CLINICAL ORAL IMPLANTS RESEARCH

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Accuracy assessment of cone beam computed tomography-derived laboratory-based surgical templates on partially edentulous patients

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Date:
Accepted 16 January 2011

To cite this article:
Behneke A, Burwinkel M, Knierim K, Behneke N. Accuracy assessment of cone beam computed tomography-derived laboratory-based surgical templates on partially edentulous patients.
Clin. Oral Impl. Res. **23**, 2012; 137–143.
doi: 10.1111/j.1600-0501.2011.02176.x

Key words: computer-aided implant planning, cone-beam computed tomography, dental implants, surgical template

Abstract

Objectives: The aim of the present prospective clinical study was to evaluate the match between the positions and axes of the virtually planned and the placed implants using laboratory-based surgical guides generated from cone beam computed tomography (CBCT).

Materials and methods: A total of 132 implants were placed with the aid of 3D-based transfer templates in 52 consecutive partially edentulous patients between April 2008 and March 2010. After individual adaptation of the scan templates and CBCT scanning, the acquired data for virtual implant planning and simulation were processed using the med3D software program. After finalizing the virtual placement of the implants the radiographic templates were converted into operative guides containing titanium sleeves for cavity preparation. Preoperative planning was merged with postoperative CBCT data to identify linear and angular deviations between virtually planned and placed implants.

Results: Compared with the planned implants the installed implants showed linear deviations in the median at the neck and apex of 0.27 mm (range 0.01–0.97 mm), and of 0.46 mm (range 0.03–1.38 mm), respectively. The angle deviation was 1.84° in median, with a range of 0.07–6.26°. The extent of deviation depends on the size of the tooth gap and the distribution of the remaining teeth.

Conclusion: The results of this study suggested that laboratory-fabricated surgical guides using CBCT data may be reliable in implant placement under prosthodontic considerations in partial edentulism.

The common goal of computer-based guiding systems is to achieve an ideal prosthetically orientated implant position combined with a safe, fast and, if possible, minimally invasive surgery. Three-dimensional (3D)-based pre-implantological diagnosis has become considerably more widespread in dentistry with the introduction of cone beam computed tomography (CBCT). The CBCT technology may combine the advantage of a significantly reduced radiation exposure to the patient (Ludlow & Ivanovic 2008) with a detailed view of the 3D bone architecture and adjacent anatomically relevant structures. Acquisition of 3D image data, however, is only one component in the complex overall system of a prosthetically orientated implant planning concept. In addition to a suitable software program for virtual planning and simulation of the superstructure, it is essential to have guiding systems that can transfer the planning data acquired from the computer simulation to the actual surgical site. The transfer approaches for computer-assisted implant planning could be differentiated in dynamic navigation real-time tracking systems and static transfer techniques based on templates. For the static templates, virtual planning data become translated into corresponding guidance-sleeve positions within a template. Static template production may be subdivided into stereolithographic technologies (CADCAM) and laboratory-based procedures. In the laboratory-based systems, the template is fabricated on a dental stone model. The template is used for visualizing the subsequent idealized superstructure and the accurate fit of this template can be checked intraorally and finely adjusted occlusally before producing the CBCT images. After CBCT acquisition the radiological template is converted into a surgical template.

Template-guided implant surgery requires several pre-operative steps, starting with fabrication of a radiographic template, the CBCT acquisition with the template in position, computer-assisted implant planning and ending in fabrication and use of a surgical guide for drilling and implant insertion. With such a complex sequence, where every step is prone to errors, accuracy is of utmost importance. The accuracy of dynamic navigation and stereolithographic guide systems has been investigated and was found to be superior to conventional implant surgery (Sarment et al. 2003; Brief et al. 2005). The purpose of the present study was to assess the accuracy of placed implants, compared with the planned implants for a CBCT-based, computer-aided implant planning concept using laboratory-fabricated templates.

Material and methods

In a prospective monocentric study between 1 April 2008 and 31 March 2010 a total of 132 implants were placed in 52 consecutive partially edentulous patients following CBCT diagnostics with the aid of 3D-based, laboratory-fabricated templates. The remaining dentition had a healthy periodontium without excessive tooth mobility. The patients were informed about the approach of computer-aided implant planning, template-guided implant surgery and the pre-and post-operative CBCT scan protocol. All patients gave their informed and written consent. Based on an alginate impression of the patient's jaw, tooth-borne templates were fabricated on plaster models by the dental laboratory. The template bases were made of clear acrylic and the missing teeth were fabricated in the ideal prosthetic position using a barium sulphate–acryl mixture (30% barium sulphate powder/70% methacrylate) or a pre-fabricated radio-opaque acrylic (Acryline, anax dent GmbH, Stuttgart, Germany). The templates were additionally equipped with a 2 × 3-unit lego brick as referential marker.

Planning procedure

Before producing the CBCT, the templates were tried intraorally. For reaching a reproducible and definite fitting position control windows were inserted in the templates and the occlusal fit was finely adjusted using Pattern Resin (GC Europe, Louvain, Belgium). With the templates in place, pre-operative volume data of the region of interest were obtained with the Accuitomo (J. Morita Europe GmbH, Dietzenbach, Germany) CBCT. The scanning parameters were as follows: voxel size 0.125 mm, acquisition time 18 s, FOV 6 cm × 6 cm and slice thickness 0.25 mm. Based on the acquired image data and following transfer into DICOM format (slice thickness and slice spacing 0.25 mm), implant planning and simulation was completed using the software program implant 3D (med3D GmbH, Heidelberg, Germany). With the later prosthodontic reconstruction taken into consideration, the implants were planned by two clinicians (A. B./N. B.). After completion of the virtual implant planning and based on the drilling plan calculated by the software program, the imaging template was transformed into a surgical template. Using the lego brick, the template is locked into the Schick Hexapod positioning device (X1med3D positioner, SchickDental GmbH, Schemmerhofen, Germany) and for each implant position the settings of the surgical drilling plan were transferred onto the six legs of the hexapod. Titanium tubes were polymerized into the templates by the dental technician.

Surgical protocol

In the present study different guide tube systems, drill keys and drills were used. Steco titanium sleeves (steco-system-technik GmbH, Hamburg, Germany) with an inner diameter of 3.5 mm (length 6 mm, distance of the sleeve above the future implant shoulder 4 mm) were used via interchangeable inner tubes for cavity preparation in combination with drills with a 10 mm shaft extension. The Straumann-guided surgery system (Institut Straumann AG, Basel, Switzerland) comprising guided drills with depth control and drill handles based on the sleeve-in sleeve concept was used for controlling all steps of the osteotomy. If the NobelGuide system (Nobel Biocare AG, Gothenburg, Sweden) was used, according to protocol, sleeves with different diameters (NP, RP, WP) were utilized with a guided start drill, twist drills in ascending order with depth stops and guided drill guides. Implant bodies were template guided inserted through the sleeves.

Following local anaesthesia and after soft tissue removal using mucosal punch (flapless surgery) or flap mobilization, the templates were stabilized on the natural teeth as near as possible to the identical position as on the CBCT image. After completion of the template-guided surgery, augmentation measures were completed on the hard and soft tissue if required and implants were left to osseointegrate for 1.5–4 months, depending on the anatomical situation. The subsequent treatment and recall measures did not differ from the generally accepted regimen for implant-prosthetic restorations.

Fig. 1 illustrates an example of the procedure on an actual patient.

Image fusion and accuracy evaluation

For the evaluation of the surgical results in contrast to the pre-operative planned virtual positions all patients were rescanned after implant insertion with the CBCT. The postoperative control CBCT data sets were first processed in the same manner as the planning CBCT data sets. All implants were identified by their X-ray shadow and new virtual implants were superpositioned on their images to achieve a congruent overlapping with the X-ray shadows. In the next step, the pre-operative CBCT images containing the information of the originally planned implants were transferred to the postoperative control data set using the matching module of the med3D planning software (Fig. 2). The pre- and postoperative data sets were first fused with the automated tool, using the lego brick as registration unit. Subsequently the images were manually aligned observing the superposition of anatomic markers. The software allows one to evaluate the correct registration of both images in the transverse, coronal and sagittal planes.

Deviations between planned and placed implant positions were calculated utilizing the linear and angle measurement tools of the matching module of the med3D planning software. Linear and angular deviations (Fig. 3) were measured on the fused 3D images:

- Radial deviation (mm) – horizontal distance between the middle axis of the virtual planned and actual placed implant; measures at the level of the implant shoulder (shoulder radial deviation) and apex (apex radial deviation).
- Depth deviation (mm) – vertical distance in coronal–apical direction between the middle axis of the virtual planned and actual placed implant; measures at the level of the implant shoulder (shoulder depth deviation) and apex (apex depth deviation).
- Angulation (°) – angular deviation between the long axis of the virtual planned and actual placed implant.

The acquisition of image data and the accuracy evaluation was carried out by implant dentistry specialists (A. B., N. B., M. B.) with government-certified expertise in 3D imaging and CBCT usage.

Statistical analysis

The statistical analyses were performed using the software program StatView 5.0. Quantitative data are described with mean values, standard deviations, median values, minima and maxima. Accuracy data were illustrated using box plots. According to the slightly skewed distribution of the data, non-parametric statistics were performed. Wilcoxon's signed rank test was performed for crestal and apical deviations. Differences were considered statistically significant if $P<0.05$. The Bonferroni test was performed to compare the linear deviations between the different kinds of templates.

Results

Fifty-two partially edentulous patients were consecutively included in the study period from 1 April 2008 until 31 March 2010. Seventeen patients were treated in different regions of the arches, and therefore the number of computer-aided surgical interventions was 69, for a total of 132 planned implants (89 Straumann Dental Implants [Institut Straumann AG, Basel, Switzerland], 43 Nobel Replace Implants [Nobel Biocare AG, Gothenburg, Sweden]). All implants could be placed as planned. Table 1 provides a description of the patient pool. The population consisted of 28 (54%) females and 24 (46%) males; the mean age was 54.2 ± 15.1 years. The mean observation time determined from implant placement to the final checkup was 1.1 years (range 0.4–2.1 years). None of the 132 implants failed (overall survival rate 100%). 17 of the patients were each fitted with separate restorations in different regions of the jaws, as a result a total of 69 sites were treated with implants; 87 (66%) were in the maxilla and 45 (34%) in the mandible. The majority of restorations were in the shortened dental arch with 39% (27 sites) of the sites involving 52 implants. The second most common area of indication with 27.5% (19 sites) was the interrupted dental arch (43 implants), followed by single-tooth restorations with also 27.5% (19 implants). The remaining 6% involving 18 implants related to the reduced residual dentition.

The half (66) of the 132 implants were inserted using a minimally invasive technique due to an adequate width of bone availability and an adequate zone of fixed mucosa. These implants were placed after template-guided marking and removal of soft tissue using a mucosal punch without flap mobilization. There were no nerve injuries, abnormal haemorrhages, sinus pathologies or other complications to the anatomy related to inaccurately placed implants.

None of the 132 implants were inserted in a different position from planning; there was also no change in relation to the planned type of implant. There were no discrepancies in length or diameter of the inserted implants compared with the pre-operative planning.

In two templates, the sleeves detached, but they were successfully replaced. One template cracked without breaking and served its purpose until the end of the surgery. One hundred and thirty-two implants were placed as planned and were available for accuracy calculations via image fusion technique.

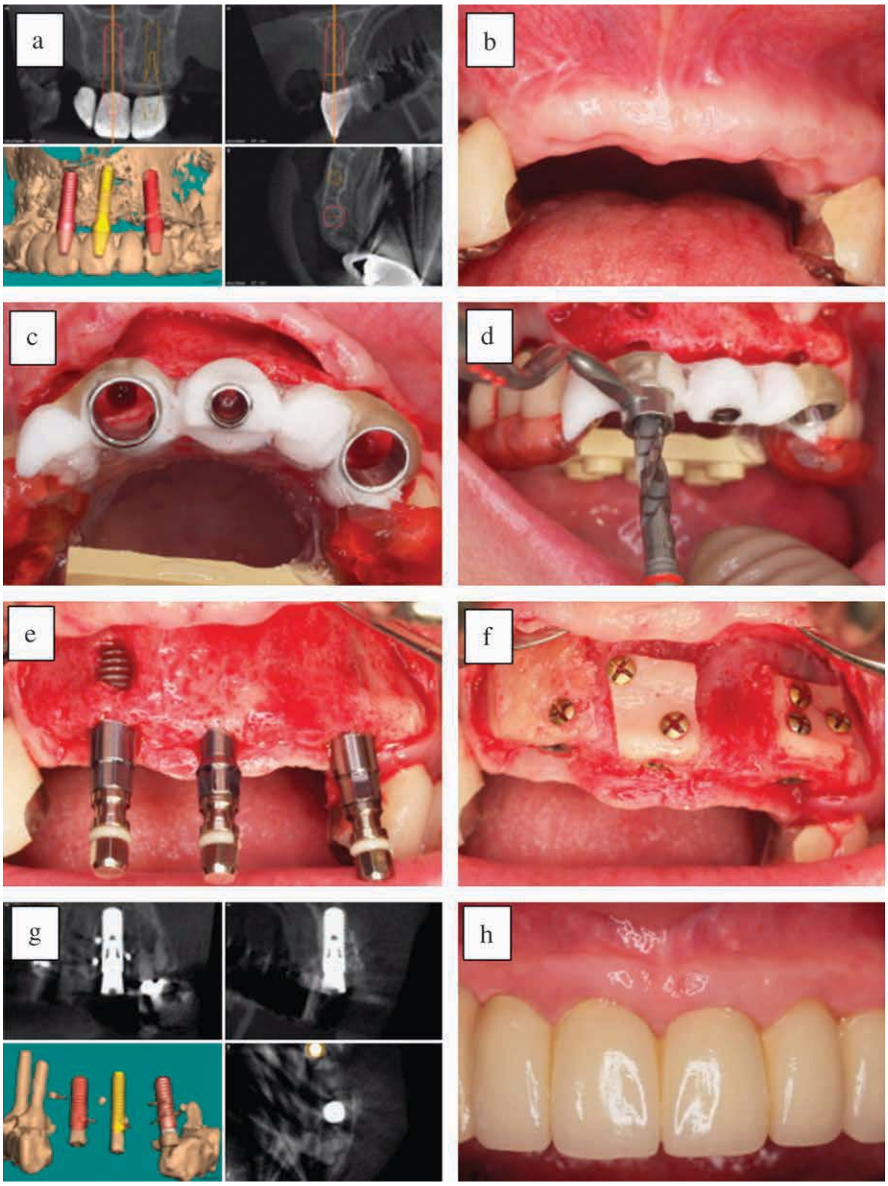


Fig. 1. Clinical example illustrating the treatment protocol. (a) Virtual 3D planning by simultaneous views in several planes, (b) pre-operative clinical situation, (c) surgical guide with the drilling sleeves corresponding to the location and the inclination of the planned implants in place, (d) osteotomy preparation performed using the Straumann-guided system, (e) situation after implant installation, (f) augmentation with autogenous blocks fixed with osteosynthetic screws, (g) postsurgical cone beam computed tomography, (h) clinical situation with the fixed superstructure.

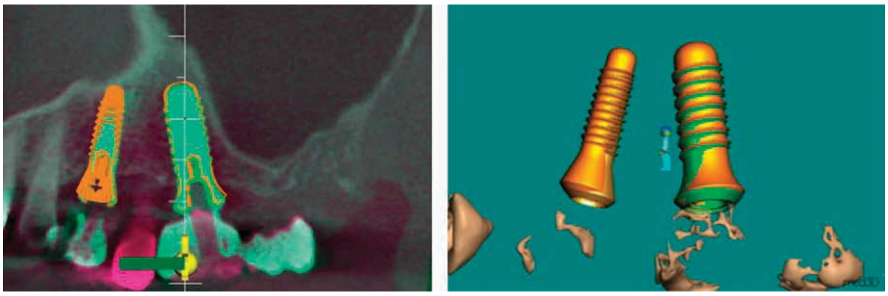


Fig. 2. The matching procedure on fused 3D images of pre-surgical planning and postsurgical cone beam computed tomography scan generated by the med3D software. Planned implants are represented by the orange colour and actual implants are represented by various colours.

Accuracy analysis

Mean deviations for the achieved implant positions were 0.32 mm (range 0.01–0.97, SD 0.23) at the crestal and 0.49 mm (range 0.03–1.38, SD 0.29) at the apical end in the horizontal plane. The mean depth deviation between planned and placed implant positions was –0.02 mm (range –1.21 to 1.46, SD 0.4) at the implant shoulder and –0 mm (range –1.2 to 1.47, SD 0.41) at the implant apex. A mean angular deviation of the long axis between planned and installed implants of 2.1° (range 0.07–6.26, SD 1.31) could be detected. Deviation outcomes are shown in Table 2 and Figs 4–6.

The box-and-whisker diagram (Fig. 4) of the radial deviation at the implant shoulder shows that 50% of the data range between 0.15 mm (lower quartile) and 0.41 mm (upper quartile) with a median of 0.27 mm. Ninety percent of the values lay within the range of 0–0.7 mm. All outliers remained below the border of 1 mm. The box plot for the radial deviation at the implant tip indicates, as identifiable by the median (0.46 mm), the interquartile range (0.24–0.68 mm) and the position of the whiskers, a larger value dispersion. Ninety percent of the values were nevertheless below 0.9 mm and only outliers exceeded the value of 1 mm. The Wilcoxon signed rank test calculation for the comparison of the crestal and apical radial deviations was highly significant ($P<0.0001$), yielding generally smaller crestal than apical horizontal deviations. The depth deviation was at the apex, with a median of –0.04 mm and an interquartile range of –0.22 to 0.25 mm similar to the shoulder depth deviation (median –0.06, interquartile range –0.24 to 0.2 mm). The location of the outliers is based on the fact that it was in some cases deliberately deviated from the originally planned depth to achieve a better primary stability or to obtain an adequate alignment of the coupling site for the superstructure. For the angular deviation (Fig. 6), a median of 1.84° was observed and the 25th and the 75th percentile ranged between 1.11 and 2.85°. Ninety percent of the data were found below 4°.

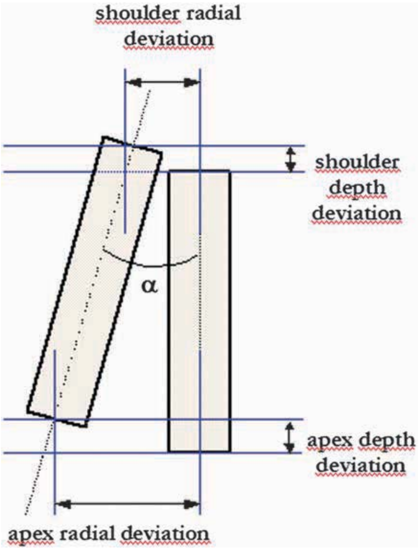


Fig. 3. Measurement of deviations between placed and planned implants.

Table 1. **Description of patient pool**

Number of patients	52 Women: 28 (54%) Men: 24 (46%)
Sites	69
Implants	132 planned, 132 placed (89 Straumann Dental Implants, 43 Nobel Replace Implants)
Average observation	1.1 years
Type of arch	
Maxilla	87 implants
Mandible	45 implants
Areas of indication	
Single tooth gap	19 implants
Interrupted dental arch	43 implants
Shortened dental arch	52 implants
Reduced residual dentition	18 implants
Surgical technique	
Flapless	66 implants
Open flap	66 implants
Implant failures	0 implants

Table 2. **Deviations between planned and actual implant positions ($n=132$)**

	Mean	SD	Median	Range
Shoulder radial deviation (mm)	0.32	0.23	0.27	0.01–0.97
Apex radial deviation (mm)	0.49	0.29	0.46	0.03–1.38
Shoulder depth deviation (mm)	– 0.02	0.4	– 0.06	– 1.21 to 1.46
Apex depth deviation (mm)	– 0	0.41	– 0.04	– 1.2 to 1.47
Angulation deviation (deg.)	2.1	1.31	1.84	0.07–6.26

Fig. 7 represents the amount of deviation related to the kind of template, i.e. free ending template in the case of shortened dental arch or reduced residual dentition versus mesial and distal tooth-supported template in the case of single tooth gap or interrupted dental arch. Statistically significant differences were found when comparing the coronal and apical deviations for the different template groups. The smallest degree of dispersion in the data for implants placed with single tooth gap templates was noticed (median 0.16, 90th percentile 0.46, range 0.01–0.92 mm at the implant shoulder and median 0.34, 90th percentile 0.56, range 0.03–0.59 mm at the implant tip). The visual analysis of Fig. 7 shows that reduced residual dentition templates are to some extent separated from the other kind of templates, representing a larger amount of coronal and apical deviation (median 0.46, 90th percentile 0.86, range 0.04–0.92 mm at the implant shoulder and median 0.75, 90th percentile 1.08, range 0.21–1.26 mm at the implant tip). No significant effect on accuracy could be demonstrated for implants placed using free ending templates in the shortened dental arch compared with mesial and distal tooth-supported templates in the interrupted dental arch.

Discussion

Computer-guided implant planning and placement is an upcoming technology with the potential for a more predictable and less invasive implantation procedure. The goal of computer-assisted implant planning should be the achievement of maximal surgical safety on the basis of a 3D diagnosis, virtual planning and high accuracy for the surgical transfer. The accuracy of the transfer procedure is defined as the deviation between the position of the implant postoperatively and the position of the implant in the planning. Deviations between planned and actual implant position can occur at each step of the ‘‘computer-aided implant placement’’ cascade, starting from the planning stage to the operative stage (for a review, see Vercruyssen et al. 2008; Jung et al. 2009; Schneider et al. 2009; D'haese et al. 2010). Errors at the planning stage can be generated from the acquisition of the CBCT data set (image quality, reliability, motion or metal artefacts). The accuracy of CBCT has been previously reported to be within 0.5 and 0.7 mm (Loubele et al. 2007; Behneke et al. 2009). Software planning and examiner errors (conversion, volume rendering, visualization detail accuracy, referential marker registration) were possibly additional factors influencing the precision at the planning stage. In an *in vitro* study evaluating a CT-guided laboratory-fabricated template-assisted implant placement system the accuracy

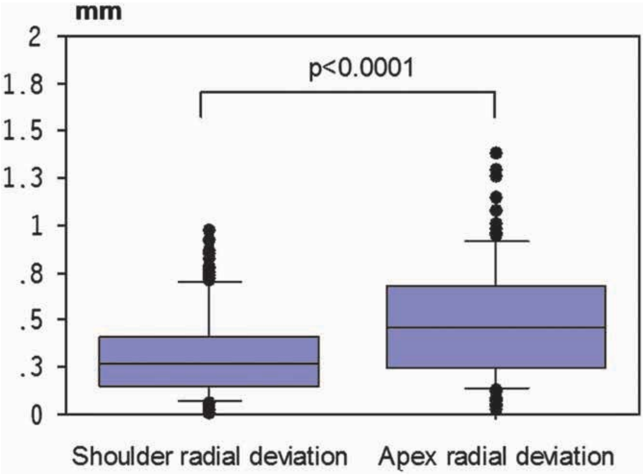


Fig. 4. Box plots showing median, percentiles and outliners of radial deviations of implants ($n = 132$). Boxes contain 50% of all values, the horizontal lines outside the box indicate the 10th and 90th percentile. Circles represent outliers.

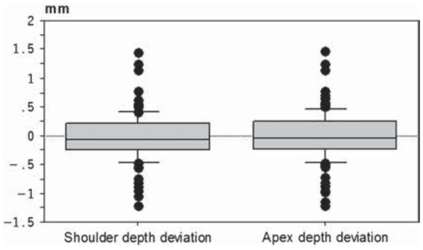


Fig. 5. Box plots showing median, percentiles and outliers of depth deviations of implants ($n = 132$).

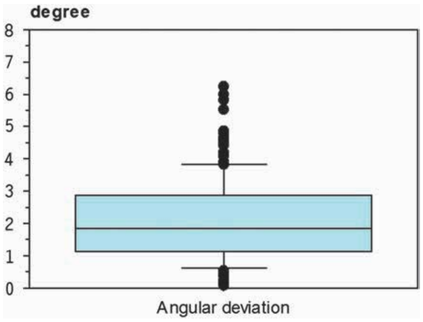


Fig. 6. Box plots showing median, percentiles and outliners of angular deviation of implants ($n = 132$).

related to the CT process and presurgical planning phase was found to have a mean shoulder radial deviation of 0.31 ± 0.15 mm, an apex radial deviation of 0.4 ± 0.1 mm and an angular deviation of 1.33 ± 0.69° (Horwitz et al. 2009).

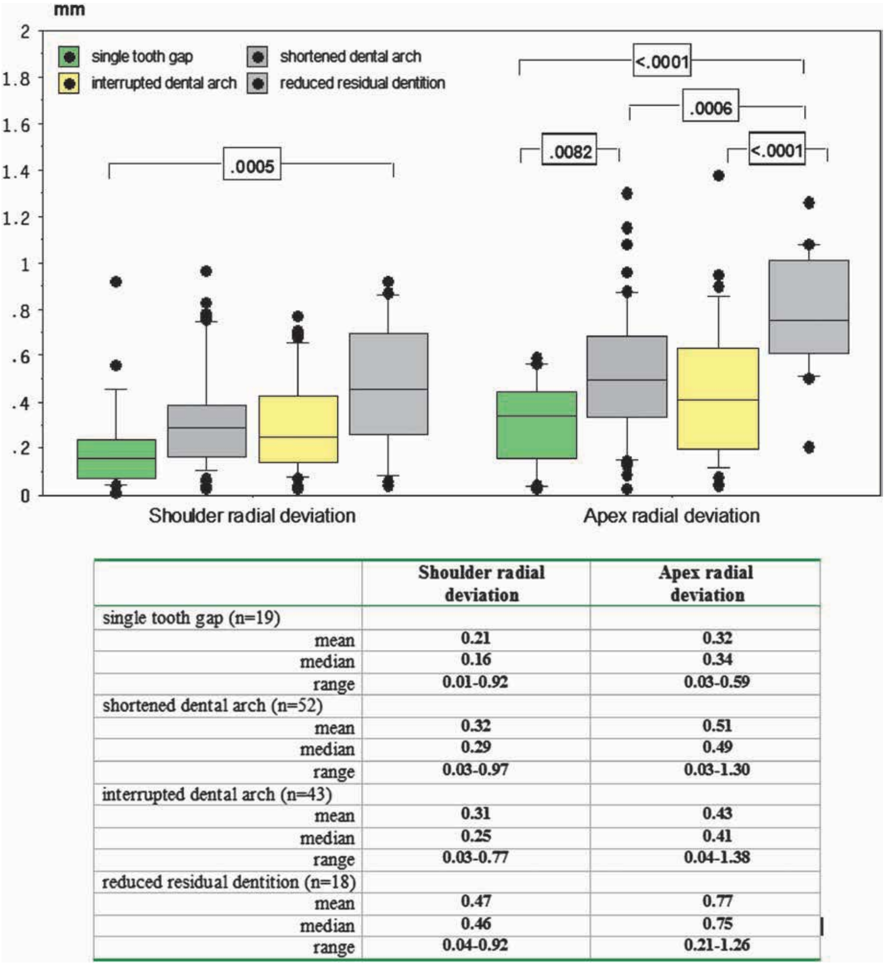
Furthermore, deviations could be generated from an incorrect guide positioning and fixation in the mouth during surgery. Therefore, in the laboratory-based guiding systems, the most important goal is to achieve a stable and reproducible fitting position of the template during the radiological investigation and the implant placement. In the present study the stability of the templates was ensured by a rigid template material, a proper fitting on the natural teeth and relining of the templates. This creates the ideal conditions for producing a template that fits as identically as possible during CBCT imaging and subsequent surgery, particularly for patients with a partial or residual dentition.

The results of this image fusion evaluation indicate a good agreement between the pre-operative planning data and the intraoperative achieved implant positions. The mean angular and linear deviations were 2.1° and 0.32 mm at the implant shoulder and 0.49 mm at the implant tip, respectively. These means of the radial and angular deviations in the present study and the means for the control implants which served in the above-mentioned study of Horwitz et al. (2009) to evaluate pre-operative system errors, were relatively similar. Thus it can be derived with caution that the deviations in the present study were interpreted to be mainly related to the pre-operative phase (CBCT process and planning phase) rather than to the operative phase.

Apart from the mean deviations of planned and actual values, the data of standard deviation and maxima are of particular importance. These values determine the safety margins that have to be maintained to avoid injury of vital structures, especially in implantations without flap mobilization. In the present evaluation an SD of 0.23 mm with a maximum of 0.97 mm at the entrance and an SD of 0.29 mm with a maximum of 1.38 mm at the apex was found for linear deviations. Typically, control limits are set at one to three times the SD (Hanold et al. 1998; Horwitz et al. 2009). Based on the present results and computing three times the SD, a safety zone should be kept by 0.9 mm. Related to the maximum deviation, a safety margin of 1.4 mm may be recommended. These values for the safety zone are slightly lower as the recommendations of the planning system company (1.5 mm), but agree in the order of magnitude.

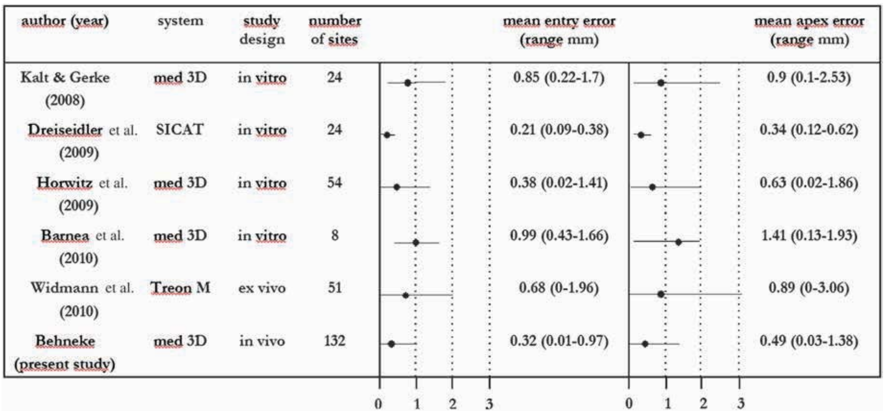
The technique presented using tooth-supported laboratory-based templates generated from CBCT with mean deviations of 0.32 mm (shoulder) and 0.49 mm (tip) and maxima of 0.97 mm (shoulder) and 1.38 mm (tip) produced a result that is unattainable using conventional templates in terms of the accuracy of surgical transfer. Unfortunately, only limited data about the accuracy of conventional implant placement are available in the literature. In an *in vitro* study, Sarment et al. (2003) established a mean deviation of 1.5 mm with a maximum deviation of 1.8 mm at the entrance and a mean deviation of 2.1 mm with a maximum deviation of 3.7 mm at the apex for conventional templates with occlusal drilling channels. In an another *in vitro* study, the accuracy of freehand dental implant placement in single tooth gaps was evaluated (Brief et al. 2005). The average distance between the planned and actual osteotomy was 1.35 with a maximum of 2.16 mm at the entrance and 1.62 with a maximum of 2.68 mm at the apex when a manual implantation was performed.

The accuracy of the system tested in the present study should be compared with the laboratory-based guide studies available in the literature using the image fusion technique as a method to investigate the problem of possible deviations between virtually planned and actually placed implant positions. A directly comparison is difficult, since publications that deal with the problem of the accuracy are often based on image data acquired using CT units. After knowledge of the authors only *in vitro* studies dealing with med3D system and using the image fusion technique are so far available in the literature. Kalt & Gehrke (2008) established mean horizontal deviations at the implant entry point of 0.85 with a maximum of 1.7 mm and mean deviations at the apex of 0.9 with a maximum of 2.53 mm with eight study models from calf ribs. For angular deviations a range of 0.02–7.57° was reported. Another recent *in vitro* study on resin models (Horwitz et al. 2009) reported a range of 0.5–4.7° for angular deviation and 0.02–1.41 mm (shoulder) and 0.02–1.86 mm (tip) for linear deviations in 54 implants that were placed with med3D system, as in the present study. Barnea et al. (2010) have calculated the deviations for eight implants inserted in a partially edentulous sheep mandible by laboratory-based guides according to the med3D technique. In the horizontal plane, mean deviation at the shoulder of 0.99 mm with a range of 0.43–1.66 mm and at the apex of 1.41 mm with a range of 0.13–1.93 mm have been reported. Further *in vitro* studies (Dreiseidler et al. 2009; Widmann et al. 2010) to laboratory-based templates with other planning systems revealed results comparable to the present study (Fig. 8).



	Shoulder radial deviation	Apex radial deviation
single tooth gap (n=19)		
mean	0.21	0.32
median	0.16	0.34
range	0.01-0.92	0.03-0.59
shortened dental arch (n=52)		
mean	0.32	0.51
median	0.29	0.49
range	0.03-0.97	0.03-1.30
interrupted dental arch (n=43)		
mean	0.31	0.43
median	0.25	0.41
range	0.03-0.77	0.04-1.38
reduced residual dentition (n=18)		
mean	0.47	0.77
median	0.46	0.75
range	0.04-0.92	0.21-1.26

Fig. 7. Box plots for radial deviations between the planned and placed implants at the shoulder and tip for the indication groups in partial edentulism. *P*-values of the Bonferroni test for the comparison between different kinds of templates are demonstrated. According to the Bonferroni method, the comparisons were significant when the *P*-value was <0.0083.



author (year)	system	study design	number of sites	mean entry error (range mm)	mean apex error (range mm)
Kalt & Gerke (2008)	med 3D	in vitro	24	0.85 (0.22-1.7)	0.9 (0.1-2.53)
Dreiseidler et al. (2009)	SICAT	in vitro	24	0.21 (0.09-0.38)	0.34 (0.12-0.62)
Horwitz et al. (2009)	med 3D	in vitro	54	0.38 (0.02-1.41)	0.63 (0.02-1.86)
Barnea et al. (2010)	med 3D	in vitro	8	0.99 (0.43-1.66)	1.41 (0.13-1.93)
Widmann et al. (2010)	Treon M	ex vivo	51	0.68 (0-1.96)	0.89 (0-3.06)
Behneke (present study)	med 3D	in vivo	132	0.32 (0.01-0.97)	0.49 (0.03-1.38)

Fig. 8. Articles published reporting on accuracy using dental laboratory surgical guides based on mean deviation, minima and maxima at entry and apex point.

The results from the present study can be compared with studies using stereolithographic-based systems in partially edentulous patients. The accuracy of surgical transfer for stereolithographically fabricated guides is based on image data acquired using CT or CBCT units and was assessed by pre-clinical and clinical models. In an *in vitro* study with cadavers treated according to the NobelGuide technique, van Assche et al. (2007) established a mean deviation at the entry point of 1.1 mm (maximum 2.3 mm) and of 1.2 mm (maximum 2.4 mm) at the apex. As assessed by four recently published clinical studies with stereolithographic templates from NobelGuide, SimPlant or StentCAD systems, mean horizontal deviations of 0.6–1.1 mm and maxima between 1.4 and 1.8 mm were recorded at the entry point using the image fusion tool (Ersoy et al. 2008; Ozan et al. 2009; Arisan et al. 2010a; van Assche et al. 2010). At the implant tip the mean horizontal deviations ranged from 0.9 to 1.3 mm and the maxima from 1.7 to 2 mm, respectively. The tooth-supported laboratory-based guides investigated in the present study provided an accuracy similar or better to the above-cited tooth-supported stereolithographically fabricated templates. This may have its explanation in the fact that in a laboratory-based system, the same guide was used for radiographic examination and surgery. Therefore a stable and reproducible fitting position of the template could be assured before CBCT acquisition and operative steps during the drilling phase were performed with the original template, improving the accuracy.

The mean deviations at the implant tip were higher than at the implant head. Deviation at the shoulder should be less, because of the fact that implant guidance is most optimal in the coronal part of the boreholes because of the lack of angular deviation, which is added by drilling farther into the bone. Higher deviation rate at the apical end of the implant position is a characteristic of the static template solution.

In the present study, a correlation could be found between the amount of deviation and the kind of template. Less scattering of values and maximum deviations could be observed, if single tooth gaps with mesial and distal tooth-supported templates were treated. There was a wider distribution of values for sites with a reduced residual dentition, since only few teeth could ensure the support. In accordance with van Assche et al. (2010) no significant differences could be determined between free ending templates in the shortened dental arch and bilateral anchored templates in the interrupted dental arch. This is remarkable, since larger deviations for guides with unilateral anchorage could be expected due to tilting and bending of the templates. It seems that by the rigid template material, used in the present study, and the relining of the templates a sufficient stiffness could be obtained, to prevent such a tilting.

In patient-oriented dental implant research clustered or dependent observations, resulting of multiple implants placed in the same patient is a common problem, that may cause statistically invalid analysis. This also applies for the present study. The randomized selection of one implant per patient was not performed in the present data set, because of the limited sample size. Moreover, a randomized selection can also result in an inefficient statistical estimation because not all of the data are used (Chuang et al. 2002).

The presented technique of template-supported, CBCT-based implant planning with mechanical transfer illustrates a procedure that provides a range of advantages. At the virtual planning stage the implant can be positioned more favourably in relation to the superstructure and the effect on the restoration of any necessary deviations from the prosthetic ideal alignment can be analysed. There is increased safety with regard to protecting the anatomical structure, as the 3D image provides more information about nerve paths, root curvature of adjacent teeth and other important anatomical structures. The minimally invasive nature of the procedure is a considerable advantage for the patient, as even with compromised bone anatomy the existing hard tissue can be ideally analysed and utilized, consequently reducing the amount of augmentation measures. More implants can be placed without flap mobilization, so that not only the amount of pain and swelling can be reduced (Arisan et al. 2010b) but also the bone resorption associated with detachment of the periosteum (Araújo et al. 2005).

These advantages involve increased logistical and economic investment, which is justified to a great extent if there is an adequate degree of accuracy in the surgical transfer of the planning data to the actual surgical situation. The results of the present study indicate a good transfer accuracy for patients with partial dentitions.

References

Araújo, M.G., Sukekava, F., Wennström, J.L. & Lindhe, J. (2005) Ridge alterations following implant placement in fresh extraction sockets: an experimental study in the dog. *Journal of Clinical Periodontology* **32**: 645–652.

Arisan, V., Karabuda, C.Z. & Özdemir, T. (2010a) Accuracy of two stereolithographic guide systems for computer-aided implant placement: a computed tomography-based clinical comparative study. *Journal of Periodontology* **81**: 43–51.

Arisan, V., Karabuda, C.Z. & Özdemir, T. (2010b) Implant surgery using bone- and mucosa-supported stereolithographic guides in totally edentulous jaws: surgical and post-operative outcomes of computer-aided vs. standard techniques. *Clinical Oral Implants Research* **21**: 980–988.

Barnea, E., Alt, I., Kolerman, R. & Nissan, J. (2010) Accuracy of a laboratory-based computer implant guiding system. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **109**: e6–e10.

Behneke, A., Burwinkel, M., d'Hoedt, B. & Behneke, N. (2009) Clinical assessment of the reliability of a computer-aided implant planning concept using laboratory-fabricated templates based on cone beam computed tomography. *Zeitschrift für Zahnärztliche Implantologie* **25**: 339–352.

Brief, J., Edinger, D., Hassfeld, S. & Eggers, G. (2005) Accuracy of image-guided implantology. *Clinical Oral Implants Research* **16**: 495–501.

Chuang, S.K., Tian, L., Wei, L.J. & Dodson, T.B. (2002) Predicting dental implant survival by use of the marginal approach of the semi-parametric survival methods for clustered observations. *Journal of Dental Research* **81**: 851–855.

D'haese, J., van de Velde, T., Komiyama, A., Hultin, M. & De Bruyn, H. (2010) Accuracy and complications using computer-designed stereolithographic surgical guides for oral rehabilitation by means of dental implants: a review of the literature. *Clinical Implant Dentistry & Related Research*. doi: 10.1111/j.1708-8208.2010.00275.x.

Dreiseidler, T., Neugebauer, J., Ritter, L., Lingohr, T., Rothamel, D., Mischkowski, R.A. & Zöller, J.E. (2009) Accuracy of a newly developed integrated system for dental implant planning. *Clinical Oral Implants Research* **20**: 1191–1199.

Ersoy, A.E., Turkyilmaz, I., Ozan, O. & McGlumphy, E.A. (2008) Reliability of implant placement with stereolithographic surgical guides generated from computed tomography: clinical data from 94 implants. *Journal of Periodontology* **79**: 1339–1345.

Hanold, L., Vinson, B.E. & Rubino, A. (1998) Evaluating and improving your medication use system. In: DeMichele Cousins, D., ed *Medication Use: A Systems Approach to Reducing Errors. Ch. 5.* 2nd edition, p. 101. Illinois: Joint Commission Resources.

Horwitz, J., Zuabi, O. & Machtei, E.E. (2009) Accuracy of computerized tomography-guided template-assisted implant placement system: an in vitro study. *Clinical Oral Implants Research* **20**: 1156–1162.

Jung, R.E., Schneider, D., Ganeles, J., Wismeijer, D., Zwahlen, M., Hämmerle, Ch.H.F. & Tahmaseb, A. (2009) Computer applications in surgical implant dentistry: a systematic review. *The International Journal of Oral & Maxillofacial Implants* **24**: 92–109.

Kalt, G. & Gehrke, P. (2008) Transfer precision of three-dimensional implant planning with CT assisted offline navigation. *International Journal of Computerized Dentistry* **11**: 213–225.

Loubele, M., Guerrero, M.E., Jacobs, R., Suetens, P. & van Steenberghe, D. (2007) A comparison of jaw dimensional and quality assessments of bone characteristics with cone-beam CT, spiral tomography, and multi-slice spiral CT. *The International Journal of Oral & Maxillofacial Implants* **22**: 446–454.

Ludlow, J.B. & Ivanovic, M. (2008) Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **106**: 106–114.

Ozan, O., Turkyilmaz, I., Ersoy, A.E., McGlumphy, E.A. & Rosenstiel, S.F. (2009) Clinical accuracy of 3 different types of computed tomography-derived stereolithographic surgical guides in implant placement. *The International Journal of Oral and Maxillofacial Surgery* **67**: 394–401.

Sarment, D.P., Sukovic, P. & Clinthorne, N. (2003) Accuracy of implant placement with a stereolithographic surgical guide. *The International Journal of Oral & Maxillofacial Implants* **18**: 571–577.

Schneider, D., Marquardt, P., Zwahlen, M. & Jung, R.E. (2009) A systematic review on the accuracy and the clinical outcome of computer-guided template-based implant dentistry. *Clinical Oral Implants Research* **20** (Suppl. 4): 73–86.

Van Assche, N., van Steenberghe, D., Guerrero, M.E., Hirsch, E., Schutyser, F., Quirynen, M. & Jacobs, R. (2007) Accuracy of implant placement based on pre-surgical planning of three-dimensional cone-beam images: a pilot study. *Journal of Clinical Periodontology* **34**: 816–821.

Van Assche, N., van Steenberghe, D., Quirynen, M. & Jacobs, R. (2010) Accuracy assessment of computer-assisted flapless implant placement in partial edentulism. *Journal of Clinical Periodontology* **37**: 398–403.

Vercruyssen, M., Jacobs, R., van Assche, N. & van Steenberghe, D. (2008) The use of CT scan based planning for oral rehabilitation by means of implants and its transfer to the surgical field: a critical review on accuracy. *Journal of Oral Rehabilitation* **35**: 454–474.

Widmann, G., Zangerl, A., Keiler, M., Stoffner, R., Bale, R. & Puelacher, W. (2010) Flapless implant surgery in the edentulous jaw based on three fixed intraoral reference points and image-guided surgical templates: accuracy in human cadavers. *Clinical Oral Implants Research* **21**: 835–841.