







Implant digital impression accuracy using extraoral scanners: a three-dimensional analysis

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Editor: Altair A. Del Bel Cury

Received: February 08, 2022

Accepted: April 10, 2022

Aim: To analyze the accuracy of extraoral systems (Ceramill Map400+, AutoScan-DS200+, and E2) in full implant-prosthetic rehabilitation three-dimensionally. **Methods:** A metallic edentulous maxilla with four implants was digitalized by a contact scanner (MDX-40 - Roland, control) and used as a control image to compare with other images generated by three laboratory scanners (10 samples per group). Letters identified all the four components: A and D angled 45°, and B and C parallel. The BioCAD software exported the images (.STL) to compare and verify deviations of the analogs on the X, Y, and Z axes. The nonparametric Kruskal-Wallis test and the two-way ANOVA on ranks with a post hoc Tukey test analyzed the data with 5% significance. **Results:** No statistical differences were observed in the accuracy between the extraoral scanners ($p=0.0806$). However, when analyzing only the components, component D was more accurate when scanned with Ceramill Map400+ compared with AutoScan DS200+ ($p<0.001$) and with E2 ($p=0.002$). **Conclusions:** All extraoral systems assessed showed digitalization accuracy but with more deviations in angled implants. The Ceramill Map400+ scanner showed the best results for the digital impression of a complete arch.

Keywords: Dental impression technique. Dental implants. Dental prosthesis. Dental prosthesis, implant-supported.



Introduction

The use of conventional complete dentures is one of the most common options for treatment in cases of complete edentulism¹. Nevertheless, low retention and stability in patients with considerable bone resorption resulted in a greater demand for implants². Therefore, the All-on-four concept is an option in cases of anatomical limitations and severe bone resorption. This protocol uses four implants, two parallel and two 45° angled, in the anterior and posterior region, respectively—this aim to reduce the cantilever length and improve the transmission of strength³.

The implant impression technique has the objective of transferring intraoral positions of implants. An accurate impression is vital to obtain a passive fit: a clinical condition in prosthetic rehabilitation which avoids static load on the prosthetic system or alveolar bone^{4,6}. However, incompatibility may cause mechanical and biological failures, such as poor adjustment, fracture of screws or components, and loss of osseointegration^{7,8}.

The literature mentions several impression techniques, such as using stable impression material, splinted or non-splinted, or even using only implants or with abutments⁹⁻¹¹. However, the contraction of impression materials and clinical and laboratory processes, such as improper leakage time and the plaster type used, can influence the accuracy of the final impression^{9,12,13}.

In addition, impression on implants, distance, and angulation may negatively affect the final passivity¹⁴. Due to these problems caused by conventional impressions, CAD/CAM (Computer-aided-design/manufacturing) systems were introduced to eliminate impression materials and some laboratory processes¹⁵. CAD/CAM systems comprise three stages: data acquisition, prosthesis design, and manufacturing processes^{16,17}. Besides, two scan modalities are available: extraoral and intraoral^{18,19}.

Intraoral digitalization is performed directly in the patient's mouth. The advantages include eliminating impression material, patient comfort, and a faster treatment^{18,20-22}. However, studies show that buccal humidity, patient's head movement, and restrictions in the scanner movement can limit the use of this technique²³⁻²⁵.

However, there are two systems concerning extraoral scanners: (1) one allows the digitalization of a cast created from the conventional impression; (2) another digitalizes the impression. Unfortunately, both modalities may have errors resulting from the impression, manufacture of the dental cast, or even failures in digitalization²⁶.

During the process, the scanning is performed with light sources, such as light rays, laser, infrared light, LED, or structured light¹⁶. For example, laser scanners use a pattern of one-dimensional lines, whereas structured light scanners project a two-dimensional light to obtain three-dimensional data of the scanned object²⁷. In addition, scanners with blue LED technology have a shorter wavelength, resulting in better accuracy¹⁷.

Thus, although digitalization is a simple process, the operating mechanism of scanners is complex and may influence its final accuracy, characterized by the combination of trueness and precision²⁸. Trueness is the scanner's ability to digitalize an object

with its real dimensions. Precision is the scanner's ability to create repeatable images using different measurements of the same object^{12,29}. Other factors that can influence the extraoral scanner precision include device hardware, software algorithms, digitalization technology, and the shape and size of the master model¹⁷; however, there is literature lacking about the accuracy of extraoral scanners in angled implants associated with the all-on-four technique.

Due to the importance of obtaining an accurate final impression, this study assessed, and three-dimensionally compared, the accuracy of different extraoral scanners (Ceramill Map400+, AutoScan-DS200+, and E2) in parallel and angled implants. Our null hypothesis states that different laboratory scanners do not present differences in accuracy.

Materials and Methods

Sample Size Estimation

The sample size was calculated using a software program (GPower; Heinrich-Heine-Universität Düsseldorf). In this study the parameters for analysis of variance (ANOVA) were used, which effect size $f = 3.60$, $\alpha = 5\%$, power = 80%, number of groups = 3 (extraoral scanings). The sample size was calculated to be 6. Considering a loss of 30%, the final sample of this study consisted of 10 scanning for each extraoral system analyzed.

Obtaining the Master Impression

Initially, an edentulous maxilla cast model was used to obtain a metallic model (Figure 1A) through the Lost-wax casting technique. Next, a precision lathe performed four 4.1-mm-diameter perforations in this metallic model and installed external hexagon implants with a regular platform (Conexão, Sao Paulo, Brazil). Then, two parallel perforations were done in the premaxilla region to install 13-mm-long implants; two other perforations angled 45° were conducted in the canine fossa's posterior area, installing 15-mm-long implants. The implants were named A, B, C, and D (Figure 1A) to facilitate analysis.

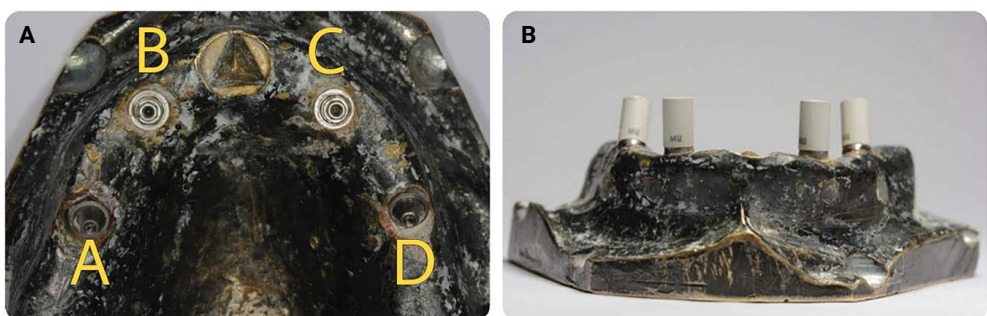


Figure 1. (A) Scheme of the metallic master cast. (B) A metallic model with scan bodies in position.

Abutments with a 3-mm collar were installed on anterior implants (Micro Unit, Conexão), and 30° angled abutments (Micro Unit) with a 3-mm collar were installed on 45° angled posterior implants, which compensated for implant angulation (a 15° final angulation). All abutments were applied a 20 N.cm torque, as recommended by the manufacturer.

Digital Impression

Due to high accuracy, the metallic master cast was initially digitalized with an industrial contact scanner (MDX-40, Roland, Centro de Tecnologia da Informação - CTI, Campinas, SP, Brazil) due to high accuracy³⁰. The distance between the contact tip and the model surface was calibrated to 0.2 mm, resulting in a high-precision digital model, which was then exported as an STL file to be used as a control image and compared with the other scanners.

Subsequently, we used three laboratory scanners, including two structured light (Ceramill map400+, Amann Girrbach Charlotte USA; AutoScan DS200+, SHINING 3D, Zhejiang China) and a multilinear blue LED light (E2, 3Shape Copenhagen, Denmark) (Table 1), to digitalize the metallic master model and generate the STL images. In addition, scan bodies were installed on the abutments of the master cast (Scan-Connect Micro Unit, Conexão) (Figure 1B), which allowed the components to shift position.

Table 1. Experimental groups

System	Scanner	Technology	Manufacturer	Country
MDX-40	Control	Contact scanner	Ronald	São Paulo, Brazil
Ceramill Map400+	Scanner 1	Structured light Lab scanner	Amann Girrbach	Charlotte, USA
AutoScan-DS200+	Scanner 2	Structured light Lab scanner	SHINING 3D	Zhejiang, China
E2	Scanner 3	Multilinear blue LED light	3Shape	Copenhagen, Denmark

Scanners used (laboratory scanner and contact scanner) and their features.

A thin, uniform layer of titanium dioxide powder (D70, Metal Chek, Uberaba, Brazil; SKD-S2 Spotcheck, Magnaflux, Glenview, USA) was used on the surface of the master model to be digitalized by all three scanners to generate an opaque surface and avoid the reflection of light on the metallic model, thus preventing interferences on the final accuracy of the digital model. Subsequently, each scanner performed 10 scans following the manufacturer's instructions, and STL images were obtained (n=30).

After obtaining the digital models, the digitalization system replaced the scan bodies present in the digital images for mini pillars available at the digital library, generating the images to be analyzed; we then used interest areas (pyramid and components) for a subsequent 3D analysis. The professionals trained in each system used conducted the digitalization processes: NB for Ceramill Map400+, APS for AutoScan DS200+, and NP for E2.

Determining the Distances between the Pyramids and the Components

All models were digitalized in STL files, including one control image (contact scanner) and 30 experimental (extraoral scanners), and then these files were imported to a Bio-CAD program (Computer Assisted Design; Rhino3D, Rhinoceros, USA) to determine measures to be later compared (Figure 2). Initially, each image was imported to select the reference points and build references between the pyramid (creating schemes to represent the pyramidal geometry and obtain the pyramid's edges and apex) and the components to measure distances (Figure 3A).

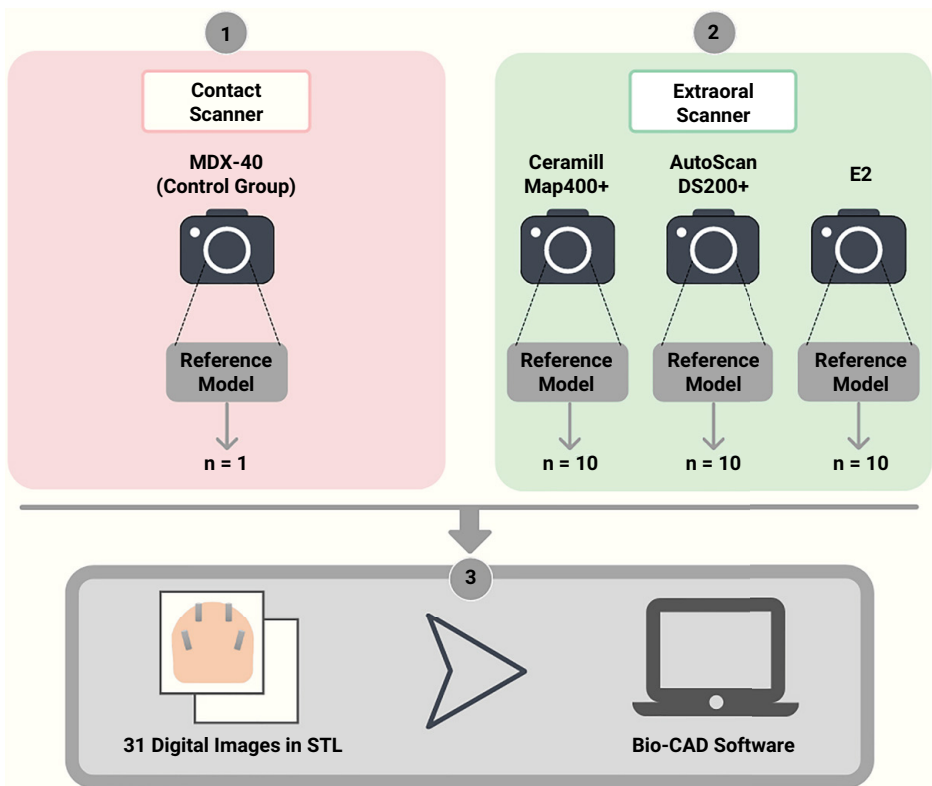


Figure 2. Flowchart of the steps performed.

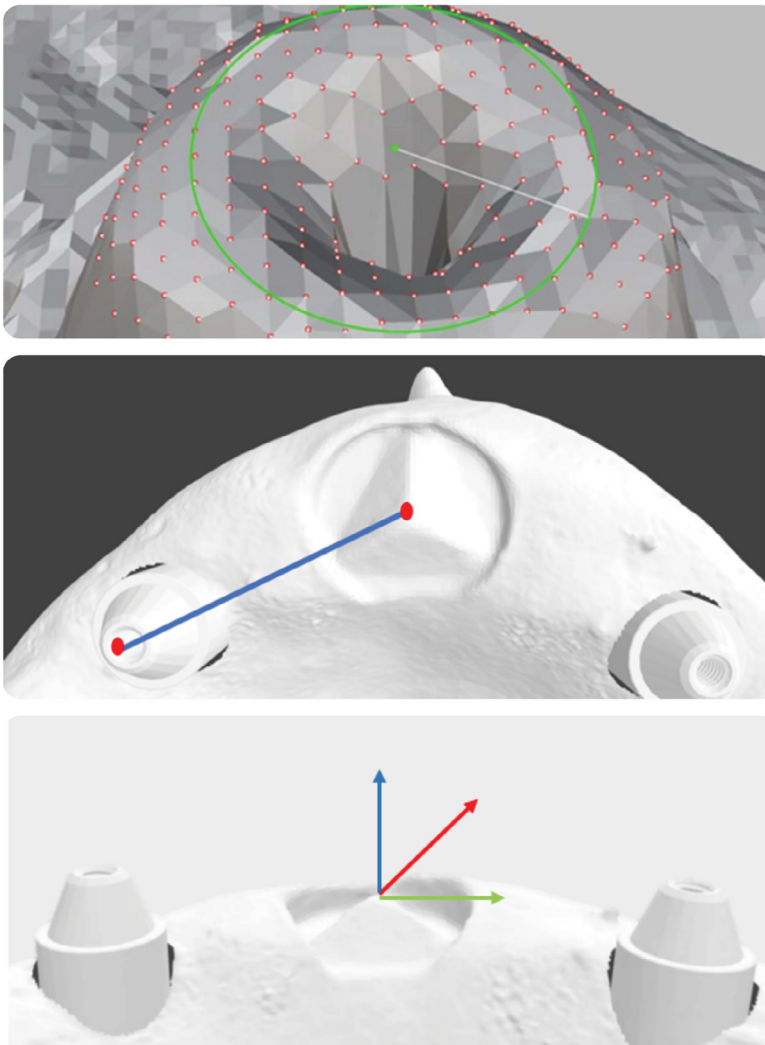


Figure 3. (A) Selection of reference points of the components. (B) Measurements of the distances between the origin and the center of the analogs. (C) X, Y, and Z axes to determine the measurements of all three axes.

After obtaining the reference points in the experimental images (extraoral scanners), we imported the control image to the Bio-CAD program, repeating the previous steps described to create the reference points to analyze the images. The pyramid's apex was used as the origin of the coordinate systems of models to calculate the distance between the origin and the centers of analogs (Figure 3B), generating the measurements necessary for verifying the deviations. These measurements were performed in the axes of the pyramid (X, Y, and Z), the X-axis being the vertical deviation, the Y-axis being the anteroposterior deviation, and the Z-axis being the lateral deviation (Figure 3C). As a result, we obtained three measurements for each component. The process was conducted with all 30 images generated by the laboratory scanners and compared with the control image generated by the contact scanner.

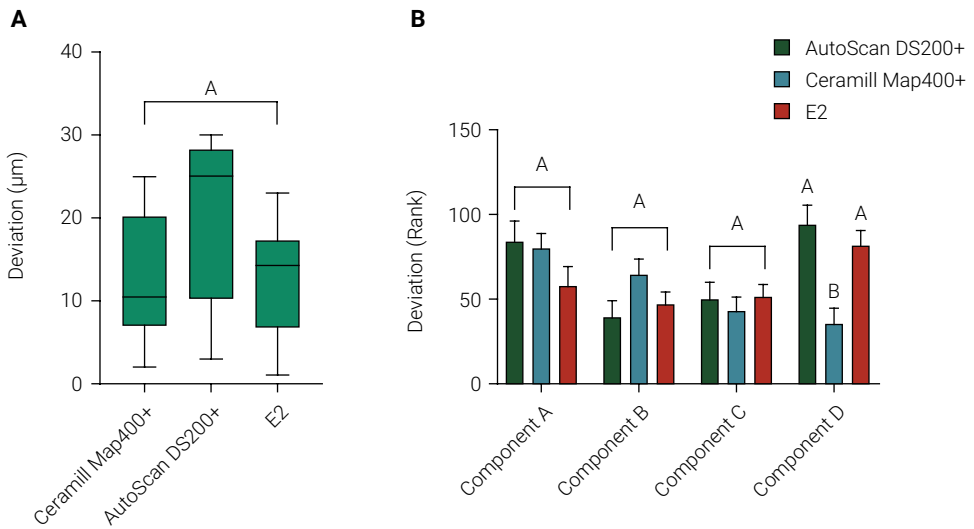


Figure 4. (A) Deviations of scanners related to manufacturers compared with the master model. (B) Components A, B, C, and D, when compared with the master model, about manufacturers of extraoral scanners. The components were analyzed individually and with no multiple comparisons between A, B, C, and D. Same letters represent no statistical difference ($\alpha=0.05$).

Statistical Analysis

This study has one dependent variable (accuracy) and two independent (extraoral scanning and components). However, before performing a statistical test, the data were treated: the master model deviation values were subtracted from all images, and the value of each sample was acquired. Next, two variables were analyzed: Scanners and Components.

When analyzing scanners, an average of the values (from the four components, considering all axis) was used to obtain a mean of each model. Besides, a mean of the components for each model was performed to analyze the components.

A normality test (Shapiro-Wilk) analyzed the measurements, and the nonparametric Kruskal-Wallis test was applied to analyze the scanners.

The average values of components A, B, C, and D were determined by a two-way ANOVA on ranks and a post hoc Tukey test. All the tests with a 5% significance level. GraphPad Prism6 software (San Diego, CA, USA) was used to perform the statistical tests.

Results

Considering the scanners variable, this study did not find any difference ($p=0.0806$). However, when analyzing by component (A, B, C, and D) and the different scanners technologies (Figure 4A), there is an interaction ($p<0.001$) between component ($p=0.001$) and scanner ($p=0.262$).

This interaction is related to scanners accuracy in each component, as observed in component D, despite greater deviations, was more accurate for the Ceramill Map400+ model when compared with AutoScan DS200+ ($p < 0.001$) and E2 ($p = 0.002$) (Figure 4B). However, all the other components (A, B, and C) presented no statistical differences, independent of the scanners.

Discussion

Our null hypothesis was partially accepted, as we did not find statistically significant differences in accuracy among the laboratory scanners; however, we found such differences between the components.

Component D was the only one to present a statistical difference in digitalization accuracy, as the Ceramill Map400+ scanner had a better performance than AutoScan DS200+ and E2. Probably the difference found in the last quadrant to be scanned, precisely the component D, occurred due to an increase in the area to be digitalized. Vecsei et al.³¹ found that the digitalization accuracy of laboratory scanners was influenced by the length of the arch included in the impression - the longer the arch to be scanned, the lower the accuracy of the digital impression^{32,33}. Several images are merged when digitalizing a more extensive area, leading to progressive distortion and more significant errors¹⁷. Thus, the digital impression of a complete-arch is less accurate due to the overlapping of partial scans of quadrants¹².

Our results showed greater deviations in all extraoral systems, in components A and D: Ceramill Map400+ (93.7 mm / 32.4 mm), AutoScan-DS200+ (113.1 mm / 144.11 mm), and E2 (64.3 mm / 97.8 mm), respectively. These errors may be related to the interaction between the angulation of implants and the distance between the scan bodies, as both implants are positioned in the reference model extremities. These extremities might distort the last components in a complete scan. Concerning the distance between scan bodies, only four implants in a completely edentulous arch result in a greater distance between the pillars. Additionally, distal angulation of posterior implants may increase the final interimplant distance.

Referring to angulation, Pan et al.³⁴, using an experimental block that simulates the All-on-four concept, found that laboratory scanners had a significant distortion in tilted sites. In addition, sizeable interimplant distance magnified the errors induced by the 45° implants. Pan et al.³⁴ explained this finding based on light scattering and rotation. In a 3D structured light scan, light patterns are projected on the target surface and captured by cameras. Therefore, minimal light obstruction from projectors to cameras is fundamental for such a difference in accuracy. Thus, the undercut areas of angulated implants might be avoided because the cameras did not receive sufficient signals due to shadows, affecting scanning accuracy³⁴.

Studies assessing implant angulation on digital models of intraoral scanners showed that $\leq 15^\circ$ angulation does not affect scanning accuracy^{9,35}. Furthermore, regarding the distance between scan bodies, studies showed that the accuracy of laboratory scanners was not affected by interimplant distances^{31,33}. Nevertheless, according to Vandeweghe et al.³², if the distance between scan bodies increases, scanning processes would become more complex, which would decrease scanning accuracy.

Scan bodies B and C positioned parallel to each other in the anterior region showed minor deviations in scanning accuracy, probably due to the morphology of the anterior arch, which presents a linear scan path. Concerning scanners, Ceramill Map400 showed the best results for the digital impression of a complete-arch, considering even the extremities quadrant with minor deviations. Furthermore, we did not find differences between the structured light and blue LED technologies.

Emir and Ayyıldız¹⁷ analyzed the accuracy of eight different extraoral scanners and their respective technologies. The authors concluded that the blue light scanners had more accurate results than white light ones¹⁷. Structured light scanners project a bi-dimensional pattern and have good scanning velocity; however, they lack repeatability and may present errors in narrow and deep areas. On the other hand, LED light scanners have better scanning repeatability and fewer errors due to short wavelengths¹⁷. In this study, the scanners or the product software technology might have reduced this repeatability error in structured light scanners.

Despite our results, some limitations must be considered. Because this is an *in vitro* study whose methodology was standardized, in everyday clinical practice, several variables may influence accuracy in the CAD/CAM method, such as the stage of the impression, material used, and scanning procedures³¹, as well as the device hardware, software algorithms, and scanning technology. Even the shape and size of a model may significantly impact the accuracy of an extraoral scanner¹⁷. Some scanners use powder during digitalization, and its thickness may contribute to differences between scanners in the final accuracy of digital impression^{16,23,36}.

Although there are advances in the launch of laboratory scanners on the market, few studies have approached the accuracy of extraoral scanners in complete-arch implant rehabilitation. Scientific literature is scarce, and results are divergent, meaning there is no agreement on the best extraoral systems.

In conclusion, all extraoral systems showed accuracy in digitalization. However, the angulated components may result in insufficient scanning accuracy. The Ceramill Map400+ scanner showed the best results for the digital impression of a complete-arch, which suggests that the AutoScan DS200+ and E2 scanners should be used for single or partial prostheses.

Acknowledgment

The work was supported by São Paulo Research Foundation – FAPESP (Grazielle Franco Gomes was supported by FAPESP grant #2019/22509-9) and CAPES (Coordination for the Improvement of Higher Education Personnel - Finance Code 001).

Data Availability

Datasets related to this article will be available upon request from the corresponding author.

Conflicts of interest

None.

Author Contribution

All authors declare that they actively participated in the discussion of the results, reviewed, and approved the final version for submission.

Grazielle Franco Gomes: Substantial contributions to the conception of the work; the acquisition, analysis, interpretation of data and final approval of the version to be published.

Mónica Estefanía Tinajero Aroni: Drafting the work and revised it critically for important intellectual content and and final approval of the version to be published.

Lucas Portela Oliveira: Substantial contributions to the conception of the work; the acquisition of data, analysis and final approval of the version to be published.

João Neudenir Arioli Filho: Interpretation of data and final approval of the version to be published.

Carolina Mollo Binda: Interpretation of data and final approval of the version to be published.

Francisco de Assis Mollo Júnior: Substantial contributions to the conception of the work, acquisition, analysis, interpretation of data and final approval of the version to be published.

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