Technical Accuracy of Printed Surgical Templates for Guided Implant Surgery with the coDiagnostiX^{TM} Software

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ABSTRACT

Background: Printing of templates for guided surgery represents an alternative to laboratory manufactured templates.

Purpose: To determine the technical accuracy of a virtually designed and printed surgical template for guided implant surgery based on a surface scan of a cast model using the coDiagnostiX^{TM} software.

Materials and Methods: Cast models and the virtual planning data of nine patients receiving guided implant surgery with the coDiagnostiX software were analyzed. The original cast models were equipped with three titanium pins and scanned with a three-dimensional scanner. The scans were uploaded in the coDiagnostiX software and the virtual surgical templates were designed including the sleeves at their original positions. After printing the surgical templates, the sleeve positions were determined by optical scanning, and deviations were calculated and compared with the virtual positions of the sleeves.

Results: The sleeves showed a mean three-dimensional deviation of 0.22 mm (range: 0.07–0.38 mm) in the center of the sleeve top, 0.24 mm (range: 0.08–0.36 mm) in the center of the sleeve bases and a mean angular deviation of 1.5° (range: 0.4°–3.3°) compared with the virtual positions.

Conclusions: A high accuracy can be achieved using printed templates for guided implant surgery, by taking into account all sources of inaccuracies.

KEY WORDS: accuracy, computer-aided design/computer-aided manufacturing technology, implantology, stereo lithography

INTRODUCTION

Surgical templates for guided implant surgery have gained more and more importance in implant dentistry.[1] Although the clinical benefit of guided implantation is a matter of controversy,[2] a general consensus exists about the advantages associated with guided surgery, such as virtual backward-planning, facilitated surgical procedure, reduced surgical intervention time, and reduced postoperative sequelae.[3] Today, several different systems are available for guided implant surgery.[4–8] Irrespective of the system's approach, they commonly include drilling sleeves, which guide the drill during cavity preparation and the implant during its insertion.[3,6] Disparities between systems affect the transfer of the virtual planning into reality, for example, including the drilling sleeves into a template according to the virtual positioning. Two generally different

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approaches can be distinguished. While manually fabricated templates (MFT) are produced in a dental laboratory using a system-specific drilling machine, stereolithographic templates (ST) are produced by computer-aided design/computer-aided manufacturing technology.[9–11] The latter is mainly performed in specialized milling centers. For most MFT and ST-systems it is mandatory to perform a three-dimensional radiography with a diagnostic (radiographic) template including reference elements, which facilitate the transfer of the virtual sleeve positions into reality.

The template fabrication for the radiographic planning is costly and time-consuming. Recently the coDiagnostiX™ software (Version 9.0, Dental Wings GmbH, Freiburg, Germany) was equipped with an option to design surgical templates for guided implant surgery without requiring a radiographic template and using three-dimensional printing technology for surgical template fabrication. A three-dimensional radiographic data set is uploaded into the planning software, which allows virtual implant planning. To transfer this planning into reality, a three-dimensional optical scan of a cast model (or intraoral scan) must be uploaded into the software and superimposed to radiographically visible matching references. Based on the optical scan a virtual framework of the template can be included by mouse-click into the original planning. The sleeves can be included into the virtual framework, and the template is then printed with any (home–office) three-dimensional printer. However, though this technology seems to improve template fabrication due to time and cost reductions, there are no data concerning the technical accuracy of this manufacturing approach.

The aim of the present study was to determine the technical accuracy of printing surgical templates for guided implant surgery using an optical scan of a cast model.

MATERIAL AND METHODS

Data sets of nine patients (three edentulous, two single tooth gaps and four free-end situations), who received guided implant insertion ($n = 17$ implants) after virtual planning with the coDiagnostiX software, were used. Informed consent was obtained from all patients to retrospectively use the cast models and virtual planning data.

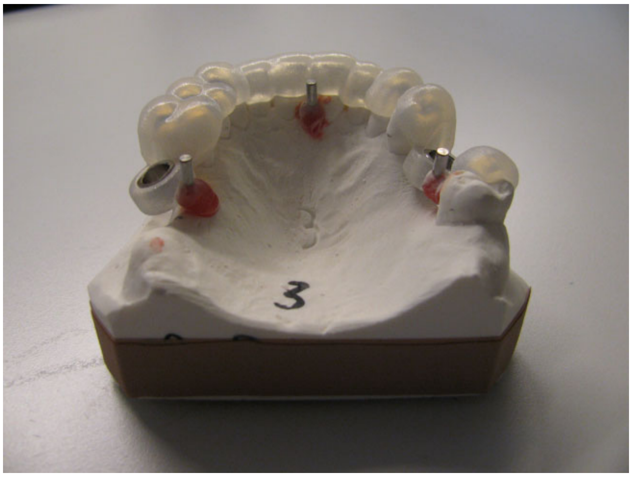

Figure 1 Printed template mounted on the original cast model equipped with three titanium pins for accuracy measurements.

Virtual Template Design

The cast models were equipped with three titanium pins, which were fixed on each cast model (Figure 1). These served as reference elements to evaluate the accuracy of the sleeve positioning/template printing as described below.

An optical scan of each cast model (including the titanium pins) was performed with a three-dimensional scanner (DW-3–90, Dental Wings Inc., Montreal, Canada). The data were transformed into Surface Tesselation Language (STL) files and uploaded into the coDiagnostiX software. The STL files of each patient were included into the original planning data by matching the scanned model with the three-dimensional radiography. This matching was based on anatomical landmarks, which were clearly visible and mainly represented by natural teeth. Once the matching was completed, a virtual template including the original sleeves for guidance was designed using the three-dimensional scan of the model. Therefore, single points on the vestibular and oral side of each tooth, which indicate the direct contact zone of the virtual template on the teeth, were determined manually via mouse-click. The software automatically connected these single points creating the template's framework including nots for the system specific metal sleeves at the respective three-dimensional position (Figure 2).

Template Printing

The designed virtual templates were exported as STL files and printed with a three-dimensional printing

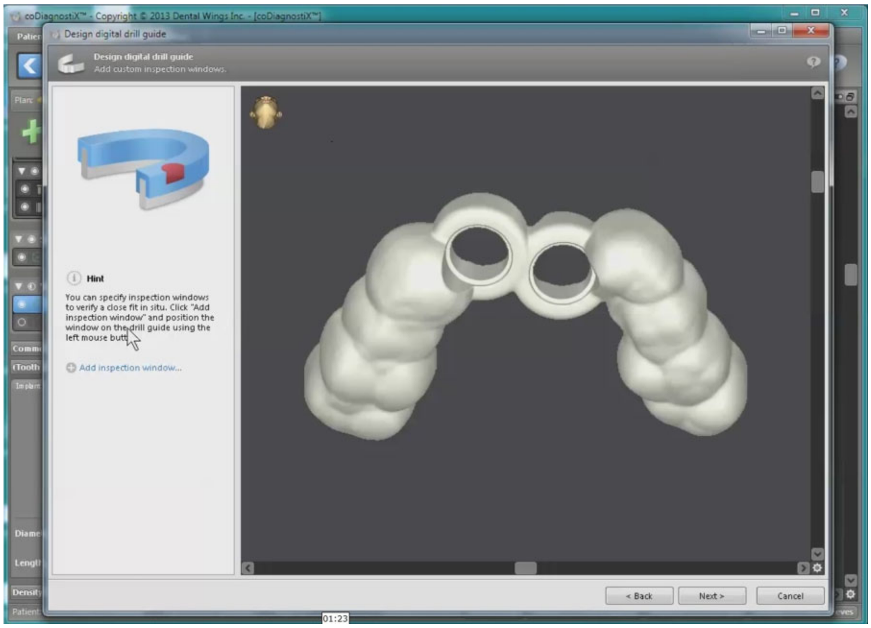

Figure 2 Virtually designed template with nots for the system-specific metal sleeves.

device (Objet Eden 260 V, Material: MED610, Stratasys Ltd, Minneapolis, MN, USA). The system-specific metal sleeves with 5 mm diameter (T-sleeves, Institut Straumann AG, Basel, Switzerland) for guided surgery were manually pushed into the respective nots.

Accuracy Measurement

The accuracy measurements were performed in two steps. First, the three titanium pins were used to create a virtual three-dimensional coordinate system within the coDiagnostiX software and the positions of the virtually planned sleeves within this three-dimensional coordinate system were determined. These positions were compared with the real position of the sleeves in the printed templates, again by determining the sleeve position within the three-dimensional coordinate system of the three titanium pins. Therefore, the templates were placed on the original cast models (equipped with the three titanium pins) and scanned with a surface scanner (OGP Smartscope CNC 250, Optical Gaging Ltd, Singapore). The scan was used to determine the three-dimensional positions of the sleeves within the coordinate system of the titanium pins and compared with the position of the sleeves in the virtual planning. Measurements were carried out in the center of the respective sleeve's tops and bases (Figure 3).

Statistical Evaluation

A descriptive statistic was performed showing the maximum, minimum, and mean deviation (in mm) of the sleeve top centers, the sleeve base centers, and the angular deviation (in degrees). Additionally, the theoretical deviation of a 10 mm implant was calculated, based on the measured angular deviations using the tangent (tan) function as following.

$$\begin{aligned}&\textit{Apical deviation}\\&\quad=\tan(\textit{angular deviation})\times(\textit{total length of the sleeve}\\&\qquad+\textit{implant length}+\textit{distance sleeve to implant})\end{aligned}$$

A sleeve's length of 5 mm and a distance from the sleeve's bases to the top of the implant of 4 mm was used.

RESULTS

The lowest three-dimensional deviation at the sleeve center top was 0.07 mm, and the highest three-dimensional deviation was 0.38 mm with a mean three-dimensional deviation of 0.22 mm (Table 1). The lowest three-dimensional deviation at the sleeve center bases was 0.08 mm, and the highest three-dimensional deviation was 0.36 mm with a mean three-dimensional deviation of 0.24 mm (Table 1). A mean angular deviation of 1.5 (range: 0.4°–3.3°) was calculated (Table 1), resulting in a virtual implant mean apical deviation of 0.49 mm. The maximum and minimum apical implant deviation ranged from 0.13 mm to 1.09 mm.

DISCUSSION

The present investigation demonstrated that printing of virtually designed templates was associated with

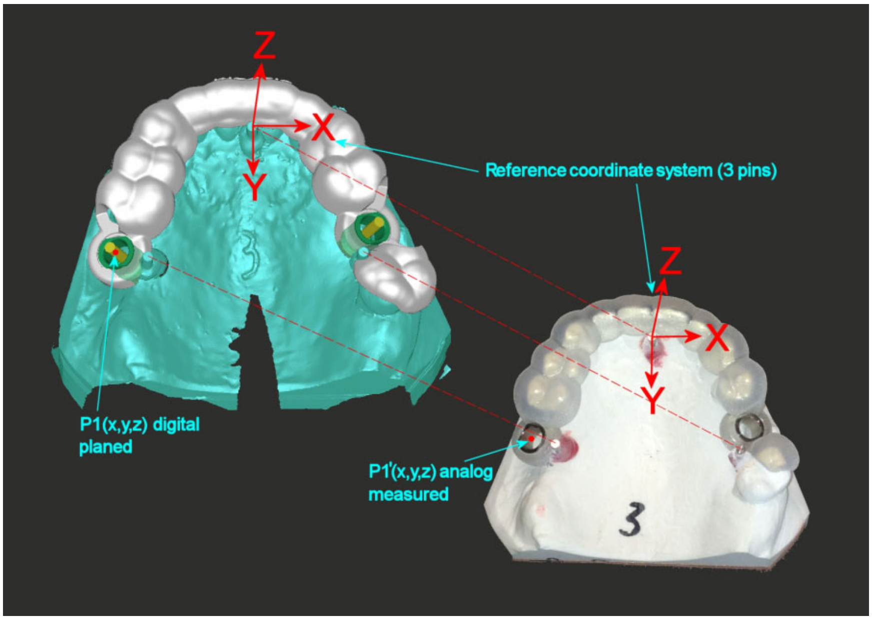

Figure 3 Accuracy measurement: A three-dimensional coordinate system was created using the titanium pins (right image) and the positions of the sleeves in the coordinate system were calculated. After template production surface scans of the template were performed using again the identical titanium pins to create a coordinate system and determine the (real) sleeves positions.

potential technical inaccuracies of the sleeves' center positions ranging from 0.07 mm to 0.38 mm and an angular deviation of 0.4–3.3 when compared with the virtual sleeve positions.

Many factors potentially affected the accuracy of the template production and sleeve positioning including scanning procedure, registration of the titanium pins, accuracy of the virtual template design, accuracy of the three-dimensional printer, accuracy of including the sleeves into the specific nots, template fit on the cast model, and finally accuracy of the surface scanner.

TABLE 1 Three-Dimensional (3D) and Single Deviations (in mm and degree [°]) of the Sleeves Compared with the Virtual Position. P1 = Sleeves' top, P2 = Sleeves' Bases

	Mean	Min	Max
Deviation P1 X:	0.0633	0.0034	0.1639
Deviation P1 Y:	0.0820	0.0071	0.2731
Deviation P1 Z:	0.1719	0.0255	0.3699
Deviation P1 3D:	0.2240	0.0765	0.3808
Deviation P2 X:	0.1007	0.0093	0.295006
Deviation P2 Y:	0.0969	0.0197	0.184711
Deviation P2 Z:	0.1588	0.0124	0.352737
Deviation P2 3D:	0.2370	0.0807	0.3607
Angle Deviation:	1.4994	0.3936	3.3004

According to manufacturer's information, the scanning accuracy of the three-dimensional scanner is higher than 15 μm, the registration accuracy of the titanium pins measures at least 100 μm, the printing accuracy of the three-dimensional printer is 200 μm, and the virtual template design has an accuracy of $<1^{-7}$ mm. Taking all these cumulative inaccuracies into account (approximately 0.3 mm when adding all above mentioned variances), the presently measured sleeve deviations seem to be rather small. However, in clinical application additional sources of inaccuracies such as the intraoral fit of the template, radiographical inaccuracies,[12] and patient- or operator-related inaccuracies have to be accounted for.[13] Applying the tangential function on the mean angular deviation of 1.5 and calculating the resulting theoretical inaccuracy with a 10 mm implant inserted through a 5 mm long sleeve with a distance of 4 mm to the implant shoulder would result in a mean apical deviation of 0.49 mm. The maximum and minimum deviations would range between 0.13 mm and 1.09 mm. However, these data represent theoretical results and do not include all patient- and treatment-related clinical inaccuracies. A comparison of these results with data in the literature is difficult due to differences in the study designs (in vitro and in vivo). According to a meta-analysis evaluating the accuracy of different systems, the deviation at the entry point measured 1.07 mm and

1.63 mm at the apex.[11] The authors included clinical and in vitro studies on models and found no statistically significant differences among the studies regarding the accuracy of different methods for template production.[14] However, in one of the clinical studies included in the review a maximum deviation of 7.1 mm was observed at the implant apex.[15] In a more recent review on the accuracy of stereo-lithographically manufactured templates, inaccuracies between 0.6 mm and 4.5 mm at the implant apices and angular deviations ranging from 0.2 up to 8.1 were reported.[3] Though the present study shows a highly achievable accuracy in template manufacturing comparing these data with the results of the current study is not fairly possible because the referred papers include all, or most of the possible errors that can occur during guided implant surgery where the surgical template is only one of these possible sources. In contrast to MFT, printing of templates is associated with a favorable cost benefit. This can be explained by the cheap printing (<40$ per template) in contrast to the elevated time rate of a technician producing a MFT manually in his laboratory (>400$ per template). The virtual templates can be designed by the dentist/surgeon on his own computer, thus giving the opportunity to reduce the time for template fabrication and to increase its application. The time that is needed to virtually design the templates in the software took us less than 15 minutes per template. Once the virtual template is finally designed, printing is possible within minutes thus giving the opportunity to receive the template within several hours after planning. MFTs, in contrast, are associated with much more technical and thereby time-consuming steps such as the setting time of plaster, mounting the cast model into a drilling device, curing of resin or methacrylate, transforming the radiographic template into the template for guidance by drilling holes for the tubes into the template, finishing and polishing etc. This results in a cumulative duration of at least 24–48 hours for finalization of MFT, depending on the number of included implants. However, printing of templates also shows inevitable disadvantages such as the manual incorporation of the metal sleeves into the template by the dentist/surgeon and the need of surface polishing and finishing. Finally the dentist/surgeon needs access to printing devices that still seem too cost extensive for private ownership in dental offices. Within the limits of this investigation the results are promising; however, clinical studies must be performed to confirm the accuracy estimation of the present study for virtually planned and printed templates in vivo.

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