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ACCURACY OF IMPRESSION AND MODEL OBTAINED FROM DIFFERENT DIGITAL TECHNIQUES IN PARTIAL EDENTULISM IN VIVO

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ABSTRACT

Objective: To evaluate the accuracy of data obtained from two intraoral scanners and models fabricated using two 3D printers for maxillary unilateral partial edentulism in vivo.

Methods: The working models were obtained from 20 different participants. The reference datasets were acquired using irreversible hydrocolloid impression material. Two distinct intraoral scanner systems were evaluated: Cerec Omincam (Dentsply Sirona Dental GmBH, Salzburg, Austria) and 3Shape Trios (3Shape Dental Systems, Copenhagen, Denmark). Additionally, data extracted from intraoral scanners of cast models with four unilateral missing teeth in the posterior region of the maxillary arch, classified as Kennedy Class III, were obtained using 3D printers with two different production techniques. The Solflex 650 (W2P, Klosterneuburg, Austria), a 3D printer utilizing DLP technique, used Varseo Wax resin (Bego, Bremen, Germany), while the AccuFab-L4D (Shinning, Hangzhou, China), a 3D printer utilizing LCD technique, used Shinning brand resin. Deviation analysis was conducted to assess accuracy using Geomagic 3D image processing software. Statistical analysis was performed using t-test and Kruskal-Wallis test ($P < 0.05$).

Results: No significant differences were observed in the accuracy of digital impressions among intraoral scanners and 3D printers. However, a significant difference was noted in the z coordinates across all groups where digital production techniques were applied. The highest accuracy value was observed in the model produced with the Trios intraoral scanner and AccuFab-L4D 3D printer, while the lowest accuracy value was found in the model produced with the Cerec intraoral scanner and Solflex 650 3D printer.

Conclusion: The cast models obtained with intraoral scanners and 3D printers in the Kennedy Class III cases demonstrated potential as viable alternatives to study models obtained through conventional techniques.

KEYWORDS: Intraoral scanner, 3D Printer, partial edentulousness, digital workflow.

INTRODUCTION

For the past 30 years, computer-aided design and manufacturing (CAD-CAM) techniques have been utilized in dentistry (1). The development of CAD-CAM techniques in the area of removable partial dentures was initially slow due to the absence of specific software to support it. Rapid advancements in CAD-CAM have subsequently opened new avenues in the fabrication of RPD frameworks through additive and subtractive processes (2,3).

Currently, RPD frameworks are created using additive manufacturing, and CAD/CAM systems are employed in either a fully digital or a hybrid analog-digital workflow. In the fully digital workflow, a digital scanner is utilized to capture a digital model (4,5). Accurately capturing digital impressions of the scanned area's surface structure is crucial for fabricating dentures with an optimal fit (6).

For partially edentulous dentitions, two distinct structures require precise scanning: the edentuluos area and the teeth. The teeth possess a more complex geometric shape than the edentulous area; consequently, the captured images of the teeth can be merged with minimized error. (7). Although, long edentulous areas with smoother surfaces present challenges in obtaining accurate scans due to difficulties in the stitching process, lack of clear anatomical landmarks, and poorly differentiated structures. As a result, the objective of new hardware and software development has been to enhance the accuracy of digital impressions. The role of digital workflows has become increasingly significant as they conserve time and reduce material usage (8). Additionally, they assist in eliminating the risks of errors in conventional workflows, reduce the number of sessions, and enable more predictable treatment planning. During the model acquisition phase, defects and deficiencies may occur due to dental technician errors and/or material usage. To prevent time wastage, high costs, and data losses, resin models produced by three-dimensional printing technology have become widespread in dentistry, in alignment with advancing technology (9).

The first type of 3D printer, utilizing stereolithography (SLA) technology, was introduced by Charles Hull in 1986. Currently, numerous types of 3D printing technologies are available. The most frequently employed three dimensional technologies in dentistry are Direct Light Processing (DLP), SLA and Liquid Crystal Display (LCD) (10,11). DLP technology 3D printers can produce highly precise models and are faster than SLA 3D printers (12).

Although numerous studies in the literature compare 3D printers, there is a deficiency of research comparing the accuracy of 3D printers whose data are obtained from two different intraoral scanners. This study aimed to evaluate the accuracy values of models obtained from two different 3D printers using two different intraoral scanners for maxillary unilateral partial edentulism in vivo. The null hypothesis was that highest accuracy value of model will be obtained by DLP technique by using 3Shape Trios intraoral scanner.

MATERIAL AND METHODS

This study received ethical approval from the Ethical Committee of Marmara University Faculty of Dentistry. (Protocol No: 2022-77). The following materials and equipment were utilized in this investigation: irreversible hydrocolloid impression (Topicaljin, Zhermack, Italy), Type III plaster (Elitemodel, Zhermack, Dentsply Sirona Dental GmBH, Salzburg, Austria), Eos x5 (Dentsply Sirona

Dental GmBH, Salzburg, Austria), Cerec Omnicam (Dentsply Sirona Dental GmBH, Salzburg, Austria), Trios 3 (3Shape Dental Systems, Copenhagen, Denmark), Solflex 650 (Bego, Bremen, Germany), AccuFab-L4D (Shinning, Hangzhou, China), and Geomagic Control X, 2020.0.1-3D Systems (Rock Hill, SC, USA). The number of subjects in the groups was determined as 20 according to the power analysis results (n=20). Inclusion criteria specified that subjects must present with maxillary Kennedy III classification, exhibiting missing maxillary first and second premolar, molar teeth. The subjects (8 male and 12 female) were 30-70 years of age with a mean age of 57.2 ± 8.5 years. All participants provided signed informed consent forms. Six different groups were established according to on the utilization of different intraoral scanners and 3D printers (n=20 per group):

Group C: Impression with Conventional Methods, Manufacturing Model with Conventional Methods (n=20) (Control Group)

Group C1S1: Impression with Conventional Methods, Manufacturing Model with Accufab-L4D (n=20)

Group C2S1: Impression with Cerec Scanner, Manufacturing Model with Accufab-L4D (n=20)
Group TS1: Impression with Trios Scanner, Manufacturing Model with Accufab-L4D (n=20)
Group C1S2: Impression with Conventional Methods, Manufacturing Model with Solflex 650 (n=20)

Group C2S2: Impression with Cerec Scanner, Manufacturing Model with Solflex 650 (n=20)
Group TS2: Impression with Trios Scanner, Manufacturing Model with Solflex 650 (n=20)

Reference Model

The reference models were obtained for each patient using irreversible hydrocolloid impression material (Tropicalgin, Zhermack, Italy) and prefabricated metal trays. After cleaning with tap water, each impression was disinfected with alcohol-based disinfectant (Ecolab, Istanbul Turkey) and immediately poured with type III plaster (Elitemodel, Zhermack, Dentsply Sirona Dental GmBH, Salzburg, Austria). The cast models were stored at 23 °C humidity for five days. The dental models were scanned with Eos x5 (Dentsply Sirona Dental GmBH, Salzburg, Austria) to convert the data to STL files.

Use of Intraoral Scanners

Digital optical impressions of the subjects were taken using two different digital impression scanning systems: Trios 3 (3Shape Dental Systems, Copenhagen, Denmark) and CEREC Omnicam (Sirona Dental GmbH, Salzburg, Austria). Maxillary arches of twenty subjects were scanned with both systems, and the scanned data were exported in STL format.

Trios (3Shape Dental Systems, Copenhagen, Denmark)

The open file system, powder-free Trios scanner utilizes rapid optical scanning technology. Digital intraoral images were captured by the scanner, enabling the acquisition of high-definition images for documentation purposes. Extraneous objects, such as the tongue, cheeks, or lips, are automatically identified and digitally eliminated. [13,14] The scanner was calibrated prior to taking digital impressions, and the scanner head was allowed to warm up. Each scan was captured using the most accurate scan sequence reported in the literature, which commences at the maxillary posterior region's occlusal-palatal surfaces, progresses toward the opposite side of the arch, consistently covering two surfaces, and concludes on the buccal side [15].

CEREC Omnicam (Sirona Dental GmbH, Salzburg, Austria)

The CEREC new OmniCam employs digital streaming to generate a full-color digital cast for capturing images without the need for powder, utilizing Sirona's 4.3 software for this investigation [16]. The scanner was calibrated prior to taking digital impressions, and the scanner head was allowed to warm up. Each scan was captured using the most accurate scan sequence reported in the literature, which commences at the maxillary posterior region's occlusal-palatal surfaces, progresses toward the opposite side of the arch, consistently covering two surfaces, and concludes on the buccal side [15].

Obtaining resin models with 3-D Printer

Resin models were obtained from STL formats utilizing two distinct 3D printers. The first 3D printer, Solflex 650 (Bego, Bremen, Germany), employed the DLP technique with Varseo Wax resin. The second, AccuFab-L4D (Shinning, Hangzhou, China), utilized the LCD technique with Shinning resin.

Superimposition and digital calipers

The digital data were compared using three-dimensional inspection software (Geomagic Control X, 2020.0.1-3D Systems, Rock Hill, SC, USA). This software employs the best fit alignment technique to compare STL files obtained through different methods. The length of the edentulous area was measured by connecting 2 points on the reference model, determined between the canine cusp tip and the central fossa of the second molar.

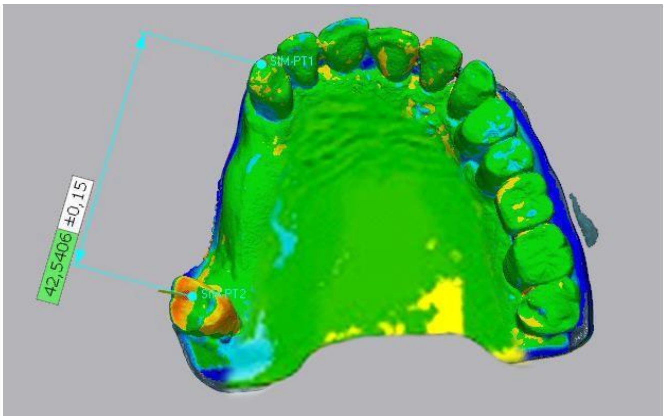

***Figure 1** (Presents color map images that illustrate the three-dimensional surface deviation observed in the complete-arch scan data of the partially-edentulous dentitions.)*

Statistical Methods

An inspection software program (Geomagic Control X; 3D SYSTEMS) was employed to assess the accuracy of each group. All speciments were trimmed to the vestibular sulcus depth and were individually superimposed onto the reference scan utilizing the best fit algorithm. This algorithm was applied to a predefined region of interest, which encompassed the ridge area and palate for the maxillary arches. Following superimposition, distance deviation values were calculated across the entire region of interest.

Trueness was determined by computing the root mean square (RMS) of the absolute deviation values. Precision was assessed by selecting the sample with the highest trueness within each group as the reference. The remaining speciments in the group were then superimposed onto this reference speciment using the same method as for trueness, and the distances between the scans were measured [17]. The RMS of the absolute distance values within each group was calculated to quantify precision.

The experimental data were summarized using means and standard deviations across all scanners and 3D printers. Fixed-effects statistical models were employed to examine trueness and precision separately. The dependent variables were trueness and precision, while the main effects included the scanner type (including conventional impressions). Statistical analyses were conducted using t-test and Kruskal Wallis test. Statistical significance was determined at p < 0.050. The formal t-statistic formula utilized to examine the between-groups differences of means is as follows:

$$t = \frac{(\bar{X}_1 - \bar{X}_2) - (\mu_{S1} - \mu_{S2})}{\sqrt{s_p^2 \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

where the pooled variance, which is the weighted variance of two compared speciments, is given by:

$$S_p^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{(n_1 - 1) + (n_2 - 1)}$$

The range of departure was subsequently recorded using the root mean square (RMS) error values that were produced. The algorithm below was employed to obtain the RMS error value between scan data:

$$\mathrm{RMS} = \frac{\sqrt{\sum_{i=1}^{n} (X_{1,i} - X_{2,i})^2}}{\sqrt{n}}$$

RESULTS

The mean values, standard deviation (SD), root mean square (RMS), and p-value for all the groups were shown in Table 1.

Table 1 *(Displays the all groups mean values, standart deviation (SD), root mean square (RMS) and p value.)*

Group	Mean Value	Standard Deviation	RMS	P Value
C	34,279	4,659	34,563	
C1S1	34,234	4,658	34,518	0,982
C2S1	34,221	4,699	34,51	0,978
T1S1	34,276	4,686	34,563	0,998
C1S2	34,3	4,63	34,58	0,991
C2S2	34,203	4,736	34,497	0,971
T1S2	34,223	4,752	34,519	0,979

One-way ANOVA demonstrate any statistically significant difference between the intraoral scans and 3-D printers according to the truennes of impression models.

The mean equivalency of 20 subjects, each comprising a different patient, was assessed using six different techniques of casting model manufacturing, and the root mean square (RMS) values for each sample are provided.

The median RMS error was 34.56 µm for the Group C, 34.51 µm for the Group C1S1, 34.51 µm for the Group C2S1, 34.56 µm for the Group T1S1, 34.58 µm for the Group C1S2, 34.49 µm for the Group C2S2, and 34.51 µm for the Group T1S2.

The mean deviations for each of these treatments are statistically tested against the control group.

No significant differences were detected between the two intraoral scanners and two 3-D printers regarding cast a model measurement ($p \geq 0.05$).

The T1S1 group exhibited the value closest to the control group, while the C2S2 group demonstrated the value furthest from it.

Table 2 summarizes the RMS values for each of the six impression methods in the X, Y, and Z directions, including mean value, SD, RMS, and p-value for all groups.

In the three-dimensional deviations, the intraoral scans presented a minor displacement to the measurement; however, there was no statistically significant difference between them (evaluated with paired t-test, Table 2).

Table 2 *(In the X-Y-Z direction show the mean value, SD, RMS and p value.)*

Group	Mean Value	Standard Deviation	RMS	P Value
C X- directional displacement	18,94	9,857	21,123	
C Y- directional displacement	26,222	7,085	27,07	
C Z- directional displacement	3,1482	2,519	3,952	
C1S1 X- directional displacement	18,952	9,819	21,118	0,997
C1S1 Y- directional displacement	26,211	7,099	27,063	0,997
C1S1 Z- directional displacement	3,078	2,419	3,839	0,95
C2S1 X- directional displacement	18,937	9,779	21,088	0,999
C2S1 Y- directional displacement	26,149	7,282	27,046	0,982

C2S1 Z- directional displacement	3,0097	2,427	3,789	0,901
T1S1 X- directional displacement	18,984	9,818	21,146	0,992
T1S1 Y- directional displacement	26,196	7,256	27,086	0,993
T1S1 Z- directional displacement	2,9693	2,362	3,72	0,871
C1S2 X- directional displacement	18,971	9,826	21,138	0,994
C1S2 Y- directional displacement	26,249	7,119	27,104	0,993
C1S2 Z- directional displacement	3,0384	2,384	3,787	0,921
C2S2 X- directional displacement	18,893	9,773	21,045	0,991
C2S2 Y- directional displacement	26,181	7,329	27,088	0,989
C2S2 Z- directional displacement	2,9263	2,31	3,656	0,839
T1S2 X- directional displacement	18,927	9,788	21,082	0,997
T1S2 Y- directional displacement	26,221	7,159	27,087	0,999
T1S2 Z- directional displacement	2,9173	2,365	3,68	0,835

P values were obtained from paired *t* test. *X*, *Y*, and *Z* directions indicate mediolateral, superoinferior, and anteroposterior directions, respectively.
SD standard deviation

No significant differences were detected between all groups of x coordinate displacement measurements ($p \geq 0.05$). The C1S1 group exhibited the value closest to the control group, while the C2S2 group demonstrated the value most distant from it.

No significant differences were detected between all groups of y coordinate displacement measurements ($p \geq 0.05$). The C1S1 group exhibited the value closest to the control group, while the C1S2 group demonstrated the value most distant from it.

The most substantial difference was observed in the z coordinate direction according to the control group (Table 2). The C1S1 group exhibited the value closest to the control group, while the C2S2 group demonstrated the value most distant from it.

In all of these cases, there was no statistically significant difference between the combination of two intraoral scanners and two 3-D printers.

DISCUSSION

The null hypothesis that the highest accuracy value of the model would be obtained using the 3Shape Trios (3Shape Dental Systems, Copenhagen, Denmark) intraoral scanner was accepted.

Intraoral scanners were commonly utilized for missing teeth that could be restored with fixed partial dentures. They were infrequently employed in cases of multiple missing teeth that require removable partial dentures. Although there were in-vitro studies examining the accuracy of intraoral scanners based on the width of the edentulous region at the literature, there were few in-vivo studies [12, 17, 18, 19].

Furthermore, while studies in the literature evaluated the accuracy of working models obtained with 3D printers compared to conventional systems, studies using 3D printers and intraoral scanning systems in combination were limited [20, 21].

Resende et al., in 2021, in their in vitro study, evaluated the trueness and precision of scans performed by 3 professionals with different levels of experience using 2 IOSs; Trios (3Shape Dental Systems, Copenhagen, Denmark) and CEREC Omnicam (Sirona Dental GmbH, Salzburg, Austria) and reported that for complete-arch scans, the TRIOS 3 group demonstrated better precision than the CEREC Omnicam group ($P<.001$) [22]. In an in vitro study reported by Diker and Tak in 2021, the accuracy rates of 6 different intra-oral scanners on 2 different partially edentulous models were evaluated. The highest accuracy value on models with partially edentulous models was observed in Trios and Primescan and iTero intra-oral scanners, respectively, while the lowest accuracy value was observed in the Emerald intra-oral scanner. In this study, the accuracy value of the measurement taken with the Trios 3 intraoral scanner was found to be higher than the Cerec Omnicam intraoral scanner, but no significant difference was observed between them ($p \geq 0.05$) [20].

The data obtained from this study indicate that the impression taken with the Trios (3Shape Headquarters, Copenhagen, Denmark) has the highest accuracy value compared to the conventional method, although the clinical usability of the CEREC Omnicam (Sirona Dental GmbH, Salzburg, Austria) has also been confirmed. No significant difference was observed between them ($p \geq 0.05$).

The null hypothesis that the highest accuracy value of the cast model would be produced using the Solflex 650 3D printer with the DLP technique was rejected.

In the in vitro study conducted by Banjar et al. in 2021, the accuracy of models with two implants in the anterior region of the maxillary arch obtained by digital impression was evaluated. Digital impressions were obtained using White Light IOS (Trios, 3 Shape). The models were fabricated with 3D printers operating on two different working principles. The study found that models produced with the Varseo S printer, which utilizes the DLP working principle, exhibited higher accuracy compared to those fabricated with the Form 2 printer, which operates on the SLA working principle [19]. Tsolakis et al., in 2022, evaluated the printing accuracy of dental models using Liquid Crystal Display (LCD) against Direct Light Processing (DLP) 3D printers in vitro. For this investigation, 10 STL reference files were employed. The comparison between the DLP and LCD 3D printers was statistically significant in terms of trueness. When obtaining dental models, DLP 3D printers demonstrate higher accuracy than LCD 3D printers. Although, both DLP and LCD printers can produce dental models with sufficient accuracy for fabricating dental appliances [12].

In this study, median value closest to the control group was 34.276 µm in the impression with the Trios scanner and manufacturing model with the Accufab-L4D group, while the median value farthest from the control group was 34.203 µm in the impression with the Cerec scanner and manufacturing model with the Solflex 650 group. Statistically significant differences were not found between the median values of the groups according to the Kruskal-Wallis test ($p \geq 0.05$).

One of the limitations of this study was that only maxillary Kennedy III classification with 4 unilateral missing teeth models were tested. Different Kennedy classification models and the length of the edentulous area may affect the accuracy of digital workflows. In this study, Cerec Omincam and 3Shape Trios intraoral scanners and Solflex 650, AccuFab-L4D were used. Different results may be obtained with different intraoral scanners and 3D printers.

CONCLUSION

Within the limitations of this study, no significant difference in accuracy was observed between the digital models and the conventional model. As the utilization of digital workflows may become more prevalent in future clinical studies, it is recommended that the accuracy of cases with other Kennedy classifications could be investigated in subsequent research.

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