Accuracy of Conventional and Digital Methods for Obtaining Dental Impressions and 3D Printed Models

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Research article

Keywords: Dental impression technique, Printing, Three-Dimensional, Data Accuracy

Posted Date: September 17th, 2020

DOI: https://doi.org/10.21203/rs.3.rs-66906/v1

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Abstract

Background: Different sizes of arch could influence in digital methods to obtaining dental impressions and 3D models. The purpose of this study was to evaluate and compare the accuracy of two intra-oral scanners and conventional impression methods for the fabrication of working casts.

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 bench top 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 conventional models based on PVS impressions and 3D printed models using 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 six 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 benchtop 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.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

All data generated or analysed during this study are included in this published article [and its supplementary information files].

Competing interests

The authors declare that they have no competing interests

Funding

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code APQ-03595-18.

Authors' contributions

Tiago Augusto Quirino Barbosa – Acquisition of data, Analysis and interpretation data, Drafting of manuscript.

Caio César Dias Resende – Study conception and design, Acquisition of data, Analysis and interpretation data, Drafting of manuscript.

Guilherme Faria Moura - Acquisition of data, Analysis and interpretation data, Drafting of manuscript.

Lucas do Nascimento Tavares - Acquisition of data.

Fabio Antonio Piola Rizzante - Analysis and interpretation data, critical review.

Furat George - Study conception and design, Analysis and interpretation data.

Gustavo Mendonça - Study conception and design, Analysis and interpretation data.

Flávio Domingues das Neves – Study conception and design, critical review.

Acknowledgements

The authors thank CNPq, FAPEMIG, CPBio and EFF – Dental components.

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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

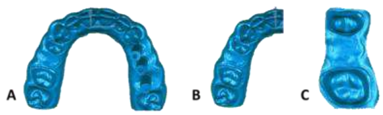

Fig. 1. A) Complete arch; B) Partial arch; C) Prepared teeth area

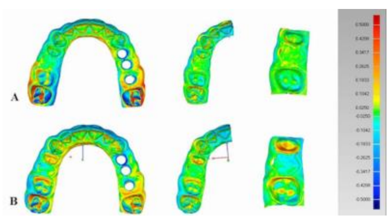

Fig. 2. Color-coded map. Images of the 3D analysis comparing the 3D printed cast from Ominicam (A) and Trios (B) with the reference cast.

Figures

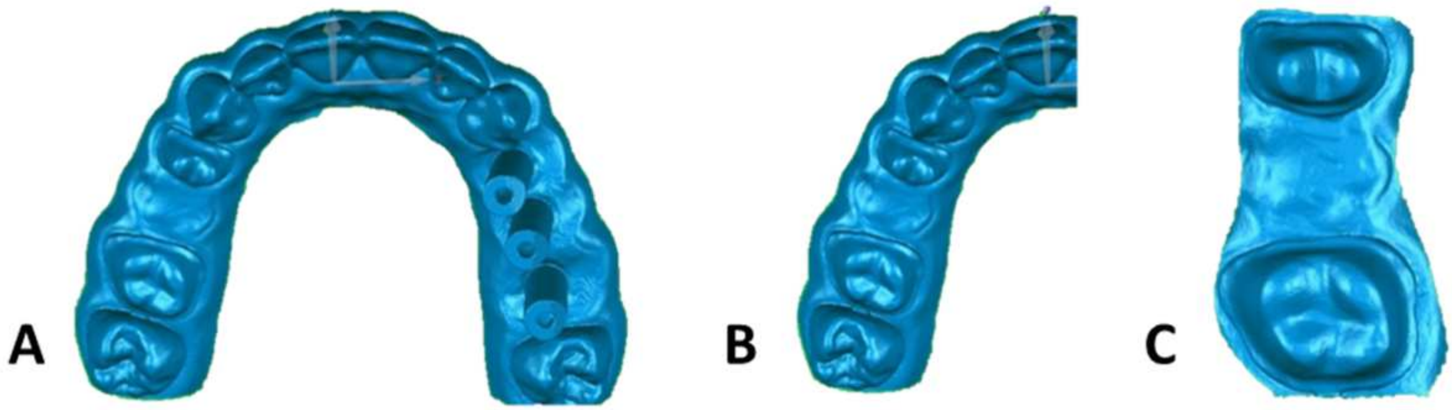

Figure 1

A) Complete arch; B) Partial arch; C) Prepared teeth area

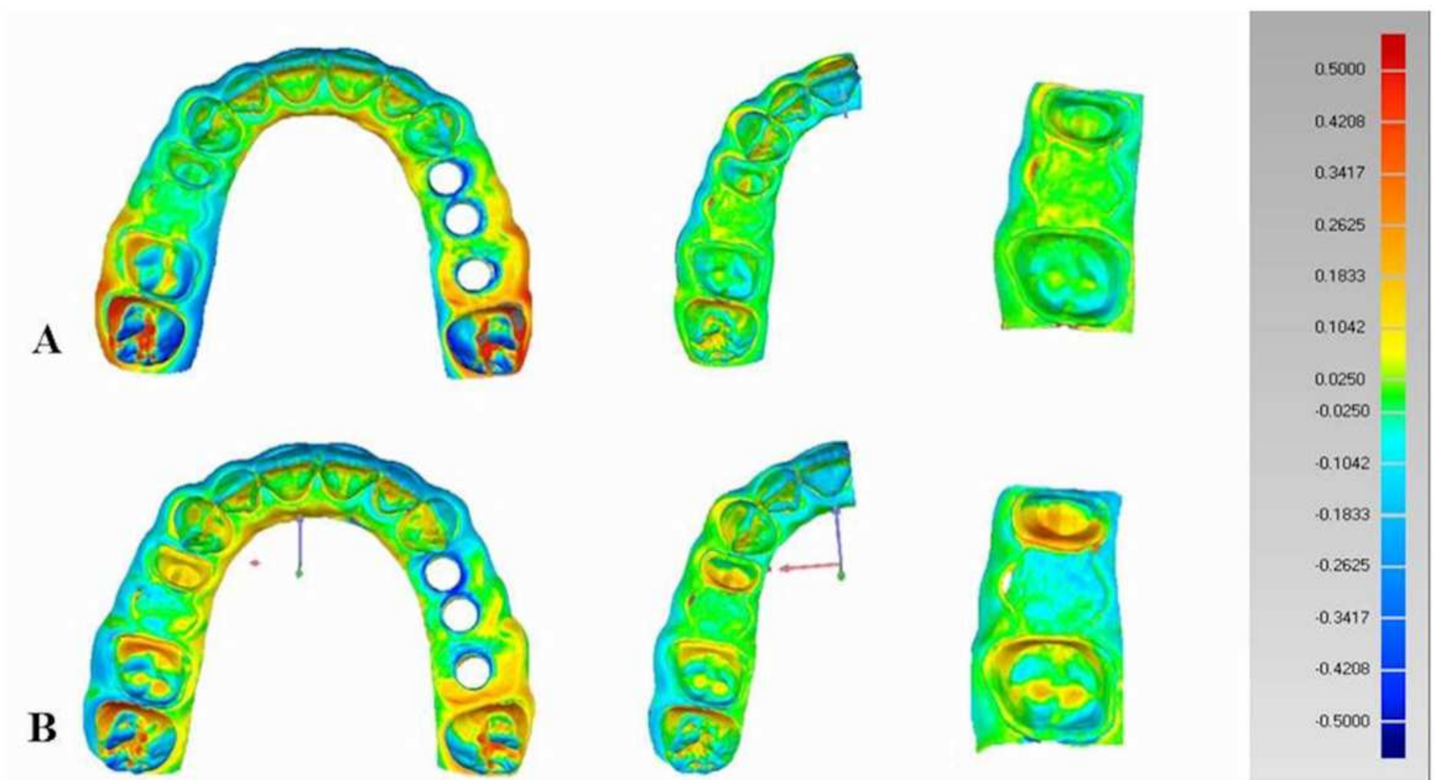

Figure 2

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