Accuracy of Three-Dimensional Printed Templates for Guided Implant Placement Based on Matching a Surface Scan with CBCT

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ABSTRACT

Background: Reference elements are necessary to transfer a virtual planning into reality for guided implant placement. New systems allow matching optical scans with three-dimensional radiographic images.

Purpose: To test whether digitally designed three-dimensional printed templates (D-temp) fabricated by matching surface scans and cone beam computed tomography (CBCT) images differ from the templates fabricated in-lab (L-temp) by using a physical transfer device for the positioning of the guiding sleeves.

Materials and Methods: L-temp were fabricated for eight human lower cadaver-jaws applying a digital planning software program (smop, Swissmeda AG, Zürich, Switzerland) using a Lego® (Lego Group, KIRKBI A/S, Billund, Denmark) brick as reference element and the respective transfer device (X1-table). Additionally, digital templates (D-temp) using the identical planning data sets and software were virtually designed and three-dimensional printed, after matching a surface scan with CBCT data. The accuracy of both templates for each planning was evaluated determining the estimated coronal, apical, and angular deviation if templates were used for implant placement.

Results: Mean coronal deviations for L-temp were 0.31 mm (mesial/distal), 0.32 mm (lingual/buccal), and 0.16 mm and 0.23 mm for D-temp, respectively. The mean apical deviations for L-temp were 0.50 mm (mesial/distal), 0.50 mm (lingual/buccal). and 0.25 mm and 0.34 mm for the D-temp, respectively. Differences between both devices were statistically significant ($p < .05$).

Conclusions: A higher accuracy of implant placement can be achieved by using three-dimensional printed templates produced by matching a surface scan and CBCT as compared with templates which use physical elements transferring the virtual planning into reality.

KEY WORDS: accuracy, CBCT imaging, computer assisted

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INTRODUCTION

Several advantages are associated with guided implant surgery (GIS) such as step-back planning and three-dimensional evaluation of the relationship between final reconstruction and local anatomy.[1] Transferring this virtual information into reality might be helpful in avoiding malposition of implants or injury of vital anatomical structures. However, any of these advantages is depending on a high accuracy transferring the virtual planning into reality.[2] Recent reviews have shown that

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the accuracy of GIS is still far beyond expectations, with a mean coronal deviation of 1.12 mm and a mean apical deviation of 1.39 mm.[3]

There are many sources of inaccuracies for GIS. Some are basic and common irrespective of the used system (such as artifacts occurring during image acquisition); others are specific and related to the respective software and technique transferring the virtual planning into reality.

Laboratory-based templates (L-temp), in which the radiographic template for planning purposes is transformed into a surgical template, are also associated with many sources of inaccuracy, ranging from impression taking, cast fabrication, intraoral fit of the templates during radiography and surgery, and finally the insertion of the sleeves for guidance by a technician in the lab 3.[4] Any L-temp system needs a combination of a specific reference element and a lab device (machine or table) in order to transfer the virtual planning into reality, for example, incorporation of the sleeves in the most correct position into the radiographic template. One of the first laboratory-based systems for GIS was the Med3D-device (Med3D, Med3D AG, Heidelberg, Germany) using a Lego® brick as reference-element and the X1-table for sleeve insertion.[5]

Recently, the smop technique (smop, Swissmeda AG, Zürich, Switzerland) was introduced into the field of GIS.[6] It allows a new approach transferring a virtual planning into reality. The three-dimensional radiography (cone beam computed tomography [CBCT] or computed tomography [CT]) is uploaded into the planning software (without any radiographic template in dentated situations without artifact) and the implants' position may be planned (a wax-up can additionally be uploaded for prosthodontic-derived step-back planning) virtually. The virtual planning is transferred into reality by superimposing either an intraoral surface scan in fully digital workflow or a surface scan of a cast model to the radiography in partially digital workflow. The latter is associated with the same sources of inaccuracies as for the diagnostical part in L-temp, including radiography, impression taking, and cast model fabrication. The crowns of teeth are used as landmarks for matching which are visible in both the surface scan and radiography. In a second step, a virtual template for GIS is designed based on the surface scan including all information of the sleeves' position for surgical guidance. This virtual template can be stored as a surface tessellation (STL) file and it may be sent to any three-dimensional printing device in order to print the template for surgery. Comparing this workflow with L-temp, it is obvious that many potential steps of inaccuracy may be avoided. However, other steps can be introduced, including, for example, the virtual matching of the STL scans with the CBCT data, whose precision apparently is mainly unknown. Presently, there are no studies that have compared the accuracy of templates for GIS which were produced based on printing technique after matching a surface scan with radiography without using any specific additional reference element with the accuracy of L-temp. The aim of the present study was to compare the accuracy of the D-temp based on matching a surface scan with CBCT with the accuracy of L-temp.

MATERIALS AND METHODS

The study design was approved by the ethical committee of the University of Basel (EK: **77/**13).

Template fabrication

Eight human lower cadaver-jaws with different dentition were used. According to the available bone and dentition of the mandible, representing the different clinical situations, three to six (min. 3 implants, max. 7) dental implants of identical diameter (3.8 mm) and length (9 mm) were inserted into each jawbone according to general and the manufacturer's recommendations (Guide System CAMLOG® SCREW-LINE Implant, Promote® plus, Camlog Biotechnologies AG, Basel, Switzerland). In edentulous jaw, three implants were additionally inserted in a most parallel position (one in the anterior region and two in the posterior region) and equipped with straight abutments in order to have precise reference elements allowing to securely fix the templates. In all other jaws, teeth were used for fixation of the templates. The L-temp fabrication was performed according to the following protocol: Impregum impressions were taken from each jaw and radiographic templates were fabricated on cast models using the abutments for fixation (Figure 1). For the smop approach (D-temp), surface scans of the cast model were additionally performed using a three-dimensional scanner (Dental Wings 3-series, Dental Wings Inc., Montreal, Canada). The radiographic templates for the L-temp were equipped with Lego bricks as a reference element. These templates were mounted on the jaws and CBCT scans were obtained (Morita Accuitomo 80, J.

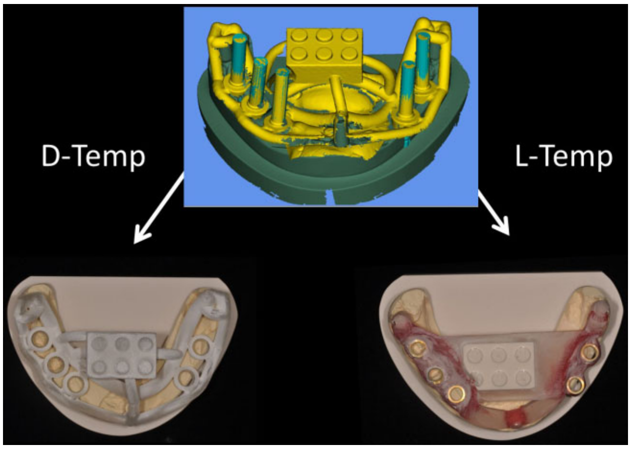

Figure 1 Two templates were performed of each single planning.

Morita Mfg. Corp., Irvine, CA, USA). The CBCT scans were uploaded as digital image and communication files (DICOM) into the smop-software (version 2.7.0; smop, Swissmeda AG). In the first step, the Lego brick of the CBCT data was aligned to a virtual Lego brick provided by the software and as generally known for the Med-3D System. Then implants were planned by superimposing virtual identical implants (CAMLOG SCREW-LINE Implants) in the radiographical images. Based on the general approach for L-temp, the sleeves (Guide System Guiding sleeves, 3.8 mm, CAMLOG Biotechnologies AG) for implant guidance were included into the radiographic template using the specific X1-table (Georg Schick Dental GmbH, Schemmerhofen, Germany) in a dental lab. The algorithm used for alignment was the bestfit algorithm as described by Funke (http://www.google.ch/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CCAQFjAA&url=http%3A%2F%2F3d-sw.com%2FDiss_Sourlier_1995.pdf&ei=1rG_VLSbOYX8UPuPhOgC&usg=AFQjCNGrdVK0s6j-kV-WrqKKsUedDkUtug&sig2=Cyk5OiMr6NoQp8VrDu1AM).

For the D-temp manufacturing, the identical planning as for the L-temp was used. Instead of a Lego brick, the surface scans of the models were uploaded into the smop-software and superimposed to the radiographies using the three titanium abutments. Virtual templates were designed as a frame template, fitting on the abutments and including cavities for manual insertion of the sleeves for guidance. In order to evaluate the accuracy (for detail, see below), a Lego brick was additionally virtually designed and included into the planning. The planning was stored in the smop-software and sent as STL file to a three-dimensional printing device (Objet Eden 260 V, Material: MED610, Stratasys Ltd., Minneapolis, MN< USA) for fabrication. In contrast to the L-temp, the sleeves for guidance were inserted manually into the cavities of the D-temp.

Therefore, a total of 16 templates were fabricated (Figure 1), whereas for each planning one template was fabricated in a lab using the X1-table (L-temp) and another template was fabricated according to the smop procedure by printing device (D-temp). In order to reduce the tolerance error during manual sleeve insertion, a guide rod was used in L-temp.

Accuracy measurements

For the accuracy measurement, specific titanium pins were inserted into the guiding (Figure 2). The titanium pins clamped due to the exact fit into the sleeves. A surface scan of these templates (dental wings 3series, Dental Wings Inc.) was performed and uploaded as STL data into the original planning. The surface scan of each template was aligned to the corresponding virtually planned template using the Lego brick. Applying virtual implants in the long axis of the fixed titanium pins, it was possible to use the evaluation tool of the software analyzing the expected deviation of each implant with regard to the original planning data. Therefore, the surface scan of the template (with titanium pins) is

Figure 2 Titanium pins were inserted into the sleeves, allowing to determine the expected implant deviations if used for surgery.

uploaded into the software and superimposed to the original data set. The implants are included in the long axis of the titanium pins and marked in the software. After fitting the scan two positions of the implant stand in the actual position and the planned position within the same coordinate system. Then significant geometric positions like the zero or the apex or the axis of the implant can be compared with each other, applying the respective positions within the coordinate system and the software automatically generated the three-dimensional deviations (Figure 3). The geometry of the pin/implant assembly is known. By determining the position of the pin by best-fitting a virtual pin to the measured surface points of the real pin, the known geometric relations between the pin and the implant can be applied to deduce the implant position from the reconstructed pin position.

This way, the deviations of implant positions were evaluated. The following parameters were determined: Coronal and apical deviations were measured as mesial/distal, lingual/buccal and apical-/coronal height deviation in mm. Additionally, the angular deviations were determined in degrees (°) (Figure 3).

Statistical analysis

A descriptive analysis was performed including maximum, minimum, mean, and standard deviation. A significance analysis was performed by means of a *t*-test for unpaired samples to evaluate the differences between both template modalities i.q. L-temp and D-temp. The level of significance was set as $p < .05$.

RESULTS

A total of 34 implants were planned (4 in the lower anterior region, 30 in the premolar or posterior region of lower jaws). One data set (five implants) could not be included into the evaluation because the Lego brick was positioned too far away from the implants. The mean deviations were generally higher for the L-temp than for the D-temp, except for the mean angular deviation which was slightly higher for the D-temp (Table 1). The range of deviations (maximum and minimum) was higher for the L-temp than for the D-temp, except for the angular deviation (Table 1). Differences between L-temp and D-temp were statistically significant, with an overall higher accuracy for the D-temp with regard to

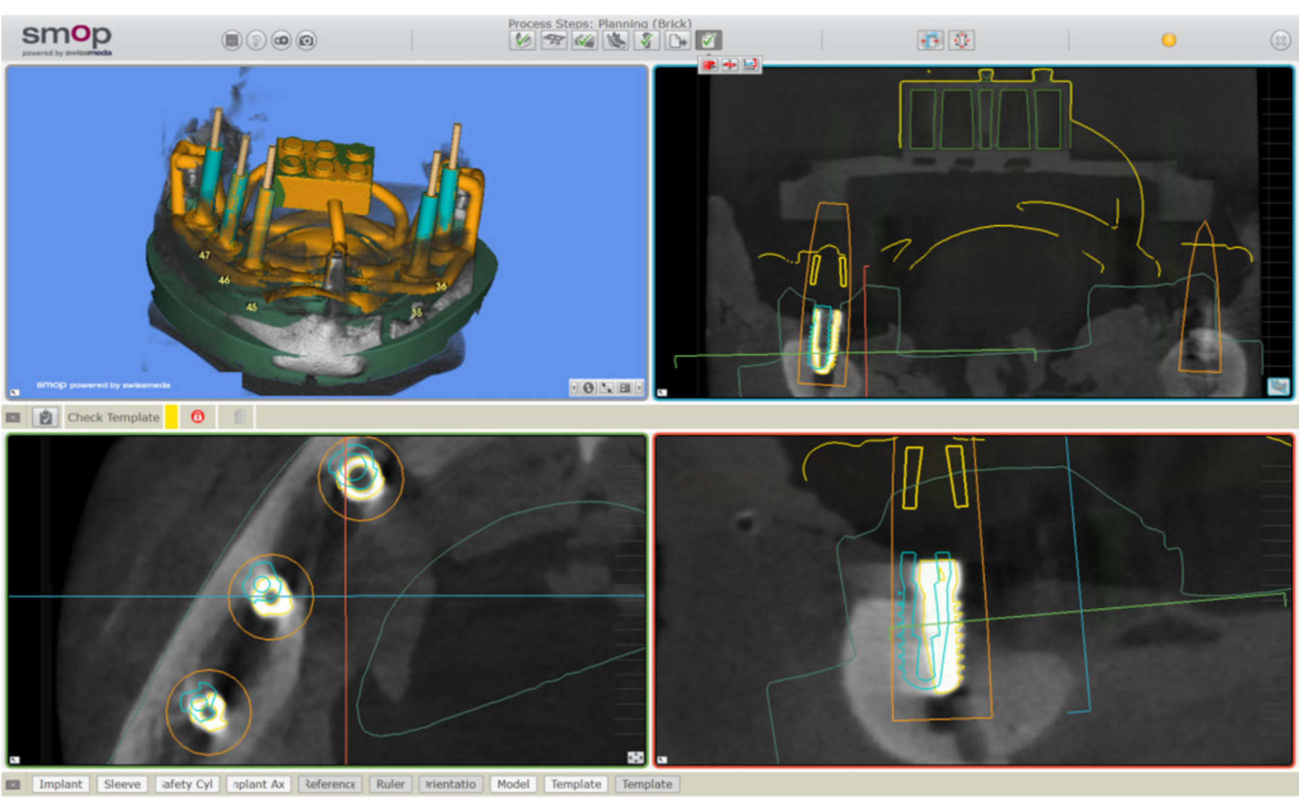

Figure 3 Determination of the accuracy by calculating the coronal, apical, and angular deviation between the virtual planning (yellow) and estimated implant (blue) if the template would have been used for surgery.

TABLE 1 Descriptive Analysis of the Mean Deviations (mm) with Minimum, Maximum, Mean, and Standard Deviation for Both Template Modalities

Method		Minimum	Maximum	Mean	Standard deviation
L-temp	Mesial/Distal (crestal)	0.01	0.74	0.31	0.22
	Lingual/Buccal (crestal)	0.01	0.91	0.32	0.27
	Height crestal	0.01	1.65	0.50	0.46
	Angle (°)	0.10	3.70	1.11	0.81
	Height apical	0.05	1.56	0.49	0.44
	Mesial/Distal (apical)	0.01	3.46	0.50	0.67
	Lingual/Buccal (apical)	0.06	2.07	0.50	0.45
D-temp	Mesial/Distal (crestal)	0.00	0.66	0.16	0.17
	Lingual/Buccal (crestal)	0.00	0.82	0.23	0.21
	Height crestal	0.00	0.66	0.20	0.16
	Angle (°)	0.10	4.60	1.15	1.01
	Height apical	0.00	0.57	0.20	0.14
	Mesial/Distal (apical)	0.01	1.00	0.25	0.27
	Lingual/Buccal (apical)	0.02	1.20	0.34	0.31

the mesial/distal deviation crestal and the height on crestal and apical level (Table 2).

DISCUSSION

The study showed a statistically significant higher accuracy for the printed templates (D-temp) after matching a surface scan with CBCT data than for laboratory-fabricated templates (L-temp). As both template modalities used identical CBCT and planning data sets, the study was designed to reliably compare the accuracy of both fabrication techniques. Comparing the workflow for template fabrication, there are two main differences between both approaches, which may explain the statistically significant difference in accuracy: Transforming the virtual planning into reality i.q. matching the reference element with CBCT data for the L-temp may be one important source of inaccuracy which may be reduced if a surface scan is matched with CBCT. The main reason for this higher accuracy can be related to the extended amount of matching points of a surface scan with CBCT. The distance between triangular end points for matching (in our study, molars and incisor teeth or the abutments) is much higher in a surface scan of a jaw than for a Lego brick. The second aspect of inaccuracy may be related to the potential source of inaccuracies associated with the use of the X1-table in the lab for L-temp in comparison with the high precision of printing technique, even if guide rods are used for the X1-table. According to the manufacturer's information, the accuracy of printing an STL file is higher than 200 μm. The cavities of D-temp are virtually designed and the guiding sleeves can manually be inserted. Due to a sufficient friction, no additional material for fixation is needed. In contrast to this, for L-temp manufacturing it is necessary to fix the radiographic template with cast on the specific lab device (the X1 table) and cavities have to be drilled into the template

TABLE 2 Significance Analysis Comparing the Accuracy of Both Modalities with $p < .05$

	Template	Significance
Mesial/Distal (crestal)	L-temp D-temp	$\boldsymbol{p = .009}$
Lingual/Buccal (crestal)	L-temp D-temp	$p = .164$
Height crestal	L-temp D-temp	$\boldsymbol{p = .006}$
Angle [°]	L-temp D-temp	$p = .878$
Mesial/Distal (apical)	L-temp D-temp	$p = .051$
Lingual/Buccal (apical)	L-temp D-temp	$p = .103$
Height apical	L-temp D-temp	$\boldsymbol{p = .006}$

before attaching the guiding sleeves with pattern resin™. Obviously, this workflow is associated with more sources of inaccuracies than for the smop-temp.

Barnea and colleagues investigated the accuracy of the Med3D system using a Lego brick as in the present study for the L-temp and found deviations ranging from 0.04 mm to 0.84 mm at apical level.[5] Comparing these data with the results of the present study, it is obvious that only D-temp showed similar deviations ranging from 0.01 mm to a maximum of 1.2 mm, whereas L-temp showed much higher inaccuracy values ranging from 0.02 mm to 3.46 mm. There seems to be more sources of inaccuracies for L-temp fabrication.

Comparing the accuracy of the D-temp with data from literature is difficult as to the best knowledge of the authors this is the first study that compared the accuracy of the D-temp based on matching a surface scan with CBCT with the accuracy of L-temp. However, the authors recently evaluated the technical accuracy of printed templates using the coDiagnostiX™ device which is based on a similar workflow as for the D-temp of the present study.[7] In this study, a mean apical deviation of 0.49 mm was calculated. With regard to this result, the mean apical deviation for the L-temp was almost identical with a mean apical deviation of 0.5 mm, whereas D-temp showed lower mean inaccuracies with 0.25 mm in apical mesial/distal direction and 0.34 mm in the apical lingual/buccal direction.

The mean angular deviation was slightly higher for the D-temp than for the L-temp, which can be related to a spike in the D-temp group.

Comparing the accuracy of the D-temp to stereolithographic-manufactured templates which have a similar workflow, it seems that the printing technique is more precise. D'haese and colleagues determined apical inaccuracies between 0.6 mm and 4.5 mm, and angular deviations ranging from 0.2° up to 8.1° according to their review.[8] Both the D-temp and L-temp showed lower inaccuracy values in the present study.

Though the overall accuracy of both template manufacturing approaches revealed high accuracy, the data of the present study are based on an in vitro model which has generally shown to produce better results than in clinical application.[9] In clinical field, many additional sources of inaccuracies might cumulate, such as patient- and operator-related factors.[10] Nevertheless, the technology is innovative and shows several benefits for the patients such as time and cost reductions when compared with L-temp, as less appointment is necessary in digital proceeding.

Additionally, the Lego brick mask out the fitting errors and fitting issue is a main source of error in traditional dual-scan technique which might have impaired the determination of the accuracy measurement. However, because this aspect was common for any accuracy measurement of the present study, this inaccuracy may be regarded as systematic and allow to reliably compare both D-temp with L-temp. Alternatively, a postoperative CBCT scan with the templates in situ might have been used. Due to metal artifacts of the implants, it was assumed that the determination of deviation would even have been less precise than applying the surface scan in combination with the specific titanium pins.

Within the limits of the study, it can be concluded that a higher accuracy may be achieved if templates are virtually designed and printed after superimposing a surface scan with CBCT in order to transform the virtual plan into reality, applying the smop-technology. If intraoral scans are additionally used instead of surface scans of a cast model after impression taking, as performed in this study, the accuracy may even improve as the intraoral scan may reduce the sources of inaccuracies associated with cast model fabrication if intraoral scanning is proven to show a superior precision. However, clinical studies are needed to confirm our findings.

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