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PROGRAMA DE PÓS-GRADUAÇÃO EM ODONTOLOGIA

CAIO CÉSAR DIAS RESENDE

Análise da acurácia de modelos digitais e impressos obtidas pelas tecnologias CAD/CAM

Tese apresentada à Faculdade de Odontologia da Universidade Federal de Uberlândia, como requisito parcial para obtenção do Título de Doutor em Odontologia na Área de Concentração de Clínica Odontológica Integrada

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"Meu sonho não tem fim, e eu tenho muita vida pela frente."
Ayrton Senna, 1991

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RESUMO

RESUMO

O fluxo digital na odontologia trouxe algumas mudanças na rotina clínica, como: obtenção de modelos impressos, guias cirúrgicos, próteses totais e parciais, coroas provisórias e outras possibilidades. Existem vários sistemas de impressoras 3D, tipos de resinas e escâneres que podem gerar alterações. Este estudo foi dividido em cinco objetivos específicos; **Objetivo específico 1:** O objetivo deste estudo in vitro foi avaliar a precisão e fidelidade de escaneamentos realizados por 3 profissionais com diferentes níveis de experiência utilizando dois escâneres intraorais e dois tamanhos de arcos. **Objetivo específico 2:** O objetivo deste estudo foi avaliar e comparar a acurácia de dois escâneres intraorais e modelos fabricados por impressão 3D e método convencional. **Objetivo específico 3:** O objetivo desse estudo foi avaliar e comparar a acurácia de modelos convencionais e impressos confeccionados por 5 diferentes impressoras 3D. **Objetivo específico 4:** O objetivo desse estudo foi avaliar a acurácia de modelos impressos confeccionados por 3 diferentes espessuras de impressão (25, 50 e 100 Microns) e dois tipos de resinas. **Objetivo específico 5:** O objetivo desse estudo foi avaliar o deslocamento e angulação de implantes dentais em modelos impressos e escaneados por dois escâneres e modelos convencionais. A acurácia dos escaneres intraorais foi influenciada pela experiência do operador, tipo de escâner e o tamanho do arco de escaneamento. Operadores mais experientes e menores tamanhos de arco geraram escaneamentos mais próximos da realidade. Diferentes impressoras 3D tiverem influência na acurácia dos modelos e as impressoras 3D foram mais precisas para a obtenção de modelos que a impressão convencional. Os laboratórios protéticos digitais podem trabalhas de forma mais rápida de acordo com a escolha da resina e camadas de espessura selecionada para impressão, porque estes fatores não influenciaram na qualidade final. Modelos impressos podem ser utilizados para a estratificação de cerâmicas em infraestruturas fresadas sobre implantes.

Palavras chaves: Odontologia digital, CAD/CAM, Impressoras 3D.

ABSTRACT

ABSTRACT

The use of digital workflow in Dentistry brings a new reality to obtain models, surgical guides, partial and total prosthodontics, provisional crowns, and other possibilities. There are several 3D printer systems, resins and scanners types that could obtained differences. This study was divided into five specific objectives; **Specific objective 1:** the purpose of this in vitro study was to evaluate the trueness and precision of 2 intraoral scanning systems operated by 3 professionals with different levels of experience and with 2 scan sizes. ***Specific objective 2:*** The purpose of this study was to evaluate and compare the accuracy of two intra-oral scanners and manufactured casts by 3D printer and conventional impression methods. ***Specific objective 3***: The aim of this study was to evaluate and compare the accuracy of conventional and 3D printed casts using five different 3D printers. ***Specific objective 4***: The objective of this study was to evaluate the accuracy of 3D printed models with 3 different layers thickness (25, 50 and 100 microns) and using two different resins. ***Specific objective 5***: This study aimed to evaluate the three-dimensional positioning of dental implants in casts obtained by using conventional and digital impressions. The accuracy of intraoral scans was influenced by operator experience, type of scanners, and scan size. More experienced operators and smaller scan sizes made for more accurate scans. Different 3D printers have influence in the models'accuracy and 3D printers are more precise than cast models obtained by conventional impression. The laboratorial digital workflow could be faster according to resin and model layer chosen because the type of resin and layers did not influence the quality of the tested models. Printed models could be used for stratification of milled structures over implants.

Keywords: Digital dentistry, CAD/CAM, 3D printer,

INTRODUÇÃO E REFERENCIAL TEÓRICO

1. INTRODUÇÃO E REFERENCIAL TEÓRICO

Nas últimas décadas, muitas mudanças ocorreram na odontologia e novas tecnologias estão cada vez mais presentes na prática clínica diária. Muitos recursos modernos foram incorporados e têm mostrado resultados promissores (de França *et al*., 2015). O Computer-Aided imaging/Computer-Aided Design/Computer-Aided Manufacturing (CAI/CAD/CAM) é um sistema que possibilita a obtenção de restaurações, modelos impressos, infraestruturas implantadas, guias cirúrgicos, permite o planejamento de maneira robótica e tem conquistado cada vez mais o seu espaço dentro das diversas áreas da odontologia, dentre elas, a odontologia restauradora (Neves *et al,*. 2014a, 2014b, 2015, carneiro *et al*., 2016, Buda *et al*., 2018).

Esse sistema tem apresentado grande aceitabilidade e pode ser utilizado tanto nos consultórios odontológicos quanto em laboratórios de prótese dentária, tornando o sistema cada vez mais popular (Kayatt & Neves, 2012). O desenvolvimento da tecnologia CAI/CAD/CAM na fabricação de restaurações e modelos sobre dente e implante revolucionou a odontologia, proporcionando uma nova forma de reabilitar os pacientes, facilitando o fluxo de trabalho (Fuster-Torres *et al*., 2009; Patel *et al*., 2010; Drago *et al*., 2010; Abduo *et al*., 2011).

Para obter uma restauração/modelo confeccionado por meio dessa tecnologia são necessárias três etapas. A primeira etapa é a aquisição de dados, realizada por meio do escaneamento do molde, ou modelo, ou ainda intra-oral, ou seja, diretamente na boca do paciente. Esta etapa é denominada de CAI. A segunda etapa é o processamento dos dados, realizado por meio de um software, no qual um projeto virtual da referida restauração e/ou modelo é obtido. Essa etapa possibilita o desenho e planejamento do trabalho desejado no software do computador. Essa etapa de processamento dos dados constitui o CAD. A manufatura constitui a terceira etapa, denominada CAM. A partir do projeto da estrutura pronta no software, os dados são enviados para uma máquina de manufatura, fresadora ou impressora 3D, que executará o processo de usinagem ou impressão das peças com uma significativa diminuição do tempo clínico e laboratorial (Wesemann *et al*., 2017; Eftekhar *et al*., 2017; Kim *et al*., 2017). Assim, além da técnica convencional (moldagem com material de moldagem, confecção de modelos de gesso, fundição e aplicação de cerâmica), essas tecnologias ampliaram as possibilidades de confecção de modelos e próteses.

No entanto, ainda existe uma escassez de estudos disponíveis que comparam a confecção de restaurações e modelos obtidos por diferentes sistemas de fresadoras e impressoras 3D. Esses dados ainda são mais escassos em relação as reabilitações envolvendo restaurações e modelos confeccionados por meio da tecnologia de impressão 3D. Entretanto é sabido que desadaptações podem comprometer a longevidade e o sucesso das restaurações dentais (Jansen *et al*., 1997; Ortorp *et al*., 2004; Drago *et al*., 2006; Gomes *et al*., 2009; Drago *et al*., 2010; Borba *et al*., 2011; Koutouzis *et al*., 2011; Resende *et al*., 2015; Woelber *et al*., 2016). Adaptação passiva e boa adaptação marginal são fatores essenciais para diminuir complicações mecânicas e biológicas (de Torres, *et al.,*2011; Koutouzis *et al.*, 2011; Resende *et al.*, 2015; França *et al.*, 2015). Não há um consenso na literatura dos valores de desadaptação clinicamente aceitáveis para restaurações implantadas. Embora não se possa ainda quantificar o que realmente é aceitável, a adaptação de restaurações implantadas confeccionadas em ouro é de 12 µm (Sartori *et al*., 2004). Em próteses sobre dente, a literatura mostra trabalhos onde a adaptação ideal varia de 75 µm (Hung *et al.,* 1990) até 120 µm (Mclean *et al.,* 1971). Considerando os diferentes métodos de obtenção de restaurações e modelos, é de extrema importância conhecer o nível de adaptação que cada técnica permite alcançar e suas limitações. Porém, ainda não está claro se essas técnicas permitem alcançar adaptações que sejam compatíveis com os valores presentes na literatura.

O tipo do escâner pode influenciar na acurácia e isto refletir na qualidade final da reabilitação. Essa acurácia é determinada pela análise da fidelidade e precisão (ISO 5725-1) (Cho *et al*., 2015; Ender *et al*., 2015; An *et al.,* 2014; Jeong *et al*., 2016; Guth *et al.,* 2013; Fleming *et al.,* 2011; Flugge *et al.,* 2011; Hack *et al*., 2015; Su *et al.,* 2015, Zeller *et al*., 2019, Resende *et al*., 2020; Papaspyridakos *et al.,* 2020) Além disso, alguns estudos relatam a importância da curva de aprendizado no processo de escaneamento (Kim *et al.,* 2016; Lim *et al*., 2018) e uma variação na fidelidade do escâner intraoral pode estar associada à experiência do operador (Mizumoto *et al*., 2018; Kim *et al.,* 2016; O'Toole *et al*., 2019; Cappare *et al*., 2019). Outro questionamento importante diz respeito a influência do número de imagens realizadas durante o escaneamento, pois aumentará o número de imagens e o tempo de escaneamento em áreas maiores. A associação de um operador menos experiente com maior número de imagens pode introduzir erros no processo.

A impressora 3D é uma máquina de manufatura que permite a fabricação de modelos, guias cirúrgicos e coroas (Fleming *et al.,* 2011; Rossini *et al.*, 2016; Stansbury *et al.*, 2016; Torabi *et al.*, 2015). Sua produção é baseada em um projeto 3D desenvolvida no CAD e transferido por meio de um arquivo em formato .stl (Standard Tessellation Language) para materializar por meio de um polímero um objeto sólido através de um laser UV (Patente US 4575330 1986) (Hull *et al.*, 1986; Jacobs *et al.*, 1992; Horn *et al.*, 2012). Esse processo tem algumas vantagens, como o baixo custo do material e rapidez de impressão. Atualmente, pouco se sabe sobre a precisão de modelos digitais e modelos impressos produzidos pelas impressoras 3D. Não está claro se os modelos impressos em 3D apresentam acurácia semelhante aos modelos de gesso convencionais para reabilitação em próteses sobre dente e se a alteração do tipo de impressora e resina podem influenciar na qualidade final.

Diferentes fluxos de trabalho digitais permitem processos de escaneamento com escâner intraoral (IOS) ou de laboratório e são integrados aos processos de fabricação por meio de tecnologias CAI/ CAD / CAM. Nas reabilitações implanto suportadas, os moldes de gesso ainda têm sido tradicionalmente usados por serem essenciais na aplicação de cerâmica sobre a infraestrutura previamente fresada, verificação de ajuste, refinamento de ajustes proximais e estéticos mesmo utilizando o fluxo de trabalho digital. Com o desenvolvimento das impressoras 3D, o modelo físico pode ser fabricado por prototipagem (impressão) a partir dos dados obtidos pelo escaneamento (Kim *et al*., 2016; Lim *et al.,* 2018; Isharbaty *et al.,* 2019; Gedrimiene *et al*., 2019; Jang *et al.*, 2020; Lee *et al.,* 2019). Porém ainda não está claro se o posicionamento tridimensional dos implantes nos modelos impressos permitirá substituir os modelos convencionais em gesso.

Diante desse contexto, é necessário avaliar o comportamento de modelos confeccionadas por diferentes métodos de fabricação, desde técnicas que dependem diretamente das habilidades do técnico em prótese dentária até as técnicas obtidas por meio das tecnologias supracitadas. Sendo assim, este trabalho tem como objetivo avaliar a acurácia de modelos com implantes dentais e modelos com preparo dental confeccionados por diferentes impressoras 3D e técnica convencional por meio de um software específico para essa análise (Geomagic, control x, 3D System). O nível de desadaptação marginal da infraestrutura fresada foi mensurado por imagens de Microscopia Eletrônica de Varredura.

OBJETIVOS

2. OBJETIVOS

Objetivo Geral

Analisar a acurácia de modelos digitais e impressos obtidas pelas tecnologias CAI/CAD/CAM e modelos confeccionados pela técnica convencional.

Objetivos específicos

Objetivo específico 1

Capítulo 1 - ***Influence of operator experience, scanner type, and scan size on 3D scans***

O objetivo deste estudo in vitro foi avaliar a precisão e fidelidade de escaneamentos realizados por 3 profissionais com diferentes níveis de experiência utilizando dois escâneres intraorais.

Objetivo específico 2

Capítulo 2 - **Accuracy of conventional and digital methods for obtaining dental impressions and 3D printed models**

O objetivo deste estudo foi avaliar e comparar a acurácia de dois escâneres intraorais e modelos fabricados por impressão 3D e método convencional.

Objetivo específico 3

Capítulo 3 – **Accuracy of five 3D printers to obtaining dental models to partial fixed prosthesis**

O objetivo desse estudo foi avaliar e comparar a acurácia de modelos convencionais e impressos confeccionados por 5 diferentes impressoras 3D.

Objetivo específico 4

Capítulo 4 – **Comparison of the accuracy of 3D printed model using three different printing layer parameters and two resins**

O objetivo desse estudo foi avaliar a acurácia de modelos impressos confeccionados por 3 diferentes espessuras de impressão e dois tipos de resinas.

Objetivo específico 5

Capítulo 5 – **Three-dimensional positioning analysis of dental implants in printed casts**

O objetivo desse estudo foi avaliar o deslocamento e angulação de implantes dentais em modelos impressos escaneados por dois escâneres e modelos convencionais.

CAPÍTULOS

3. CAPÍTULOS

3.1 CAPÍTULO 1

Artigo publicado no periódico Journal of Prosthetic Dentistry

Full title: Influence of operator experience, scanner type, and scan size on 3D scans

Running title: Influence on the accuracy of intraoral scanners

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ABSTRACT

Statement of problem. Intraoral scanners have some inherent distortions caused by optical and/or software imperfections. However, how other factors such as operator experience, scan time, scanner type, and scan size influence scan accuracy is not clear.

Purpose. The purpose of this in vitro study was to evaluate the trueness and precision of scans performed by 3 professionals with different levels of experience using 2 intraoral scanners.

Material and methods. Three operators with low, medium, and high levels of experience scanned a master model 10 times using 2 intraoral scanners (CEREC Omnicam; Dentsply Sirona and TRIOS 3; 3Shape), resulting in 10 standard tessellation language (STL) files for each group (N=60). Each STL file was divided into 2 areas (prepared teeth and complete arch). Precision was evaluated by comparing the 10 scans from each examiner for each system. Trueness was evaluated by comparing each scan file with a reference scan obtained from a laboratory scanner (D2000; 3Shape). A 3D analysis software program (Geomagic Control; 3D Systems) was used to perform all the comparisons and superimpositions. The 3-way ANOVA test followed by the Tukey HSD test were used to assess precision and trueness. The 2-way ANOVA followed by the Tukey HSD test was used to assess scan time. The Pearson correlation test was performed between scan time and trueness for both scanners. An additional correlation was performed between scan time and number of images, as well as between number of images and trueness, and number for the TRIOS 3.

Results. Statistically significant influences of operator (*P*<.001), scanner (*P*<.001), scan size (*P*<.001), operator and scan size (*P*<.001), and scanner and scan size (*P*<.001) were observed. The TRIOS 3 group showed higher precision than the CEREC Omnicam group for complete- arch scans (*P*<.001), although no difference was observed for scans of the prepared tooth. Medium (P=.002) and low experience operators ($P<.001$) showed lower precision for complete- arch scans performed with CEREC Omnicam when compared with TRIOS 3. The low experience operator showed significantly worse results for complete-arch scans in comparison with the medium (P=.008 and $P<.001$) and high experience operators ($P<.001$ and P=.001), using TRIOS 3 and CEREC Omnicam respectively. Medium and high experience operators showed similar results among themselves. The CEREC Omnicam scanner showed lower trueness for complete-arch scans when compared with the prepared tooth ($P<.001$); for TRIOS 3, a difference was only observed for the low experience operator when compared with the high experience operator ($P<.001$). The CEREC Omnicam showed lower trueness than the TRIOS 3, except for the medium experience operator with the prepared tooth scan. Comparing the trueness between operators and considering the same scanner and scan size, all groups were similar. The low experience operator had a longer scanning time than the medium and high experience operators. For TRIOS 3, the low experience operator obtained the highest number of images during each scan.

Conclusions. The accuracy of intraoral scans was influenced by operator experience, type of IOS, and scan size. More experienced operators and smaller scan sizes made for more accurate scans. In addition, more experienced operators made faster scans, and the TRIOS 3 was more accurate than the CEREC Omnicam for complete-arch scans.

CLINICAL IMPLICATIONS

Operator experience and scanner type play an important role in accuracy and scanning time. Moreover, larger scans (complete arch versus partial arch) tend to be less accurate, especially when associated with low experience operators and should be limited when not required. As an accurate scan is essential for the long-term success of restorative treatment, understanding the influence of the scan type, size, and operator experience on the scan quality is essential.

INTRODUCTION

Digital technology in dentistry has evolved rapidly since the introduction of computer-aided imaging, computer-aided design, and computer-aided manufacturing (CAI, CAD, CAM) to oral rehabilitation, allowing the analysis, planning, and fabrication of dental crowns and veneers, implant frameworks, 3D printed models, dental aligners, and surgical guides.[1] Impressions or scans of the oral cavity represent an important step, and intraoral scanners (IOSs) enable direct data acquisition without the need for impression materials or devices.[1] In addition, the digital workflow allows 3D previsualization of hard and soft-tissues, is able to avoid distortions from impression materials and stone casts, can reduce laboratory and clinical time, and increases patient acceptance and comfort, providing a cost- and time-effective workflow.[2-6] If a physical cast is necessary, it can be fabricated by prototyping (3D printing or milling) of the intraoral scan data.[7-11]

Digital scans have disadvantages. Besides the costs involved, scanner accuracy plays a major role in the definitive result. Accuracy is determined by trueness and precision (ISO 5725-1).[12-21] Trueness describes how far the measurement deviates from the actual dimensions of the measured object. A high trueness delivers a result that is close or equal to the actual dimensions of the measured object. Precision describes how close repeated measurements are to each other. The higher the precision, the more predictable is the measurement.[22] In addition, a few studies have reported the importance of the learning curve,[10,11] and a variation in the trueness of an intraoral scanner could be associated with the experience of the practitioner.[3,10,23] Another important concern is related to the number of images made. This will increase when scanning larger areas and/or taking longer to scan, as with a less experienced operator, as each new image is aligned to the previous ones by the software, thereby introducing inherent errors.[19]

Considering the lack of studies assessing the impact of operator experience on the intraoral scanning process, the purpose of this in vitro study was to evaluate the 2 components of the accuracy (trueness and precision) of 2 intraoral scanning systems operated by 3 professionals with different levels of experience (low, medium, and high) and with 2 scan sizes (prepared tooth and complete arch). In addition, the present study assessed the influence of the operator experience on the scan time and file size, as well as their relationship with accuracy.

The null hypotheses tested were that no differences in accuracy would be found between the different scanners regardless of the operator; that no differences in accuracy would be found between the different scanners regardless of the scan size; that no differences in scan time would be found regardless of the operator and scanner; and that no correlation would be found between scan time and trueness.

MATERIAL AND METHODS

The present study followed a 3×2×2 factorial design having as main study factors the operator experience at 3 levels: low, medium, and high experience; intraoral scanners at 2 levels: Omnicam (CEREC Omnicam v4.5.1; Dentsply Sirona) and TRIOS 3 (TRIOS 3 Dental Desktop v1.6.4.1; 3Shape); and scan size at 2 levels: complete arch and single prepared tooth; having as response variables the precision and trueness assessed using a 3D analysis software program Geomagic Control (3D Systems). In addition, the scanning time (for both scanners) and number of images (for TRIOS 3) were assessed as secondary outcomes.

The experimental unit was composed of 10 scans in standard tessellation language (STL) files for each group (N=60), which were compared among themselves (precision) or with a master scan of the same model (trueness) obtained using a high precision laboratory scanner (D2000 Dental Desktop v1.6.4.1; 3Shape) (Table 1).

All the scans were obtained based on a 3D printed typodont (master maxillary model) (Fig. 1) with 2 prepared teeth (first maxillary right premolar and first maxillary right molar) and 3 implants (from first maxillary left premolar to first maxillary left molar) to receive a fixed dental prosthesis (FDP). Before image acquisition, CEREC Omnicam, TRIOS 3, and D2000 scanners were calibrated following the calibration guidelines of the respective manufacturers.

Three dentists with different levels of experience (high experience, medium experience, or low experience) scanned the master model 10 times for each of the 2 tested scanners. All 3 evaluators had the same training for the intraoral scanner. The high experience operator, in addition to the training, had used the scanner for more than 2 years with at least 3 scans a day. The medium experience operator, in addition to the training had used the scanner for more than 1 year with at least 1 scan a week. The low experience operator had only the training experience. The scanning was divided into 3 steps: scanning the occlusal surface, scanning the buccal surface by inclining the scanner wand toward the buccal surface while moving the reference model, and scanning the lingual surface by inclining the scanner wand toward the lingual surface and scanning the lingual surface.[3] Each scan was evaluated in 2 areas: prepared teeth and complete arch using analysis software (Geomagic Control; 3D Systems, Inc). A researcher (T.Q.) recorded the scan time using a digital stopwatch.

All obtained files were exported to STL using the respective manufacturers software (using the highest quality available) and imported into the 3D analysis software program. For precision, all acquired images from each of the groups (CEREC Omnicam and TRIOS 3) were paired and superimposed (in a total of 45 analyses for each group) using a best fit algorithm tool, which automatically aligned both reference and test model files, allowing subsequent objective measurements of variances across the 3D models.[23] For each pair of scans, irregular parts of the gingiva, including the buccal vestibule (beyond 2 to 3 mm apical of the gingival margin) were cut out to make the refined alignment (second best fit alignment) more accurate. Each superimposed file was analyzed with the 3D comparison tool, which assessed the average maximum and minimum deviation (in μm) and the standard deviation between the scanned files. For trueness, the same protocol was followed, but each of the 10 scans for each group was compared with the master scan file (D2000). Additionally, the TRIOS 3 scanner system recorded the number of images per scan, which was also evaluated.

Data were evaluated for normality using the Shapiro-Wilks test. The 3-way ANOVA test followed by the Tukey test were used to assess precision and trueness. The 2-way ANOVA followed by the Tukey test were used to assess scan time. The Pearson correlation test was performed between scan time and trueness for both scanners. An additional correlation was performed between scan time and number of images, as well as between number of images and trueness, and number for TRIOS 3 (α=.05 for all tests).

RESULTS

Precision was influenced by operator (*P*<.001), scanner (*P* <.001), scan size (*P* <.001), scanner and scan size (*P*<.001), and operator and scan size (*P*<.001). All operators showed lower precision (higher values) for complete-arch scans when compared with prepared tooth scans, except for the medium experience operator using TRIOS 3. Considering the complete-arch scans, the medium and low experience operators showed lower precision with the CEREC Omnicam when compared with the TRIOS 3 scanner. In addition, the low experience operator showed significantly worse results for complete arch scans with both scanners when compared with the medium and high experience operators, who had similar results. The highest precision (lowest values) was observed for all prepared tooth scans performed with TRIOS 3. The lowest precision was observed for the complete-arch scan performed by the low experience operator using the CEREC Omnicam scanner (Table 2).

Analysis of trueness showed the influence of scanner (*P*<.001), scan size (*P*<.001), scanner and scan size (*P*=.004) and operator, scanner, and scan size (*P*=.023). All operators showed similar results considering the same scanner and scan size. All complete-arch scans performed with the CEREC Omnicam presented lower trueness (higher deviation) than the tooth preparation scans. For the TRIOS 3, this was observed only for the low experience operator. All operators had lower trueness with the CEREC Omnicam when compared with the TRIOS 3 scanner, except the medium experience operator with the prepared tooth scan. The highest trueness (lowest values) was observed for the prepared tooth scans with the TRIOS 3. The lowest trueness was observed for the complete-arch scans with the CEREC Omnicam scanner (Table 3).

Operator (*P*<.001) and scanner (*P*=.025) played an important role in scan time. The low experience operator took significantly more time to perform the scans when compared with the medium and high experience operators. Although the TRIOS 3 resulted in faster scans than the CEREC Omnicam (*P*<.025), no significant differences were observed between scanners with the same operator (*P*=.322) (Table 4). The Pearson correlation showed very weak to weak correlation between time and trueness for both scanners (0.342 – TRIOS 3 and 0.153 – CEREC Omnicam). For TRIOS 3, there was a strong correlation between scan time and the number of images (0.729), but a weak correlation between the number of images and trueness (0.202).

DISCUSSION

Different factors play important roles in determining the success of an indirect restoration. With the development of digital technologies, intraoral scanners are able to avoid distortions from impression materials, as well as save time and space from impression processing and transportation.[2-6] Nevertheless, digital scanners can introduce inherent errors of alignment within the software, and the effects of the scan size, scan type, scanner time, and operator experience on the definitive results is unclear.[1,3,10,11,19]

Based on the results of the present study, the first 3 null hypotheses (that no differences in accuracy would be found between the different scanners regardless of the operator; that no differences in accuracy would be found between the different scanners regardless of the scan size; and that no differences in scan time would be found regardless of the operator and scanner) were rejected. The fourth null hypothesis (that no correlation would be found between scan time and trueness) was accepted.

Accuracy is determined by precision and trueness.[12-21] Precision describes how close repeated measurements are to each other and was influenced by the operator experience ($P<.001$), scanner ($P<.001$), and scan size ($P<.001$), as well as by the interaction between operator and scan size ($P<.001$). Complete-arch scans had lower precision than tooth scans, probably because of the larger area involved; within this context, more experienced operators (medium and high experience) showed higher precision than low experience operators, especially with TRIOS 3. These results evidence the importance of operator experience. However, the average 6-μm lower precision when compared with more experienced operators is probably not clinically relevant. The results of precision for the present study are consistent with those of previous reports,[3,14,15] except for the results of CEREC Omnicam for complete arches (which is not an indication of the scanner) and TRIOS 3 for the complete arch scanned by the low experience operator (which might be explained by the use of experienced operators in previous studies).

Considering trueness, the increase in the scan area resulted in lower trueness for all groups, except medium and high experience using TRIOS 3, indicating that the experience of the operator can play an important role. Considering the same scan size, TRIOS 3 showed higher trueness than CEREC Ominicam for all groups, except the medium experience operator for the prepared tooth scan, which indicated that a medium experienced operator could obtain similar results with both scanners and supported the use of the CEREC Omnicam as a chairside scanner for single and short-span fixed dental prostheses. Nevertheless, with the same scanner and scan size, all operators obtained similar trueness, indicating that even the low experience operator can achieve adequate results. Thus, it seems that precision (variation of points) depended more on the experience of the operator, although the differences may not be clinically significant. The tendency of higher trueness (lower values) for operators with longer experience was also observed previously, although only in the short term.[11]

As expected, the learning curve and level of experience played an important role in the scan time for both scanners, with the low experience operator taking significantly longer times when compared with the medium and high experience operators. Such results are consistent with those of a previous study.[10] Moreover, although the TRIOS 3 tends to be faster than the CEREC Omnicam, with the same scan size and operator, both scanners performed similarly. Nevertheless, the longer postprocessing time for the CEREC Omnicam scanner could be an important factor in practice.

Correlations between time and trueness for both scanners were low, as well as between the number of images and trueness for TRIOS 3. This might indicate that the scan technique and movement play a more important role than the time and number of images by itself. Such results are supported by the increased differences with complete-arch scans, especially for the low experience operator.

The CEREC Omnicam is a powder-free, color video speed scanning system which uses active triangulation and emits white light to measure surfaces.[20] It was designed as a chairside solution for single unit and fixed partial dentures in a single visit when a milling machine is also available. The TRIOS 3 is based on video technology (based on confocal microscopy) that captures the anatomy and color of the oral tissues with a broad focal depth camera.[7,9,20] It was designed mostly to send intraoral scans to laboratories for all prostheses, although it can also be used with a chairside milling machine.

Evaluation of the accuracy of digital scans is treated differently and has been reported in the literature to be accurately analyzed with sophisticated 3D software.[1,3,6,11] The software used in the present study relied on best-fit mathematical algorithms to overlay a digital scan and a digital master file to objectively measure variances across the entire experimental model in relation to the master.[7,19-21]

Trueness was based on the comparison with a master model scan performed with the laboratory scanner, which acquires the image using built-in cameras with 5 megapixels for texture mapping and features multi-line technology, resulting in precision ≤20 μm (ISO 12836).[24]

This study evaluated scans of a typodont performed extraorally, which reduced some differences since it is more complicated to perform intraoral scans in patients. Nevertheless, the present results showed the importance and the impact of the scan size, scanner type, and operator experience on the accuracy of digital scans. Future studies should research the influence of the scan size, scanners, and operator experience on the accuracy of scans performed intraorally.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The accuracy of intraoral scans was influenced by operator experience, type of IOS, and scan size.

2. More experienced operators and smaller scan sizes contribute to more accurate and faster scans.
3. The TRIOS 3 was more accurate than the CEREC Omnicam for complete-arch scans.

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TABLES

Table 1. Scanners evaluated.

Scanners	Manufacturer	Scanner Technology	Acquisition	Necessity of Coating
CEREC Omnicam	Dentsply Sirona	Active triangulation	Color Video	Free
TRIOS 3	3Shape A/S	Ultrafast Optical sectioning	Color Video	Free
D2000	3Shape A/S	Multi-line scanning	Color Video	Free

Table 2. Precision results ±standard deviation considering different scanners, scan size, and operators

Scanner×Arch size	Medium experience (mm)	High experience (mm)	Low experience (mm)
CEREC Omnicam and Complete Arch	0.12 ±0.06 Aa1	0.10 ±0.029 Aa1	0.16 ±0.12 Ab1
CEREC Omnicam and prepared arch	0.04 ±0.05 Aa2	0.04 ±0.020 Aa2	0.040 ±0.020 Aa2
TRIOS 3 and Complete Arch	0.05 ±0.04 Ba1	0.07 ±0.040 Aa1	0.11 ±0.06 Bb1
TRIOS 3 and prepared arch	0.03 ±0.02 Aa1	0.03 ±0.04 Aa2	0.03 ±0.02 Aa2

Uppercase letters indicate difference between scanners considering same operator (column) and scan size.

Lowercase letters indicate difference among operators considering same scanner and scan size (difference between columns).

Numbers indicate difference between scan size considering same operator and scanner.

Table 3. Trueness results considering different scanners, scan size, and operators

Scanner×Arch size	Medium experience (mm)	High experience (mm)	Low experience (mm)
CEREC Omnicam and Complete Arch	0.14 ±0.02 Aa1	0.12 ±0.01 Aa1	0.12 ±0.03 Aa1
CEREC Omnicam and prepared arch	0.06 ±0.01 Aa2	0.07 ±0.04 Aa2	0.08 ±0.04 Aa2
TRIOS 3 and Complete Arch	0.03 ±0.01 Ba1	0.03 ±0.003 Ba1	0.03 ±0.005 Ba1
TRIOS 3 and prepared arch	0.06 ±0.01 Aa1	0.06 ±0.02 Ba1	0.07 ±0.02 Ba2

Uppercase letters indicate difference between scanners considering same operator (column) and scan size.

Lowercase letters indicate difference among operators considering same scanner and scan size (difference between columns).

Numbers indicate difference between scan size considering same operator and scanner.

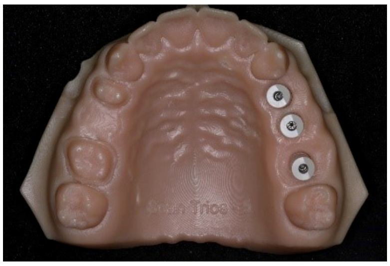
Table 4. Scanning time and number of images considering operator and scanner

Operator×Scanner	Scanning time (sec) (Mean)	Number of images (Mean)
Medium experience and TRIOS 3	186.22 A	1720
High experience and TRIOS 3	189.88 A	2046
High experience and CEREC Omnicam	191.88 A	-
Medium experience and CEREC Omnicam	212.88 AB	-
Low experience and TRIOS 3	242.77 BC	2405
Low experience and CEREC Omnicam	260.66 C	-

Different letters indicate statistically significant difference between groups (*P*<.05).

FIGURE

Figure 1. Master model.



CAPÍTULOS

3.2 CAPÍTULO 2

Artigo enviado para publicação no periódico BMC ORAL HEALTH

Accuracy of conventional and digital methods for obtaining dental impressions and 3D printed models

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ABSTRACT

Purpose: The purpose of this study was to evaluate and compare the accuracy of two intra-oral scanners and manufactured casts by 3D printer and conventional impression methods.

Methods: Conventional impressions of a reference cast were obtained. Digital impressions were obtained with two intra-oral scanners: Cerec Omnicam (CO) and 3Shape Trios (ST). The obtained digital stereolithographic casts were printed on Zenith D 3D printer. The reference cast and fabricated casts were scanned with a laboratory scanner and saved in STL format. All STL records were analyzed in specific software: complete arch (CA), partial arch (PA) and prepared teeth area (PT). One-way and two-way analyses of variance were performed to compare the accuracy, followed by the Tukey test.

Results: No significant intergroup differences in trueness and precision were observed for the two intra-oral scanners. 3D printed casts had the lowest trueness when complete arch was analyzed and differed statistically from the stone cast. For complete arch precision, stone cast presented better results, however statistically different only from the CO.

Conclusions: The two intraoral scanner systems had similar accuracy. Stone casts had higher trueness than 3D printed casts for CA. For CA precision, 3D printed cast presented similar results to the stone cast.

Key Words: Dental impression technique. Printing, Three-Dimensional. Data Accuracy.

INTRODUCTION

Dental impression is an important step in restorative dentistry. It allows to transfer the intra-oral situation to an extra-oral cast. The accuracy of the cast influences the restoration fit, an important factor that may affect in the longevity of the final restorations (Perakis et al, 2004; Wettstein et al, 2008; Persson et al, 2008). Currently, elastomeric impressions with custom or stock trays are considered as gold standard, resulting in a physical gypsum cast (conventional impression) (Ragain et al, 2000). However, the development of CAI/CAD/CAM (computer Aided Imaging/Computer Aided designing/ Computer Aided manufacturing) is becoming increasingly popular, offering a digital workflow, such as: 3D planning, crowns and 3D printed casts (Guth et al, 2013). The workflow for fabricating an implant-supported prosthesis or fixed dental prosthesis could be entirely digital. This method uses an intra-oral scanner directly in the patient's mouth to capture the digital impression that can be also be combined with traditional laboratory procedures, scanning a conventional cast extra-orally (indirect technique) (Guth et al, 2013; Van der Meer et al, 2012).

The American Society for Testing and Materials (ASTM) has defined additive manufacturing (AM) as "a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies" (Alcisto et al, 2011). The ASTM international committee on AM technologies has determined 7 AM categories. The stereolithography is a method used for manufacturing dental casts (Fleming et al, 2011; Rossini et al, 2016; Stansbury et al, 2016; Torabi et al, 2015). It is based on a 3D design made by CAD, transferred to a rapid prototyping machine which turns the polymer into a solid object through the repeated solidification of liquid resin through a UV laser (US Patent 4575330 1986) (Hull et al, 1986; Jacobs et al, 1992;

Horn et al, 2012). Many advantages, such as easy copying, small volume, small size, and low material cost, the possibility to prepare rapid prototypes and trial restorations has been described for this procedure.

Currently few studies are available assessing the accuracy of digital impression and 3D printed casts produced by intra-oral scans (Guth et al, 2013; Rossini et al, 2016; Ziegler et al, 2009). Accuracy describes closeness to the real dimensions of the object and consists of precision and trueness (ISO 5725-1). Precision describes how close repeated measurements are to each other (Ziegler et al, 2009). Trueness describes how far the measurement deviates from the actual dimensions of the measured object (ISO 5725-1). A high trueness means how close or equal to the actual dimensions of the measured object it is. To evaluate the accuracy, 3D software has been used (Geomagic Control, 3D system) (Rhee et al, 2015; Mangano et al, 2016, Cho et al, 2015; Jeong et al, 2016; Kane et al, 2015). It is not clear if 3D printed dental casts present similar accuracy of conventional dental casts for prosthesis rehabilitation. Therefore, the purpose of this study was to evaluate and compare the accuracy of two intra-oral scanners and compare the accuracy of conventional models based on PVS impressions and 3D printed models by different intra-oral scanners. Two null hypotheses will be tested: 1) There would not be statistical differences in the accuracy of scanners 2) There would not be statistical difference in the accuracy of manufactured casts.

MATERIALS AND METHODS

A reference cast with two prepared teeth (first upper premolar and first upper molar, right side) to receive a fixed partial prosthesis was used. A sequence of diamond burs[1] was used to prepare the teeth. Tooth preparation was made with rounded angles and axial walls with 6-degree convergence to the occlusal surface. The margins were prepared with heavy chamfer using rounded axio-gingival angles. For control group, CG (n=5), conventional impression using light and heavy body PVS impression[2] were performed using the reference cast. Five stone casts[3] were poured following the manufacturer's instructions. For the test groups, the reference cast was scanned five times with each of the two intra-oral scanners; CEREC Ominicam[4], CO (n=5) and 3Shape TRIOS[5], ST (n=5). All scans were performed by a single trained investigator with over five years of experience. The digital casts were converted into surface tessellation language (STL) format and sent to manufacture the printed casts with the Zenith D 3D printer[6]. This system is a vat SLA 3D printer with a variable layer thickness from 50 and 100 μm controlled by software. For the present study, 50μm was adopted.

Accuracy of casts created by conventional elastomeric impression and digital workflow/3D printing was measured using 3D software Geomatic Control (3D Systems). This software uses best-fit mathematical algorithms to overlap the digital files and measure variances across the entire casts. Using the software, each impression file was divided and compared in three different sizes: complete arch (CA), partial arch (PA) and prepared teeth area (PT) (Fig. 1). To ensure a precise superimposition, irrelevant areas such as below the mucogingival junction and beyond the field of interest were removed.

A laboratory scanner[7] with high precision was used to obtain 3D reference data of the reference cast, stone casts and 3D printed casts. To measure the trueness of scanners, the STL files used to print the casts (5 CO and 5 ST) were compared to the STL file of the reference cast scanned by D2000 scanner. First, CA analysis was completed followed by PA, where the right hemiarch was cut out for analysis. Finally, the PT area was isolated and analyzed. After each analysis, a new alignment was performed to the reference dataset using the built-in best-fit algorithm. In addition, precision was assessed after overlapping all the STL files (only for CA) for each group (1x2, 1x3, 1x4, 1x5, 2x3, etc). To measure the trueness of stone and printed casts, all models were scanned by D2000 scanner, transformed into an STL file and calculated by overlapping all the data from each group with the reference data (reference model scanned with the D2000 scanner), as mentioned above. In order to evaluate trueness, the same protocol describe for CA, PA and PT analyses were performed. The precision was obtained based on the overlap of the CA data within each group. Differences between reference and test casts were illustrated in a color-coded map (Fig. 2). The green areas represent perfectly matching surfaces, the red areas represent positive deviations from the reference cast and the blue areas represent negative differences between the test and the reference casts.

Data distribution and equality of variances were analyzed by the Shapiro-Wilk and Levene tests, respectively. One-way ANOVA test was applied to the comparisons of the precision of the scanners, and the two-way ANOVA test for the trueness evaluation, followed by the Tukey test to identify where there were differences between the groups. All tests were performed with a significance level of 5%.

RESULTS

Mean and standard deviation for accuracy of tested scanners are shown in Table 1 and 2 and mean and standard deviation for accuracy of 3D printed casts are shown in table 3 and 4. Absolute values were used to assess the differences between the scans. Table 1 presents the comparison of STL files generated by each scanner with the STL file of the reference cast generated by the Scanner

D2000. It shows that there was no statistical difference between the groups. Intra-group analysis, comparing the trueness of the CA, PA and PT, it was observed that there was no statistical difference for the ST, whereas in the CO, a statistical difference was observed between total arch and prepared teeth. Table 2 shows the precision of the different scanners. There was no statistical significant difference between the scanners.

Table 3 presents trueness data of the digital casts printed by the 3D printer and stone. For CA. Stone casts presented a statistically significant difference compared to the digital casts. For PA, the stone casts were statistically similar to the omnicam system and different from the trios system. For PT, there was no statistical difference between the 3 groups. In the intra group comparison, the stone cast showed no statistical difference. For both scanning systems, no statistical difference was observed between PA and PT, however, these were statistically significant differences to CA. Table 4 shows that the stone cast presented better results; however, statistically different only from the omnicam system.

DISCUSSION

The present study investigated the accuracy of two different scanners and respectively 3D printed casts, as well as the accuracy of a conventional impression technique. Based on the results of this study, the first null hypotheses were accepted because no significant differences were found among the accuracy of the scanners. The second null hypotheses were rejected because significant differences were found among the accuracy of conventional manufactured cast and 3D printed casts. The CO scanner is a powder-free, color video speed scanning system. It uses active triangulation and emits white light to measure surfaces and is based on video technology that captures the anatomy and color of the oral tissues with a broad focal depth camera (Patzelt et al, 2013; Ender et al, 2016). The ST scanner is based on confocal microscopy capturing multiple images in a very short time (Patzelt et al, 2013; Ender et al, 2016; Birnbaum et al, 2009). Even though there is a difference in the acquisition mechanism, there is no difference between the two evaluated scanners. The present study showed differences only when comparing CA against PT in the CO group. When the deviation patterns were evaluated from the color map, the CO tended to produce images that had higher deviations in the molar region and the phenomenon of arch expansion at the posterior region is more likely to occur (Birnbaum et al, 2009) (Fig. 2). Besides that, ST group presented images a little bit narrower on posterior areas.

Three-dimensional printed models obtained using an intra-oral scanner can eliminate the use for a conventional impression and model fabrication. There are several advantages, such as the permanent storage of data, and reduction of patient discomfort associated with the use of impression materials (Ender et al, 2016). Furthermore, physical casts can be created based on datasets obtained by an intraoral scanner using either milling or a 3D printer. In this study, we used the 3D printer of the stereolithography category (Zenith). This printer is based on technology by digital light processing (DLP) 3D printing. DLP 3D printers use a digital projector screen to flash a single image of each layer across the entire platform at once. Because the projector is a digital screen, the image of each layer is composed of square pixels, resulting in a layer formed from small rectangular bricks called voxels.

Comparing the three groups by using complete arch, the trueness of the stone cast was significantly better than 3D printed. On the other hand, in these small areas of the dental arch, 3D printed casts presented high accuracy and no statistical difference with conventional stone models. In other words, the digital method is compatible with conventional methods in terms of prepared teeth surface accuracy. Because prepared teeth surface accuracy is critical for fitting of fixed prosthodontic restorations, digital impression and cast fabrication could be a useful method for achieving adequate internal fit and marginal gap. DLP printing can achieve faster print times for some parts, as each entire layer is exposed all at once, rather than drawn out with a laser. Though faster, printing full volume with DLP 3D printers introduce tradeoffs in resolution and surface finish, whether with large parts or sets of many smaller, finely detailed parts. For 3D printed and stone casts precision analysis, both printed casts presented worse results compared to the stone cast, however just the group CO against the group CG presented statistical difference.

CONCLUSION

Within the limitations of this in vitro study, the following conclusions were drawn:

1) The two intra-oral scanner systems had no statistically significant difference in trueness and precision.

2) 3D printed casts presented lower trueness than conventional manufactured cast when analyzed in a complete arch, but similar results for PA and PT. Therefore, cautious clinical use for complete arch models is suggested.

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TABLES

Table 1 – Scanners trueness: Comparison with the STL file of reference cast scanned on D2000.

Dental cast method	**Complete arch** µm	**Partial arch** µm	**Prepared teeth** µm
Trios	172.0 Aa	150.4 Aa	142.2 Aa
Omnicam	161.2 Ba	126.4 ABa	91.6 Aa

* Different letter means significant difference calculated by Tukey HSD test (P < .005).

Table 2 - Scanners precision: Comparison of original scans files (pre-print) with each other.

Dental cast method	Accuracy of complete arch µm	Tukey's ranking
Trios	31.94 ± 22.0	a
Omnicam	32.29 ± 10.0	a

* Different letter means significant difference calculated by Tukey HSD test ($P < .005$).

Table 3 – Cast trueness: Comparison of the stl file of the printed models and stone obtained by the D2000 with the stl file of the reference model.

Dental cast method	**Complete arch** µm	**Partial arch** µm	**Prepared teeth** µm
Trios	230.13 Bb	153.2 Ab	124.2 Ab
Omnicam	184.55 Bb	111.8 Aab	76.0 Aa
Stone	87.0 Aa	87.0 Aa	80.87 Aab

* Different letter means significant difference calculated by Tukey HSD test (P < .005).

Table 4 – Cast precision: Comparison of the stl file of the printed cast and stone obtained by the D2000 with each other.

Dental cast method	**Accuracy of complete arch μm**	**Tukey's ranking**
Omnicam	89.1± 23.0	*b*
Trios	66.35± 16.0	*ab*
Stone	60.15± 9.0	*a*

* Different letter means significant difference calculated by Tukey HSD test ($P < .005$).

FIGURES

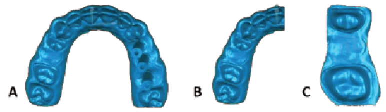

Fig. 1. A) Complete arch; B) Partial arch; C) Prepared teeth area

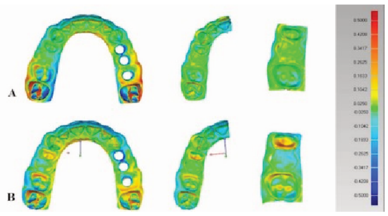

Fig. 2. Color-coded map. Images of the 3D analysis comparing the 3D printed cast from Ominicam (A) and Trios (B) with the reference cast.

CAPÍTULOS

3.3. CAPÍTULO 3

Artigo aceito para publicação no periódico The International Journal of Prosthodontic

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Accuracy of five 3D printers to obtaining dental models to partial fixed prosthesis

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Accuracy of five 3D printers to obtaining dental models to partial fixed prosthesis

ABSTRACT

Purpose: The aim of this study was to evaluate and compare the accuracy of conventional and 3D printed casts using five different 3D printers.

Materials and Methods: For the control group (CG group, N=5), five conventional impressions using light and heavy body polyvinylsiloxane were obtained from the master model, resulting in five stone models. For the test groups, 5 different scans were performed by a well-trained and experienced clinician using a TRIOS intraoral scanner. All data were exported as a .STL file format, processed and sent to five 3D Printers. Five casts were manufactured in each group: SG group (CARES® P20, Straumann), FG group (Form 2, Formlabs), WG (Duplicator 7, Wanhao), ZG group (Zenith D, Zenith) and MG group (Moonray S100, Moonray). Measurements of the accuracy (trueness and precision) of the casts obtained from conventional elastomeric impression and 3D printing methods were accomplished using a 3D analysis software (Geomagic Control).

Results: FG group showed the lowest values for trueness (closer to real dimensions), which was similar to SG group only (P>0.05). Groups MG, WG, and ZG presented higher values, and were similar among themselves. Data on precision demonstrated that all 3D printed groups showed lower values for precision (smaller deviation) when compared with the control group.

Conclusion: The trueness depends on the chosen 3D printer. All the tested 3D printers are more precise than cast models obtained from conventional elastomeric impression.

Key words: Printing, Three-Dimensional; Dimensional Measurement Accuracy; Dental Models.

INTRODUCTION

Dental impression is an especially important step in restorative dentistry to provide a reliable and accurate copy of the area of interest. Impression accuracy plays a major role on the cast precision, restoration fit and, the longevity of treatment.[1-3] Polyvinylsiloxane (PVS) is the current gold standard for conventional/analogic dental impressions and allows the fabrication of a physical stone cast (conventional impression [CI])[4]. Development and improvement of Computer Aided Imaging/Computer Aided designing/ Computer Aided manufacturing (CAI/CAD/CAM) has expanded the use of the digital workflow in dentistry,[5-9] which is based on digitation of regular impressions and/or casts using a laboratory scanner, or on digital impressions acquired using intraoral scanners. Following image acquisition, a software creates a file, usually in Standard Tessellation Language (.STL), which can be milled (more expensive and time consuming) or 3D printed (faster and more affordable) to generate a physical model.[7,8] Considering 3D printers in dentistry, Selective Laser Sintering (SLS) and Selective Laser Melting (SLM) 3D printers could be used to create a solid, such as fixed and removable partial dentures' frameworks, implants, among others.[10]

More recently, laser-based Stereolithography (SLA) and Digital Light Processing system (DLP) systems are becoming more popular.[11-16] SLA method uses a laser beam that creates the shape of the object and polymerize a liquid resin into a solid object, one layer at a time. DLP method uses a digital projector screen to flash an image of each layer across the entire platform at once, resulting in a faster printing process but with limited layer precision[13,17] (Table 1) as the projector could lead to some distortion at the outer edges of the building platform. DLP and SLA 3D printers use different polymers to generate a solid model and present a wide range of applications such as study models, surgical guides, removable and total partial dentures, orthodontic appliances, among others. 3D printing tends to be faster, more versatile, and more cost-effective than traditional milling (subtractive) manufacturing processes. The difference between the 3D printers relies on their polymerization method, type of resin (which also defines their indication), and printing parameters. Although such 3D printers are becoming very popular in dentistry, there is limited data about the accuracy of casts obtained from intraoral scans compared with casts obtained from regular PVS impressions.[18-25]

According to ISO 5725-1, the accuracy of an object is described as how close the test data is when compared to the dimensions of the reference object. It consists in two analyses: precision and trueness.[26] Precision describes the reliability of scanning the data multiple times. The higher the precision, the more predictable is the scanning process. Trueness describes how far the measurements deviates from the actual dimensions of the measured object.[2] A high trueness means that the dimensions are similar between the digital and the actual objects. Accuracy of intraoral scanners can be influenced by scanner type, scanning size and experience of the professional.[27]

It is still not clear the influence of different 3D printers on the accuracy of casts obtained by intraoral scanners compared with casts obtained through conventional impressions, especially considering fixed prosthodontics. The purpose of this study was to evaluate and compare the accuracy (precision and trueness) of conventional and 3D printed casts using five different 3D printers. The null hypothesis was that the accuracy of 3D printed and conventional casts would be similar.

MATERIALS AND METHODS

A dentate typodont (P-Oclusal, São Paulo, SP, Brazil) with two resin teeth (first upper premolar and first upper molar, both on the right side) prepared to receive a 3-unit porcelain fused to metal (PFM) fixed partial prosthesis was used as reference (master model). A sequence of diamond burs was used to prepare the teeth (#2200, #1014, #2143, #283, KG Sorensen, São Paulo, SP, Brazil) with supra-gingival cervical margin determined as heavy chamfer, axial walls with 6-degree total occlusal convergence and rounded angles.28

A reference file was obtained through scanning the master model using a laboratory scanner (D2000, 3Shape, Copenhagen, Denmark) which acquires the image using built-in cameras with 5 megapixels for texture mapping and features multi-line technology, resulting in precision ≤20 μm (ISO 12836).29

For the control group (CG group, N=5), five conventional impressions were acquired from a master model using light and heavy body polyvinylsiloxane (PVS) (Silagum, DMG, Hamburg, Germany) and five stone models were obtained (Zero stone, Dentona, Dortmund, Germany) following the manufacturer's instructions. For the test groups, TRIOS intraoral scanner (TRIOS 3 Dental Desktop v1.6.4.1, Copenhagen, Denmark) was used by a well-trained and experienced clinician to acquire 5 different scans of the master model. All data were exported as a .STL file format, processed and sent to five 3D Printers. Five casts were manufactured on each group, according to Table 1. After removal from the building platform, all the 3D printed models were washed with Isopropyl Alcohol, followed by immersion in an ultrasonic cleaner filled with clean Isopropyl Alcohol to remove the uncured resin before being post-cured following manufacturer's recommendation. This step was essential to produce accurate models. Post-curing enables 3D printed parts to achieve their highest possible strength and stability.

All casts (printed and conventional) were scanned using the D2000 laboratory scanner and measurements of the accuracy (trueness and precision) were performed using a 3D analysis software (Geomagic Control, 3D system, Rock Hill, SC, United States). This software uses best-fit mathematical algorithms to overlap 2 digital files and objectively measure variances across the entire tested model. To ensure a precise superimposition, irrelevant areas such as below the mucogingival junction and beyond the field of interest were removed. To measure trueness of printed models (SG, FG, WG, ZG and MG groups), the STL files used for printing were compared with the STL files of printed models scanned by D2000 laboratory (D2000 Dental Desktop v1.6.4.1; 3Shape, Copenhagen, Denmark). For this, each reference and test scan file were imported into the software, overlapped and compared using the 3D analysis tool. To measure precision of the stone and printed casts, the respective digital files were compared among all the models within the same group in pairs. The data obtained in the analysis included the mean positive/negative values (±AVG) and standard deviations (SD).

The differences between reference and test casts STL files were illustrated in a color-coded map (Figure 1). The green areas mean a perfectly matching surface, the red areas mean that the test model surface was positively positioned relative to the reference model and the blue area mean that the test model surface was negatively positioned relative to the reference model. Data distribution and equality of variances were performed and one-way ANOVA test was used for trueness and precision analysis, followed by Tukey HSD test. All tests were performed with a significance level of 5%.

RESULTS

Trueness data showed are shown on Table 2. FG group presented the lowest values (34.3±10 μm) for trueness (closer to real dimensions), which were similar to SG group only (47.6±16 μm). SG group showed similar values as WG group (71.1±20 μm), but better than ZG (72±10 μm) and MG (73.9±29 μm) groups. WG, ZG and MG groups were similar among themselves. Data on precision (Table 3) demonstrated that all 3D printed groups showed lower values for precision (smaller deviation) when compared with the control group.

DISCUSSION

The null hypothesis was rejected since there were statistically significant differences between the accuracy of 3D printed and conventional casts. Models obtained by 3D printing were considered more accurate when compared to the conventional cast models (Table 3). The decreased precision for conventional cast models may be related with the increased difficulty in perfectly standardizing the cast manufacturing process since the distortion from the impression material and stone cast plays an important role on the final result. The digital workflow is controlled by a computer (except the impression using the intraoral scanner), 1,2,6,8,23 resulting in a lower number of steps and human interference. Such results are in agreement with the literature.17 Thus, 3D printed models present better precision and a more efficient workflow as 3D printers are capable of manufacturing several models simultaneously.6,7,18,25

According to Table 2, the 3D printers presented different trueness. FG (34.3±10 μm) and SG (47.6±16 μm) showed less distortion (lower values for trueness). FG showed lower values for trueness when compared with WG (71.1±20 μm), ZG (72±10 μm) and MG (73.9±29 μm) 3D printers, which were similar among themselves. Interestingly, both DLP and SLA based processes seem to be capable of delivering accurate results as models printed using SG (DLP) and FG (SLA) presented the best results. Nevertheless, it seems clear that different 3D printers, even when based on similar technologies, can produce different results. Although the FG printer is cheaper than the SG, SLA printers takes longer to print.7,18

It is noteworthy that printing using 100 μm layer results in the fastest printing parameters available for mostly of the 3D printers. Nevertheless, there is a possibility of introducing inaccuracies during the printing process. Thus, the professional needs to choose the 3D printing method (DLP or SLA) and layer thickness (i.e. 25, 50, 100 μm), taking into consideration the cost, time and necessary fidelity. In addition, the size of the printing platform also influences the number of models that can be printed simultaneously.

Different 3D printers present different workflows. FG, SG, and MG printers have specific resins for dental use (and pre-set printing parameters), while ZG and WG printers could use a broader range of resins as the printing parameters can be customized (although there is usually no recommendation from the manufacturers). Thus, ZG and WG printed the same resin as MG, since both are based on DLP process. All characteristics must be observed when choosing a digital workflow.24,25

The present study's results need to be interpreted with some caution. Although the trueness changed based on different 3D printers, different resins were used to match the manufacturer's recommendations and the observed differences could change based on different resin formulations. Moreover, the differences in trueness did not take into account the accuracy of the intraoral scanners and, although the present study did not intend to test this factor, it may play an important role in the final result. Also, the presented outcomes are affected by the choice of the impression materials/technique and might have been different using different impression materials and techniques for the conventional workflow and different digital scanners or different impression techniques for the digital workflow.

CONCLUSION

Based on this study results:

1) Different 3D printers have influence in the models'accuracy.

2) 3D printers are more precise than cast models obtained by conventional impression.

3) Several models could be obtained more precisely using 3D printers when compared with conventional methods.

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TABLE LEGENDS

Table 1: 3D Printers tested.

Table 2: For trueness, STL files generated by scanning models from each 3D printer compared to the STL file of the reference cast.

Table 3: For precision, intra-group comparison of the STL files generated by each group.

FIGURE LEGENDS

Fig.1: color-coded map analysis.

Table 1: 3D Printers tested.

Groups	3D printer	Building Platform	Resolution	Manufacture type	Layers
SG	CARES® P20, Straumann	130x75 mm	34 µm	DLP	50 and 100 µm
FG	Form 2, Formlabs	145x145 mm	140µm	SLA	25, 50 and 100 µm
WG	Duplicator 7, Wanhao	120x68 mm	395 µm	DLP	25, 50 and 100 µm
ZG	Zenith D, Zenith	128x80 mm	405 µm	DLP	50 and 100 µm
MG	Moonray S100, Moonray	125x80 mm	100 µm	DLP	20, 50 and 100 µm

Table 2: For trueness (μm), STL files generated by scanning models from each 3D printer compared to the STL file of the reference cast.

Printer (Group)	N	Mean (SD)
Formlabs (FG)	5	0.0343 (0.010) A
Straumann (SG)	5	0.0476 (0.016) BA
Wanhao (WG)	5	0.0711 (0.020) BC
Zenith (ZG)	5	0.0720 (0.010) C
Moonray (MG)	5	0.0739 (0.029) C

SD: standard deviation. Means that do not share a letter are significantly different.

Table 3: For precision (μm), intra-group comparison of the STL files generated by each group.

Printer (Group)	N	Mean
Straumann (SG)	5	0.0387 (0.013) A
Formlabs (FG)	5	0.0420 (0.013) A
Wanhao (WG)	5	0.0494 (0.012) A
Zenith (ZG)	5	0.0454 (0.013) A
Moonray (MG)	5	0.0407 (0.009) A
Cast – Control group (CG)	5	0.0635 (0.021) B

SD: standard deviation. Means that do not share a letter are significantly different.

CAPÍTULOS

3.4. CAPÍTULO 4

Artigo enviado para publicação no periódico Brazilian Oral Research

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Original research - Prosthesis

Comparison of the accuracy of 3D printed model using three different printing layer parameters and two resins

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Comparison of the accuracy of 3D printed model using three different printing layer parameters and two resins

ABSTRACT

The objective of this study was to evaluate the accuracy of 3D printed models using a SLA 3D printer (Forms2, Formslab, Somerville, Massachusetts, United States) with 3 different layers thickness (25, 50 and 100 microns) and using two different resins (Grey and model resin – Formslab, Somerville, Massachusetts, United States). One master model cast was scanned and one single file was printed several times. The printed models were then scanned using a laboratory scanner (D2000; 3Shape, Copenhagen, Denmark). The stl. files provided by the laboratory scanner were superimposed and compared using a software program (Geomagic Control; 3D Systems, North Carolina, United States). Results showed that there is no statistical difference between the 3 different layers in both resins to fidelity. Printing time doubled as layer thickness decreased. This study showed that to print teeth models the fast printing settings could be used without losing quality. The laboratorial digital workflow could be faster according to resin and model layer chosen because the type of resin and layers did not influence the quality of the tested models.

Key words: Computer-Aided Design; Dimensional Measurement Accuracy; Printing, Three-Dimensional.

INTRODUCTION

The use of digital workflow in Dentistry brings a new reality to obtain models, surgical guides, partial and total prosthodontics, provisional crowns, and other possibilities. An intraoral or laboratory scanners could be used and 3D printers manufacture the rehabilitation. Studies have demonstrated good advances in the accuracy of prosthesis obtained by digital workflow.[1-11]

There are several 3D printer systems, and the difference between them is how the models are obtained: SLA or DLP. The laser-based stereolithography system (SLA) is the most popular in dentistry nowadays and uses a laser beam, creating the shape of the sample. Then, liquid resin turns into a solid object, layer by layer.[7] The Digital Light Processing system (DLP) is faster than the SLA method and uses a digital projector screen to flash a single image of each layer across the entire platform at once.[12] The operator could choose the 3D print layer thickness and sometimes, the resin brands. But the precision of each layer is still unknown because the projector could lead to some distortion at the outer edges of the building platform.

Different kinds of 3d printer resins could be used according to the trade mark, clinical indication, cost, 3D printer compatibility and commercial availability.[13-18] The chemical composition of each resin is different and the time spent to print could also change. The operator could change the type of resin and the printing layer thickness of each model, controlling all steps to obtain a model by using digital workflow.

So, the aim of this study was to evaluate if different printing layer thickness and resin brand affect the accuracy of 3D printed cast. The null hypothesis is that there is no difference in the accuracy of 3d printed models in an SLA 3d printer in different layers' size and different resins.

METHODOLOGY

A dentate typodont (P-Oclusal, São Paulo, SP, Brazil) with two resin teeth (first upper premolar and first upper molar, both on the right side) prepared to receive a 3-unit porcelain fused to metal (PFM) fixed partial prosthesis was used as reference (master model). A sequence of diamond burs was used to prepare the teeth (#2200, #1014, #2143, #283, KG Sorensen, São Paulo, SP, Brazil) with supra-gingival cervical margin determined as heavy chamfer, axial walls with 6-degree total occlusal convergence and rounded angles.[19]

For all tested groups, TRIOS intraoral scanner (Trios, 3shape, Copenhagen, Denmark) was used by a well-trained and experienced clinician for 5 different scans. All data were exported as a .STL file format processed and sent to 3D printer (Forms2, Formlabs, Somerville, Massachusetts, United States). Five casts were manufactured in each group, according to Table 1.

Measuring the accuracy (trueness and precision) of the casts created by conventional elastomeric impression and printed models created by digital impressions was accomplished with 3D analysis software (Geomagic Control; 3D Systems, North Carolina, United States).[8]

This software uses best-fit mathematical algorithms to overlap a digital impression on a digital master to objectively measure variances across the entire experimental model in relation to the master. To ensure a precise superimposition, irrelevant areas such as below the mucogingival junction and beyond the field of interest were removed. To measure trueness of printed models (M100, M50, M25, G100, G50, G25 – Table 1), .STL files of the master model that were sent for printing were compared to the .STL files of printed models scanned by D2000 laboratory scanner (D200, 3Shape, Copenhagen, Denmark). It was calculated by overlapping all the data from each group with the reference data. Each step of analysis was aligned to the reference dataset by a repeated best-fit algorithm. To measure precision of the stone cast and printed models, .STL files of printed models scanned by D2000 laboratory scanner (D2000, 3Shape, Copenhagen, Denmark) were compared among all the models of the same group in pairs. The data obtained in the analysis included the standard deviations (SD), mean positive/negative values (±AVG).[20]

The differences between tested groups .STL files were illustrated in a color-coded map. The green means a perfectly matching surface, the red means that the test model surface was positively positioned relative to reference model and the blue means that Printing time of all printed groups were also recorded. Data distribution and equality of variances were done. One-way ANOVA test were used for the trueness evaluation, followed by the Tukey test to identify where there were differences between the groups. All tests were performed with a significance level of 5%.

RESULTS

Statistical data on the accuracy of 3D printed casts are shown in Table 2 and 3 (trueness) and Table 4 and 5 (precision). Absolute values were used to assess the differences between each printer when comparing a scan with the reference.

DISCUSSION

The present study evaluated the effect of different layer thickness and resins on the accuracy of 3D printers using SLA technology applying 3D superimposition analysis. The null hypothesis was rejected, since there are differences in the accuracy of 3D printed models in a SLA 3D printer by using different layers' size and different resins.

Accuracy is determined by precision and trueness.[1,3,6,8,13,14,17] Precision describes how close repeated measurements are to each other and was influenced by the layer (P<.001) for grey resin. For a higher workflow, as it happens in prosthesis laboratories, the ideal choose would be to print the models in a faster configuration (100 microns), because the model is obtained faster without losing in quality, especially if the gray resin is used (Tables 4 and 5). The number of layers changes considerably the time spent to print the models. However, the amount of material spent is exactly the same.[18]

The 100-micron printed model has less layers and requires less demand on printers. Also, with less layers, less errors could be imbued in the final model, without influencing the final result of the accuracy of the models. This effect can be observed clearly with the use of the gray resin, as it is not optimized to be used as a model resin, and resulted in a lower precision when smaller layers were used (25 and 50um). Such results are consistent with those of a previous study to dental model resin.[18]

The success rate of an indirect restoration is determined by several factors, but the development of digital technologies, professionals save time and space from impression processing and transportation, also avoid distortions from impression materials.[2-6] During intraoral scanning the fit of the prosthesis is obtained through the scan itself, and not through the printed model. This model will only be used for covering ceramics, aesthetic checking, planning, mock up, among others. Thus, it also does not justify printing a multilayer model.

In a fully digital prosthetic workflow, the absence of physical models could difficult to check the adaptation of the rehabilitation and perform some adjustments. 3D printed models could be used on Removable Partial Dentures (RPD) to check adaptation or even result of casting techniques. It also can be used to check adaptation and adjustments in more delicate cases such as laminate veneers and to refine proximal and/or aesthetic adjustments.[4] According to the results of the present study, the laboratory could use the gray resin and 100 microns layer to speed up the production of the laboratory, since the gray resin at 100 microns took 3:45 hours and 25 microns took 09:08 hours.

Evaluation of the accuracy of digital scans is treated differently and has been reported in the literature to be accurately analyzed with sophisticated 3D software.[1,3,6]

The software used in the present study relied on best-fit mathematical algorithms to overlay a digital scan and a digital master file to objectively measure variances across the entire experimental model in relation to the master.[9-11,13]

CONCLUSION

Based on this study results:

1) Fast-printing settings (100µm) for printed teeth models could be used without losing quality.
2) Resin type could affect the accuracy of 3D printed cast.

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The authors report no conflicts of interest related to this study.

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TABLE LEGENDS

Table 1: Tested groups.

Table 2: For trueness, .STL files generated by scanning models from each 3D printer, using Model resin, compared to the .STL file of the reference.

Table 3: For trueness, .STL files generated by scanning models from each 3D printer, using Gray resin, compared to the .STL file of the reference.

Table 4: For precision, intra-group comparison of the STL files generated by each group, using Model resin.

Table 5: For precision, intra-group comparison of the STL files generated by each group, using Gray resin.

TABLES

Table 1: Tested groups.

Groups	3D printer	Type of resin	Printing time	Layers tested
M100	Form 2, Formlabs	Model resin, Formlabs	4h	100 μm
M50	Form 2, Formlabs	Model resin, Formlabs	6h 45min	50 μm
M25	Form 2, Formlabs	Model resin, Formlabs	15h	25 μm
G100	Form 2, Formlabs	Gray resin, Formlabs	3h 45min	100 μm
G50	Form 2, Formlabs	Gray resin, Formlabs	5h 30 min	50 μm
G25	Form 2, Formlabs	Gray resin, Formlabs	9h 08min	25 μm

Table 2: For trueness, .STL files generated by scanning models from each 3D printer, using Model resin, compared to the .STL file of the reference (μm).

Group	N	Mean (SD)
M100	5	36.0 (8.0) A
M50	5	34.0 (10.0) A
M25	5	32.0 (12.0) A

SD: standard deviation. Means that do not share a letter are significantly different.

Table 3: For trueness, .STL files generated by scanning models from each 3D printer, using Gray resin, compared to the .STL file of the reference (μm).

Group	N	Mean (SD)
G100	5	38.0 (9.0) A
G50	5	38.0 (7.0) A
G25	5	37.0 (6.0) A

SD: standard deviation. Means that do not share a letter are significantly different.

Table 4: For precision, intra-group comparison of the STL files generated by each group, using Model resin (μm).

Group	N	Mean (SD)
M100	5	37.0 (10.0) A
M50	5	40.0 (13.0) A
M25	5	35.0 (9.0) A

SD: standard deviation. Means that do not share a letter are significantly different.

Table 5: For precision, intra-group comparison of the STL files generated by each group, using Gray resin (μm).

Group	N	Mean (SD)
G100	5	32.0 (7.0) A
G50	5	44.0 (17.0) B
G25	5	45.0 (13.0) B

SD: standard deviation. Means that do not share a letter are significantly different.

CAPÍTULOS

3.5. CAPÍTULO 5

Artigo que será enviado para publicação no periódico Clinical Oral Implants Research

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Title: Three-dimensional positioning analysis of dental implants in printed casts

Short title: 3D positioning of dental implants in printed casts

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The authors report no conflicts of interest related to this study.

AUTHOR CONTRIBUTIONS:

C.C.D.R., G.F.M. and F.D.N. conceived the ideas.

A.V.C.P., C.C.D.R. and G.F.M. collected the data.

F.A.P.R. and G.M. analyzed the data.

K.Z. led the writing.

ABSTRACT

Objectives: This study aimed to evaluate the three-dimensional positioning of dental implants in casts obtained by using conventional and digital impressions.

Material and methods: A printed typodont with three digital analogues for a fixed implant-supported prosthesis was used as a master cast. On each implant, a scan body for mini abutment was fixed and scanned five times (n=5) by two different scanners. Five stone casts were fabricated through five conventional impressions from the master cast, using a conventional open tray impression technique using light and heavy body polyvinylsiloxane (PVS). All obtained files were printed and scanned by using a laboratory scanner. Dental implant angulation and displacement was calculated by overlapping the data from each group with the reference data. One cobalt-chrome metal framework was manufactured over the master cast, by a CAD/CAM system, and positioned over each cast. The accuracy of all casts was determined by measuring the vertical and horizontal misfit between the framework platform and the shoulder implant using Scanning electron microscope

Results: Buccal-lingual angle shown no statistical differences when compare all implants and casts type. Mesio-distal angle shown no statistical differences to cast types and worst results to distal dental implant. Dental implants displacement shown better results for stone casts for all directions (p=.001). Prosthetic interface region shown better results when compare with chamfer region for all directions (p=.001). SEM evaluate shown not statistically differences by vertical misfit when all implant prosthetic screw was tightened for all groups.

Conclusions: Printed models could be used for stratification of milled structures over implants.

MeSH term keywords: Imaging, Three-Dimensional; Dimensional Measurement Accuracy; Dental Implants; Printing, Three-Dimensional; Dental Prosthesis, Implant-Supported

1) INTRODUCTION

Digital technology has been incorporated into dentistry and has shown promising results (de França, Morais, das Neves, Barbosa, 2015). Computer-aided imaging, Computer-Aided Design / Computer-Aided Manufacturing (CAI/ CAD / CAM) is a system that makes possible to obtain restorations and dental casts in a digital manner and has increasingly conquered its space within the different areas in dentistry, including restorative dentistry (Neves, et al., 2014a, das Neves, et al., 2015)

Different digital workflows allow intraoral scanning or laboratory scanning processes and are integrated with manufacturing processes through CAD / CAM technologies. Such integration is a great alternative in rehabilitation procedures such as the planning and fabrication of dental crowns and veneers, implant frameworks, printed casts, dental aligners and surgical guides (Buda, Bratos, Sorensen, 2018). In implant-supported rehabilitations, the stone casts still have been traditionally used because it is essential (Lee, Jung, Wang, Lee, 2019), such as ceramics application, fit check, refine proximal and/or aesthetic adjustments, even when using a digital workflow. If a physical cast is necessary, it can be fabricated by prototyping (printing or milling) the scan data (Lim, Park, Kim, Heo, Myung, 2018). However, printed casts are not used for the framework manufacturing, the same scanning to cast manufacturing is used to framework.

Adequate implant supported oral rehabilitations depends on accurate reproduction of implants' angulation and position (Papaspyridakos et al, 2014). Although the development of printers machines increased the possibility of a completely digital flow resulting in faster, more comfortable and more predictable procedures (Camardella, de Vasconcellos, Breuning, 2017), there are not enough studies to support the reliability and accuracy of digitally obtained casts for implant supported oral rehabilitations when compared to conventionally obtained casts (Cappare, Sannino, Minoli, Montemezzi, Ferrini, 2019; Alsharbaty, Alikhasi, Zarrati, Shamshiri, 2019).

This study aimed to evaluate the three-dimensional (3D) positioning of dental implants in casts obtained using conventional and digital impressions. The null hypotheses tested was that there would be no differences between dental implant angulation and displacement considering conventional and printed casts.

2) MATERIAL AND METHODS

The present study followed a 2×2x2 factorial design having as main study factors intraoral scanners in 2 levels: Omnicam (CEREC Omnicam v4.5.1; Dentsply Sirona) (OG Group) and TRIOS 3 (TRIOS 3 Dental Desktop v1.6.4.1; 3Shape) (TG group). Casts manufacturing in 2 levels: printed casts and stone cast (Control Group) and the 3D implant position in 2 levels: chamfer and prosthetic interface deviation (figure 1), The response variables were precision and trueness, assessed by using a 3D analysis software program (Geomagic Control, 3D Systems) which has been well documented recently (Güth, Runkel, Florian, Stimmelmayrl, Edelhoff, Keul, 2017; Zeller, Guichet, Kontogiorgos, Nagy, 2019; Park, Son, Lee, 2019). In addition, the misfit of implant structure over each cast was evaluated using Scanning Electron Microscopy (SEM) (ESEM XL-30, Philips Research) (Neves, et al., 2014b).

A printed typodont with three mini-abutment digital analogues for a fixed implant-supported prosthesis (EFF – dental components, São Paulo, Brazil) from first maxillary left premolar to first maxillary left molar was used as a master cast, simulating a clinical situation of a partially edentulous posterior maxillar (Kennedy class II).

2.1) Implant framework obtention

One cobalt-chrome metal framework was manufactured based on the master cast using a CAD/CAM system (EFF, dental components). The framework was used to repositioning the three mini-abutment digital analogues in master cast to ensure the marginal fit.

2.2) Intraoral scanning: Digital impressions with intraoral scanning OG and TG

On each implant of the master cast, scan bodies for mini abutment (EFF – dental components) were fixed with a preload of 10Ncm using a manual torque wrench prosthetic (Neodent) and the cast was scanned five times (n=5) with each of the two intraoral scanners (OG group - CEREC Omnicam, Dentsply Sirona, and TG group - TRIOS 3, 3Shape TRIOS, 3Shape North America). All scans were performed by two trained investigators with over five years of experience. The scanning procedure was made in 3 steps: scanning the occlusal surface, scanning the buccal surface by inclining the scanner tip towards the buccal surface while moving the master cast, and scanning the lingual surface by inclining the scanner tip towards the lingual surface (ARAKIDA et al., 2018; Gedrimiene Adaskevicius, Rutkunas, 2019).

2.3) Casts manufacturing

The stone casts were fabricated through five conventional impressions from the master cast, using a conventional open tray impression technique with splinted mini abutment transfers (Marghalani, et al., 2018), using light and heavy body polyvinylsiloxane (PVS) (Silagum, DMG, Hamburg, Germany). Five stone casts were obtained (Zero Stone, Dentona, Dortmund, Germany) following the manufacturer's instructions, using digital mini abutment analogues (EFF – dental components).

2.4) 3D printed models – intra oral scanning

To print digital impressions, the files obtained from intraoral scanning were exported to Standard tessellation language (STL) using the respective manufacturers' software with the highest quality available. The respective casts were printed using a printing machine (Zenith D, Zenith, Dong-gu, Daegu, Korea), based on stereolithography (SLA), with 50μm layer thickness.

2.5) Digital models – laboratory scanning

Scan bodies were tightened with 10Ncm to the digital analogues on all casts (printed and stone casts) and they were scanned by high-resolution using a laboratory scanner D2000 (version 1.6.4.1; 3Shape) obtaining .STL files, that were imported into the 3D analysis software program (Geomagic Control X, version 2018.1.1, 3D system) for analysis.

2.6) 3D implant position analysis

Measuring the accuracy of casts created by all groups were possible by using sophisticated 3D software (Geomagic Control X, 3D system) which uses best-fit mathematical algorithms to overlap the surface of digital files (intra oral scanner files and laboratory scanner files) and objectively measure variances across the entire casts. To ensure a precise superimposition, irregular parts of the gingiva, including the buccal (beyond 2 to 3 mm apical from the gingival margin) were cut out to make the refined alignment (second best fit alignment) more accurate.

All the analyses of dental implants were evaluated from the scan bodies and measured the displacement of the chamfer and prosthetic interface (P/I) region (Figure 2), and the dental implant angulation by mesio-distal and buccal-lingual angle (Figure 3).

The differences between master and test casts were illustrated in a color-coded map. The green areas represent perfectly matching surfaces, the red areas represent positive deviations from the master cast and the blue areas represent negative differences between the test and the master casts.

2.7) SEM evaluation

Cobalt-chrome metal framework was positioned over each cast (printed and stone cast) and the accuracy of the casts was determined by measuring the vertical and horizontal misfit between the framework platform and the implant shoulder using SEM with a 400x magnification (ESEM XL-30, Philips Research) (Figure 4). Before each analysis, the framework was cleaned by immersion in alcohol for 10 minutes followed by immersion in acetone for 15 minutes, both using an ultrasonic bath, followed by drying using dry nitrogen jets, in order to prevent any debris interference.

The framework was dried and manually attached to all groups. The misfit was measured twice: first with only the middle implant prosthetic screw tightened and second: following de 2-1-3 implant sequence for torqueing the screws (Sartori IA, Ribeiro RF, Francischone CE, de Mattos Mda G., 2004). The screws were tightened with a 10 Ncm torque using a manual torque wrench prosthetic (Neodent). Six images were obtained for each cast for each of the misfit measurements, corresponding to one mesial and one distal image for each implant.

The vertical and horizontal misfit values were measured. The vertical misfit was determined by measuring the distance between two straight lines drawn tangentially to the abutment and implant platform (Neves et al., 2014b). The horizontal misfit was quantified by measuring the distance between the lines drawn tangentially between the abutment and the implant. The values were grouped into two categories: under/equally extended and overextended.

2.6) STATISTICAL ANALYSIS

For precision and trueness, data distribution and equality of variances were analyzed using the Shapiro-Wilk and Levene's tests, respectively. Precision was assessed using one-way ANOVA; Trueness was assessed using two-way ANOVA. Both analysis of variance were followed by Tukey's test. All tests were performed with a significance level of 5%.

Vertical and horizontal misfit values did not follow a normal distribution (Kolmogorov-Smirnov test; $p>0.05$). The Kruskal-Wallis test was used to assess statistical significance among the groups, and the Wilcoxon signed rank test was used for post hoc analysis ($\alpha = .05$). For the purpose of data analysis, the minimum critical value of vertical misfit for final fit was determined to be 16μm (Sartori, et al., 2004). Thus, percentage values higher or lower than 16μm were calculated.

3) RESULTS

Statistical data on the 3D positioning of dental implants was performed in both casts (printed and stone casts).

Buccal-lingual angle shown no statistical differences when compare all implants (table 1) and casts type (table 2). Mesio-distal angle shown no statistical differences to cast types (table 3) and worst results to distal dental implant (table 4).

Dental implants displacement (tables 5 and 6) shown better results (smallest displacement) for stone casts for all directions (p=.001). P/I region (table 7 and table 8) shown better results when compare with chamfer region for all directions (p=.001).

SEM evaluate shown not statistically differences by vertical misfit when all implant prosthetic screw was tightened for all groups. OG, TG, and stone cast groups presented worst results when only middle implant prosthetic screw tightened compared with all screws tightened (control group). For horizontal misfit, only OG group showed statistical differences comparing one or all 3 screws tightened.

4) DISCUSSION

The objective of this in vitro study was to assess the accuracy of the three-dimensional position of dental implants in digital and conventional impressions (stone and printed casts respectively). To the best of the authors' knowledge, this is the first study that used a milled metal framework to measure the marginal misfit level between a framework and casts obtained using different workflows (conventional and digital) by SEM evaluation. The null hypothesis that no differences in 3D positioning of dental implants would be found between printed and stone casts, was rejected.

The findings of this research showed statistically significant difference between the

3D position of implants considering printed casts obtained from digital impressions and conventional stone casts obtained from conventional open tray impression technique with splinted transfers. Printed casts had higher local deviations than conventional casts. Regarding 3D angulation of the implants, there were no statistical differences considering the buccal-lingual or mesio-distal angles for printed and conventional casts, although all casts showed worse results in the distal area of the dental implants. This result is probably due to greater technical difficulty in scanning this region. This factor can also be influenced by the scanning technique used and the operator's skill and experience (Resende, et al., 2020).

The prosthesis must be fabricated from an accurate master cast to achieve passive fit and guarantee adequate longevity of implant restorations and fewer risk of biologic and technical complications (Papaspyridakos et al., 2014). To evaluate the 3D positioning and the angulation of the impressions of the dental implants of the printed casts, the Geomagic Control software was used, which is a reliable comparison method and well documented in the literature measuring the 3D displacement (Papaspyridakos, et al., 2018; Resende, et al., 2020; Güth, et al., 2017; Zeller, et al., 2019; Park, et. al, 2019). But still lacking data from accuracy of printed casts for implant-supported restorations. (Flügge, et al., 2018; Cappare, Sannino, Minoli, Montemezzi, Ferrini, 2019; Alsharbaty, Alikhasi, Zarrati, Shamshiri, 2019; Andriessen, Raijkens, van der Meer, Wismeijer, 2014).

The results of the Scanning Electron Microscopy showed that the printed casts showed greater vertical misfit when only the middle screw was tight, compared to the impression casts, but no significant misfit when all screws were tightened with the torque indicated by the manufacturer. As for horizontal misfit, there were no statistical differences between groups, regardless of how many screws were tightened. Printed casts could be used for the application of ceramics and refine proximal and/or aesthetic adjustments in milled structures over implants, even when using a digital workflow. Because marginal fit of framework is not dependent of printed casts, the same scanning to cast manufacturing is used to framework.

Although the digital workflow is dominating the market, it still has some deficiencies when compared to the conventional cast which is still considered the gold standard. Previous studies reported that STL file accuracy is comparable to or even superior to the conventional approach, in Kennedy class II scenarios (Chew et al., 2017; Chia et al., 2017; Marghalani et al., 2018). The present study reports the outcomes when the actual STL files are used to print physical casts and mill metal framework to support a 100% digital workflow. Several studies also compared the accuracy of printed implants casts to stone casts for a partial edentulism scenario. Their results also showed that stone casts from the conventional splinted implant impression technique had less 3-D deviations then the printed casts from digital impression technique. (Papaspyridakos et al., 2018; Gedrimiene, et al., 2019; Jang, et al., 2020; Al-Abdullah, Zandparsa, Finkelman, Hirayama, 2013). In digital workflow, there is some limitations that could be identified as influencing factors of accuracy, such as operator technique, master cast undercuts, differences in implants angulation and probably the accumulation of error that were noticed from the intraoral scanning stage to the printing stage (Papaspyridakos et al., 2018), even in workflow associated with conventional impressions (Baig, M.R., 2014; Papaspyridakos et al., 2014,2018; Lee, 2019). Nonetheless, as scanners, software and printers evolve and operators become more experienced (Resende et al.; 2020) it will be possible to achieve an accurate result so that the structures can be produced using printed casts. More research is needed to identify the influencing factors.

For single crowns on implants, the use of intraoral scanning system and CAD/CAM technology offer the possibility of a digital workflow, is already documented (Lee, Gallucci, 2013). For a full arch implant rehabilitation, a fully digital workflow is not yet fully feasible

(Papaspyridakos et al., 2014,2020; Lee, 2019), and maybe, needs a combination of digital and conventional workflow. If a physical cast is necessary, it can be fabricated by prototyping (printing or milling) the scan data (Ender, Mehl, 2013; Ender, Zimmerman, Attin, Mehl, 2016; Patzelt, Emmanoullidi, Stampf, Strub, Att, 2013; Kim et al., 2016; Lim, et al., 2018).This study reveals that in situations with partially edentulous arch, despite the statistical difference in the 3D displacement of the implants in the printed casts, they can still be used for customized treatment protocol of the milled infrastructures. Using this method, a 100% digital workflow for various implant supported prostheses may be used, which until then was not viable and needed a workflow that combined the digital cast with the conventional one. Thus, due to avoidance of impression tray and materials, the digital workflow might offer an increased comfort for patient, and quicker treatment. Furthermore, can also provide to dentist time and cost savings, digital data storage and analysis. (Joda T, Katsoulis J, Brägger U. 2016).

This in vitro study presents some limitations, because the conditions for obtaining conventional and digital impressions are easily controlled in in vitro studies, however the presence of saliva and blood could influence the results. Furthermore, this current study was limited to only one scenario of number of implants, position, and angulation. All of these variables are identified as influencing factors in the accuracy of both conventional and printed casts.

According to the limitations of our study, although the results are statistically different, printed models could be used for ceramics application and refine proximal and/or aesthetic adjustments in milled structures over implants, even when using a digital workflow.

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TABLES

Table 1: Dental implant angulation by buccal-lingual angle (Implant factor).

Implant	Mean
First maxillary left premolar	0.497 A
Second maxillary left premolar	0.606 A
First maxillary left molar	0.801 A

Mean that do not share a letter are significant different.

Table 2: Dental implant angulation by buccal-lingual angle (cast type factor).

Cast type	**Mean**
OG	0.540 A
SG	0.547 A
TG	0.817 A

Table 3: Dental implant angulation by mesio-distal angle (implant factor).

Implant	Mean
Second maxillary left premolar	0.177 A
First maxillary left premolar	0.426 A
First maxillary left molar	0.803 B

Mean that do not share a letter are significant different.

Table 4: Dental implant angulation by mesio-distal angle (cast type factor).

Cast type	**Mean**
SG	0.385 A
OG	0.494 A
TG	0.528 A

Mean that do not share a letter are significant different.

Table 5: Dental implants displacement by buccal-lingual (cast type factor).

Cast type	Mean
SG	0.059 A
OG	0.094 B
TG	0.122 B

Mean that do not share a letter are significant different.

Table 6: Dental implants displacement by mesio-distal (cast type factor).

Cast type	Mean
SG	0.042 A
OG	0.058 AB
TG	0.076 B

Mean that do not share a letter are significant different.

Table 7: Displacement of the chamfer and P/I region by buccal-lingual.

Region	Mean
I/P	0.055 A
Chamfer	0.126 B

Mean that do not share a letter are significant different.

Table 8: Displacement of the chamfer and P/I region by mesio-distal.

Region	Mean
I/P	0.041 A
Chamfer	0.076 B

Mean that do not share a letter are significant different.

FIGURES

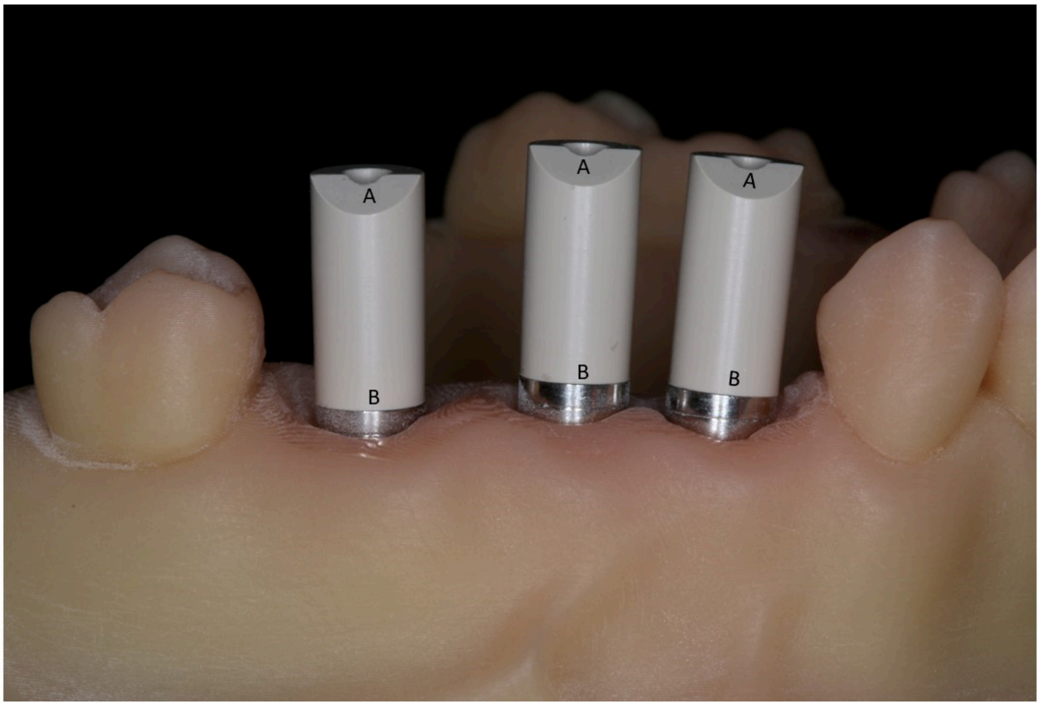

Figure 1: Letter A represents chamfers region and letter B represents prosthetic interface region.

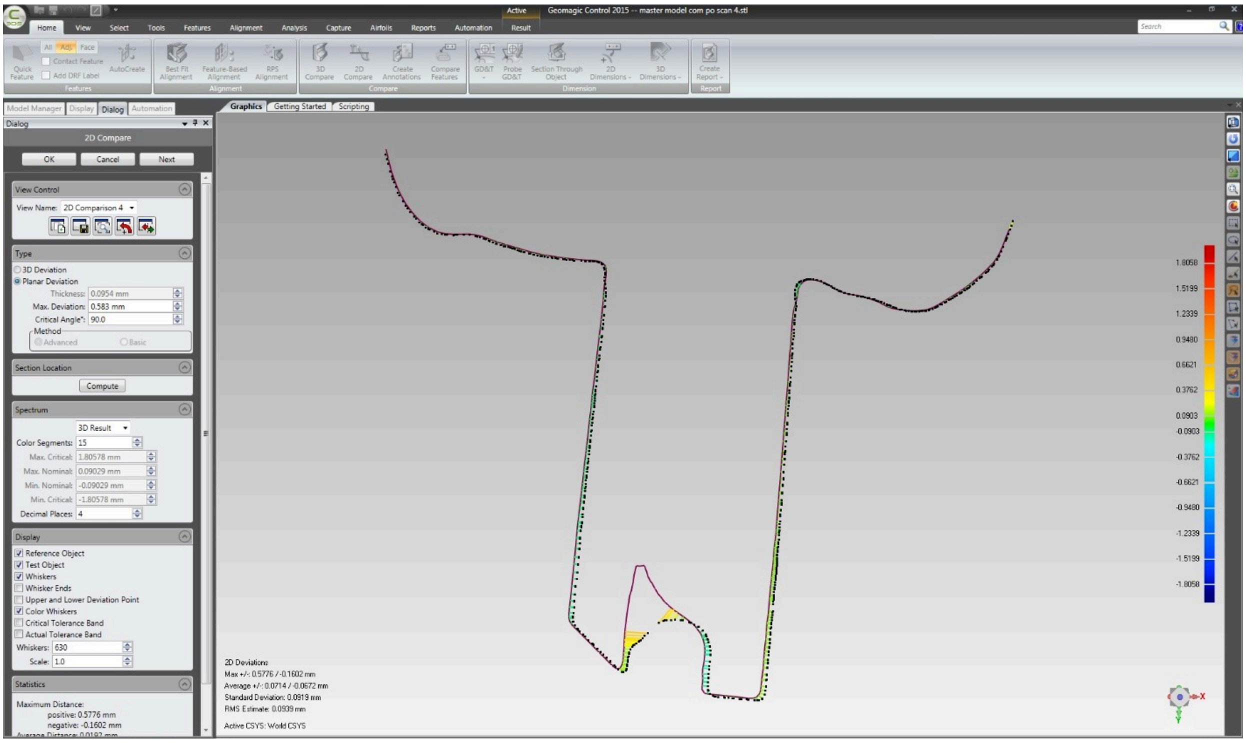

Figure 2: Displacement between master (continue line) and test (dotted line) casts were measured.

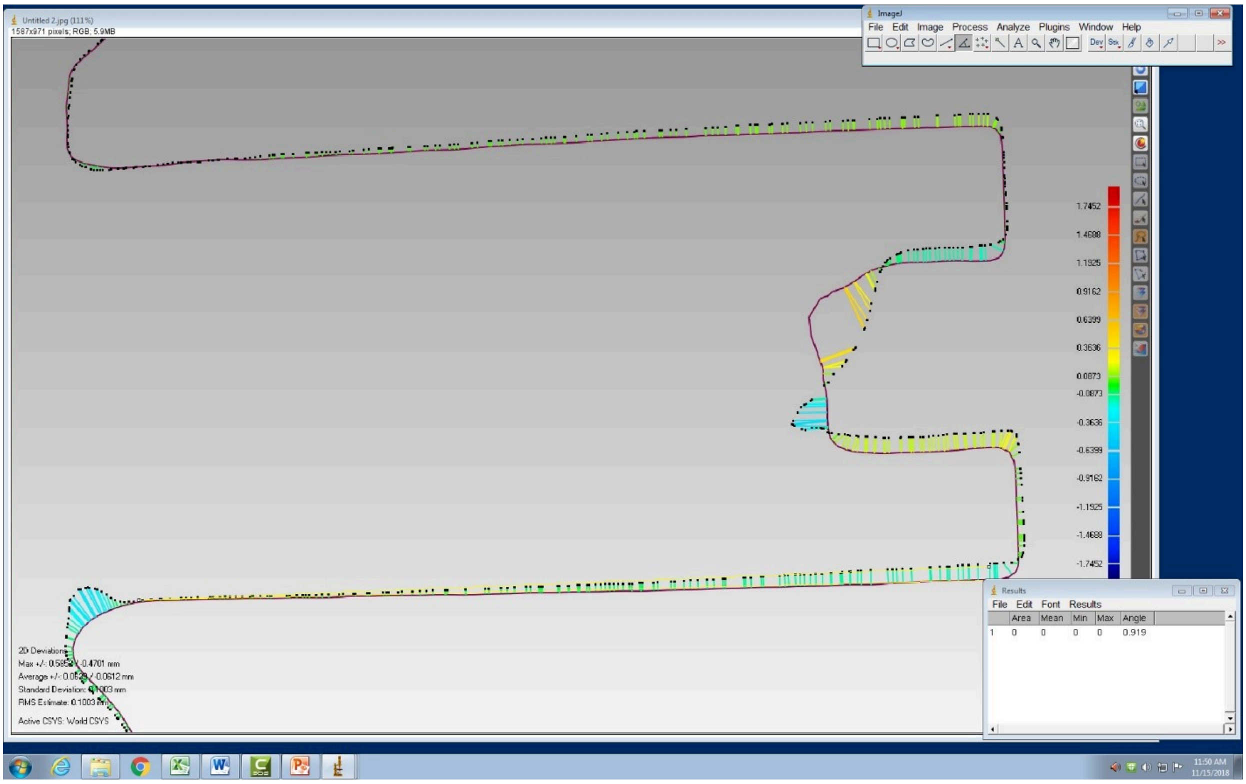

Figure 3: Dental implant angulation by mesio-distal and buccal-lingual angle was measured by Image J software.

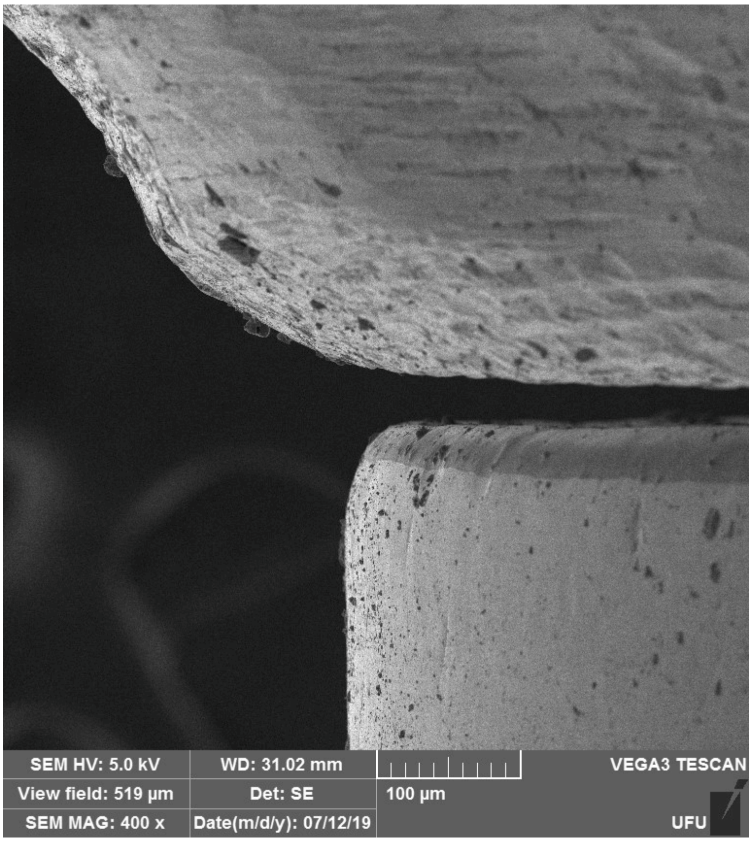

Figure 4: Vertical and horizontal misfit values were measured by SEM evaluation.

CONCLUSÕES

4. CONCLUSÕES

Dentro das limitações metodológicas impostas pelo delineamento experimental destes 5 estudos *in vitro*, pode-se concluir-se que:

- A acurácia dos escaneres intraorais foi influenciada pela experiência do operador, tipo de escâner e o tamanho do arco de escaneamento. Operadores mais experientes e menores tamanhos de arco geraram escaneamentos mais próximos da realidade. A associação de operadores menos experientes e maiores arcos para escaneamento resultaram escaneamentos mais distantes da realidade. O escâner trios 3 teve melhor acurácia nos escaneamentos de arcos totais quando comparado com o escaner Omnicam.

- Diferentes impressoras 3D têm influência na acurácia de modelos impressos. As impressoras 3D foram mais precisas para a obtenção de modelos quando comparado com a técnica convencional.

- O tipo de resina e a espessura de camada para impressão altera significativamente o tempo de impressão dos modelos. Os laboratórios protéticos podem trabalhar de forma mais rápida e otimizar sua produção de acordo com a escolha da resina e camadas de espessura selecionada para impressão.

- Modelos impressos podem ser utilizados para aplicação de cerâmica e ajustes proximais/estéticos em próteses implantadas.

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