Accuracy of Casts Fabricated by Digital and Conventional Implant Impressions

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The purpose of this study was to compare the accuracy of stereolithographic casts (SCs) with those obtained using conventional implant impressions. An epoxy resin model containing dental implants was used as master model. Dental casts ($n = 10$) were fabricated through both conventional and digital implant impressions. The conventional casts (CCs), SCs, and the master model were digitized, and the accuracy was determined through a deviation analysis and linear measurements. Data were analyzed using paired Student *t* test with $P < .05$. The SCs showed higher deviation at the vestibular area (CC: 41 $\pm$ 28.87 μm; SC: 117 $\pm$ 36.83 μm) and lingual cusps (CC: 40.70 $\pm$ 19.79 μm; SC: 80 $\pm$ 42.95 μm) in comparison with CCs. No statistically significant difference was found for linear measurements of conventional and digital casts. The entire-arch accuracy was comparable between casts. However, SCs were less accurate at the cusp level in comparison with CCs.

Key Words: CAD-CAM, dental impression, dental implants

INTRODUCTION

Dental casts are widely used in several fields of dentistry, as they allow for the evaluation of the occlusal relationship during all treatment phases.[1] Gypsum casts provide the required accuracy to fabricate restorations through laboratorial procedures,[2,3] as they are able to replicate anatomical conditions of a dental arch.[4] Nevertheless, discrepancies related to distortion of impression material and dental stone still exist.[5,6]

As an alternative to conventional impression, optical scanning allows the acquisition of digital casts,[7–9] which eliminates potential errors related to the use of impression materials.[10] In addition, additive (eg, stereolithography) or subtractive (milling) manufacturing techniques may be used to fabricate physical casts with higher durability and resistance than conventional ones.[11–14]

In this regard, stereolithography allows for the creation of 3-dimensional (3D) physical objects, such as dental casts, through the solidification of liquid photopolymer resins into a mold of the intended shape. This technique includes the application of a laser beam, which illuminates the liquid resin, resulting in the polymerization of the acrylic material. The referred process is repeated several times, creating 3D objects by curing the resin in additive layers.[15]

The quality of digitally obtained casts relies on digitizing and machining processes provided by computer-aided design–computer-aided manufacturing (CAD-CAM) systems.[16] To ensure correct occlusion and restoration fitting, accuracy is required for the entire arch model. However, as geometric errors may be introduced during the steps of dental-arch scanning and casts manufacturing, their accuracy is still questionable.[17–24] Kim et al[25] found high accuracy with laser-scanned casts for orthodontic purposes, whereas Asquith et al[26] found differences up to 4.7 mm in linear arch measurements of digital and dental stone casts. In the field of restorative dentistry, Cho et al[12] found no difference in internal area and finish line of prepared teeth for casts obtained using digital and conventional methods. However, when the overall area was taken into consideration, the same study showed more inaccuracy in digital casts.

Lee et al[14] investigated the accuracy of gypsum casts obtained by a closed-tray implant impression and milled casts from digital implant impressions. Although the casts seem to present comparable accuracy, higher discrepancy in teeth fossae areas was found for milled casts in comparison with a conventional one. The discrepancies were associated with the limited capability of manufacturing process, which is unable to mill complex contoured areas.[8]

Nonetheless, it is assumed that the additive manufacturing technique may overcome the limitations of the subtractive method, as it is able to create fine details and complex geometries that are not easily obtained with the milling

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process.[27] So far, the accuracy of the full arch of a stereolithographic cast (SC) for implant treatment is not yet known. Thus, the purpose of this study was to compare the accuracy of SCs in relation to those obtained using conventional implant impressions. The null hypothesis is that there is no difference between the casts.

Materials and Methods

Master model

Sample size calculation for the Student *t* test was performed based on a pilot study (n = 3). Considering a $P = .05$ and power level of 80%, the required sample was n = 6. Because of the availability, 10 samples were included for each group. An epoxy resin model containing dental implants (3.5 × 8.5 mm; SW Morse, S.I.N. Implant System, São Paulo, Brazil) at the sites of lateral incisor (No. 1), premolar (No. 2), and molar teeth (No. 3) was used as master model (MM). Impressions (n = 10) from the MM were obtained using both conventional and digital methods.

Conventional casts

For conventional impression, a direct open-tray technique was chosen. For this purpose, an individual tray with a perforation at the implant site was made with acrylic resin (JET, Clássico, São Paulo, Brazil). Impression copings (S.I.N. Implant System) were screwed to the implants of the MM and splinted with dental floss and a self-curing acrylic resin (Dencrilay, Dencril, São Paulo, Brazil). The splint was sectioned after material curing and reconnected with the same material. Heavy and light polyvinyl siloxane (Futura AD, DFL, Jacarépaguá, Brazil) were simultaneously placed into trays, and an impression was made. After curing of impression material, analogs were connected to the impression copings. A type IV dental stone (Durone, Dentsply, Petrópolis, Brazil) was mechanically mixed using a vacuum spatulator and poured for cast obtention. This procedure was repeated for each conventional cast (CC).

Stereolithographic casts

Initially, scan bodies were connected to the implants, and the MM was scanned 10 times by the same operator using a desktop scanner (DentalWings 7series, Montreal, Canada).[28] Stereolitographic files were exported to the software (DWos 3.8, DentalWings, Montreal, Canada), and CAD models were fabricated by means of a 3D printer (Envisiontec, Gladbeck, Germany).

3D data obtention

The casts (CC and SC) and the MM were digitized using an extraoral scanner (IneosBlue, Cerec, Sirona, Bensheim, Germany) to create digital data sets. To standardize the scanning process and avoid its influence on results, scanning was performed on the same day and by the same operator.[28] The accuracy of the SCs and CCs was determined using a specific software (GOM Inspect, GOM, Braunschweig, Germany) using MM as the reference data set. A schematic representation from the study procedure is shown in Figure 1.

Deviation analysis

The discrepancies between the test and reference data set were appointed by the software. For this purpose, each cast was aligned with the reference data set using the best-fit alignment tool, available within the software configurations. The discrepancy between the test and reference data set was qualitatively presented as a color-labeled map, on which the green color presents a close fit between the models, red indicates a positive deviation, and blue indicates a negative deviation. The maximum discrepancy appointed by the software was 0.5 mm.

Subsequently, the entire arch accuracy was quantitatively analyzed. Sectional planes of the upper, middle, and inferior third of the dental arch were determined for this purpose. Scattered 2-mm equidistant points were selected through the sectional plane, and deviation at each point was measured automatically by the software. The results were exported as a .csv file, and a median deviation value was obtained for each model.[29]

In addition, the deviation between the reference and test data set was calculated in locations of interest: fossae, vestibular area, and lingual cusps of premolar and molar teeth. Three measurements were made with each tooth, and the average mean was pooled for each location.

Linear measurement

The dimensional accuracy was determined by linear measurements performed on digital images of MM, CC, and SC using the same GOM Inspect software. The MM was used to determine reference values as well as the tridimensional orientation of evaluated models during the measurements. Thus, five measurements were conducted on the MM, and the mean value was calculated and used as a reference.

In addition, prior to each measurement, the MM file was opened, and its orientation on the coordinate systems was used as reference to orientate the test data sets. Further, each data set was first aligned to the MM, which was then removed to proceed with the measurements of the evaluated model.

Measurements were performed as follows: distance between center points of implant 2 and the first premolar from the opposite side (M1) and the distance for center points of implant 3 and the first molar from the opposite side (M2) were calculated for each cast (Figure 2). In this regard, the center of the structures was considered the most central point of the circle surrounding them, as determined by the software. To validate intrareliability of the measurements, the described procedures were performed in triplicate by the same examiner, with a 1-week interval between repeated measurements. The differences between the measurements from test data sets (CC and SC) and the reference values (MM) were calculated and defined as measurement errors.

Statistical analyses

Statistical analyses were performed with the aid of specific software (SPSS 20.0, SPSS, Chicago, Ill). Shapiro-Wilk test was

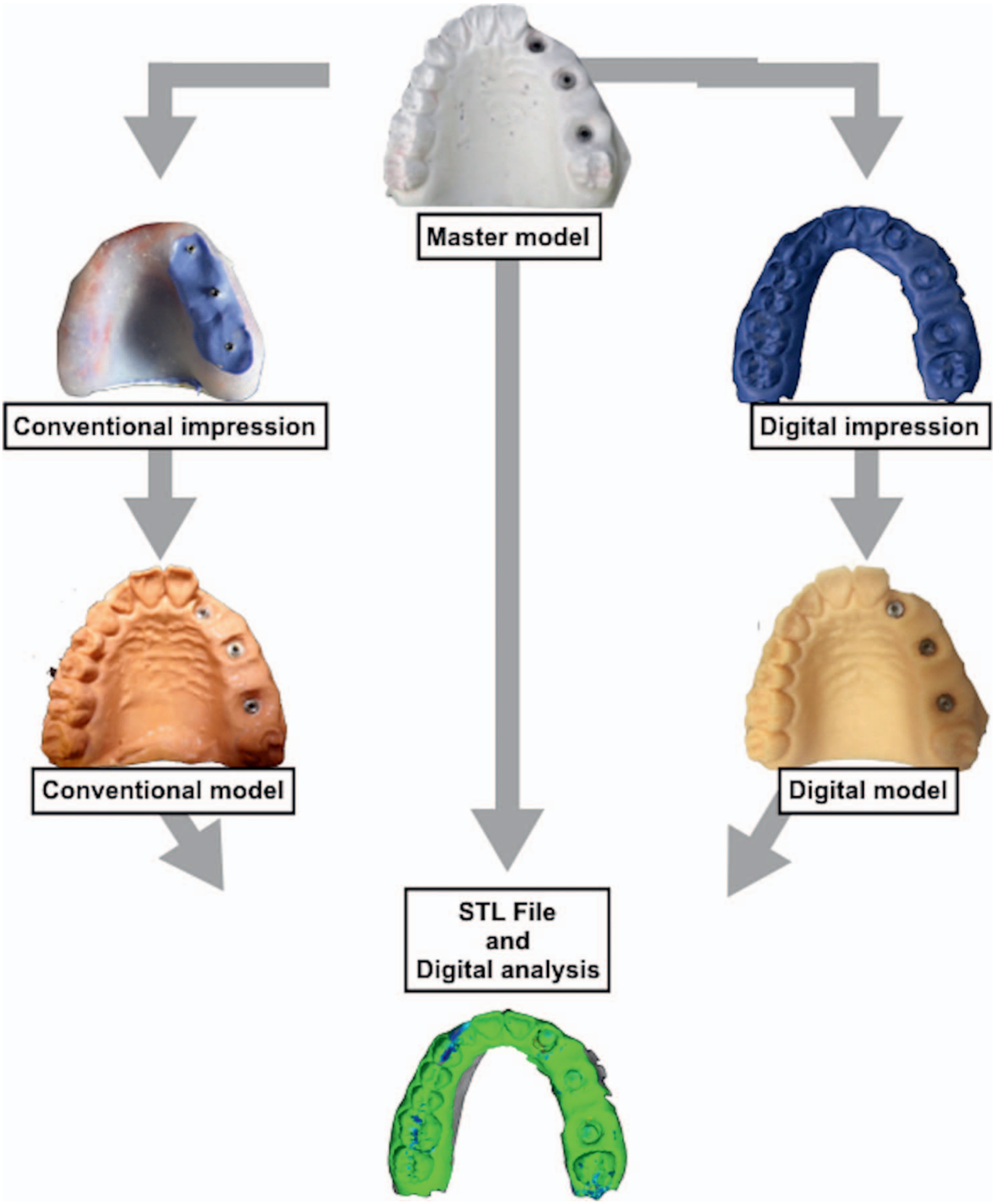

Figure 1. Schematic representation from the methodology used for deviation analysis from conventional and prototyped models.

used to determine normality. Paired Student *t* test ($P < .05$) was performed to compare the mean deviation values between the CC and SC. First, the deviation of the whole model was considered for analysis. Further, the deviation values were considered for three points of interest: vestibular cusps, lingual cusps, and fossae.

Repeated measurements from M1 and M2 were evaluated using the intraclass correlation coefficient. The mean value of

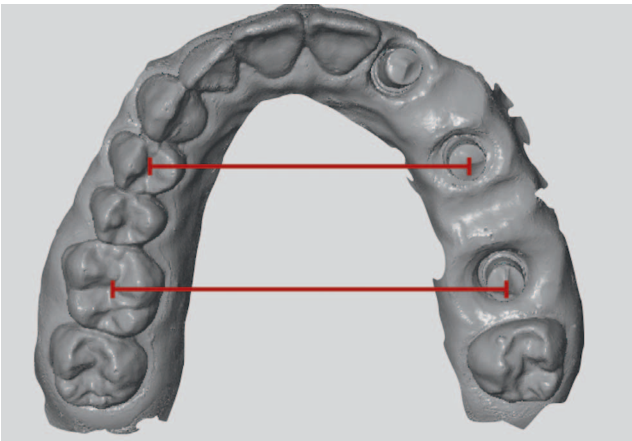

Figure 2. Measurements performed from the center point of implant 2 to the first premolar (M1) and from the center point of implant 3 to the first molar (M2).

each group was used for statistical analysis. In addition, paired Student *t* test was used to compare the mean between the linear measurements performed for the CC and SC.

Results

All groups presented normal distribution ($P > .05$), and descriptive analyses are described as mean ± standard deviation.

Deviation analysis

There was no statistically significant difference in the entire arch deviation for CCs and SCs, as described in Table 1. In points of interest, higher deviations ($P < .05$) were found at the vestibular area and lingual cusps for the SC in comparison with the CC (Table 2; Figure 3).

Linear dimensions

The intraobserver reliability for linear measurements was 0.91. The evaluated casts did not differ statistically for interarch measurements ($P < .05$). Although the CC showed a measurement deviation of 149 ± 124 μm for M1 and 550 ± 275 μm for M2, SC showed a measurement deviation of 239 ± 100 μm and 570 ± 317 μm for M1 and M2, respectively.

Discussion

Based on findings of this study, the null hypothesis was rejected. Although no statistically significant difference was found for the entire arch discrepancy, in located points, the SC showed less accuracy in comparison with CCs.

Table 1

Mean ± standard deviation values (μm) for comparison between the test (CC and SC) and the master model*

CC	SC	*t*-Value	Degree of Freedom	*P*-Value
16.20 ± 14.50	19.70 ± 13.30	1.41	9	.191

*CC indicates conventional cast; SC, stereolithographic cast.

Studies evaluating casts obtained by digital techniques are still contradictory regarding their entire-arch accuracy.[8,12] Cho et al[12] showed a smaller discrepancy for gypsum casts in comparison with SCs, whereas Lee et al[8] found no difference between milled and CCs. In an in vivo study, Rhee et al[24] showed that a conventional impression resulted in a more buccal positioning of premolar and molar teeth. These results are comparable with the present study, as positive and negative deviations showed that conventional and SCs were located above and below the reference surface, respectively.

A higher deviation was found for SCs when the vestibular area and lingual cusps were evaluated. These results are in agreement with the study performed by Rhee et al,[24] on which digital casts obtained using an intraoral scanner showed a higher deviation in the buccal and lingual cusps of the second premolar and molar when compared with dual and full-arch impressions. In the study by Lee et al,[8] the author claimed that deviation in the fossae area of milled casts may result from the difficulty of scanning and milling detailed anatomical surfaces using CAD-CAM.[8] Despite the fact that no differences were found for fossae areas in this study, SCs seem to present less detailed surfaces in comparison with the reference model.[8]

Furthermore, cast geometry accuracy was obtained with the application of interarch measurements.[1,9,25] No statistically significant differences in both the premolar and molar relationship were found between CCs and SCs, and the maximum discrepancy was 570 ± 310 μm. Kim et al[25] found a similar result when comparing laser-scanned and plaster casts, and this was considered clinically acceptable. Nevertheless, it was noted that the discrepancy was higher when measuring greater distances.[24] This result is possibly related to the difficulty of working in full-arch scans with laser scanners.[18]

To isolate errors that usually occur during the manufacturing process, a desktop scanner was used for the acquistion of digital images used to fabricate SC. When comparing intra- and desktop scanners, studies have shown that desktop scanners provided more accuracy for full-arch scans.[30,31] Moreover, CAD-

Table 2

Mean ± standard deviation values (μm) between the test (CC and SC) and the master model in points of interest†

Point	CC	SC	*t*-Value	Degree of Freedom	*P*-Value
Vestibular cusps	41.00 ± 28.87	117.00 ± 36.83*	−4.72	9	.001
Lingual cusps	40.70 ± 19.79	80.00 ± 42.95*	−2.43	9	.037
Fossae	43.80 ± 32.62	44.50 ± 27.20	−0.05	9	.958

*Statistically significant difference at 5%.
†CC indicates conventional cast; SC, stereolithographic cast.

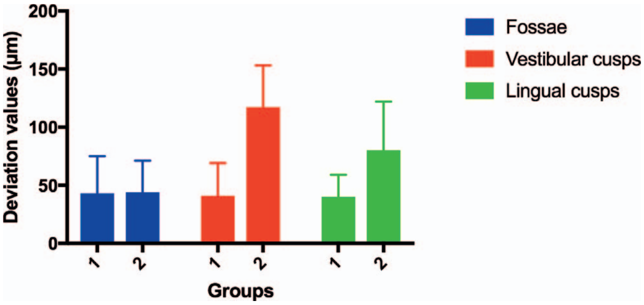

FIGURE 3. Deviation values (μm) according to the location of measurement.

CAM systems implement different technologies for image acquisition. In this context, the accuracy of intraoral scanning would be influenced by factors that were disregarded in this study, such as powder usage and the image acquisition method provided by CAD-CAM systems, which may hamper a full-arch scanning. Patzelt et al[5] evaluated full-arch scans acquired by different systems and found a mean accuracy ranging from 32.00 μm to 332.90 μm among intraoral scanners. Thus, these systematic errors must be considered and added to that obtained in the manufacturing phase to define the final accuracy of SC.

Best-fit alignment and linear dimension measurements were used to evaluate the accuracy of CCs and SCs. The use of these techniques was described in previous studies.[20–23] However, it is important to emphasize that the larger the scanned area, the higher amount of errors introduced by the superimposition technique.[29,32] In this study, the alignment between casts was controlled on the basis of scanbody positions, as the accuracy position was previously determined by a coordinate-measuring machine.

The main limitation of this study is its in vitro environment, which does not allow for the consideration of the the influence of intraoral conditions on the final accuracy of evaluated casts. In addition, the acquisition of stereolithographic models implies a multistep process from the intraoral scanning to the impression of casts. Thus, the present methodology hinders the designation of a specific point as an error source, which could influence the final result.

In summary, SCs show higher durability and resistance in comparison with plaster casts.[14] Their use allows a whole digital workflow, on which the checking of occlusal relationship, proximal contacts, and fit of restorations may be assessed before try-in in the patient's mouth.[33] To date, few studies have evaluated the accuracy of SCs, and the findings have been limited to implant sites.[8,24] Although higher discrepancies were found for SCs in located points, their entire accuracy seems to be clinically acceptable.

However, restoration quality relies on the accuracy of dental casts, especially when the occlusal relationship is considered.[1] If not, dimensional discrepancies from the final cast would result in the need for occlusal and proximal adjustments.[12] Thus, further studies focusing on the accuracy of interocclusal registrations would be valuable to support the current findings.

Conclusions

The entire-arch accuracy was comparable between casts. However, at the cusp level, SCs were less accurate in comparison with CCs.

Abbreviations

3D: three-dimensional
CAD-CAM: computer-aided design–computer-aided manufacturing
CC: conventional casts
MM: master model
SC: stereolithographic cast

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Note

The authors declare no conflict of interest.

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