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ABSTRACT

In dentistry, 3D IOS (intra-oral scanners) are gaining an increasing popularity essentially for the production of dental prostheses. Until now, there is no normalized procedure to determine the resolution of IOS. Such a procedure could be a positive parameter for the IOS market and a first step in their normalization.
The aim of this study is to present a reproducible methodology to estimate the noise and resolution of any type of IOS. For the noise, we used the IOS Trios 2 (3Shape) and the Carestream 3500 (Carestream) for noise and resolution.
As reference, we used an ultra-flat and ultra-smooth alumina. Being perfectly flat, any record of roughness should be interpreted as noise.
In this study, the root mean square (RMS) values obtained are ranged between 5.29 and 12.58 micrometers. Significant differences have been found between the central part and the whole mesh. This is due to edge effect: deviation from a flat surface is more important on the edge of meshes than the internal part.
To evaluate the resolution, a ceramic tip, well-polished was recorded with the IOS's and compared to the mesh obtained with micro tomography (5 micrometer resolution). We measured the distance between the two plans of the tip, considered as the small detail recorded. We found a distance from 89 to 121 micrometers with IOS studied and 25 micrometers with micro CT.
Those methods, simple and reproducible, could be perfectly suitable to evaluate and compare commercial all types of IOS's.

Key-word: intra oral scanner, noise, resolution, micro CT, mesh.

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1 Introduction

Since 30 years and its creation[1], CAD-CAM systems (computer-aided design and computer-aided manufacturing) are more and more present in dentistry and compete for conventional polymer material techniques in dental offices. The IOS permit to realize prosthesis by machining in a single visit for the patient. They provide a three-dimensional mesh calculated by software. Then, the practitioner designs a virtual prosthesis to be fabricated by a milling. They are medical devices subject to strict regulations.

To allow optimum acquisition by avoiding light reflection and transparency, powder system with TiO_2 nanoparticles were used. Nowadays, new intra-oral scanners are actually powder free[2].

The error of measurement and the impact of deviation from ideal angulation of intra-oral scanners were studied[3], and the whole CAD-CAM system including the production unit, was also investigated[4]. In 2000 another study, evaluates the effect of operator-controlled camera misalignment on restoration adaptation[5].

But until now, there is no normalized method to evaluate the performance of IOS. Some studies use registration of 3D images from high performance scanner and IOS's to compare them and evaluate accuracy and trueness[6]. But the evaluation of noise induces and the resolution of IOS were not established.

This study establishes a clear, simple and repeatable method assessing noise and resolution of the IOS.

Noise is a relevant parameter to estimate the performance of IOS. To validate this methodology, the performances of the two powder free IOS's were evaluated by determining their noise: CS 3500 (Carestream, Rochester, USA) and the Trios 2 (3shape, Copenhagen, Denmark). A blank test was realized with an ultra-flat and smoothed alumina wafer, recorded with the two IOS's. The noise was evaluated with RMS (root mean square) roughness.

Then, the resolution was evaluated by an original method: a piece of ceramic was polished to create a tip, very thin at the top. We used the 3500CS (Carestream, New York State, USA).The reference method used to obtain meshes of the ceramic tip is microtomography (EasyTom 150 kV, Chavanod, France) and a precision measurement machine (Microvu Excel 502, Mircrovu, Windsor, California). Those values were comparing to the measurements obtained with the optical measuring machine on the tip profile.

2 Material and method

2.1 Material

2.1.1 Alumina Wafer

The wafer is a white square 99.6% alumina made by the Optics Concept Company (Paris, France). Flatness indicated is lambda/2, corresponding to a maximum wafer peak to valley length, and controlled by a Fizeau interferometer.

2.1.2 Ceramic tip

Feldspathic ceramic Vita Mark II block (Vita Zahnfabrik, Bad Säckingen, Switzerland) were sectioned by using a high-speed diamond saw (Isomet 2000, Buehler, USA) longitudinally to have a 4 cm matches-like specimen. The cutting faces were polished with abrasive discs up to 1200 grit and followed by polishing with diamond pastes of 0.25 and 0.1-µm particle size using a polishing machine (Escil, France).

2.1.3 Micro Computed Tomography (micro CT)

Tomography of the tip was recorded with an EasyTom 150 kV system (RX Solution, Chavanod, France). X ray source was 70 kV voltage, voxel size was 5.4 micrometer and an aluminum filter was placed front of the X ray generator.

2.1.4 Optical measuring machine

The Excel 502 Multisensor Measuring machine provides high speed and accuracy measurements. The Excel 502 UM/UC (Windsor, California 95492, USA) allows measurement of 400x500x250 mm specimen with XY Accuracy of 2.8+L/200, a Z accuracy of 3.0+L/100 and a scale resolution of 0.1 micrometer.

2.1.5 Atomic force microscope (AFM)

The flatness of the wafer was attested with an AFM Nanoscope 3A Quadrex (Bruker instruments, Billerica, USA). A 30*30 micrometers image was recorded in tapping mode. The soft Gwyddion v.2.43 (Czech Metrology Institute, Prague, Czech Republic) performed the RMS roughness calculation.

2.1.6 IOS

We conducted this study with the CS3500 intra-oral scanner from Carestream (Rochester, New York State, USA) and Trios 2 Pod (3Shape, Copenhagen, Denmark). Both are powder free systems.

2.2 Method

2.2.1 Roughness RMS of the wafer

In this study, we assume that roughness RMS calculate on 3D images of the wafer recorded by IOS is the noise of the system. Calculations on meshes were realized with Cloud Compare v2.6.0 software (Research and Development Institute of Electricité De France EDF, Paris, France).

2.2.2 Roughness RMS of mesh recorded by the IOS

Each IOS scanned the wafer with 3 angulations (0, 30 and 45 degrees) and two different orientations. Everytime, 10 scans were recorded to verify reproducibility of the manipulation. To calculate the noise, the RMS of each mesh was calculated through the distance from each vertex to the mean plan, formed by the whole mesh. Coordinates of vertices and distances from vertices to the mean plan were exported into Excel (Microsoft, Redmond, USA) files. RMS is calculated with the equation:

$$R_q = \sqrt{\frac{1}{n}(x_1^2 + x_2^2 + x_3^2 + \cdots + x_n^2)}$$

2.2.3 Resolution of camera

We assume that the resolution of the IOS is the distance between the points localized at the edge of the two plans, which formed the tip. No trivial method exists to select automatically vertex before curvature, on the edge of the tip. Distances were calculated with the Meshlab software tool, by selection of the vertex of interest. To avoid error by the manipulator, 30 measures were collected for each 3D images, and means and standard deviations were calculated. This was done both on meshes reconstructed with Micro CT and with IOS.
To confirm those results, curvature of the top of the tip was measured using Meshlab Software (ISTI, Italian National Research Council, Italia).

2.2.4 Statistical test

Results to evaluate noise and resolution were tested with current ANOVA one way test, realised with Sigmaplot v. 11.0 (Systat Software Inc, San Jose, USA).

3 Result and discussion

3.1 Noise

The RMS calculated on the 900 µm² surface is 17.52 nm with AFM (Fig 1 A). The RMS values are calculated from meshes from intra-oral scanners. RMS values for the whole meshes varied between 5.29 (SD ±0.82) and 10.68 (SD ± 0.92) micrometers for CS3500 and between 6.79 (SD ±1.56) and 12.58 (SD ±4.95) micrometers for Trios. Figure 1 B and C represents examples of 3D meshes colored with a look-up table corresponding to the vertices-to-virtual plan distance.

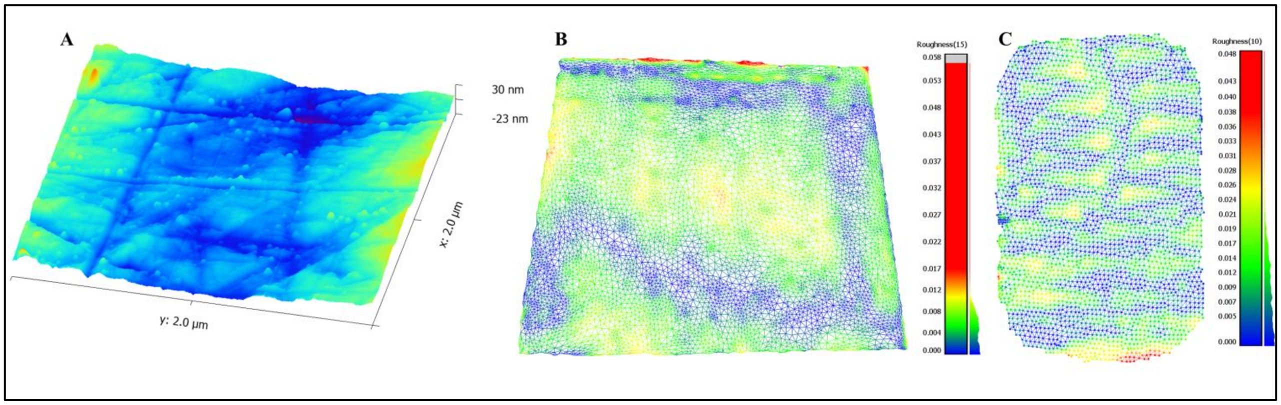

Figure 1

A) Wafer scanned with AFM ; B) mesh of wafer scanned with Trios ; C) mesh wafer scanned with Carestream CS3500 IOS

As we can see in Figure 1, noise is more important on the edge of mesh scanned with IOS. Indeed, for the whole mesh, we found a RMS roughness statistically most important than for the central part of the same mesh, as it is shown in Table I.

Table I

RMS results for CS3500 and Trios IOS. Superscripts letters indicate whether there was a significant difference.

		0 (a)		**30.1 (b)**		**30.2 (c)**		**45.1 (d)**		**45.2 (e)**		Total	
		Whole	Central part	Whole	Central part	Whole	Central part	Whole	Central part	Whole	Central part	Whole	Central part
Carest	**RMS (µm)**	**7.54**^{b,c}	5.85	**10.68**^{a,d}	7.24	**8.80**^{d}	7.29	**5.29**^{a,b,c}	4.36	**7.74**^{b}	6.16	**8.01**	6.18
Trios	**RMS (µm)**	**6.79**^{c,e}	2.91	**7.89**^{c}	4.26	**9.87**^{a,b}	3.08	**7.22**^{e}	1.77	**12.58**^{a,d}	2.15	**8.86**	2.83

Values of RMS roughness in the center of scanned zone indicate that the IOS has a low ratio signal on noise (RSN). But the impact of the edge effect on the reconstruction of teeth in current practice could be a problem. Further investigation must be realized to estimate such impact.

3.2 Resolution

The profile of the tip, recorded with optical measurement machine, gives an idea of the reality of the 2D profile of the tip, as represented on Fig 2-A.

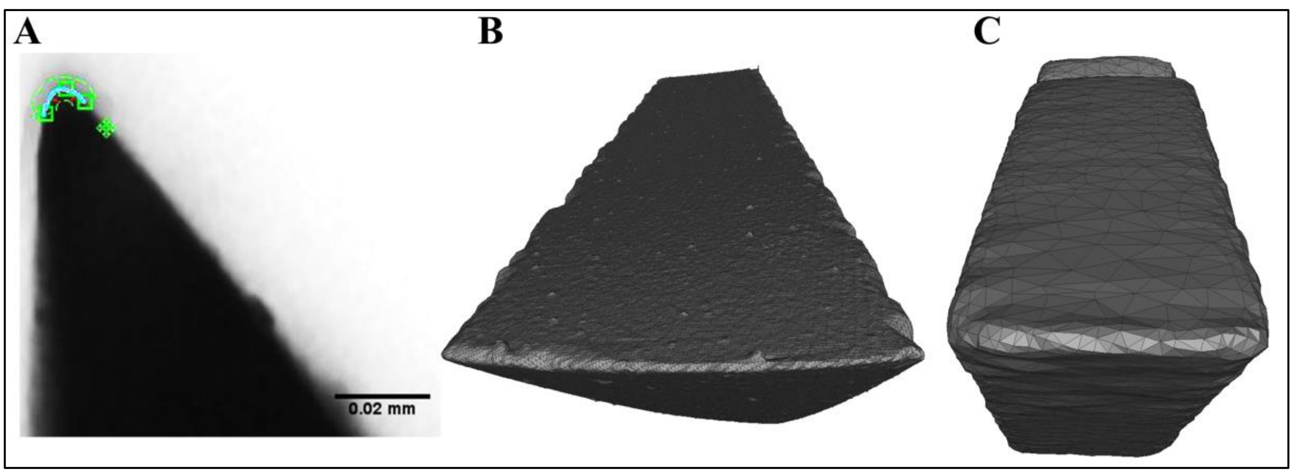

Figure 2

A) the profile tip recorded B) the mesh of the tip reconstructed with Micro CT C) the mesh of the tip scanned with CS3500 IOS

The distance between the two plans of the tip is 8.7 and 18.6 micrometers. We found a distance of 25.98 micrometers for the mesh reconstructed with micro CT, and around a hundred micrometers with CS3500 IOS, as reported in Table 2.

Table 2

The distance measured between two plans of the tip calculated with Micro CT mesh (a) and with IOS (b to f)

	a. Micro CT	b. Cam test 1	c. Cam test 2	d. Cam test 3	e. Cam test 4	f. Cam test 5
Mean (µm)	25.98[b,c,d,e,f]	121.22[a,d,f]	110.61[a]	89.67[a,b,e]	124.28[a,d]	91.67[a,b]
SD (µm)	7.10	20.85	22.70	14.19	31.18	25.03
Median (µm)	24.50	118.50	109.50	89.50	124.50	86.00

We note that from one scan to another, values could vary from ~90 to ~120 micrometers. The reproducibility is not optimal, while it was the same person, a specialist of CAD CAM, in the same condition, who realized the gesture. Moreover, those values do not mean that the IOS does not see anything from, but we not that the soft create a mean value from all shots. Number of images needed to reconstruct such an object is variable and could be count as decade. So the software may play a role in the reduction of a high angulation and smooth it. The result could be a loss of information.

4 Conclusion

This study highlights the important performance of IOS. The two methods used to determine the noise and the system resolution could be standardized and automated to make comparisons between IOS's, and help practitioners in choosing the best system. Regarding the noise, it seems that it does not play an important role, which shows the good performance of IOS. However, the poor camera results studied are an indication of a significant loss of information, especially on abrupt surface changes, as is the case with a tip.

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