Accuracy of Conventional and 3D-Printed Casts for Partial Fixed Prostheses

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Purpose: To evaluate and compare the accuracy of conventional and 3D-printed casts using five different 3D printers. ***Materials and Methods:*** In the control group (CG group, n = 5), five conventional impressions using light- and heavy-body polyvinyl siloxane were obtained from the master model, resulting in five stone models. In the test groups, five different scans were performed by a well-trained and experienced clinician using a TRIOS intraoral scanner. All data were exported in STL file format, processed, and sent to five 3D printers. Five casts were manufactured in each printer group: SG (CARES P20, Straumann); FG (Form 2, Formlabs); WG (Duplicator 7, Wanhao); ZG (Zenith D, Zenith); and MG (Moonray S100, Moonray). Measurements of the accuracy (trueness and precision) of the casts obtained from conventional elastomeric impressions and 3D-printing methods were accomplished using a 3D analysis software (Geomagic Control). ***Results:*** The FG group showed the lowest values for trueness (indicating a value closer to real dimensions), which were similar to the SG group only ($P > .05$). MG, WG, and ZG groups presented higher values and were similar compared to each other. Data on precision demonstrated that all 3D-printed groups showed lower values for precision (smaller deviation) when compared to the CG. ***Conclusions:*** The trueness depends on the chosen 3D printer. All of the tested 3D printers were more precise than cast models obtained from conventional elastomeric impressions. *Int J Prosthodont 2024;37(suppl):s13–s17. doi: 10.11607/ijp.7361*

Dental impression-making is a very important step in restorative dentistry for providing a reliable and accurate copy of the area of interest. The accuracy of an impression plays a major role in the cast precision, restoration fit, and longevity of treatment.[1–3] Polyvinyl siloxane (PVS) is the current gold standard for conventional/analog dental impressions, allowing for the fabrication of a physical stone cast (conventional impression [CI]).[4] Development and improvement of computer-aided imaging/computer-aided design/computer-aided manufacturing

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Table 1 3D Printers Tested

Groups	3D printer	Building platform, mm	Resolution, μm	Manufacture type	Printed layer, μm	Resin type	Layers
SG	CARES P20, Straumann	130 × 75	34	DLP	50	P Pro Master Model	50 and 100 μm
FG	Form 2, Formlabs	145 × 145	140	SLA	50	Model resin	25, 50, and 100 μm
WG	Duplicator 7, Wanhao	120 × 68	395	DLP	50	Grey resin	25, 50, and 100 μm
ZG	Zenith D, Zenith	128 × 80	405	DLP	50	ZMD-1000B Model	50 and 100 μm
MG	Moonray S100, Moonray	125 × 80	100	DLP	50	Model 1.0	20, 50, and 100 μm

(CAI/CAD/CAM) has expanded use of the digital workflow in dentistry,[5–9] which is based on the digitization of regular impressions and/or casts using a benchtop scanner or on digital impressions acquired using intraoral scanners. Following image acquisition, a software creates a file, usually in standard tessellation language (STL), that can be milled (more expensive and time consuming) or 3D printed (faster and more affordable) to generate a physical model.[7,8] For the purposes of 3D printing in dentistry, selective laser sintering (SLS) and selective laser melting (SLM) 3D printers can be used to create a solid object, such as fixed and removable partial denture frameworks, implants, and others.[10] More recently, laser-based stereolithography (SLA) and digital light processing (DLP) systems are becoming more popular.[11–16] The SLA method uses a laser beam that creates the shape of the object and polymerizes a liquid resin into a solid object one layer at a time. The 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 complete partial dentures, and orthodontic appliances. 3D printing tends to be faster, more versatile, and more cost-effective than traditional milling (subtractive) manufacturing processes. The differences between 3D printers have to do with polymerization method, type of resin (which also defines their indication), and printing parameters. Although such 3D printers are becoming very popular in dentistry, there are limited data about the accuracy of casts obtained from intraoral scans compared to casts obtained from regular PVS impressions.[18–25]

The accuracy of an object is described as how close the test data are when compared to the dimensions of the reference object. Accuracy consists of two analyses: precision and trueness.[26] Precision describes the reliability of scanning the data multiple times. The higher the precision, the more predictable the scanning process. Trueness describes how far the measurements deviate 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]

The influence of different 3D printers on the accuracy of casts obtained by intraoral scanners compared to casts obtained through conventional impressions is still not clear, 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) with two resin teeth (first maxillary premolar and first maxillary molar, both on the right side) prepared to receive a three-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) with a supragingival cervical margin determined as heavy chamfer, axial walls with 6-degree total occlusal convergence, and rounded angles.[28]

A reference file was obtained by scanning the master model using a laboratory scanner (D2000, 3Shape), which acquires the image using built-in cameras with 5 MP for texture mapping and features multiline technology, resulting in a precision ≤ 20 μm (ISO 12836).[29]

For the control group (CG group, n = 5), five conventional impressions were acquired from a master model

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using light- and heavy-body PVS (Silagum, DMG), and five stone models were obtained (ZERO stone, Dentona) following the manufacturer's instructions. For the test groups, the TRIOS intraoral scanner (TRIOS 3 dental desktop scanner, version 1.6.4.1, 3Shape) was used by a well-trained and experienced clinician (G.M.) to acquire five different scans of the master model. All data were exported in STL file format, processed, and sent to the five 3D printers.

Five casts were manufactured in each group, as shown in Table 1. The layer thickness (50 μm) was the only one common to all tested printers without prejudice to print quality.[30] After removal from the building platform (build angle of 0 degrees),[31] all 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 postcured following manufacturer recommendations. This step was essential to produce accurate models. Postcuring enables the 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 were performed using a 3D analysis software (Geomagic Control, 3D system). This software uses best-fit mathematical algorithms to overlap two 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 the trueness of the printed models (SG, FG, WG, ZG, and MG groups), the STL files used for printing were compared to the STL files of the printed models scanned by the D2000 benchtop scanner (D2000 Dental Lab Scanner, version 1.6.4.1; 3Shape). For this, each reference and test scan file was 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 SDs.

The differences between reference and test cast STL files are illustrated in a color-coded map (Fig 1). The green areas indicate a perfectly matching surface, the red areas indicate that the test model surface was positively positioned relative to the reference model, and the blue area indicates that the test model surface was negatively positioned relative to the reference model. Data distribution and equality of variance 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%.

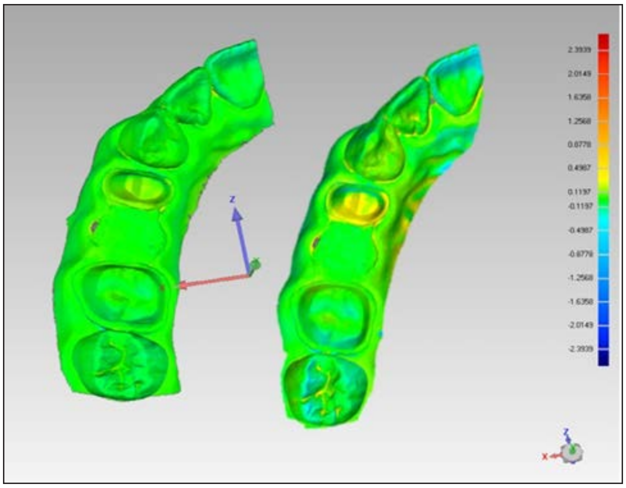

Fig 1 Color-coded map analysis.

Table 2 Trueness (μm) Compared to STL File of the Reference Cast

Group	N	Mean (SD)
FG	5	34.3 (10.0) [a]
SG	5	47.6 (16.0) [b, a]
WG	5	71.1 (20.0) [b, c]
ZG	5	72.0 (10.0) [c]
MG	5	73.9 (29.0) [c]

Means that do not share a letter are significantly different.

RESULTS

Trueness data are shown in Table 2. The FG group presented the lowest values (34.3 ± 10 mm) for trueness (indicating a closer value to real dimensions), which were similar to the SG group only (47.6 ± 16 mm). The SG group showed similar values compared to the WG group (71.1 ± 20 mm), but better values than the ZG (72 ± 10 mm) and MG (73.9 ± 29 mm) 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 (indicating a smaller deviation) when compared to the CG.

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 more accurate when compared to the conventional cast models (see Table 3). The decreased precision for conventional cast models may be related to the increased difficulty in perfectly standardizing the cast

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Table 3 Precision (μm) of the STL Files Generated in Each Group

Group	N	Mean
SG	5	38.7 (13.0) [a]
FG	5	42.0 (13.0) [a]
WG	5	49.4 (12.0) [a]
ZG	5	45.4 (13.0) [a]
MG	5	40.7 (9.0) [a]
CG	5	63.5 (21.0) [b]

Means that do not share a letter are significantly different.

manufacturing process because the distortion from the impression material and stone cast plays an important role in 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]

As shown in Table 2, the 3D printers presented different trueness. The FG (34.3 ± 10 mm) and SG (47.6 ± 16 mm) groups showed lower values for trueness (indicating less distortion). FG showed lower values for trueness when compared to WG (71.1 ± 20 mm), ZG (72 ± 10 mm), and MG (73.9 ± 29 mm) 3D printers, which were similar among themselves. Interestingly, both DLP -and SLA-based processes seem 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 take longer to print.[7,18]

It is noteworthy that printing using 100-μm layers results in the fastest printing parameters available for most 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 (ie, 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 preset printing parameters, while ZG and WG printers could use a broader range of resins because 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 the DLP process. All characteristics must be observed when choosing a digital workflow.[24,25]

The present study's results need to be interpreted with 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, intraoral scanner accuracy may play an important role in the final result. The present outcomes are also affected by the choice of impression materials/techniques and might have been different using different impression materials and techniques for the conventional workflow and different digital scanners or impression techniques for the digital workflow. Also, this laboratory study investigated several parameters that could increase the risk of bias. While the authors of the present study tried to standardize all variables, controlling possible biases for greater reliability of the results, the results should still be interpreted with caution.

CONCLUSIONS

This study concluded the following:

1. Different 3D printers have an influence on model accuracy.
2. 3D printers are more precise than cast models obtained by conventional impressions.
3. Several models could be obtained more precisely using 3D printers when compared to conventional methods.

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