Influence of Different Fabrication Techniques on the Accuracy of Radiographic Scan Templates in Cases of Full-Arch Computer-Guided Implant Placement: An In Vitro Study

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Purpose: To evaluate the influence of using different fabrication techniques, including intraoral scans, CBCT scans of patients’ existing dentures, or denture duplicates, on the accuracy of radiographic scan templates. The influence of selecting different segmentation threshold values during reconstruction of CBCT data was also evaluated. Materials and Methods: A reference model was obtained by scanning five pairs of maxillary and mandibular acrylic complete dentures using a desktop laboratory laser scanner (DWOS 7Series, Dental Wings). Test scans were obtained from intraoral scans of dentures, CBCT scans of dentures and denture duplicates reconstructed at different grayscale segmentation thresholds, and a laboratory scan of denture duplicates. The resultant STL scan files were imported to an open source and cloud storage software (Medit Link) for the accuracy measurements by calculating root mean square estimate (RMSE) between reference and test scans. Collected data were then analyzed. Qualitative analysis was also performed using 3D color maps. Results: The lowest RMSE (352.7) was found with intraoral denture scans. The highest RMSE (1,336.3) was found with the CBCT scans of the denture duplicates at segmentation threshold of –700 grayscale level. Qualitative analysis revealed that the intraoral denture scans exhibited the most homogenous deviation pattern relative to reference lab scans. Conclusion: Within the limitations of this study, the intraoral scans of the patients’ existing dentures resulted in the fabrication of the most accurate radiographic scan templates. The improved accuracy of scan templates fabricated using the intraoral scanners can eliminate the possible laboratory errors associated with the conventional technical procedures as well as reduce the inaccuracies resulting from the image processing and segmentation of CBCT data. Int J Oral Maxillofac Implants 2022;37:30–37. doi: 10.11607/jomi.9084

Keywords: accuracy, CBCT scans, computer-guided implant placement, intraoral scans, radiographic template, scan template

Full-arch implant rehabilitation has been successfully employed for the management of the edentulous predicament. With the development of digital technology, it is now possible to have a complete digital workflow and computer-guided implant placement, not to mention the implementation of a prosthetic-driven approach.1–3 Guided implant placement is commonly recommended, as it improves the accuracy of implant placement over conventional surgical procedures.2 To date, two types of guided implant surgery are available—static and dynamic navigation systems.1,4 Static guided implant surgery is based on the use of a surgical template for implant placement, so that virtual implant planning can be accurately replicated during the actual surgical procedure.4 The virtual implant planning is performed on 3D images of jawbone reconstructed from CBCT images of edentulous jaws.5 To incorporate the planned prosthetic setup that represents the future restoration into the anatomical image of jawbone relative to virtually planned implant positions, a scan appliance has to be constructed.5–8 The patient wearing the appliance is CBCT scanned, and the resultant files are uploaded to planning software, where the virtual implant planning is executed.1 Scan prostheses can be fabricated in the laboratory based on a prosthetic template that is created and checked in the patient’s mouth for esthetics and phonetics.6–8 Alternatively, if the patient exhibits a well-fitting satisfactory denture, the denture can be used for the scanning procedure, either through a single- or double-scan technique. In the single-scan technique, the existing prosthesis can be duplicated in radiopaque resin and then the patient is CBCT scanned wearing the scan/radiographic template. In the double-scan technique, the denture is equipped with radiopaque markers and the patient is scanned with the prosthesis in the mouth.9,10 The scan
The dentures were obtained from completely edentulous patients attending the outpatient clinic of the Prosthodontic Department, Faculty of Dentistry, Cairo University, and were planned for guided implant placement as a part of their oral rehabilitation procedure with fixed, full-arch implant prostheses. The study protocol was explained to the patients and their informed consent was obtained to scan their dentures to be used as reference and test models. Reference scans of the dentures were obtained using a desktop laboratory laser scanner, and test scans were obtained with different methods, including intraoral scans of dentures, CBCT scans of dentures and denture duplicates reconstructed at different grayscale levels, and laboratory scans of denture duplicates. All scan files were saved in STL format, and the test scans were superimposed on reference scans for accuracy measurements using the digital subtraction technique.

**Reference Scans**
A desktop laboratory laser scanner (DWOS 7Series, Dental Wings) was used for 3D scanning of maxillary and mandibular dentures to acquire reference data. Each denture was sprayed with a homogenous layer of scan powder (SHERA scan spray, Shera Dental) from a fixed distance of approximately 25 to 30 cm to enhance the scanning procedure. Initially, the denture fitting surface with the adjoining polished surface were scanned. The teeth and polished surfaces were then scanned. The two scans were automatically aligned in relation to each other using the common scanned areas of the polished surfaces. The scanned meshes were then cleaned and the two scans were exported as separate STL files. On the blender software version 2.8, the two scans were imported in their respective orientation and were then merged as a single object. Tiny holes and mesh imperfections were detected and corrected automatically on the software to obtain the final denture reference scans. Before each scan, the scanner was calibrated as per the manufacturer’s instructions.

**Test Scans**
For every denture, 10 test scans were obtained: an intraoral scan, a laboratory scan of the denture duplicate, 4 reconstructed CBCT scans of dentures at four different grayscale segmentation values, and 4 reconstructed CBCT scans of denture duplicates at four different grayscale segmentation values. Again, the calibration of the scanners was ensured before any scanning procedure was performed.

**Scans of denture using an intraoral scanner.** The denture scans (Fig 1) were done using Medit i500 handheld intraoral scanner (Medit Corp). Each denture was sprayed with scan powder as previously described for the reference scans. Initially, the occlusal surface

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**MATERIALS AND METHODS**

**Study Design**
Five pairs of maxillary and mandibular acrylic complete dentures were used as sample models for this study.

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and the adjoining buccal and lingual surfaces of the denture teeth were scanned with a swinging motion starting from the last molar on one side and ending with the contralateral last molar. For scanning the mandibular and the maxillary facial flanges, the occlusal surface of the last molar of one side was used as a starting reference point from which a zigzag up-and-down motion was performed until the denture border was reached and then back to the facial/lingual surface of the neighboring teeth. This scanning pattern was continued until the flange was fully scanned. For the polished palatal surface, scanning was performed with a zigzag motion starting from the palatal surface of the last molar of one side to the midline and back again to the palatal surface of the mesially located tooth. This was done to scan half of the palate. The same procedure was repeated to scan the other half of the palate. The fitting surface of the maxillary denture was scanned in a zigzag motion starting from the border of one side to the midline and back to the border. The fitting surface of the mandibular denture was also scanned using a zigzag motion starting from the labial flange at the midline extending to the retromolar pad of one side. The contralateral sides were scanned in a similar manner. The obtained STL files were processed and checked for holes. Holes were automatically filled using the Medit software algorithm.

**Scans of denture using CBCT.** CBCT scans of dentures were performed using the PaX-i3D CBCT machine (Vatech) with 8 × 8 FOV, 80 kVp, and 6 mA, resulting in 672 × 672 × 672 voxel size. At the selected parameters, each denture was CBCT scanned. The scan data were exported as DICOM images. The obtained DICOM data were processed using 3D Slicer software (version 4.10.1). Four different reconstructed models at different grayscale segmentation values were created from each denture DICOM data. For all the models, the upper segmentation threshold value was set at 1,500 and lowest threshold was set at –700; in between thresholds of –500, –300, and –100 were also used for image reconstruction. The lowest threshold value of –700 was selected, as it was the lowest threshold after which visible noise started to be apparent around the dentures (Fig 2). The lower threshold was then gradually raised until the denture started showing visible pitting. This was achieved at a threshold value of –100 (Fig 2). Two more threshold values of –300 and –500 were selected between the two previously selected threshold values of –100 and –700. At both selected values, the scans of the reconstructed dentures seemed to be visually acceptable. Thus, for each denture, four STL models were segmented at –700, –500, –300, and –100 threshold values.

**Scan of the denture duplicates using CBCT and laboratory scanner.** Each denture was duplicated using putty silicone impression material (Zhermack) and a duplicating plastic box. The created duplication mold was packed with cold-cured resin (Vertex Dental) that was left to set under pressure of 2 bars using a hydraulic press machine. The duplicate denture was then finished by only removing excess resin flashes. The finished duplicate denture was scanned using a desktop laboratory laser scanner similar to the way the reference scans were performed. The duplicate denture was also scanned with a CBCT machine with the same parameters and same threshold values used for scanning the dentures. On the slicer software, four models were created for each denture duplicate.

**Superimposition and Accuracy Measurements**
All scanned digital files were saved in STL format and were imported to an open source and cloud storage software (Medit Link), where the accuracy measurements...
were performed. The STL file of each test scan was superimposed on the reference scan. Precise matching was done using the best-fit, three-point alignment. The root mean square estimate (RMSE) values between the STL files of the reference and test scans were calculated. RMSE is used to measure the differences in the values, which in the current study would be the difference in location between the same corresponding points on both the reference and test scans as predicted by a mathematical model. The resultant color maps were assessed to detect the deviation pattern between the same corresponding points on both the reference and test scans. A single experienced operator performed all the scanning procedures and the accuracy measurements. The data were then collected, tabulated, and statistically analyzed using the IBM Statistical Package for the Social Sciences software (SPSS, version 20, SPSS Inc) to detect the accuracy of each scan method.

Statistical Analysis
To assess observer bias, measurements of five random samples were made twice by the same observer within a 15-day interval and intraobserver reliability was checked using intraclass correlation coefficient (ICC). ICC describes the reliability of measurements by showing how strongly the measurements taken resemble each other and can be replicated. A high ICC close to 1 indicates high similarity between the values and higher reliability. The mean and standard deviation values of RMSE were calculated for each group using descriptive statistics. Data were explored for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests. Data showed parametric (normal) distribution. Two-way analysis of variance (ANOVA) was used to test the effect of interaction between different variables. One-way ANOVA followed by Tukey post hoc test was used to analyze the influence of fabrication method on RMSE of fabricated scans in each fabrication method separately.

The significance level was set at $P \leq .05$. Statistical analysis was performed with IBM SPSS Statistics Version 20 for Windows.

RESULTS
The intraclass correlation coefficient was 0.99, which indicates high intraobserver reliability and eliminates any possible observer bias.

Numeric Findings
The mean and standard deviation values of RMSE of all groups are presented in Table 1 and Figs 3 and 4, and the results for two-way ANOVA for the effect of different variables are shown in Table 2. The results showed that

<table>
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<th>Table 1 Descriptive Statistics Showing the Mean and Standard Deviation (SD) Values of RMSE of All Groups</th>
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<td><strong>Accuracy</strong></td>
</tr>
<tr>
<td>IO</td>
</tr>
<tr>
<td>–700</td>
</tr>
<tr>
<td>–500</td>
</tr>
<tr>
<td>–300</td>
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*Statistical significance at $P < .05$. 

![Fig 3](image1.png) Bar chart comparing RMSE values between different scan methods in both denture and duplicate subgroups. IO = intraoral.

![Fig 4](image2.png) Bar chart comparing RMSE values between different scan methods. IO = intraoral.
the scan method had a significant effect on RMSE of the fabricated scans. The lowest RMSE was found with intraoral denture scans (352.7), followed by dentures scanned by CBCT at grayscale segmentation threshold of –500 with a corresponding value of 499.7 (Table 1, Figs 3 and 4). There was no significant difference in mean RMSE values between intraoral and CBCT scans of dentures at grayscale segmentation threshold of –500. There was a statistically significant difference between denture scans at segmentation threshold of –100 and each intraoral scan as well as between denture scans at segmentation threshold of –100 and –500; $P < .001$ and $P = .04$, respectively (Fig 3). The highest RMSE (1,336.3) was found with the CBCT scans of the denture duplicates at grayscale segmentation threshold of –700 (Table 1).

### Qualitative Findings
The intraoral denture scans revealed the most homogenous and best deviation pattern relative to reference lab scans, displaying broad green areas of optimum tissue adaptation and slight positive deviation presented by yellow-colored areas along the palatal area and the lower alveolar ridge area, and light blue areas of slight

<table>
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<th>Source</th>
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<th>Mean square</th>
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$df$: degrees of freedom = (n – 1). *Statistical significance at $P ≤ .05.$
negative deviation along the buccal flanges (Figs 5a and 5b). With the maxillary and mandibular CBCT scans of dentures at grayscale segmentation threshold of ~500, the yellow-colored areas of positive deviation broadened to include most of the palatal area and lower ridge area with a noticeable decrease in green-colored areas of optimum adaptation (Figs 5c and 5d). A common deviation pattern with all CBCT duplicate scans was the dominance of the negative deviation (blue color) along the entire palatal area up to the palatal surface of both molars and anterior teeth, and positive deviation (red) along the labial and buccal flanges (Fig 6). A similar pattern was observed in the CBCT duplicate scans of mandibular templates, with a negative (blue) deviation pattern all over the ridge area and positive deviation (red) along the distolingual and distobuccal flange edges (Fig 6).

DISCUSSION

The use of digital technology is expanding in the field of oral implantology, with a wide array of uses ranging from diagnosis, treatment planning, and guided implant placement, to the manufacture and insertion of the implant prosthetics.1,2 A thorough understanding of the theoretical background of the technology is mandatory to optimize its use.17 This is particularly important when considering the static computer-guided implant placement for the rehabilitation of completely edentulous patients with fixed implant-supported prostheses. This procedure is technique sensitive and prone to error from radiographic acquisition to virtual implant planning to the actual surgical procedure.1,2 Cumulative errors throughout the implant placement procedure can result in diminished accuracy and loss of the main advantage of computer-guided implant placement technique. Most of the studies in the literature focused on evaluating the accuracy of computer-guided surgery in relation to the stage of virtual implant planning and the transfer of this plan to the surgical field.18-20 The importance of fabricating an accurate scan template for radiographic acquisition at the offset of the planning phase has been overlooked, though it represents an essential step for the overall accuracy of the procedure. An inaccurate scan template would lead to deficient treatment planning with subsequent technical, mechanical, and biologic complications. Therefore, the aim of the current study was to investigate which of the digital methods available—intraoral scanners, CBCT scanners—would result in the fabrication of the most accurate scan template. To the authors’ best knowledge, no previous studies exist in the scientific literature that evaluated the influence of different fabrication methods on the accuracy of constructed radiographic scan templates. Consequently, no direct comparisons can be made, but rather an interpretation and clinical implications of the results are presented.

In the current study and similar to previous studies, reference data were acquired using a laboratory laser scanner.13,21,22 The accuracy of the lab scanner is probably due to the scan object being fixed and natural light blocked, enabling the data to be acquired from a variety of angles with a high-performance camera.23,24 The RMSE between the STL files of test and reference scans was calculated rather than the arithmetic means of the deviation values. This is because the arithmetic means of deviation with positive and negative values when averaged can mask any actually existing differences.25 The first part of the study’s hypothesis, that there would be no difference in accuracy of scan templates fabricated by different techniques, was rejected. Based
on the findings of this study, the intraoral scanners demonstrated a potential to be used as a reliable method for the fabrication of scan templates with minimal deviation values and best deviation pattern when compared to all other fabrication techniques. The possibility of fabricating a scan template by intraoral scanning of the patients’ existing dentures will eliminate patients having to be without their dentures for any length of time. The clinical procedures will be simplified, and all extra time and cost involved with laboratory procedures for the fabrication of the scan template eliminated. Overall patient comfort and acceptance of the treatment will be increased. The resultant STL files of intraoral scans can be immediately sent to the laboratory for the template fabrication, further implementing the use of a fully digital workflow in implant dentistry.

As there are no reported values in the literature of an acceptable deviation value for a radiographic scan template that would not negatively impact the overall accuracy of the computer-guided implant placement procedure, there is a need to try to set a cutoff value through reliable in vivo and in vitro studies. Future studies should focus on comparing the accuracy of different available intraoral scanners. It is expected that the accuracy of scan templates would vary with the use of different scanners, as is the case when intraoral scanners are used for the acquisition of full-arch implant impressions. Furthermore, the influence of different scanning strategies should also be investigated, as very limited information is provided by manufacturers of intraoral scanners recommending any particular scanning technique. In the same context, the existing data regarding the unsuitability of intraoral scanners for the scanning of large-span areas in terms of accuracy should be cautiously interpreted. This is evidently because the speed of preparing and publishing a scientific article is very much lagging behind the introduction of newly developed powerful scanner software with a minor margin of error compared to older versions.

There are two main reasons for the negative deviation pattern that was observed with CBCT scans. The first is the smoothening procedure performed on the DICOM viewer to eliminate the stepped surface of 3D-reconstructed multislice DICOM data; this results in a reconstructed surface that can be up to 5% smaller than the actual size. There is also a tendency with CBCT data analysis to slightly underestimate measurements relevant to reference data, especially in cases of compounded measurements, owing to the partial volume effect. Although this underestimation could be clinically insignificant, in range of 0.1 to 0.2 mm, it might become an issue when several measurements are added together, as in the case of arc perimeter analysis. As per partial volume effect, all measurements are influenced by threshold settings in the software; so for a hybrid voxel that lies at the junction of two objects with different densities, any measurement made will reflect an average value somewhere in between the two true values, depending on the threshold selected, with higher threshold values creating objects smaller than the actual size. In the current study, the measurements of voxels between the resin of the scanned stent and surrounding air will reflect an average value somewhere between the true values of the air and the resin depending on the threshold value selected.

The other contributing factor to the observed negative deviation pattern, particularly in CBCT scans of denture duplicates, is the release of stresses during the cooling of the duplicate material and thermal shrinkage of duplicating acrylic almost parallel to the palatal surface, pulling the opposing teeth toward each other across the ridge, and thus the observed positive deviation presented by red areas along the buccal flanges. The second part of the study hypothesis was accepted. The findings of this study revealed that the grayscale segmentation thresholds have a significant influence on the quality of the images obtained by CBCT and hence the accuracy of the scan appliance to be fabricated. These findings are in agreement with the results of Dong et al., who concluded that for each voxel size, there exists an optimal Hounsfield unit threshold to improve the accuracy of the volumetric measurements in CBCT scanning. Thus, optimal parameters during CBCT scanning and selected grayscale values during 3D reconstruction are mandatory during the implant-planning phase. It is acknowledged that there is significant difference in grayscale values obtained from the CBCT machines of different manufacturers, and thus the results of this study cannot be generalized unless the same CBCT scanner and acquisition parameters are used. However, the negative deviation pattern observed as a result of the smoothening process and the processing of CBCT DICOM data will be a common occurrence with any CBCT scanner that is used and should be accounted for to ensure the accuracy of the procedure.

CONCLUSIONS

Within the limitations of this study and among the different fabrication techniques evaluated, the intraoral scans of the patients’ existing dentures resulted in the fabrication of the most accurate radiographic scan templates. The improved accuracy of scan templates fabricated using the intraoral scanners can eliminate possible laboratory errors associated with conventional technical procedures and the duplication process, as well as reduce inaccuracies resulting from the image processing and segmentation of CBCT data.
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