ARTIGO ORIGINAL

ACCURACY AND PRECISION OF SIX DIGITAL SCANNERS IN FULL ARCH MAXILLARY SCANS: AN IN VITRO COMPARATIVE STUDY

Acurácia e precisão de seis scanners digitais nas varreduras de arco maxilar completo: um estudo comparativo in vitro

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ABSTRACT

The objective of this study is to evaluate the accuracy and precision of full arch maxillary digital scans produced by six digital scanners. Materials and Methods: A standard model was scanned by a reference scanner to obtain a standard digital reference model. This same model was then scanned ten times by three intraoral scanners and three benchtop scanners, which are: CS3600 (Carestream Health, Rochester, New York, USA), iTero element 2 (Align Technology, San José, California, USA), Trios (3Shape, Copenhagen, Denmark), Ceramill Map 400 (Amann Girrbach, Koblach, Feldkirch district, Austria), Identica T500 (Medit), and Zirkonzahn S600 ARTI (Zirkonzahn, Gais, Trentino-Alto Adige/Südtirol, Switzerland). To evaluate accuracy and precision, each obtained scan was superimposed on the standard digital model in reverse engineering software, Geomagic Control X (Geomagic, Morrisville, NC, USA), where a color map was generated and distances between specific points of interest were quantified. A trend report calculated the standard deviation in each of these scans. A one-way analysis of variance and a Games-Howell test were performed to measure deviations. Statistical calculations were performed using SPSS 23 (IBM, Armonk, NY, USA) at a significance level of 5%. Results: The benchtop scanner Ceramill Map 400 showed greater accuracy than the intraoral scanners iTero element 2 and Trios, followed by the CS3600 scanner. The benchtop scanners Zirkonzahn S600 ARTI and Identica T500 showed the worst accuracy among all evaluated equipment. The benchtop scanners Ceramill Map 400 and Identica T500 showed better precision, followed by the iTero element 2 and Trios scanners. The intraoral scanner CS3600 presented lower precision compared to these other scanners, but the benchtop scanner Zirkonzahn S600 ARTI had the lowest precision. Conclusion: We conclude from this research that accuracy and precision were directly influenced by the scanner used. The benchtop scanner Ceramill Map 400 presented the best accuracy. The benchtop scanners Zirkonzhan S600 ARTI and Identica T500 showed the worst accuracy; the intraoral scanners iTero, Trios, and CS3600 showed intermediate and very similar results in both accuracy and precision; the benchtop scanner Identica T500, which had the worst accuracy performance, along with the benchtop scanner Ceramill Map 400, obtained the best precision. The scanner Zirkonzhan S600 ARTI showed the worst precision with much larger deviations than the other scanners.

Palavras-chave: Intraoral scanners; Extraoral scanners; Dental impression.

RESUMO

O objetivo deste estudo é avaliar a acurácia e precisão das varreduras digitais de arco completo maxilar produzidas por seis scanners digitais. Materiais e métodos: Um modelo padrão foi escaneado por um scanner de referência para obter um modelo digital de referência padrão. Após esse mesmo modelo foi escaneado dez vezes por três scanners intraorais e três scanners de bancada, são eles: CS3600 (Carestream Health, Rochester, Nova York, EUA), iTero element 2 (Align Technology, San José, Califórnia, EUA), Trios (3Shape, Copenhague, Copenhage, Dinamarca), Ceramill Map 400 (Amann Girrbach, Koblach, distrito de Feldkirch, Áustria), Identica T500 (Medit) e Zirkonzahn S600 ARTI (Zirkonzahn, Gais, Trentino-Alto Adige/Südtirol, Suiça). Para avaliar a acurácia e precisão cada varredura obtida foi sobreposta ao modelo digital padrão em um software de engenharia reversa, Geomagic Control X (Geomagic, Morrisville, NC, EUA), onde um mapa de cores foi gerado e as distâncias entre pontos de interesse específicos foram quantificadas. Um relatório de tendência calculou o desvio padrão em cada uma dessas varreduras. Uma análise de variância a um critério e um teste de Games-Howell foram feitos para mensurar os desvios. Os cálculos estatísticos foram realizados no programa SPSS 23 (IBM, Armonk, NY, EUA), ao nível de significância de 5%. Resultados: O scanner de bancada Ceramill Map 400 apresentou maior acurácia do que os scanners intraorais iTero element 2 e Trios, seguidos pelo scanner CS3600. Os scanners de bancada Zirkonzahn S600 ARTI e Identica T500 apresentaram a pior acurácia entre todos os equipamentos avaliados. Os scanners de bancada Ceramill Map 400 e Identica T500 apresentaram melhor precisão seguidos pelos scanners iTero element 2 e Trios. O scanner intraoral CS3600 apresentou uma precisão inferior a estes outros scanners mas foi o scanner de bancada Zirkonzahn S600 ARTI que apresentou a menor precisão. Conclusão: Concluímos com esta pesquisa que a acurácia e a precisão foram diretamente influenciadas pelo scanner utilizado. O scanner de bancada Ceramill Map 400 apresentou a melhor acurácia. Os scanners de bancada Zirkonzhan S600 ARTI e Idêntica T500 apresentaram a pior acurácia; Os scanners intraorais Itero, Trios e CS3600 apresentaram resultados intermediários e muito semelhantes tanto em acurácia quanto precisão; O scanner de bancada Idêntica T500 que teve o pior desempenho de acurácia, juntamente com o scanner de bancada Ceramill Map 400 obtiveram a melhor precisão. Já o scanner Zirkonzhan S600 ARTI apresentou a pior precisão com desvios bem maiores que os demais scanners.

Keywords: Scanners intraorais; Scanners extraorais; Moldagem odontológica.

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INTRODUCTION

In recent years, dentistry has been marked by ongoing modernization. While analog techniques are still established and widely used, they are increasingly being replaced by digital workflows.

The introduction of computer-aided design and manufacturing (CAD/CAM) has revolutionized the way dentistry is practiced and dental prostheses are manufactured [27,35].

Two events that increased the acceptance of digital technology were the emergence of newer, more user-friendly intraoral digital scanners and the integration of digital technology into the curricula of dental schools [22].

Intraoral digital scanners allow dentists to capture the surface of the teeth, place scan bodies, and capture soft tissues in three dimensions, enabling almost instant communication with the laboratory and patients [12,20,27].

Digital scanners project a light source (usually a structured light grid with known geometry or a laser beam) onto the surface of the teeth and capture its deformation with powerful cameras. These data are processed by acquisition software, which generates a point cloud that is triangulated to produce a mesh. This mesh represents the direct reconstruction of the object's surface [19,34,38].

With intraoral digital scanners, dentate models are captured directly; there is no need to pour a gypsum model from a negative impression, as with conventional alginate, polyvinyl siloxane, or polyether impressions. Theoretically, this is an advantage because it eliminates all potential errors related to the transition from negative to positive, material distortions, patient discomfort from receiving impressions, rubber allergies, and difficulties in storage and data transfer [19,26,27,33,34,37,38].

Digital dental models enable the creation of virtual setups for enhanced treatment planning and the fabrication of custom removable and fixed appliances [12,20,27].

In addition to time efficiency, a full-arch scan with high precision is essential for the fabrication of multiple restorations or a complete oral rehabilitation [35].

However, digital impressions also have drawbacks, and when compared to elastomeric impressions, there is a higher potential for distortion of the digital impression, possibly due to poor technique or limitations of the specific scanning technology [8].

To perform many dental procedures using a completely digital workflow without producing conventional stone molds, any scanner used must clearly achieve clinically acceptable levels of precision. The precision of these devices is largely assessed in two ways: accuracy and precision. Accuracy is an estimate of how close a measured value is to the "true" value, while precision is a measure of how closely measured values match each other [18].

Precision is also referred to in other ways: Repeatability, which generally refers to the precision involved when the same operator measures the same object multiple times in the same environment, and reproducibility, which is assessed by the extent to which results are consistent even when different operators perform the scanning or when the scanning environment changes [4].

The ideal digital scanner should be capable of reconstructing and therefore reproducing the surface of the scanned object as faithfully as possible, meaning it should have high accuracy. It should also have high precision, providing consistent and repeatable results without deviations when scanning the same object [3,11].

It is also expected that scanning gypsum dental models will play an important role in creating 3D digital impressions of oral tissue, particularly for archiving existing physical dental models or when direct intraoral scanning is not possible. In these cases, conventional gypsum dental models are constructed and then scanned with a surface scanner to create a digital model similar to that obtained intraorally [14].

Currently, there is no consensus on which scanner is best or whether the full-arch application achieves the level of precision required for clinical implementation. Existing studies also focus on a limited number of available scanners [35].

Given that there are still doubts and questions regarding the accuracy and reliability of different types of intraoral and extraoral scanners, this study aimed to compare them and observe their performance.

PROPOSITION

The objective of this in vitro study is to evaluate the accuracy and precision of full maxillary arch digital scans produced by six digital scanners.

METHODOLOGY

The present study was approved by the Research Ethics Committee of São Leopoldo Mandic College under protocol number 2020-0890.

To eliminate procedural errors in the preparation of the scanned dental model, a commercially available fully dentate maxillary model (ROIC dental models, Três Corações, Minas Gerais) was used as the standard reference model (image 1).

A scan of the standard reference model was performed using the industrial laser scanner model Edge (FARO) with a precision of 0.058mm (image 2) to obtain a reference digital model in an open format stereolithography (STL) file.

Six different digital scanners were used for the analysis. Three benchtop scanners were used: Ceramill Map 400 (Amann Girrbach), Identica T500 (Medit), and Zirkonzahn S600 ARTI (Zirkonzahn). Additionally, three intraoral scanners were used: CS3600 (Carestream Health), iTero element 2 (Align Technology), and Trios (3Shape).

Scanning was performed at room temperature (25°C) and ambient humidity. Each scanner was calibrated according to the manufacturer's calibration guidelines.

After becoming familiar with each scanner, a single investigator (L.L.C.) performed ten scans of the reference model with each intraoral scanner. Additionally, ten scans of the reference model were performed with each benchtop scanner.

To avoid operator fatigue effects, the scans were conducted sequentially, one after another, with five-minute intervals between them.

Each dataset was converted into an open format stereolithography file using the conversion recommended by the respective manufacturer.

All obtained STL files were imported into the reverse engineering software Geomagic Control X (Geomagic, Morrisville, NC, USA). The models were trimmed/cropped to remove all unnecessary information using the "cut with planes" function. One model was pre-formed to ensure that all models were cut in the most uniform manner. These models were saved in specific folders.

Accuracy indicates the closeness to a true value, while precision indicates the level of repeatability.

To determine accuracy, each scanned digital model was superimposed onto the reference digital model using an initial alignment based on the two central incisors and the two second molars, which determined the final mesh positions. A color map was generated, where distances between specific points of interest were quantified both overall and in the three spatial planes (image 3). All deviations were thus visualized and calculated. A trend analysis was conducted, and the standard deviation was obtained for each scan.

To compare the differences in distances measured between digital reference models and digital models obtained through scanning, a one-way analysis of variance (ANOVA) was employed, as the data adhered to a normal distribution. For multiple comparisons, due to the heterogeneity of variance in the data, the Games-Howell test was used. Statistical calculations were performed using SPSS 23 software (IBM, Armonk, NY, USA), with a significance level of 5%.

To evaluate precision, the minimum and maximum difference values between the distances measured in the digital reference model and those obtained through scanning were analyzed. Additionally, a standard deviation was calculated for each intraoral and benchtop scanner model.

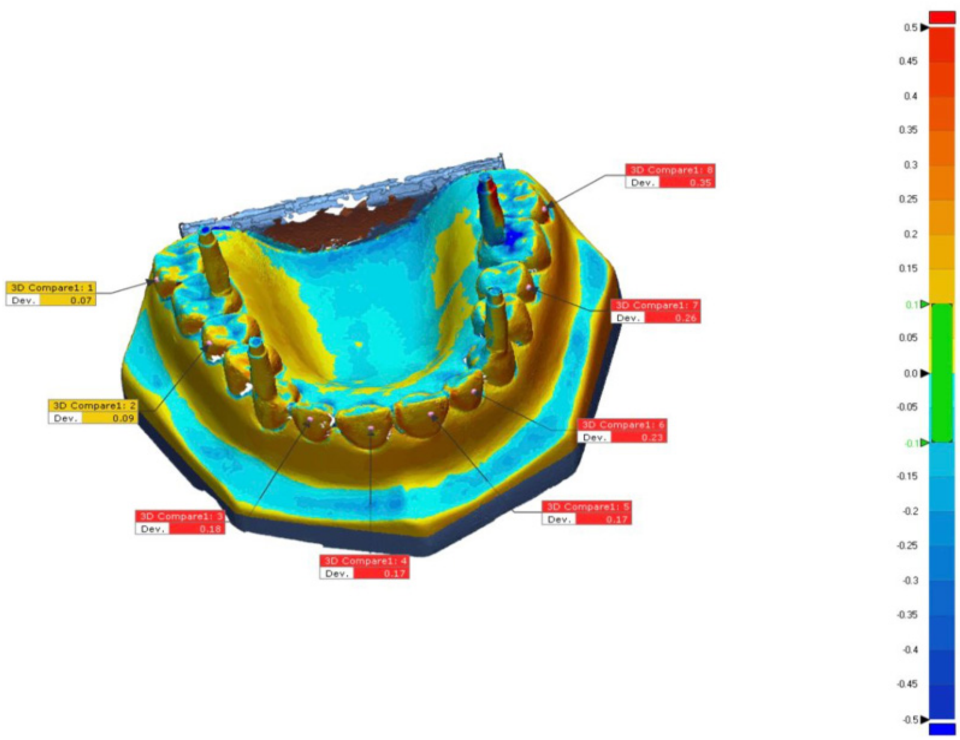
Image 1 - Standard reference model.

Source: own authourship.

Image 2 - Industrial laser scanner model Edge (FARO) with a precision of 0.058mm.

Source: own authourship.

Image 3 - Color map with the distances between specific points of interest quantified, both overall and in the three spatial planes.



Source: own authourship.

RESULTS

The one-way analysis of variance (ANOVA) demonstrated that the difference in distances measured between digital reference models and digital models obtained through scanning was influenced by the scanner used ($p < 0.001$).

Regarding accuracy, the mean deviation was significantly lower with the benchtop scanner Ceramill Map 400 compared to the intraoral scanners iTero element 2 and Trios, which did not differ significantly from each other and were followed by the scanner CS3600. With the latter equipment, deviations were significantly smaller than those produced by the benchtop scanners Zirkonzahn S600 ARTI and Identica T500, with the latter showing the largest deviations relative to all other evaluated devices (Table 1 and Graph 1).

Regarding precision, the benchtop scanners Ceramill Map 400 and Identica T500 did not differ significantly from each other and performed better than the intraoral scanners iTero element 2 and Trios, which also did not differ significantly from each other. The intraoral scanner CS3600 had lower precision compared to these other scanners, but it was the benchtop scanner Zirkonzahn S600 ARTI that showed the worst precision among the evaluated devices. (table 1).

Table 1 - Averages, standard deviations, and minimum and maximum values of the difference in distances measured between digital reference models and those obtained through scanning, according to the equipment used.

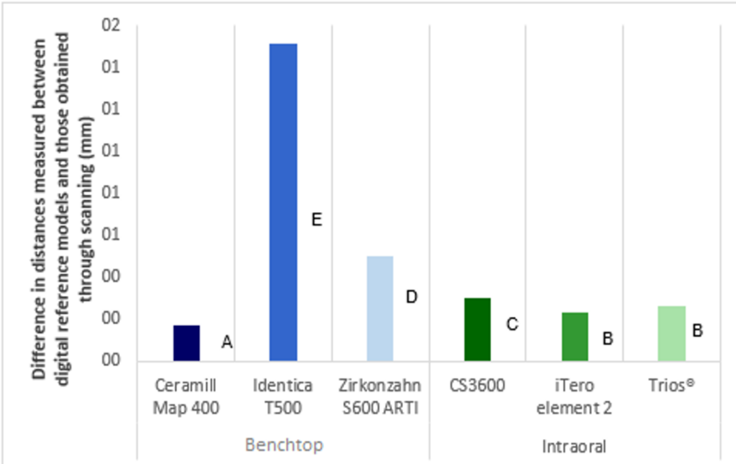
Table 1 - Averages, standard deviations, and minimum and maximum values of the difference in distances measured between digital reference models and those obtained through scanning, according to the equipment used.

Type of scanner	Equipment	Averages and standard deviation	Minimum and maximum values
Benchtop	Ceramill Map 400	0,17 (0,01) A	0,16 e 0,19
	Identica T500	1,51 (0,01) E	1,50 e 1,53
	Zirkonzahn S600 ARTI	0,50 (0,06) D	0,40 e 0,61
Intraoral	CS3600	0,30 (0,03) C	0,26 e 0,34
	iTero element 2	0,23 (0,02) B	0,20 e 0,27
	Trios®	0,26 (0,02) B	0,24 e 0,29

Legend: Averages followed by different letters indicate that there was a statistically significant difference between scanners.

Source: own authourship.

Graph 1 - Bar chart of the difference in distances measured between digital reference models and those obtained through scanning, according to the equipment used.



Legend: Columns identified with different letters indicate that there was a statistically significant difference between scanners.

Source: own authourship.

DISCUSSION

This study evaluated the accuracy and precision of six digital scanners. The use of a digital scanner to obtain intraoral impressions can be considered a significant advancement in dental treatment [16]. Due to the challenges encountered when working inside the oral cavity, it is possible to reproduce fundamental aspects for diagnosis, such as the shape and position of teeth, in dental models. These models are also widely used for planning and fabricating prostheses[15].

Intraoral scans are more comfortable than traditional impressions that use hydrocolloid and irreversible elastomeric impression materials. The user does not need to wait for the molding and subsequent gypsum model to make an assessment; they have an instant three-dimensional replica as soon as the scan is completed [16,20,31].

Overlaying digitized data is a well-established method for evaluating accuracy, where deviations between two data sets can be visualized and measured through 3D analysis [17].

In this study, the intraoral scanners iTero and Trios did not show statistically significant differences in accuracy and precision. Similarly, in the in vitro study by Anh et al. (2016), the iTero and Trios scanners also did not show significant differences in precision when compared across different degrees of dental irregularities. However, when the starting point of the scan differed, the iTero scanner was found to be less precise than the Trios [2]. In the study by Amornvit, Rokaya, and Sanohkan (2021), the Trios series showed better results in both accuracy and precision compared to other scanners [1].

Mejía et al. (2017) demonstrated that the Trios intraoral scanner can accurately record preparations made on abutment teeth, regardless of their geometry. This contrasts with elastomer-based impressions alone or those subsequently digitized with an extraoral scanner, which do not always reliably reproduce the preparations [23]. In the study by Nedelcu et al. (2018), scans obtained with an extraoral scanner from models made with elastomeric materials showed the best accuracy and precision [25]. According to Fukazawa, Odaira, and Kondo (2017), intraoral scanners can be clinically used in treatments involving multiple dental implants, as they can eliminate errors associated with materials [10].

Mutwalli et al. (2018) evaluated that regarding the measurement of implants used in the study, in terms of distance measurements between arches, the Trios 3 showed the lowest accuracy, followed by the Trios 3 Mono and the iTero. The Trios 3 also had the lowest precision, followed by the iTero and the Trios 3 Mono [24].

In the study by Renne et al. (2017), the iTero scanner demonstrated better accuracy compared to the Trios scanner, which, in turn, was better than the Carestream 3500 scanner. However, regarding precision, Renne et al. (2017) found that the CS3500 scanner performed better than the iTero and Trios scanners, which differs from the results of the present study [27].

In the study by Güth et al. (2017), the intraoral scanner CS3500 was found to be more precise than the benchtop scanner tested in the study [13]. In the present study, the intraoral scanners exhibited intermediate values of accuracy and precision compared to all other tested systems. In the study by Mangano et al. (2016), the CS 3500® scanner achieved the best accuracy and precision, followed by the Trios scanner [21]. In the study by Treesh et al. (2018), the CS 3500 scanner demonstrated lower accuracy and precision compared to the Trios scanner 35. In the study by Sason et al. (2018), the intraoral scanner CS 3500 showed higher precision and accuracy compared to the extraoral scanner LAVA™ Scan ST Design [29]. In the present study, a benchtop scanner (Ceramill MAP 400) demonstrated better accuracy, whereas the other benchtop scanners had the worst accuracy. Regarding precision, two benchtop scanners (Ceramill MAP 400 and Identica T500) exhibited better accuracy compared to another benchtop scanner that had the worst accuracy. In this study, the CS3600 scanner showed intermediate performance, slightly lower than the TRIOS scanner, similar to the findings of Winkler and Gkantidis (2020) [36].

As observed in this study, Rotar et al. (2019) also concluded that the differences in accuracy and precision among intraoral scanners were minimal [28]. According to Camardella, Breuning, and Vilella (2017), despite statistically significant differences between gypsum and digital models, these differences are not considered clinically relevant [5]. In the studies by Amornvit, Rokaya, and Sanohkan (2021), accuracy between gypsum and digital models varied, but precision was similarly favorable [1].

Su and Sun (2015) concluded in their study that the precision of intraoral scanning decreased with the increase in scan areas, being clinically acceptable only when the scan target was less than half of the arch [32]. In contrast, extraoral scanning demonstrated acceptable precision when scanning any region of the arch, supporting the findings of the study by Fukazawa, Odaira, and Kondo (2017) [10]. In the study by Shimizu et al. (2017), both intraoral and extraoral scanners exhibited clinically acceptable precision. However, intraoral scanners were significantly different from extraoral scanners in terms of accuracy, with extraoral scanners showing better performance [30].

In an in vitro study by Elkersh et al. (2023), benchtop scanners performed better than intraoral scanners, similar to the findings in this study with the Ceramill Map 400. Although they may differ insignificantly in precision, all can be applied clinically [7].

To perform scanning with the benchtop scanners in this study, it was necessary to use a powder coating to minimize the reflectivity of the models [10,25].

The initial idea of this study was to use scan bodies as reference points for measurements. However, because they were isolated in the arch, their use was impractical as scanners lost reference during scanning, potentially generating distorted information, thus rendering the study invalid and inconsistent. Similarly, scanners may encounter this difficulty in scans of fully edentulous arches.

Lee et al. (2019), in an in vitro study, found no significant difference in precision between the CS3600 and the i500 scanners. The largest deviations were observed around partially edentulous areas 18. Similarly, Nedelcu et al. (2018) concluded that intraoral scanners can be used as substitutes for conventional scanners in scans involving up to ten teeth and without extended edentulous areas [25].

Mutwalli et al. (2018) suggested that when scanning fully edentulous arches, the precision was low for all the intraoral scanners tested [24].

Tasaka et al. (2019) in an in vitro study show that if certain issues are carefully addressed, intraoral scanners can be used for residual ridges and edentulous areas [33]. Similarly, Kihara et al. (2020) concluded that due to the repeatability of intraoral scanners, they are capable of producing fixed prostheses for partially edentulous patients [16].

This study, being an in vitro test, has some limitations regarding intraoral scanners, as the oral cavity and the entire stomatognathic system cannot be replicated in the laboratory. Therefore, it is important to consider that the results obtained here may not be replicated when used on patients. In the study by Flugge et al. (2013), the iTero scanner showed lower precision compared to the D250 scanner. Intraoral scanning with the iTero was less precise than scanning the model with the iTero, which may suggest that intraoral conditions (saliva, limited space) contribute to the imprecision of a scan [9].

As new scanners and software are developed, it is possible that the accuracy and precision of impressions will improve substantially. However, ongoing studies will be necessary to evaluate these new technologies [6].

The growth of these technologies will also reduce the purchase price of the equipment and the fees paid by users, which will facilitate and benefit patients as dentistry transitions to a new generation of CAD/CAM [31].

CONCLUSION

We conclude from this research that:

Accuracy and precision were directly influenced by the scanner used.

The benchtop scanner Ceramill Map 400 showed the best accuracy, differing from the other benchtop scanners Zirkonzahn S600 ARTI and Identica T500, which had the worst accuracy.

The intraoral scanners iTero, Trios, and CS3600 showed intermediate results and were very similar in both accuracy and precision.

The benchtop scanner Identica T500, which had the worst accuracy performance, along with the benchtop scanner Ceramill Map 400, achieved the best precision. Meanwhile, the Zirkonzahn S600 ARTI scanner exhibited the worst precision with significantly higher deviations compared to the other scanners.

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Observação: os/(as) autores/(as) declaram não existir conflitos de interesses de qualquer natureza.