micro CT extracted meshes. The meshes and types scanned are shown in Fig. 3A and 3B. The measurement of distance between the meshes, by projection, is illustrated by a distance map in Fig. 3C and 3D. The look-up table allows to link the colour to a distance, in mm.

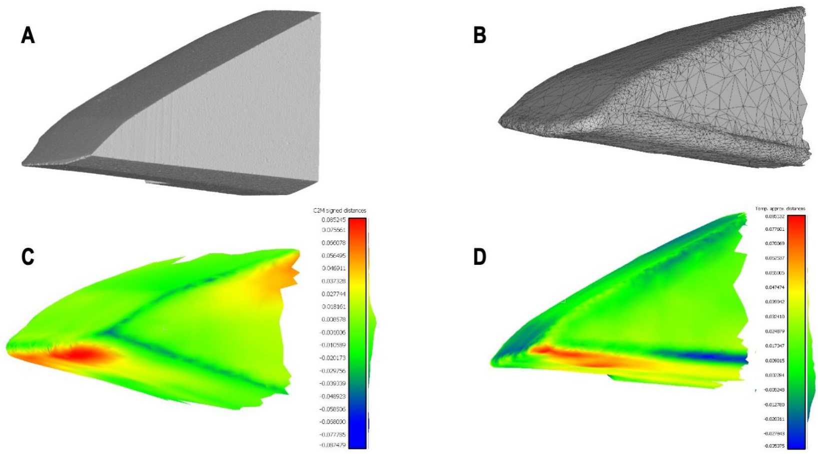

Fig. 3. a) mesh of the tip scanned with the microtomograph, b) mesh of the tip scanned with the Primescan, c) example of distance cartography between mesh clouds vertices of Primescan and microtomography to measure trueness, d) example of distance cartography between two IOS meshes for precision measurement; (the look-up table unit is one mm).

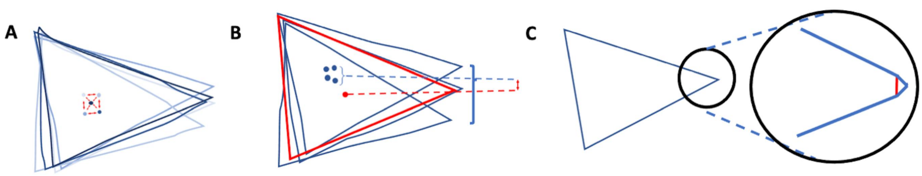

Fig. 4. Scheme of measures recorded to evaluate, with one object, the three parameters: a) precision where the blue rim represents the mean value for each triangle recorded and compared two by two. b) trueness: all the IOS meshes are aligned with the reference one (in red) to get a reference position. We then compute the mean distance between the IOS meshes, c) solution, the red line represents the minimum distance between the two faces of the tip.

3.2. Resolution and trueness

Table 1 presents the median and mean distances between two faces of the tip, considered as resolution in our study. Those measures are compared to the distance found with the mesh extracted from microtomography: mean 25.5, median 25.8 and SD 8.0 µm. Median, mean and standard deviation values from the four meshes extracted from the Primescan IOS were compared. Table 1 also reports median and mean of trueness (distance between the IOS and the micro-CT mesh).

As expected, each resolution measured is far from the data extracted from microtomography. The amplitude of difference between the two measures of the mean from the IOS are around 10 micrometres, and the standard deviation represents around 25% of the mean.

Table 1. Resolution and trueness for each mesh recorded by the Primescan IOS. Resolution: distance between two planes of tip, measured on mesh. Trueness: mean distance between the mesh recorded by the IOS and one extracted from the micro-CT grey shade image.

	Mesh 1 Primescan			**Mesh 2 Primescan**			**Mesh 3 Primescan**			**Mesh 4 Primescan**		
	Median (µm)	*Mean* (µm)	*SD* (µm)	*Median* (µm)	*Mean* (µm)	*SD* (µm)	*Median* (µm)	*Mean* (µm)	*SD* (µm)	*Median* (µm)	*Mean* (µm)	*SD* (µm)
Resolution	72.9	72.0	18.9	83.6	83.4	22.9	78.7	80.2	13.0	78.5	81.3	20.9
Trueness	16.2	27.1	24.0	14.9	15.1	9.3	11.5	13.2	8.7	17.3	17.2	9.7

3.3. Precision

To evaluate precision, distances comparison two by two of each four meshes recorded by IOS are reported in Table 2. This table represent the repeatability of our system, the deviation between two measures. With the Primescan system, measures of the mean range from 7 to 17 micrometres. These values need to be compared to usual value of practitioner.

Table 2. Mean, median and SD distances between each mesh recorded with Primescan IOS, two at a time.

Mesh	**1 vs 2**	**1 vs 3**	**1 vs 4**	**2 vs 3**	**2 vs 4**	**3 vs 4**
Mean (µm)	17.4	17.3	13.5	10.7	7.3	8.0
Median (µm)	12.7	14.0	12.0	8.7	5.9	5.8
SD (µm)	17.2	14.4	9.7	10.3	5.9	7.6

4. Discussion

In recent literature, several studies have applied well known techniques [27]. Those experiments differ depending of the reference scanner used, number of scans, number of teeth of the full arch, or the instrument used to create a reference for comparison. Numerous papers have been published on the topic of IOS performance and particularly on the accuracy attained t through mesh registration [9, 18, 28]. Some protocols studies use several precision control methods as using a vernier calliper or microtomography (micro-CT) [14]. Actually, micro-CT appears as a reference method to verify the IOS accuracy and performances [15, 21, 29]. Moreover, some authors using an *extraoral scanner* (EOS) have noted an influence of teeth surface condition on the accuracy [16]. Other methods, based on triangulation principles, are also described, but principally for the full arch [30].

Despite a large number of publications about the IOS accuracy, resolution is not really studied at the moment. This fact is due to the ease of accessibility to accuracy, with meshes obtained with the micro-CT or IOS and then aligned together. Resolution and trueness can appear close in

*Metrol. Meas. Syst.,*Vol. 31 (2024), No. 1, pp. 73–83
DOI: 10.24425/ mms.2023.148541

certain circumstances, but trueness is a distance between the mean value of measure and reality. In the case of a tip, or a small object recordable by an IOS, the difference between the measure and the real object is due to the impossibility to record under a critical size. In the case of a sharp tip, the distance between the edge of the two planes represents this difference, between which IOS could just mean the mesh to create a curve.

Such characteristics are not given systematically by IOS manufacturers. Frequently, these characteristics are confused with the number of vertices of the acquired mesh. In 2018, a study tried to link resolution and accuracy [19]. The authors took resolution as the number of “points” by mm2, but number of pixels, points or vertex could be artificially increased by software interpolation, not the resolution, because of the capacity of a 3D device to change its measurement at a minimal change in the volume of the field of view recorded. Indeed, for a same object recorded at one time, some part could have more or less density of points in a mesh. For these reasons distance between points could not be accepted as equivalent to the resolution.

Conventionally, a sample characterized by a sharp part is used to calculate the trueness and precision. The specificity of the RTP-protocol is to use the sharp part to evaluate the minimal distance between two planes recorded by the IOS. So, resolution, trueness and precision (RTP) are evaluated at the same time.

The range of values shown in Table 1 and 2 is consistent with previous study. Indeed, the trueness values previously reported, based on mesh registration, are 18 µm [13], 9.67 µm [31], 17.7 µm (SD 3.6 µm) [32], 17.3 µm (SD 4.9) µm [23], but others studies give values quite far from those results: 33.9 µm (SD 7.8 µm) [34] and 56 µm (SD 6.25 µm) [33]. The same studies give a range of values more dispersed with a large standard deviation (when they are reported) for the precision: 3.6 µm [13], 10.73 µm [31], 17.3 µm [23], 25.5 µm (SD 5.1 µm) [32], 31.3 µm (SD 10.3 µm) [34], 68.5 (SD 39.5 µm) [33]. These last results indicate a large fluctuation in values. It depends on object recorded and the conditions of scanning. They are additional arguments for having a reference object with known dimensions, reproducible, for round-robin test in a laboratory, and finally, in the dental office.

We could consider using our sample as a benchmark to validate the RPT of new IOSs. This protocol would free us from possible dependent operator interaction and manufacturers could transparently communicate the resolution values. Finally, several parameters must be evaluated to establish precise conditions for scanning, to reproduce results and avoid some bias due to a gesture of the operator. Moreover, a well-designed specific sample of known size with specific geometry and dimension provided with its reference mesh could help the practitioner and research laboratories to compare their results with a reference mesh.

5. Conclusions

In this study, we demonstrate that the three main parameters for evaluating an IOS can be measured at the same time, with an optically readable object. Another advantage of the protocol presented is the repeatability of the experiment. We use the Primescan camera in our experiments as several studies of accuracy and resolution were available but no specific feature was used. It could then be generalized to any IOS. The next step of this preliminary stage will be creation of a benchmark for testing several IOSs actually used in a dental office. An improvement of this protocol, however already exploitable, would provide t laboratories with a possibility to quickly assess IOS performances. It would be the first step to create a known and controlled dimension object to control the evolution of IOSs over time, directly in the dental office.

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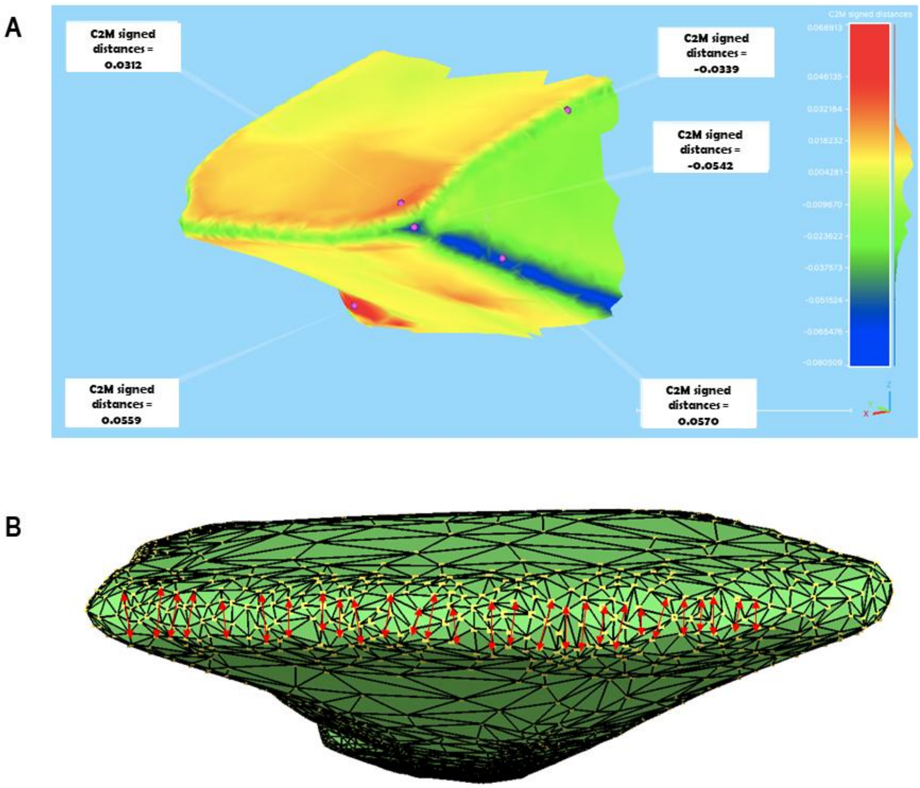

Supplementary Fig. 1. a) Example of mesh registration, with some points selected, with a distance associated. This distance is the length between a vertex and the point corresponding to the projection of this vertex on the other mesh. All these distances are averaged to evaluate the trueness of the IOS. b) Example of measurements to evaluate the resolution, i.e., the distance between a vertex on the edge of a face and another, on the other face.

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DOI: 10.24425/ mms.2023.148541

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