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

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Abstract

Over the past decade, studies published for the evaluation of intraoral scanners (IOS), have mainly considered two parameters, precision and trueness, to determine accuracy. The third parameters, the resolution, not much studied, seems essential for an application in dentistry.
Objective: The objective of this preliminary study is to create an original method (RTP protocol) to evaluate these three main parameters - resolution trueness and precision- in 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 micro tomograph, and compared with the one extracted to the IOS. It is the particular geometric shape of the object that will make it possible to assess at the same time: resolution, trueness and precision.
Results: Results shown a mean resolution of 79.2 µm, a mean for trueness of 17.5 and a mean for the precision of 12.3 µm. These values are close to previously 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 IOS 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* (IOS) as an alternative to conventional dental impressions [1]. A 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 which vertices are the measured points and to project on it the image in order to get a tridimensional representation of the teeth structure. Over the years, various applications of this data acquisition system were developed in different aspects of dentistry, as in orthodontics or prosthodontics treatments [2]–[6]. The performance of IOS for optical impressions in fixed prostheses has been widely studied in recent years. Systematic review has concluded that IOS digital impression have a better accuracy compare to conventional impressions and were acceptable for a 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.

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Precision and trueness are considered by most authors as the main criteria of IOS qualities 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 manufacturers or is substituted by an indirect indicator based on the number of vertice of the image acquired by the IOS device [19]. Notice that the number of vertices of the 3D mesh can not be directly related to the resolution, as it depends mainly of the algorithm which reconstructs the mesh software. Actually, just very few publications evaluate precisely the resolution whereas it is an important additional element to assess IOS qualities [20].

In fact, the most adapted way to perform an IOS 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, it 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. In a first time, the reference object is scanned both by micro-CT to obtain a reference mesh and by the evaluated IOS [15], [21]. In a second time, meshes obtained with the evaluated IOS mesh and the reference one 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 experimented operator respecting the scanning path recommended by the manufacturer in order to limit inter-operator variability.

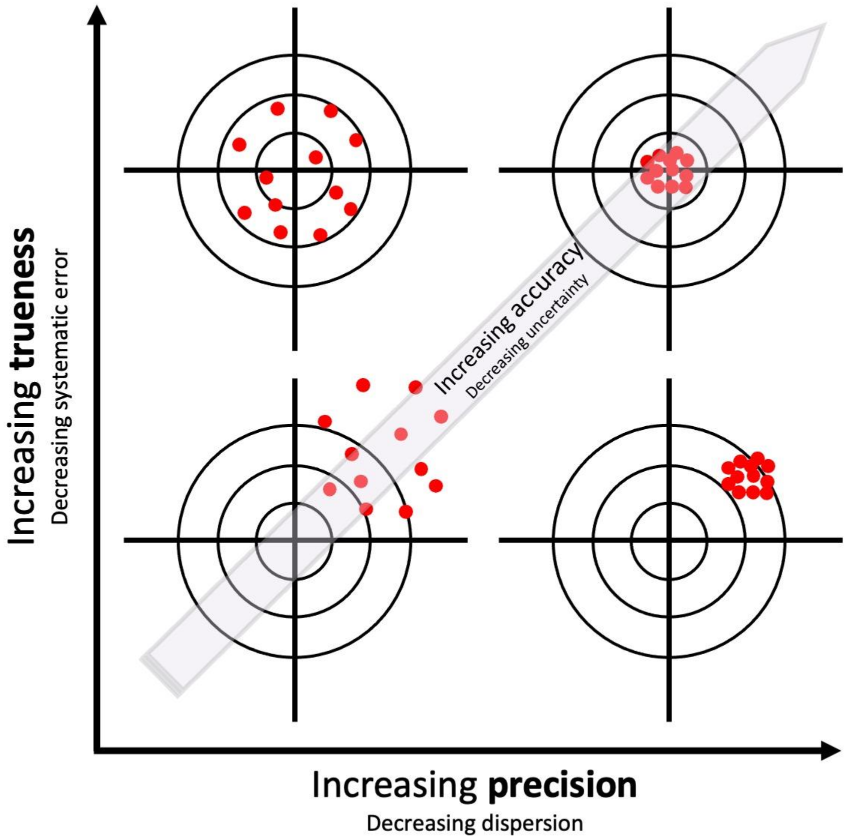

Fig. 1. Representation of precision, trueness and the resulting accuracy. Each red point represents a measure.

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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. 2-A).

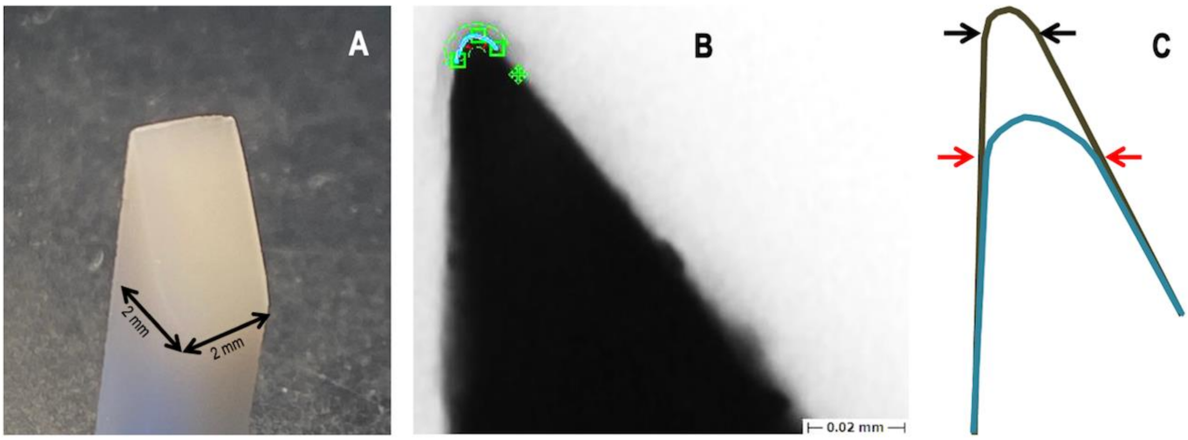

Fig. 2. a) Ceramic tip. b) Tip profile recorded with optical measuring machine. c) Scheme of resolution in IOS; in our study: the black arrows indicate the actual shape of the tip whereas red arrows show the shape recorded with the IOS due to the resolution limit.

The tip 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*4mm match like sample was then beveled cut to create the pointed tip. The cut face is 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 is ultrasonically cleaned in a distilled water bath. Verification of sharpness was done with Excel 502 Multisensor Measuring machine (Windsor). See Fig. 2-B. Tip was made of a material chosen to be as close as possible to the appearance of tooth enamel. CAD CAM ceramic is used for their esthetic properties in dentistry. Ceramic for restorative dentistry permit to mill the reference object quite easily, with optical properties close to the tooth is the for our RTP protocol. Moreover, the dimensions were selected to obtain a macroscopic and recordable object as 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 system used is EasyTom 150 kV system (RX Solution, Chavanod, France). Resolution (voxel size) was set to 5,4 micrometers with an error on the measure inferior to 0.5 micrometer. The X ray source had a voltage of 70 kV, an intensity of 66 mA and an aluminum 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 gray shade mean value of the internal material of the tip. Then, 16-bit images were transformed into 8-bit format to permit thresholding and binarization. Plugin 3DViewer in Fiji software 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 Primescan software 5.0. Then, they were exported in 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 consider that the smallest detail recorded by IOS is the smallest distance of two points of the mesh belonging to the two faces of the tip (see Fig. 4-C). Such distances were measured several times, and their mean is considered as the Resolution. IOS meshes were opened with Meshlab, and the distance tool of this software permits the 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 by registration point to point between the mesh recorded with IOS to the reference mesh recorded by the reference high-resolution micro-CT system. (see Fig. 4-B) To align similar meshes, region of interest (ROI) was selected.

Registration was performed with Meshlab, by fixing one mesh and defining manually some point landmarks on each part of the two meshes. Then, Meshlab algorithm automatically computes the optimal position of the other which minimize distances. This algorithm converges with 3 or 4 iterations. CloudCompare software measure, for a mesh, the projected distance of every vertex on each triangle face of the other. Micro-CT mesh is projected on IOS mesh. The point of one mesh are then 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 vertex on face. Variability of measurements was evaluated with four meshes of the tip (Fig. 4-A). We superimposed them two at a time, with the same method as for trueness: registration was done in Meshlab Software and cartography of distances was performed in CloudCompare software (version 2.10-alpha, EDF R&D, France). We extracted 6 list of values for each comparison.

3. Results

3.1. Mesh

Scans of tips, based on micro tomography or directly recorded with IOS, exported in STL files, were visualized, manipulated and measured with Meshlab, as explained above. Numbers of vertices and faces depends on ROI chosen for registration. For IOS, number of vertices is in the range of 3000, and 6000, and 2.5 to 3.8 millions for micro-CT extracted meshes. Meshes and type scanned are shown in Fig. 3. A and B. Measurement of distance between mesh, by

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projection, is illustrated by distance map in Fig. 3 C and D. Look up table allows to link the color to a distance, in mm.

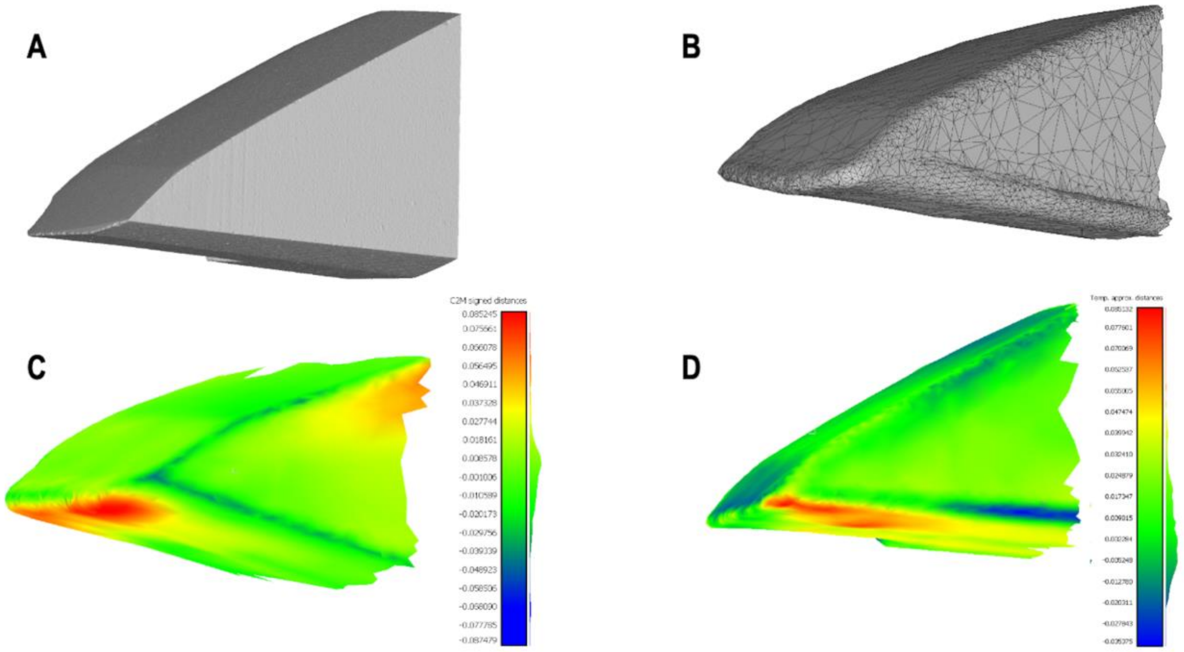

Fig. 3. a) Mesh of tip scanned with micro tomograph. b) Mesh of tip scanned with Primescan. c) Example of distance cartography between mesh clouds vertices of Primescan and micro tomography to measure trueness. d) example of distance cartography between two IOS meshes to measure precision; look up table unit is mm.

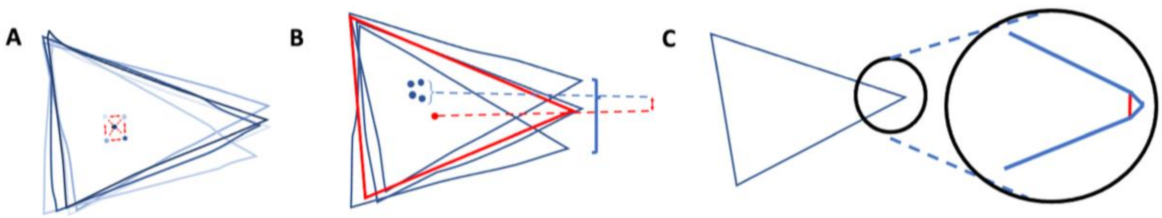

Fig. 4. Scheme of measures recorded to evaluate, with one object, the three parameters: a) precision where blue round represents mean value of each triangle recorded and compared two by two. b) trueness: all the IOS meshes are aligned with the reference one (in red) to get a reference position. We compute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

3.2. Resolution and trueness

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

As expected, each resolution measured are far from data extracted from micro tomography. Amplitude of difference between two measures of mean from IOS are around 10 micrometers, and the standard deviation represent around 25% of the mean.

Table 1. Resolution and trueness for each mesh recorded by Primescan IOS. Resolution: distance between two plans of tip, measured on mesh. Trueness: mean distance between mesh recorded by IOS and mesh extracted from 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 Primescan system, measures of the mean range from 7 to 17 micrometers. These values need to be compared to usual value of practitioner.

Table 1. Resolution and trueness for each mesh recorded by Primescan IOS. Resolution: distance between two plans of tip, measured on mesh. Trueness: mean distance between mesh recorded by IOS and mesh extracted from 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

4. Discussion

In recent literature, several studies have applied well known technics. [27] Those experiments differ depending of the reference scanner used, number of scans, number of teeth of full arch, instrument used to create a reference for comparison. Many papers were published on the topic of IOS performance and particularly on the accuracy by mesh registration [9], [18], [28]. Some protocols studies use several precision control methods as using vernier caliper or micro Tomography (micro CT) [14]. Actually, micro CT appears as a reference method to control the IOS accuracy and performances [15], [21], [29]. Moreover, some authors using *extraoral scanner* (EOS) note an influence of teeth surface condition on the accuracy [16]. Others method, based on triangulation principles, are described but principally in case of full arch [30].

Despite a large number of publications about the IOS accuracy, resolution is not really studied for the moment. This fact is due to the easy of accessibility to accuracy, with meshes obtains with micro-CT or IOS and then aligns together. Resolution and trueness could be appeared close in 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 IOS, the difference between measure and real object is due to the impossibility to record under a critical size. In

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case of a sharp tip, the distance between the edge of the two plans 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 take resolution as the number of "points" by mm2. But number of pixels, points or vertex could be artificial increased by software interpolation, not the resolution, as capacity for a 3D device to change his measurement at a minimal change in the volume of field of view recorded. Indeed, for a same object recorded in 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.

As 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 plans recorded by IOS. So, resolution, trueness and precision (RTP) are evaluated in the same time.

The range of values shown in table 1 and 2 is consistent with previous study. Indeed, trueness values previously reported, based on mesh registration, are 18 um [13], 9.67 um [31], 17.7 um (SD 3.6 um) [32], 17.3 um (SD 4.9) um [33], but others studies give values quite far from those results: 33.9 um (SD 7.8 um) [34] and 56 um (SD 6.25 um) [35]. The same studies give a range of values more dispersed with large standard deviation (when they are reported) for the precision: 3.6 um [13], 10.73 um [31], 17.3um [33], 25.5 um (SD 5.1 um) [32], 31.3 um (SD 10.3 um) [34], 68.5 (SD 39.5) [35]. These last results indicate a large fluctuation in values. It depends on object recorded and condition of scanning. They are additional arguments for having a reference object with known dimensions, reproducible, for round robbing test in laboratory, and finally, in the dental office.

We could consider using our sample as a caliber to validate the RPT of new IOS. This protocol would free us from possible dependent operator interaction and manufacturers could transparently communicate resolution values. Finally, several parameters must be evaluated to precise condition for scanning, to reproduce results and avoid some bias du to gesture of 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. Conclusion

In this study, we demonstrate that the three main parameters for evaluating an IOS can be measured in the same time, with an opto 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. Next step of this preliminary stage will be creation of benchmark for testing several IOS used actually in dental office.

An improvement of this protocol, however already exploitable, would provide for laboratories a possibility to quickly assess IOS performances. It would be the first step to create a known and controlled dimension object to control evolution IOS over time, directly in the dental office.

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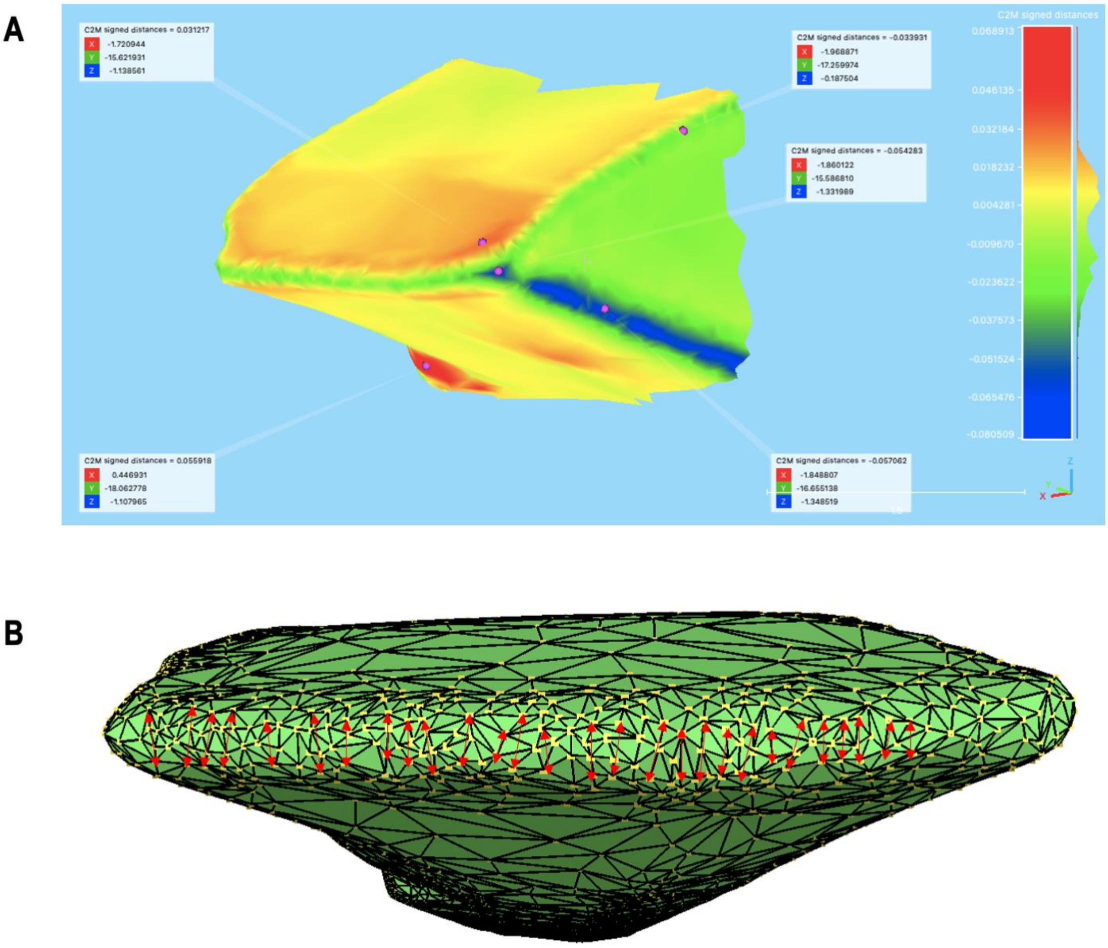

Supplementary Fig. 1. a) Exemple of meshes registration, with some points selected, with a distance associated. This distance is the length between a vertex and the point corresponding to the projection of this vertex on the other mesh. All these distances are averaged to evaluate the trueness of the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

Alban Desoutter has been working at the LBN at the University of Montpellier since 2010 as a technical assistant. He works on dental histology using a variety of techniques, including microtomography and Raman microscopy. He also works on intraoral cameras.

Gérard Subsol obtained an Engineer Diploma and a Ph.D. Thesis in Computer Science of the Ecole Centrale de Paris respectively in 1991 and in 1995. Since November 2006, he has been a CNRS Research Associate with the ICAR research team at the Laboratory of Computer Science, Robotics, and Microelectronics (LIRMM) located in Montpellier, in the South of France. He is currently working on several applications of 2D and 3D visual data processing and modelling.

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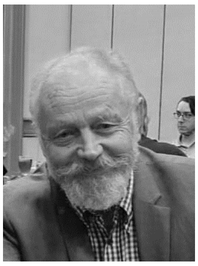
Ikram Benmoumen is currently a production engineer and support assistant at Circle Dental in France. She received a B.Sc. in Physics-Chemistry in 2020 and a M.Sc. in Biomedical Physics in 2022 from the University of Montpellier. Her activities focus on the implementation and validation of the dental prosthesis manufacturing process, as well as the support and training for the Circle Dental solution.



Frédéric Cuisinier first graduated as a dentist and entered the National Board of Periodontology. After re- ceiving a Master of Science, in 1990 he obtained a Ph.D. in High Reso- lution Electron Microscopy of bone and enamel crystal formation with Prof. Robert Frank as his supervi- sor. He has been full time professor at Montpelier University since 2005. He has created the LBN (Laboratory of Bioengineering and Nanoscience) at Montpellier University and is its acting director.

Michel Fages received his Ph.D. de- gree from the University of Szeged (Hungary) in 2013. He is currently Full Professor and Head of the Prosthodontic Department in the Faculty of Odontology of Mont- pellier, France, and Head of the Cad/Cam-Prosthetic Medical De- partment in the Dental Care Center of the University Hospital of Mont- pellier. His research activity focuses on the biomechanics of the tooth reconstructed with CAD/CAM and dental CAD /CAM technologies.

Delphine Carayon was first graduated as a dentist and worked as a general practitioner for 14 years. She obtained a Ph.D. in Anthropobiology at the University of Toulouse in the Laboratory of Molecular Anthropology and Synthetic Imaging, directed by Prof. E. Crubezy. She has been full time associate professor at Montpellier University in Prosthodontic department since 2018. She's Head of the Prosthetic Medical Department in the Odontology Service of the University Hospital of Montpellier. She worked at Bioengineering and Nanoscience Laboratory directed by Prof. F. Cuisinier. Her research activity focuses on dental CAD /CAM technologies applied on the rehabilitation of the edentulous patient.