Rodrigo Freitas da Silva

Acurácia de diferentes métodos para obtenção de modelos digitais de arco completo: Um estudo *in vivo*

Accuracy of different methods for obtaining full-arch digital models: A *in vivo* study

Dissertação apresentada à Faculdade de Odontologia da Universidade Federal de Uberlândia, para a obtenção do Título de Mestre em Odontologia na Área de Clínica Odontológica Integrada.

Uberlândia, 2022

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Orientador: Prof. Dr. Luís Henrique Araújo Raposo

Banca examinadora:

Prof. Dr. Luís Henrique Araújo Raposo

Prof. Dr. Flávio Domingues das Neves

Prof. Dr. João Paulo da Silva Neto

Uberlândia, 2022

UNIVERSIDADE FEDERAL DE UBERLÂNDIA
Coordenação do Programa de Pós-Graduação em Odontologia
Av. Pará, 1720, Bloco 4L, Anexo B, Sala 35 - Bairro Umuarama, Uberlândia-MG, CEP 38400-902
Telefone: (34) 3225-8115/8108 - www.ppgoufu.com - copod@umuarama.ufu.br

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Preocupas-te se a árvore de tua vida tem galhos apodrecidos? Não percas tempo; cuida bem da raiz e não terás de andar pelos galhos.

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SUMÁRIO

RESUMO

Escâneres intraorais (EIs) são usados rotineiramente e sua acurácia tem sido testada principalmente por estudos laboratoriais. No entanto, investigações *in vivo* são necessárias para avaliar a acurácia de diferentes equipamentos digitais usados para escaneamentos de arco completo. Este estudo teve como objetivo investigar a acurácia de diferentes EIs, usados por operadores experientes para escaneamento de arco completo. Escaneamentos de arco completo foram realizados em 15 indivíduos empregando dois EIs (Trios 3 e iTero 5D); em seguida, as impressões em PVS e modelos de gesso foram obtidos e digitalizados em escâner de bancada (inEos X5). Os escaneamentos intraorais foram realizadas nos períodos T0 e T1, para ambos os EIs. Já as impressões PVS foram realizadas em T0. A precisão entre os sistemas de escaneamento foi calculada pelo desvio médio entre as sobreposições das 4 varreduras de cada grupo, em ambos os períodos (n=12). A veracidade entre os grupos foi avaliada pela sobreposição dos 8 escaneamentos intraorais de cada participante, sendo os modelos de referência obtidos do escâner de bancada (n=10). Os modelos foram analisados em um software 3D para extração dos dados. *ANOVA* em parcelas subdivididas no tempo foi usada para análise da veracidade e um delineamento inteiramente casualizado para análise da precisão. A precisão média do Trios 3 foi de 7,0 e 8,6 µm para os modelos maxilar e mandibular, respectivamente. Para o iTero 5D, a precisão média foi de 9,0 e 8,8 µm para os modelos maxilar e mandibular, respectivamente. Não foram observadas diferenças significativas para a precisão dos sistemas de EIs ($P>0,05$). O escâner de bancada, apresentou diferenças significativas para precisão, demonstrando variações reduzidas (melhor precisão) em relação aos EIs, com precisão de 1,0 e 0,9 µm para os modelos maxilar e mandibular, respectivamente ($P<0,05$). O sistema Trios 3 apresentou melhor veracidade para os modelos mandibulares, no parâmetro inferior máximo ($P<0,05$). Os valores numéricos de veracidade foram melhorados do período T0 a T1, para ambos os sistemas de EIs ($P>0,05$). Analisando a veracidade em função do tempo, observou-se uma melhora em T1 para os modelos maxilares (parâmetros máximos e mínimos superiores), independente dos EIs ($P<0,05$). O escâner de bancada mostrou melhor precisão para varredura de arco completo em comparação com os dois sistemas de EIs. Precisão semelhante foi alcançada por operadores experientes em escaneamento de arco completo, independentemente do sistema de EIs. A veracidade dos modelos maxilares melhorou com a experiência repetida de escaneamento, independentemente dos sistemas de EIs.

PALAVRAS-CHAVE: Acurácia; escâneres; escaneamentos de arco completo

ABSTRACT

Intraoral scanner systems (IOSs) are routinely used, and their accuracy has been primarily tested by laboratory studies. However, in vivo investigations are required to assess the accuracy of different digital equipment used for full-arch scans. This study aimed to investigate the accuracy of different IOSs used by experienced operators for full-arch scanning. Full-arch scans were taken from 15 subjects using two IOSs (Trios 3 and iTero 5D); after, PVS impressions and stone casts were obtained and digitized in a desktop scanner (inEos X5). Intraoral scans were performed at T0 and T1 periods for both IOSs; PVS impressions were taken at T0. The precision between the scanner systems was calculated by the mean deviation among the overlaps of the 4 scans from each group, at both periods (n=12). The trueness between the groups was assessed by superimposing the 8 intraoral scans of each participant on their reference models obtained from the desktop scanner (n=10). The models were analyzed in a proper 3D software to extract the data. ANOVA in split-plots in time was used for test trueness and in a completely randomized design for test precision. The mean precision for Trios 3 was 7.0 and 8.6 µm for maxillary and mandibular models, respectively. For iTero 5D, the mean precision was 9.0 and 8.8 µm for maxillary and mandibular models, respectively. No significant differences were observed for the precision of the IOS systems ($P>0.05$). The desktop scanner, showed significant differences for precision, presenting reduced variations (better precision) compared to the IOSs, with 1.0 and 0.9 µm precision for maxillary and mandibular models, respectively ($P<0.05$). The Trios 3 system presented better trueness for the lower models, in the maximum inferior parameter ($P<0.05$). The numeric values of trueness were improved from the T0 to T1 period, for the both IOS systems ($P>0.05$). Analyzing the trueness as a function of time, an improvement was observed in T1 for the maxillary models (maximum and minimum superior parameters), irrespective of the IOSs ($P<0.05$). The desktop scanner showed better precision for full-arch scanning comparing to the both IOS systems. Similar precision was achieved by experienced operators in full-arch scanning, regardless of the IOS system. The trueness of the maxillary models improved with the repeated scanning experience, irrespective of the IOS systems.

KEYWORDS: Accuracy; scanners; full arch scan.

1. INTRODUÇÃO E REFERENCIAL TEÓRICO

O fluxo digital na odontologia é uma realidade e apesar de muitos profissionais ainda não terem acesso a todas as etapas dessas tecnologias, a transição do não-digital (analógico) para o digital ocorrerá gradualmente ao longo dos próximos anos. Possivelmente não será uma substituição total, mas sim uma nova ferramenta a disposição dos cirurgiões-dentistas, sempre com o intuito de aprimorar os planejamentos, aumentar a previsibilidade, reduzir tempo, facilitar a comunicação entre profissional-paciente e, se aplicadas adequadamente, entregar melhores resultados (Akyalcin *et al.,* 2013; Nedelcu *et al.,* 2014; Mizumoto *et al.,* 2018).

Como toda nova tecnologia, para a aplicação nos consultórios faz-se necessário passar por uma curva de aprendizado, tanto com os equipamentos quantos com os softwares que integram o "pacote digital" (Lim *et al.,* 2018). Para isso, os profissionais terão que entender que não basta somente investir no equipamento mais tecnológico. Entender a relação custo-efetividade é essencial para se fazer uma boa escolha, seja pensando no investimento financeiro, mas também no retorno e na acurácia que tais equipamentos garantirão (DeLong *et al.,* 2003; Nedelcu *et al.,* 2014).

Os modelos digitais de arco completo podem ser obtidos por escaneamentos com escâneres intraorais (técnica direta) ou por escaneamentos de modelos de gesso com escâneres de bancada (técnica indireta), que foram obtidos de moldagens prévias. Conhecer a acurácia de cada equipamento é fundamental! A literatura já nos mostra que os escâneres de bancada possuem maior precisão que os escâneres intraorais para este tipo de escaneamento e que os escâneres intraorais perdem em acurácia quanto maior for a área a ser escaneada (Flügge *et al.,* 2013; Su *et al.,* 2015). Já em relação a veracidade dos modelos obtidos por escâneres intraorais é variável, sendo influenciada pelo tipo de escâner utilizado, a experiência do operador e o tamanho da área a ser escaneada (César *et al.,* 2021).

Estudos laboratoriais (*in vitro*) demonstram a acurácia entre os diferentes equipamentos e sistemas, mas é importante ressaltar que os desenhos de tais modelos experimentais são diferentes quando aplicados em modelos humanos, fazendo com que tais resultados possam ser aplicados com ressalva na prática clínica (Renne *et al.,*2017; César *et al.,* 2021). Os modelos experimentais laboratoriais possuem a sua importância, mas a produção de estudos clínicos *in vivo*, faz com que parâmetros mais próximos do que é aplicado na prática clínica sejam disponibilizados.

Desta forma, esta pesquisa clínica foi proposta para colaborar com os profissionais, trazendo mais dados e informações de diferentes sistemas de escâneres digitais. Tais equipamentos são utilizados para a obtenção de modelos digitais tridimensionais. Sejam obtidos pela técnica direta ou indireta, os modelos digitais precisam reproduzir com fidelidade todos os componentes intraorais, pois os diagnósticos e planos de tratamentos que serão aplicados na rotina clínica diária serão realizados a partir dos mesmos (Sun *et al.,* 2017).

2. PROPOSIÇÃO

Em decorrência da limitada quantidade de estudos *in vivo* disponíveis na literatura, esta pesquisa clínica propôs uma investigação cujo objetivo foi comparar a acurácia (precisão e veracidade) de modelos digitais obtidos por diferentes escâneres intraorais (Trios 3 Color; 3 Shape/ iTero 5D; Align Technology) quando comparados com modelos obtidos por escâner de bancada (inEos X5; Dentsply Sirona) a partir de modelos de gesso, em diferentes tempos (T0 e T1 – 15 dias após o primeiro escaneamento). A hipótese nula do estudo foi que nenhuma diferença significante seria encontrada para o fator acurácia (precisão e veracidade) entre os diferentes equipamentos e sistemas.

3. CAPÍTULO 1

ARTIGO

Accuracy of different methods for obtaining full-arch digital models: A *in vivo* study

- **Artigo a ser enviado para o periódico (The Journal of Prosthetic Dentistry)**

Accuracy of different methods for obtaining full-arch digital models: A *in vivo* study

Rodrigo Freitas da Silva, DDS,[a], Lucas Nascimento Tavares, DDS, MS, PhD,[b], Guilherme Faria Moura, DDS, MS, PhD,[b], Christian Reis Lemes, DDS, MS,[c], Luís Henrique Araújo Raposo, DDS, MS, PhD,[d]

[a] Graduate student, Department of Occlusion, Fixed Prosthodontics and Dental Materials, School of Dentistry, Federal University of Uberlândia, Minas Gerais, Brazil.

[b] Department of Occlusion, Fixed Prosthodontics and Dental Materials, School of Dentistry, Federal University of Uberlândia, Minas Gerais, Brazil.

[c] Private practice, Uberlândia, Minas Gerais, Brazil.

[d] Professor, Department of Occlusion, Fixed Prosthodontics and Dental Materials, School of Dentistry, Federal University of Uberlândia, Minas Gerais, Brazil.

Corresponding author:

Dr. Luís Henrique Araújo Raposo

Av. Pará, 1720, Bloco 4LA, Sala 41

Campus Umuarama – Uberlândia-MG

CEP: 38400-902

Tel.: +55-34-32258105 / Fax.: +55-34-32258106

E-mail: raposo@ufu.br

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ABSTRACT

Intraoral scanner systems (IOSs) are now routinely used, and their accuracy has been primarily tested by laboratory studies. However, in vivo investigations are required to assess the accuracy of different digital equipment used for full-arch scans. This study aimed to investigate the accuracy of different IOSs used by experienced operators for full-arch scanning. Full-arch scans were taken from 15 subjects using two IOSs (Trios 3 and iTero 5D); after, PVS impressions and stone casts were obtained and digitized in a desktop scanner (inEos X5). Intraoral scans were performed at T0 and T1 periods for both IOSs; PVS impressions were taken at T0. The precision between the scanner systems was calculated by the mean deviation among the overlaps of the 4 scans from each group, at both periods (n=12). The trueness between the groups was assessed by superimposing the 8 intraoral scans of each participant on their reference models obtained from the desktop scanner (n=10). The models were analyzed in a proper 3D software to extract the data. ANOVA in split-plots in time was used for test trueness and in a completely randomized design for test precision. The mean precision for Trios 3 was 7.0 and 8.6 μm for maxillary and mandibular models, respectively. For iTero 5D, the mean precision was 9.0 and 8.8 μm for maxillary and mandibular models, respectively. No significant differences were observed for the precision of the IOS systems ($P>0.05$). The desktop scanner, showed significant differences for precision, presenting reduced variations (better precision) compared to the IOSs, with 1.0 and 0.9 μm precision for maxillary and mandibular models, respectively ($P<0.05$). The Trios 3 system presented better trueness for the lower models, in the maximum inferior parameter ($P<0.05$). The numeric values of trueness were improved from the T0 to T1 period, for the both IOS systems ($P>0.05$). Analyzing the trueness as a function of time, an improvement was observed in T1 for the maxillary models (maximum and minimum superior parameters), irrespective of the IOSs ($P<0.05$). The desktop scanner showed better precision for full-arch scanning comparing to the both IOS systems. Similar precision was achieved by experienced operators in full-arch scanning, regardless of the IOS system. The trueness of the maxillary models improved with the repeated scanning experience, irrespective of the IOS systems.

CLINICAL IMPLICATIONS

Variations in the accuracy of IOS systems are still critical when performing *in vivo* full-arch scanning, even when used by experienced operators, as the repeated scanning experience with these systems results in improved trueness. This is an important clinical aspect to be considered since adequate accuracy for *in vivo* full-arch scanning may depend as much on the experience of the operator as on the IOS system itself. Digitizing stone casts in desktop scanners is still a reliable and precise option for obtaining full-arch digital models.

INTRODUCTION

Full digital flow is a reality in contemporary dentistry, consisting in obtaining three-dimensional (3D) digital models through intraoral scanning (direct technique) or by scanning impressions/ (indirect technique) using a desktop scanner. Both the physical and the digital models are used, by different dental specialties, for the diagnosis, planning and execution of the treatment plan.[1–3] The use of digital models mitigates several obstacles and challenges inherent to the conventional impression procedures, including the possibility of distortion of the materials, following biosafety standards for disinfection, the burden of physical space for storing the models, the risks of damage, and the difficulty in sharing data with other professionals. In addition, digital files allow the workflow to be performed in fewer laboratory steps, reducing time, and improving the quality of dental treatments.[4–6]

The analysis of accuracy is composed by the evaluation of precision and trueness parameters (ISO 5725-1)[7]. Trueness is, by definition, an indication of how similar a measurement is to a known measured value. In the present study, trueness describes the deviation of the measurements in the data set compared to the actual dimensions of the scanned object. Therefore, high trueness indicates that the intraoral scanners (IOSs) deliver a result that is very close to the actual dimensions of the digitized plaster model. Precision expresses the degree of reproducibility or agreement between repeated measurements. In the present study, precision describes how close each measurement in the data set is to the other measurements taken by the same scanner.[8,9]

The accuracy of intraoral scans is an important parameter to be considered, since diagnosis and planning, in different areas of dentistry, are now performed using digital models.[1,2,8–25] These aspects have been evaluated by several studies, which demonstrated that factors such as operator experience, type of scanner and the size of the area to be scanned can influence the accuracy of digital models obtained by IOSs.[10,13,19,20]

A study comparing the accuracy of digital models obtained by different methods found that models obtained using a desktop scanner presented better accuracy (indirect technique) when compared to those obtained with IOS systems (direct technique).[15,20] However, one of these studies presents a methodological deficiency since its sample consisted of only 1 individual.[15] Similarly, other studies reported that the accuracy of models obtained by IOS systems decreases when performing full-arch scanning. The digital models obtained by extraoral scanning (desktop scanner), on the other hand, showed good accuracy results under these same conditions. As these are *in vitro* studies, such results must be carefully interpreted for clinical applications.[17,19] A previous investigation reported that it is possible to compare the reproducibility between digital models obtained using direct or indirect techniques, at different times. According to this study, a small difference (0.02mm) was found between digital *in vivo* and *ex-vivo* models.[15] For this study, stone casts were digitized using intraoral and desktop scanners, and the resulting digital models compared, which is not the most accurate approach to perform this evaluation.

An *in vitro* study comparing the accuracy of scans performed by 3 different operators with different levels of experience (low, medium and high) using 2 distinct IOS systems, found that the greater the experience of the operator and the smaller the areas to be canned, the greater is the accuracy of the digital models.[19] There are few clinical studies in the literature comparing the accuracy of IOS systems, given the difficulties in data collection when compared to laboratory studies, which in turn, are more predictable. This fact restricts the application and standardization of clinical procedures using IOSs, as the results may differ when applied from *in vitro* investigations to *in vivo* situations.

Therefore, the aim of this *in vivo* study was to evaluate the accuracy (precision and trueness) of digital models obtained by different IOS systems (Trios 3; 3Shape/iTero 5D;Align Technology) when compared with cast stone models obtained by poly (vinyl siloxane)(PVS) impression and digitized in a desktop scanner (inEos X5; Dentsply Sirona), at different periods (T0 – initial; and T1 – 15 days after T0). The null hypothesis of the study was that no differences would be found for the accuracy among the distinct scanning techniques and equipment.

MATERIALS AND METHODS

This prospective clinical study was approved by the Human Research Ethics Committee of the Federal University of Uberlandia (CAAE 28378519.5.0000.5152). The sample size was determined using the G-Power software (v. 3.1.9.4; Franz Faul, Universitat Kiel, Germany), with a 0.05 significance level and 0.8 power. The initial sample selected for this study consisted of 19 subjects (6 men, 13 women - mean age 28.5

± 0.6 years), who underwent orthodontic treatment (completed). Four individuals did not attend the subsequent phases to data collection, as were considered as dropouts. All individuals signed an informed consent form. Inclusion criteria were: (1) individuals aged between 18 and 45 years of both sexes; (2) complete and fully erupted permanent dentition (except for cases with tooth extraction for orthodontic purposes); (3) Angle class I occlusion; (4) no amalgam restorations or metal crowns; (5) no signs of temporomandibular disorders; (6) absence of trismus and/or mouth opening limitations; (7) orthodontic treatment completed at least 6 months prior to the first evaluation. Subjects were excluded from participation from the sample if they met the following exclusion criteria: (1) subjects who reported exacerbated painful symptoms in the temporomandibular joint, which prevented any attempt at mandibular repositioning, necessary for diagnosis and subsequent assembly, in semi-adjustable articulator (SAA); and (2) individuals who did not have the external auditory meatus completely formed in order to allow the adaptation of the facial bow.

All subjects underwent clinical, non-invasive procedures. Each of them received an identification number, which was used in order to store the files and during the statistical analysis. Each individual was allocated into the 3 study groups (n=15): Desktop scanner (DS) – PVS impressions of the maxillary and mandibular arches were taken, stone cast models obtained and set up in a SAA and digitized using a desktop scanner; Trios scanner (TS) – intraoral scanning using Trios 3 IOS system; iTero scanner (IS) – intraoral scanning using iTero 5D IOS system.

For the DS group, impressions of the maxillary and the mandibular arches were taken using PVS (Panasil Putty Soft + Panasil Initial Contact Light; Kettenbach GmbH & Co. KG), with putty and light components used in a single-step technique. The impressions were poured under vibration using special low-expansion stone plaster Type IV Gypsum (Esthetic base gold; Dentona) mixed in a vacuum-mixer. The stone casts were then scanned and digitized, using a desktop scanner (inEos X5; Dentsply Sirona) at distinct periods, T0 (initial) and T1 (15 days after T0). The scanning was performed using of the software (inLab CAM SW v.18.1, Dentsply Sirona), in which, a maximum length for the video capture was taken per arch to avoid any possible file corruption (Table 1). The digital models were exported using *.STL (Stereolithography) file format for subsequent analysis and superimposition in a specific software.

For the TS group, full-arch scanning of the mandibular and maxillary arches was performed using Trios (Trios 3 Color; 3Shape) IOS system, at T0 (initial) and T1 (15 days after T0). The scanning was performed using the "Insane mode" of the software (Dental Desktop v1.6.4.1, 3Shape), in which, a maximum number of 2,000 images were taken per arch to avoid any possible file corruption (Table 1). After scanning the both arches, occlusal records were taken in two distinct relationships, maximum intercuspation (MIC) and centric relation (CR) using a Lucia's JIG for stabilization. The digital models were post-processed and the resulting files exported in *.STL file format for posterior analysis.

For IS group, full-arch scanning of the mandibular and maxillary arches was performed using Itero (iTero 5D; Align Technologies) IOS system, at T0 (initial) and T1 (15 days after T0). The scanning was performed using the "iRecord mode" of the software (iTero Element 5D v5.9.1.20, Align Technologies), in which, a maximum length for the video capture was taken per arch to avoid any possible file corruption (Table1). After scanning the both arches, occlusal records were taken in two distinct relationships, MIC and CR as described. The digital models were post-processed and the resulting files exported in *.STL file format for later analysis.

All data collected as well as the clinical and laboratory procedures were performed by 3 operators, each responsible for one of the experimental groups. The operators have high clinical experience in dentistry (> 10 years of clinical experience) and handling of intraoral and desktop scanners (>5 years of experience). All the digital systems were used according to the manufacturer's instructions, standardizing the scanning sequences for all participants. Before starting the scanning procedures for each group, the IOS systems were calibrated and pre-warmed. For the intraoral scanning, all teeth were dried with an air syringe and sterile gauzes, and any accessory lighting source from the dental chair was turned off to avoid interferences. The native digital image files produced for each system were also stored directly in the respective company's software.

To verify the precision between the models from each group, all the 12 files acquired from each participant (scanner system x dental arch x period), were superimposed and the mean, maximum and minimum deviations of these pairings were calculated (n=12). Intragroup analyses were performed (DS-T0 x DS-T1; TS-T0 x TS-

T1; IS-T0 x IS-T1), for upper and lower models. To assess the trueness between the experimental groups, all the 12 files acquired from each participant (scanner system x dental arch x period) were superimposed and the mean, maximum and minimum deviations of these pairings were calculated (n=10). Intergroup analyses were performed (DS x TS-T0 and DS x TS-T1; DS x IS-T0 and DS x IS-T1), for upper and lower models. For all analyses, the individual digital model of each arch (upper or lower) from the groups was imported into the Geomatic software (Geomatic Control;3D Systems, Inc). The model obtained in T0 was considered as a reference for precision analysis, and the models obtained from DS group were considered as a reference for trueness. After the two models were inserted in the software for comparison, initial alignment of the models was performed. Following this step, excess marginal tissue was removed, both buccally and palatal/lingually, leaving only the teeth and gingival margin of approximately 2 to 3 mm (horseshoe shape). Next, fine adjustment of the models was carried, seeking the best alignment possible. Using the 3D comparison tool for each overlay, the differences between the surfaces (reference model and comparison model) were calculated along the models, resulting in mean, maximum and minimal values (mm). Furthermore, the differences were also represented by a color map scale (Fig. 1).

One-way analysis of variance (1-way ANOVA*)* test was used in a completely randomized design to determine the differences in deviations between the scanner systems considering the precision factor. To compare the groups in terms of differences in deviations to trueness according to the scanner systems, 2-way ANOVA was used in a split-plot in time scheme. The Kolmogorov-Smirnov test was used to test the normality of deviations. As the data presented non-normal distribution, root transformation (x + 1) was performed to allow ANOVA test to be performed. To assess the differences between the means, Tukey HSD test was used. All tests were performed with 5% significance level, using a statistical software package SISVAR, v.5.6, UFLA).

RESULTS

The 1-way ANOVA test showed significant differences for the precision between the different scanner systems ($P<0.05$) (Table 2). The DS group (inEos X5) showed significant lower means for model precision (better precision) than the TS (Trios

3) and IS (iTero 5D) intraoral scanning systems (P<0.05), which presented similar results between them.

The results for trueness between the groups, disregarding time factor, are presented in Table 3. The 2-way ANOVA showed significant differences for the trueness of the *mandibular maximum parameter* for the IS group (iTero 5D), disregarding the period factor, which showed higher mean values than the TS group (improved trueness for Trios 3) (P<0.05). No significant differences were detected for the other trueness parameters comparing the both IOS systems with the DS group (inEos X5). The mean values for the *maxillary and mandibular parameters* for trueness showed no significant differences between the both IOS systems.

The results for trueness between the groups, considering the period factor, are shown in Table 4. There was a numeric improvement in the trueness values for all parameters tested for the both IOS groups at T1, except for the isolated *maxillary and mandibular average DS x IS parameter*. However, no significant differences were detected among the scanners systems evaluated (P>0.05).

The split-plot ANOVA results over time also demonstrate that, regardless of the scanner system, significant differences were found for the trueness between the first (T0) and second (T1) scans for the maxillary arch in the *maximum and minimum maxillary parameters* (P<0.05). No significant differences were detected for the other trueness parameters evaluated (Table 5).

DISCUSSION

The null hypothesis was rejected as significant differences were detected for the precision between the IOS systems and the desktop scanner. For the trueness, significant differences were also detected in the upper arch scans, from T0 to T1, regardless of IOS system. This *in vivo* study presents different methodological design for accuracy analysis between different IOS systems, when compared to other investigations.[13,15,16] Questions may arise regarding the number of times each participant should be scanned to analyze the deviations among scans, but it is worth emphasizing the inherent difficulties in carrying out a *in vivo* study, a factor that made it difficult for participants to return for repeated collections.

On the present investigation, the mean precision results for the TS group were 7.0 and 8.6 µm, for the maxillary and mandibular models, respectively. For the IS group, 9.0 and 8.8 µm, for the maxillary and mandibular models, respectively. No significant differences were found when analyzing the precision factor between the IOS systems ($P>0.05$). In the DS group, the mean precision was 1.0 µm and 0.9 µm, for the maxillary and mandibular arches, respectively, being significantly lower (better precision) when compared to the values verified for the IOS systems ($P<0.05$).

In this study, the desktop scanner (inEos X5) showed greater precision when compared to the both IOSs, with results very similar to those obtained by a previous *in vitro* study.[21] This high precision may be related to the presence of a wider field of view when compared to intraoral scanners. We also relate these results to the absence of some inhibiting or limiting factors, such as: lens wetting, saliva, soft tissue, tongue, reflective surfaces (enamel), variation in tone between tooth structures and tissues and muscle movements that can prevent suitable full arch scanning.[21,22] Another factor that may have contributed to an improved accuracy for this equipment is the blue light used on the camera. Desktop scanners that use this type of light are shown to perform better full arch scanning compared to scanners that have laser or white light.[23] It is also important to mention that the inEos X5 system uses the projection of a measuring light grid onto dental structures under a definite angle causing a depth-dependent phase shift of the grid, which the camera registers on its digital sensor. This factor also contributes to an improvement in the accuracy of the scans, because regardless of the scanned model, it will always follow a movement pattern, different from what is obtained with IOSs, since even experienced operators following the movement protocols recommended by manufacturers may lead to some differences during scanning.[24]

Both intraoral scans, Trios 3 and iTero 5D, demonstrated similar precision in this study. Mean values for reproducibility can be considered excellent. This was possible probably because they present a confocal-type image acquisition technology. In addition, to offering faster scans, they also allow for better accuracy and less distortion.[19,21,25] Another factor that may have contributed to the good results observed was the fact that the operators had a high level of experience with scans.[19] Despite the difficulties inherent in the process for full arch scanning in an *in vivo* study, the operators were able to reproduce the scans with good accuracy.

When analyzing the trueness in this study, Trios 3 IOS system presented significant different results compared to iTero 5D IOS system only for the *mandibular maximum parameter*, disregarding the time factor (P<0.05) (Table 3). Even with this difference, it is noted that the both IOS systems presented excellent trueness when compared to the reference models (desktop scanner). The trueness between the groups was numerically better at T1 for almost all the parameters evaluated (except in the *maxillary and mandibular parameters* for DS x IS - T1). Even tough, no statistical differences were found between the intraoral scanners. In addition, regardless of the IOS system, a numeric improvement for the trueness of the models obtained by intraoral scanning was detected at T1 for all analyzed parameters when compared to the initial period (T0) (Table 4); however, only the *maximum and minimum* maxillary parameters showed significant differences (P<0.05) (Table 5).

It is important to emphasize that the clinical relevance of this study relies on the clinical evaluation of different IOS systems, using well-established equipment such as Trios 3 and iTero 5D. The later was launched in mid-2019, marketed with a proposal of producing high-precision images. Stone casts were considered as a reference for the analysis of the trueness factor, even though the possibility of their distortion.[11,13] Despite the limitation of evidence, a study showed that the intra and inter arch measurements using stone cast models can be equivalent to those of the digital models obtained from IOS systems.[14] In order to obtain better accuracy of the stone cast models, *in vivo* VPS impressions were taken in this study to avoid, or at least reduce distortions. As already shown by a previous investigation, this is a more precise procedure.[16] An important factor to be considered for the analysis of trueness is the use of a desktop scanner to scan the plaster models that will be considered as a reference for the analysis, given that this type of equipment usually presents better accuracy when compared to IOS systems, especially for full-arch scanning.[12,15,17] In this clinical study, the results for precision made it clear that desktop scanners have better accuracy when compared to intraoral scanners, making the decision of using this type of equipment for scanning plaster casts adequate.

The excellent trueness demonstrated by the scanning systems in this study, regardless of the IOSs used, makes it clear that experienced operators can improve the accuracy of full arch scans, with repeated experience.[19] The greater the experience, the better the operator will adapt to the difficulties imposed by the patient throughout the process. In addition, repeated training generates positioning and movement standardization, allowing to maintain a smaller distance between the scanner tip and the structure to be scanned, a situation considered ideal for better accuracy. Even during diagonal scanning, considered as a factor for decreasing accuracy in full arch scans, such operators manage to maintain caution and the correct positioning pattern, so good veracity results can be obtained.[25] This fact is in accordance with the findings of the present study for the trueness in the different periods. In addition to the experience, a better adaptation of the patient in relation to the scanner was also noticed, and this fact can also affect data acquisition, particularly when performing full-arch scanning. None of the subjects participating in this study had undergone any previous intraoral scanning experience prior to the initial evaluation (T0), which may have contributed to an increased difficulty to perform the initial scanning, even for experienced operators.

With the results presented by this investigation, it is clear that experienced IOS operators are able to obtain full-arch scans with good accuracy and trueness, regardless of the intraoral scanner system used. Besides, it is possible to improve the trueness of the images obtained through repeated experience. Even acknowledging that the digital images of the reference cast model may suffer distortions and variations (distortion of the impression/plaster materials and/or in the acquisition/digitizing process of the desktop scanner), variations tend to be minimal and often without statistical significance. Despite the disparities on the economic costs involved in the acquisition of each equipment, any of the scanners used in this *in vivo* investigation, whether one of the IOS systems or the desktop scanner, produced accurate full-arch digital models when used by experienced operators.

This *in vivo* clinical study presents intrinsic limitations such as the fact that a reduced number of participants were scanned at two periods and only two IOS systems were compared to a desktop scanner. Further studies are still required to compare the precision and trueness of desktop scanners in relation to different IOS systems, as well as repeating the tests by switching equipment and system operators or, even using a single operator for distinct equipment and systems, in order to reduce the selection bias.

CONCLUSION

Supported by the results of this *in vivo* study, the following conclusions were drawn:

1. The desktop scanner (inEos X5) showed better precision for full-arch scanning as compared to the both IOS systems (Trios 3 and Itero 5D). The precision of Trios 3 and Itero 5D intraoral scanners was similar for full-arch scans in both periods of analysis.

2. Both Trios 3 and iTero 5D produced full-arch scan images with similar accuracy. A numeric improvement of trueness was observed for full-arch scans as a function of time in the both intraoral scanning systems.

3. Operators with good experience with intraoral scanners favored the trueness of full-arch scans with repeated scanning experience, irrespective of the intraoral scanning systems.

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Table 1. Scanners evaluated

Scanners	Manufacturer	Scanner Technology	Light Source/ Color	System
TRIOS 3 Color	3Shape A/S	Confocal microscopy and ultrafast optical scanning	LED/Blue	Dental Desktop v1.6.4.1
iTero 5D	Align Technology, Inc	Laser light beams based on parallel confocal principles	Laser/Red	iTero Element 5D v5.9.1.20
inEos X5	Dentsply Sirona	Optical blue structured light	LED/Blue	inLab CAM SW v.18.1

Table 2. Mean difference values (µm) and standard deviation (±) for precision among the models obtained with DS (inEos X5), TS (Trios 3) and IS (Itero 5D).

Groups/ Parameters	DS (n=15)		TS (n=15)		IS (n=15)	
Maxillary Average	1.0	± 0.9[b]	7.0	± 5.2[a]	9.0	± 7.9[a]
Maxillary Maximum	83.0	± 54.6[b]	328.2	± 86.2[a]	313.2	± 61.2[a]
Maxillary Minimum	83.3	± 55.8[b]	321.7	± 86.1[a]	309.4	± 56.1[a]
Mandibular Average	0.9	± 0.8[b]	8.6	± 7.0[a]	8.8	± 6.1[a]
Mandibular Maximum	98.5	± 43.2[b]	380.9	± 118.2[a]	396.0	± 110.0[a]
Mandibular Minimum	98.6	± 43.5[b]	380.8	± 118.1[a]	393.8	± 110.9[a]

*Different letters indicate statistical difference in line (horizontal); Tukey test ($p<0.05$). Precision measured by polygon deviation between 2 of 12 images, which totals 6 pairs for each participant.

Table 3. Mean values (µm) and standard deviation (±) for trueness among the models obtained with DS (inEos X5), TS (Trios 3) and IS (Itero 5D), disregarding time factor.

Groups/ Parameters	DS x TS (n=15)		DS x IS (n=15)	
Maxillary Average	12.0	± 9.3[a]	8.6	± 7.2[a]
Maxillary Maximum	474.0	± 138.7[a]	461.3	± 118.3[a]
Maxillary Minimum	472.3	± 139.4[a]	460.4	± 117.2[a]
Mandibular Average	17.0	± 11.0[a]	22.2	± 13.1[a]
Mandibular Maximum	610.3	± 149.8[b]	758.0	± 239.4[a]
Mandibular Minimum	580.3	± 171.3[a]	724.3	± 260.1[a]

*Different letters indicate statistical difference in line (horizontal); Tukey test ($p<0.05$). Trueness measured by the difference in polygons between the reference model and the intraoral scan images.

Table 4. Mean values (µm) and standard deviation (±) for trueness among the models obtained with DS (inEos X5), TS (Trios 3) and IS (Itero 5D) evaluated at the different periods (T0 and T1)

Groups		Initial (T0) (n=15)		Final (T1) (n=15)	
Maxillary parameters	DS x TS – Average	14.6	± 8.8[a]	9.5	± 9.2[a]
	DS x IS – Average	8.6	± 6.6[a]	8.7	± 8.0[a]
	DS x TS – Maximum	491.3	± 157.5[a]	456.8	± 120.0[a]
	DS x IS - Maximum	480.4	± 137.7[a]	442.2	± 96.1[a]
	DS x TS - Minimum	487.9	± 159.2[a]	456.8	± 120.0[a]
	DS x IS - Minimum	480.1	± 137.1[a]	440.7	± 94.0[a]
Mandibular parameters	DS x TS – Average	19.2	± 9.6[a]	14.9	± 12.1[a]
	DS x IS – Average	21.5	± 12.7[a]	22.9	± 13.9[a]
	DS x TS - Maximum	636.4	± 171.6[a]	584.2	± 124.8[a]
	DS x IS - Maximum	776.6	± 290.0[a]	739.5	± 184.2[a]
	DS x TS - Minimum	603.2	± 202.3[a]	557.5	± 136.9[a]
	DS x IS - Minimum	728.2	± 317.5[a]	720.4	± 198.2[a]

*Different letters indicate statistical difference in line (horizontal); Tukey test ($p<0.05$). Trueness measured by the difference in polygons between the reference model and the intraoral scan images.

Table 5. Mean values (µm) and standard deviation (±) for trueness according to the parameters of the models obtained at the different periods (T0 and T1), disregarding the systems (scanners).

Parameters	Initial (T0) (n=15)		Final (T1) (n=15)	
Maxillary Average	11.6	± 8.3[a]	9.1	± 8.5[a]
Maxillary Maximum	485.9	± 145.5[a]	449.5	± 107.1[b]
Maxillary Minimum	484.0	± 146.0[a]	448.7	± 106.2[b]
Mandibular Average	20.3	± 11.2[a]	18.9	± 13.4[a]
Mandibular Maximum	706.5	± 244.7[a]	661.8	± 173.6[a]
Mandibular Minimum	665.7	± 269.2[a]	638.9	± 186.7[a]

*Different letters indicate statistical difference in line (horizontal); Tukey test ($p<0.05$). Trueness measured by the difference in polygons between the reference model and the intraoral scan images.

FIGURES

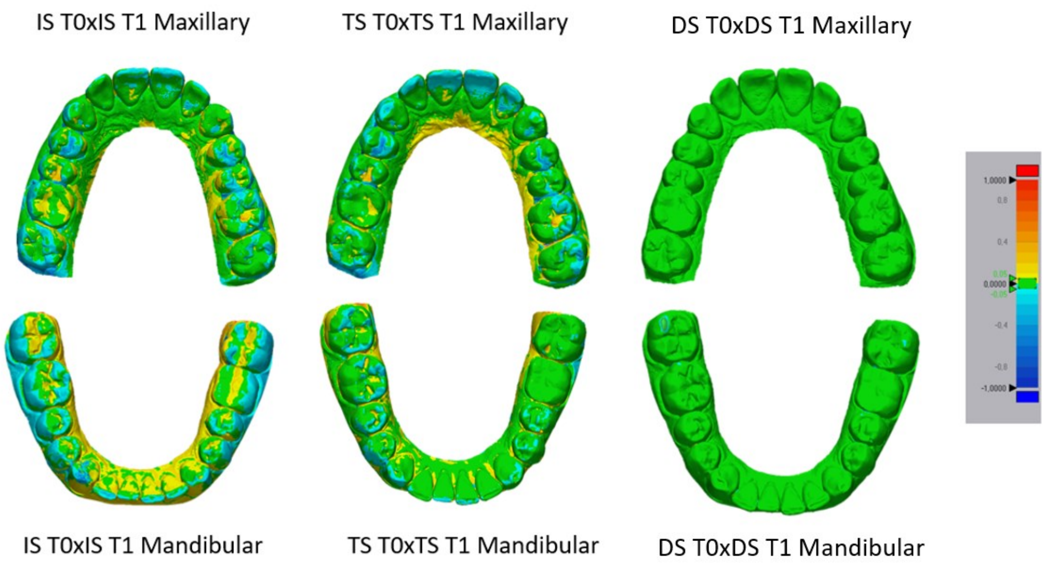

Figure 1. Color map example comparing the precision of different scanners (-1000 to +1000 mm). Towards red color, a tendency to increased deviation is shown (+); on the other hand, towards blue color, decreased trend of deviation is depicted (-).

4. CONCLUSÃO

Baseado nos resultados deste estudo in vivo, as seguintes conclusões foram tiradas:

1. O escâner de bancada (inEos X5) apresentou melhor precisão para escaneamentos de arco completo, em comparação com os dois sistemas de EIs (Trios 3 e Itero 5D). A precisão dos escâneres intraorais Trios 3 e Itero 5D foi semelhante para escaneamentos de arco completo em ambos os períodos de análise.

2. Tanto o Trios 3 quanto o iTero 5D produziram imagens de escaneamentos de arco completo com acurácia semelhante. Uma melhora numérica na veracidade foi observada nos escaneamentos de arco completo, em função do tempo, em ambos os sistemas de escaneamento intraoral.

3. Operadores com alta experiência em escâneres intraorais conseguem melhorar a veracidade dos escaneamentos de arco completo, com experiência repetida, independentemente dos sistemas de escaneamento intraoral.

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