ARTIGO ORIGINAL

ACCURACY OF FOUR INTRAORAL SCANNERS IN FULL-ARCH SCANS

Acurácia de quatro scanners intraorais em escaneamentos de arcada completa

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RESUMO

This research aims to evaluate the accuracy of four intraoral scanner models in full-arch scans. A master model was scanned using a high-precision desktop scanner, and a digital reference model was created. The master model was then scanned ten times by each of the intraoral scanners studied (TRIOS® 3, CEREC OmniCam, iTero™, and Medit i500). The digital models were compared to the master model using 3D measurement software. The analysis revealed significant differences in accuracy among the studied scanners, with the iTero™ scanner showing the best performance (p=0.0003). All scanners exhibited an average discrepancy of less than seventy micrometers in full-arch scans. These findings suggest that while all tested scanners are within clinically acceptable accuracy limits, the iTero™ may offer superior performance for full-arch digital impressions, potentially leading to improved outcomes in extensive dental rehabilitations.

Palavras-chave: CAD-CAM; intraoral scanner; full arch; accuracy; trueness; precision.

ABSTRACT

Esta pesquisa tem como objetivo avaliar a acurácia de quatro modelos de scanners intraorais em escaneamentos de arcos totais. Um modelo mestre foi escaneado utilizando um scanner de bancada de alta precisão, e um modelo digital de referência foi criado. O modelo mestre foi então escaneado dez vezes por cada um dos scanners intraorais estudados (TRIOS® 3, CEREC OmniCam, iTero™ e Medit i500). Os modelos digitais foram comparados ao modelo de referência utilizando um software de medição 3D. A análise revelou diferenças significativas na acurácia entre os scanners estudados, com o iTero™ apresentando o melhor desempenho (p=0,0003). Todos os scanners exibiram uma discrepância média inferior a setenta micrômetros nos escaneamentos de arco completo. Esses achados sugerem que, embora todos os scanners testados estejam dentro dos limites clinicamente aceitáveis de acurácia, o iTero™ pode oferecer um desempenho superior para impressões digitais de arcos totais, potencialmente levando a melhores resultados em reabilitações dentárias extensas.

Keywords: CAD-CAM; scanner Intraoral; arco total; acurácia; veracidade; precisão.

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INTRODUÇÃO

The introduction of Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) has significantly transformed dentistry by changing the planning and manufacturing of dental prostheses [1]. For instance, materials like zirconia, which are well-established in the profession, became viable options only with the advent of CAD/CAM technology [2]. The first intraoral scanning system was launched in 1985 [3], and today, there are numerous systems available, each featuring distinct software and hardware technologies.

Initially anticipated by Strub et al. [4] and later detailed by Kapos & Evans [5], Advancements in intraoral scanners (IOS) have expanded their capability from single-tooth and sextant scans to full dental arch recordings. IOSs capture the three-dimensional surfaces of teeth, implant abutments, and soft tissues, enabling immediate assessment of digital models and rapid communication with laboratories, 3D printers, or in-office milling units [1,2,5].

With continuous improvements in software and hardware, intraoral scanning has emerged as a promising alternative for obtaining accurate and enhanced digital models [6]. This technique replaces the traditional impression method and offers several benefits, including increased patient comfort, greater efficiency, and reduced working time for dental professionals [7].

The adoption of these new technologies has been encouraged by the creation of user-friendly digital systems and the integration of digital dentistry into educational programs [8]. Professionals aiming to overcome the limitations of conventional impressions have adopted digital systems as supplements or replacements for traditional materials and techniques [2]. Intraoral scanning provides the advantage of using magnification and quality control tools to identify areas with defects and offer guidance on capturing missing regions in the digital model [9].

However, despite the increasing use and potential advantages of IOSs, there remain uncertainties and disagreements about their clinical viability in extensive rehabilitation [10]. Scans can be subject to errors and distortions due to inadequate technique or the inherent limitations of image capture technology [11]. Research by Park et al. [12] and Su & Sun [13] indicates that smaller scanned areas yield higher accuracy. The current scientific literature lacks consensus on the reliability of these devices for accurately and completely capturing dental arches, particularly concerning complex anatomical details and large areas.

According to the International Organization for Standardization ISO 5725-1 [14], the concept of accuracy encompasses both 'trueness' and 'precision'. 'Trueness' refers to the discrepancy between the measured value and the actual size of the object, indicating how close the measurement is to the real value. 'Precision' refers to the repeatability, indicating how consistent a set of results are with each other [11].

Therefore, it is essential to conduct studies exploring the precision and trueness of the currently available intraoral scanners. These investigations enable direct comparisons between different devices and assist in selecting the most suitable one for obtaining reliable results.

METHODS

A digital reference model was obtained by scanning a homologated full-arch mannequin (Sirona Dentsply, Germany. Reference number: 633278) using the Ceramill Map 400 desktop scanner (Amann Girbach, Austria). Following the methodology already described by Treesh et al. (2), a white structured light laboratory scanner was used. Such scanners offer precision and accuracy up to 10 µm. To assess the quality of the digital reference model, two scans of the mannequin were performed and compared using 3D analysis software (Geomagic, USA).

Figure 1 – Full-arch resin mannequin.

The mannequin was then scanned using four different IOSs: TRIOS® 3, CEREC OmniCam, iTero™, and Medit i500. An experienced operator conducted all the scans on different occasions, ensuring the scanner was calibrated and the technique was according to the manufacturer's recommendations. Scans were performed in dark environments to minimize interference from external lighting.

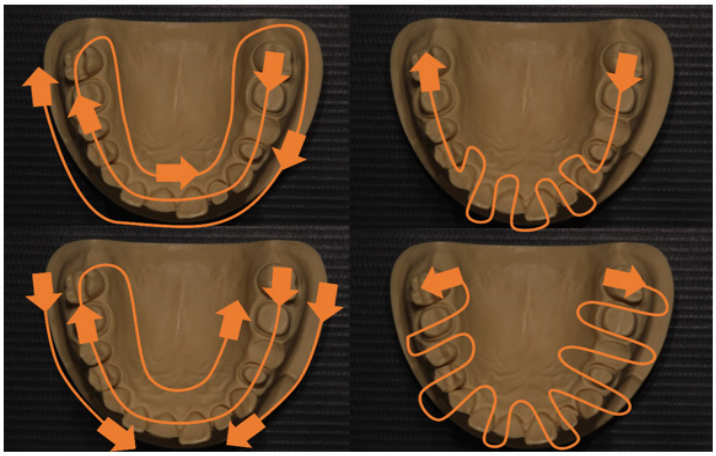

Figure 2 - Scanning techniques recommended by manufacturers.

Each IOS performed ten complete scans of the mannequin, resulting in a total of 40 scans. All scans were exported in STL format for comparison in the measurement software.

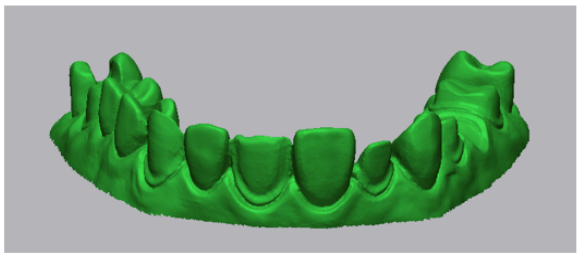

Figure 3 - Digital reference model trimmed in Geomagic Control 3D software.

The digital reference model was imported into Geomagic Control 3D measurement software as reference data and trimmed to better define the study area. The scans from each IOS were imported one by one for comparison. Each scan was aligned to the digital reference model using the software's best alignment algorithm, which analyzes the meshes in point cloud format to maximize point coincidence, ensuring optimal alignment.

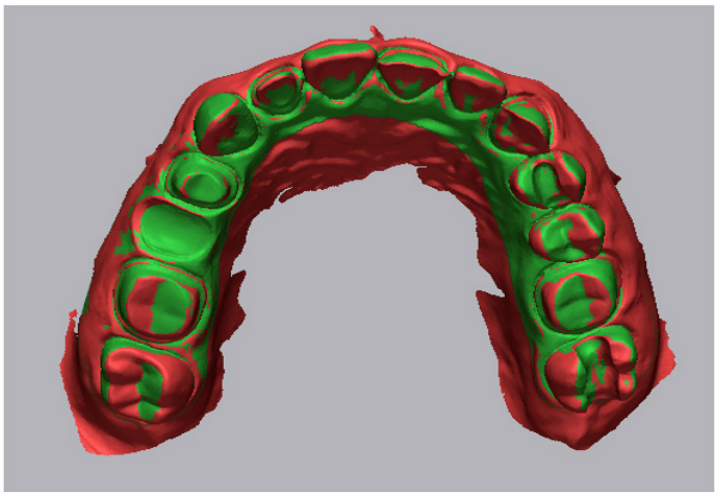

Figure 4 - Best alignment algorithm from Geomagic Control software.

Next, the software's three-dimensional analysis tool was used to compare all the points on the two surfaces, providing the average discrepancy value between the reference mesh and the compared mesh. Each of the ten scans from each IOS was compared to the digital reference model to determine trueness, or how close each scan was to the actual value. Subsequently, one scan from each IOS was compared to the remaining nine scans from the same device to determine precision, or repeatability.

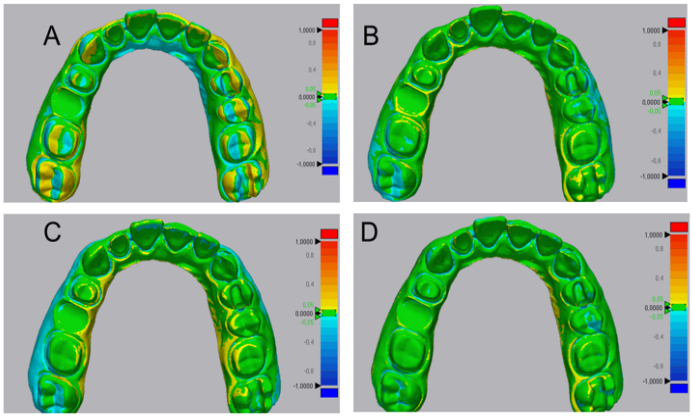

Figure 5 - Color map of the discrepancies observed in the 4 IOS studied in µm. Yellow regions represent regions with positive discrepancy values and blue regions, negative values. A) Medit i500 B) CEREC OmniCam C) TRIOS® 3 D) iTero™.

The software detected and visually represented the discrepancies (standard deviation) in µm. The data was then collected for statistical analysis. To compare the discrepancies in accuracy and precision between the scanners, the analysis of variance (ANOVA) statistical method was used. The statistical calculations were conducted using the R Core Team 2023 program (R Foundation for Statistical Computing, Austria) with a significance level set at 5%.

RESULTS

The results of the trueness and precision analyses are presented in Tables 1 and 2, respectively, and illustrated in Figures 6 and 7. The mean and median values for each IOS were used to provide a comprehensive understanding of the results, considering both the central tendency and data distribution.

Scanner	Mean (standard deviation)	Median (minimum and maximum value)
Medit *i*500	0,067 (0,006) a	0,064 (0,060-0,077)
OmniCam	0,061 (0,004) a	0,060 (0,055-0,071)
TRIOS ® 3	0,062 (0,010) a	0,062 (0,050-0,080)
iTero™	0,052 (0,008) b	0,051 (0,045-0,072)

p=0,0003

Table 1 - Mean (standard deviation), median (minimum and maximum value) of the discrepancy (µm) in the analysis of trueness according to the scanner used.

Scanner	Mean (standard deviation)	Median (minimum and maximum value)
Medit *i*500	0,056 (0,012) a	0,056 (0,037-0,071)
OmniCam	0,037 (0,006) bc	0,037 (0,028-0,051)
TRIOS® 3	0,041 (0,008) b	0,039 (0,030-0,058)
iTero™	0,032 (0,008) c	0,029 (0,027-0,051)

p<0,0001

Table 2 - Mean (standard deviation), median (minimum and maximum value) of the discrepancy (µm) in the analysis of precision according to the scanner used.

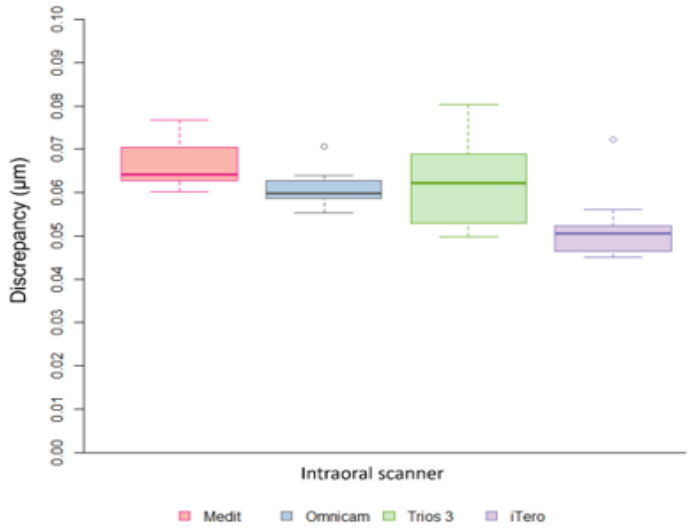

Figure 1 - Boxplot of the discrepancy (µm) in the trueness analysis as of the scanner used.

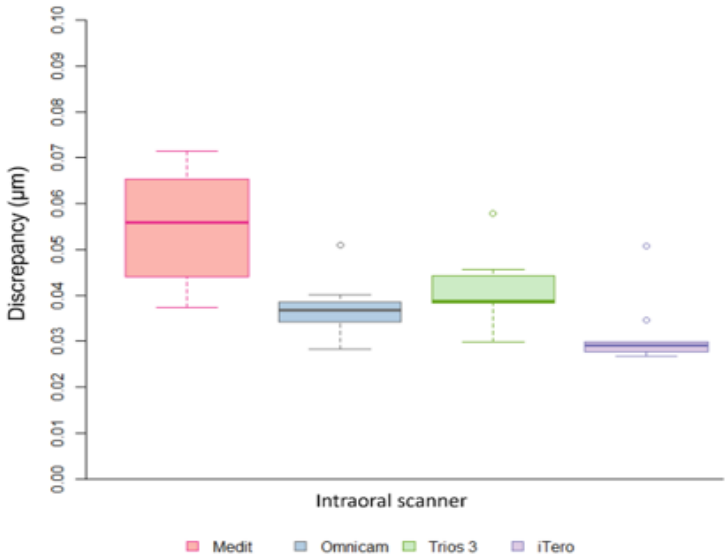

Figure 2 - Boxplot of the discrepancy (µm) in the precision analysis as of the scanner used.

The discrepancy in trueness was significantly lower when using the iTero™ ($p<0.05$), as shown in the Table 1 and Figure 6. In the precision analysis, the discrepancy was lower when using the iTero™ scanner than when using Medit i500 and TRIOS® 3 ($p<0.05$). In addition, the discrepancy was lower with OmniCam and TRIOS® 3 than with Medit i500 ($p<0.05$), as shown in the Table 2 and Figure 7.

All IOSs demonstrated an average error of less than 70 µm in full-arch scans.

DISCUSSION

This study investigated the accuracy of four intraoral scanners: iTero™, Medit i500, OmniCam, and TRIOS® 3 when scanning full arches. With the increasing availability of various

CAD/CAM systems and brands in the dental market, it is crucial to understand the specific characteristics of each system. The accuracy of IOSs is fundamental to the success of dental procedures, making it imperative to critically analyze their performance.

Previous studies, such as Vecsei et al. [15], have shown that the larger the scanned area, the greater the margin of error. One explanation is the accumulation of errors when compiling hundreds of images to create a three-dimensional surface. A key question in the literature is how this accumulated error impacts extensive prosthetic work [16].

Nodelcu & Persson [17] demonstrated that the type of material scanned directly influences the scanner's accuracy, contributing to the variability in comparative studies. These findings also apply to in vivo studies, where different filling materials such as amalgam, resin, and ceramic affect IOS accuracy [1]. To ensure consistent results, a homologated dental model designed for scanning training was used in this study. To minimize potential interference from external light sources, all scans were performed in a dark room. Wesemann et al. [18] found that high levels of external light can also interfere with the accuracy of some IOS models.

Accuracy evaluations of master models created by conventional impression techniques typically involve measuring linear distances at limited points, following ISO 4823 standardization [1]. However, accuracy evaluations of impressions use sophisticated 3D software. In this study, Geomagic Control software was used for 3D analysis. This software employs best-fit mathematical algorithms to superimpose a scan on a digital master model and objectively measure variations across the entire experimental model.

A significant difference was observed between the scanners evaluated. The iTero™ scanner demonstrated greater trueness than the other IOSs ($p<0.05$) and greater precision than Medit and TRIOS®. Additionally, OmniCam and TRIOS® were more precise than Medit i500 ($p<0.05$). The observed inter-group discrepancies can be attributed to the complex interaction between the optical scanning technology and the rendering algorithms used in IOSs. These devices capture multiple images of the dental arch, which are processed by an algorithm to produce a three-dimensional digital model. However, even with advanced technologies, a small margin of error is inherent in the reconstruction process, influenced by factors such as camera resolution, sensor accuracy, intraoral geometry complexity, and the number of images processed [19].

The results of this research corroborate previous studies [1,2,10,17], and highlight the importance of careful analysis when choosing an intraoral scanner. Differences found compared to other studies can be attributed to variations in scanned materials, software versions, and the extent of the total area analyzed.

It is essential to consider that each IOS has its unique characteristics. Beyond accuracy,

other factors such as cost, ease of use, technical support, and compatibility with existing systems and software must be considered when selecting the ideal scanner for a dental clinic [19].

There is a need for further research and a standardized method for evaluating and comparing multiple intraoral scanning systems. The results of this study should be interpreted with caution, and conclusions should only be drawn from scanning scenarios like those in this work.

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2. iTero™ also outperformed the Medit i500 and TRIOS® 3 scanners in terms of precision ($p<0.05$).
3. OmniCam and TRIOS® 3 scanners showed higher precision compared to the Medit i500 ($p<0.05$). They did not match the level of accuracy achieved by the iTero™

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