Conventional Multi-Slice Computed Tomography (CT) and Cone-Beam CT (CBCT) for Computer-Aided Implant Placement. Part II: Reliability of Mucosa-Supported Stereolithographic Guides

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ABSTRACT

Purpose: Deviations of implants that were placed by conventional computed tomography (CT)- or cone beam CT (CBCT)-derived mucosa-supported stereolithographic (SLA) surgical guides were analyzed in this study.

Materials and Methods: Eleven patients were randomly scanned by a multi-slice CT (CT group) or a CBCT scanner (CBCT group). A total of 108 implants were planned on the software and placed using SLA guides. A new CT or CBCT scan was obtained and merged with the planning data to identify the deviations between the planned and placed implants. Results were analyzed by Mann-Whitney *U* test and multiple regressions ($p < .05$).

Results: Mean angular and linear deviations in the CT group were 3.30° (SD 0.36), and 0.75 (SD 0.32) and 0.80 mm (SD 0.35) at the implant shoulder and tip, respectively. In the CBCT group, mean angular and linear deviations were 3.47° (SD 0.37), and 0.81 (SD 0.32) and 0.87 mm (SD 0.32) at the implant shoulder and tip, respectively. No statistically significant differences were detected between the CT and CBCT groups ($p = .169$ and $p = .551$, $p = .113$ for angular and linear deviations, respectively).

Conclusions: Implant placement via CT- or CBCT-derived mucosa-supported SLA guides yielded similar deviation values. Results should be confirmed on alternative CBCT scanners.

KEY WORDS: computed tomography, computer assisted, cone beam, dental implants, deviation from the planning, gray density, stereolithography

INTRODUCTION

Tomography-derived stereolithographic (SLA) surgical guides provide important benefits in the insertion of multiple implants particularly in totally edentulous jaws where no anatomical landmark exists for surgeons' reference. Especially when applied in a flapless fashion, via the mucosa-supported guides, a significant drop in the surgery duration and postoperative complications was observed in suitable cases.[1] In a recent multicenter retrospective study, 271 implants placed by an image-guide flapless technique were compared against the conventional 281 implants, and no significant difference was found in terms of success and survival within the 4 years of follow-up.[2] With the aid of special planning software, a three-dimensional model of the patient's jaw can be constructed in the computer environment, and the clinician may execute a virtual surgery using true-sized implants with respect to the individual anatomy and final prosthodontic goal. The three-dimensional visualization of the edentulous jaw allows the prosthodontist

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and the surgeon to optimize many specific parameters of the implantation such as fixture dimensions and positional conformity.[3] Physical transfer of the virtual plan to the patients' jaw by an SLA guide mandates utmost precision because the surgery is realized "blindly" in vicinity of vulnerable anatomic structures. The precision and the reliability of this transfer fundamentally depend on the accuracy of the baseline tomographic data.[4]

As a result of the rapidly increasing demand and the volume of annually inserted implants in the global market, a search for a plausible interactive instrument allowing three-dimensional exploration of the recipient anatomy provided with an acceptable amount of radiation dose was appraised.[5] Up until then, the conventional computed tomography (CT) was the only option for such purpose given the cost of high radiation dose and demanding maintainability. The cone beam CT (CBCT) scanners were then introduced as emitting significantly lower radiation than CT. Compared with the CT, the CBCT is a relatively new and more specific technology in the area of oral and maxillofacial imaging and offers reduced scan times and operational costs.[6] Nevertheless, the dynamic range of the radiographic gray intensity is reduced (16-bit in CT and 8- to 14-bit in CBCT), and image artifacts were more common in the presence of high density objects such as metallic restorations.[7] More importantly, three-dimensional modeling was not as accurate as CT.[8] Recent use of a flat panel detector instead of the former image-intensifier in CBCT improved these disadvantages thereby allowing better segmentation and three-dimensional model reconstruction capability for SLA guides.[9]

As the production of the SLA guides is performed on the basis of a segmentation procedure according to tomographic gray density, any compromise of the image quality may jeopardize the reliability of the actual surgery by inducing deviations in the physical transfer of the planned virtual implants.[10] In this respect, the aim in the second part of this study was to compare the deviations between the planned and placed implants inserted by the CT- or CBCT-derived mucosa-supported SLA guides.

MATERIALS AND METHODS

The study was approved by the Ethical Committee of İstanbul University and conducted in accordance with the Helsinki Declaration of 1975, as revised in 2008. The minimum required sample size of 108 implants, which was calculated for the first part of this study, was analyzed by a statistical software (Statmate, GraphPad Software Inc., San Diego, CA, USA) on the basis of deviation values found in a previous study.[11] Referring to average 0.73 mm (SD 0.14) linear and 2.9° (SD 0.39) angular deviation rates, the calculated number of 108 implants yielded to detect a difference of ≥0.45 mm linear and ≥0.42° angular deviation between the implants placed by CT- or CBCT-derived SLA guides at the >85.3% power level with statistical significance level over 95%. Because an implant-supported fixed prosthesis was considered for the recruited patients, a minimum of five implants deemed suitable in all cases. An implant failure rate of 2% was also incorporated.

Allocation of the patient group was based on the evaluation of the corresponding edentulous jaw(s) for the eligibility of flapless implant insertion via mucosa-supported SLA guides.[2,11] Because the smallest available implant diameter was 3.5 mm, availability of ≥5 mm bone thickness was the initial inclusion criterion in this study. A minimum of 5 mm attached mucosa was also considered essential as mobile, nonattached mucosa may wrap around the drills and traumatize the surrounding soft tissues during the instrumentation. Accordingly, 46 consecutive patients who applied to Department of Oral Implantology, Faculty of Dentistry, Istanbul University between March 2009 and April 2010 for the treatment of edentuluism via implant-supported fixed prosthesis were informed about the study and written approval was obtained from 39 volunteers. All patients were initially evaluated by panoramic X-ray and oral examination. Using a dedicated bone caliper (Osseometer, Oraltronics, Bremen, Germany) under infiltration anesthesia, the thickness of the alveolar bone was measured with reference to 2 to 3 mm apical point of the alveolar crest. These measurements were taken bilaterally from the canine and molar areas. Patients exhibiting an alveolar bone thickness and an attached mucosa width of ≥5 mm were deemed suitable for flapless implant surgery using mucosa-supported guides. Patients with unhealthy systemic health status, parafunctional habits, poor oral hygiene, insufficient alveolar bone volume, uncontrolled diabetes, current irradiation to head or neck, psychological disorders, or alcohol or tobacco or drug abuse were not included. For the 11 suitable patients (18 jaws), a wax tooth setup representing the final prosthetic outline was tried in situ.

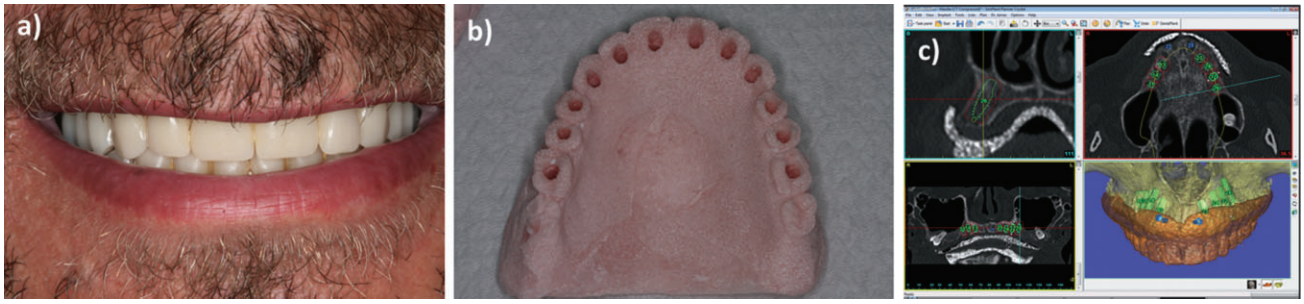

Figure 1 The "backward planning" performed in the study. *A*, A wax teeth setup representing the final prosthetic goal was tried in situ. *B*, A BaSo4-based acrylic scan prosthesis was produced using the wax teeth setup. In order to facilitate the planning, grooves were drilled in the central axis of each tooth. *C*, Following CT or CBCT scan, the data were segmented and uploaded to a personal computer in which the implants were planned using special software.

Following the approval of esthetic, functional, and prosthetic conformity, an acrylic $BaSO_4$-based radiopaque scan prosthesis was produced. To facilitate the positioning of implants on the computer, cylindrical guide holes were drilled in the center of each tooth axis. All scan prostheses were tried in situ to ensure a proper fit and patient comfort during the tomographic imaging. A radiolucent bite registration (O-bite, DMG Dental, Hamburg, Germany) was additionally prepared to ensure the accurate positioning of the scan prosthesis during imaging. Then, referring to a computer-generated randomization list (Quickcalcs, GraphPad Software Inc.), the patients were randomly assigned to be scanned by a conventional multi-slice CT (CT group) or a CBCT device (CBCT group).

Image Acquisition and Planning of the Implants on the Software

A 64-slice CT scanner (Siemens Somatom Sensation 64, Siemens Medical Solutions, Erlangen, Germany) using the setting of 130 kV, 83 mA was used for the five patients in the CT group. A daily calibration was performed in order to ensure that the air was defined as −1,000 Hounsfield units (HU) by the CT scanner. An amorphous-silicon, flat-panel CBCT scanner (Iluma, Imtec Imaging, Ardmore, OK, USA) using a standard setup of 120 kV (peak), 3.8 mA with an exposure time of 40 seconds and a standard field of view (FOV) area of 14.2×21.1 cm was used for the imaging of six patients in the CBCT group. The resulting gray scale was 14-bit and the voxel size was 0.0936 mm. Scanning procedures were performed under the control of a technician trained in SLA-related implant treatment sequence. The radiographic scan prostheses were checked for the proper fit and positioning in the mouth and held in place by the bite registration. All acquired data were saved in Digital Imaging and Communications in Medicine (DICOM) format. The data were processed and a virtual three-dimensional model was reconstructed following the segmentation of bone and the scanning prosthesis by an auxiliary individual who is trained in post-tomographic image analysis and segmentation using specific software (Simplant Pro, Materialise Dental, Leuven, Belgium). Any visual or technical problems were noted.

The images were transferred to another computer to be used by the clinician for planning the final positions of the implants using the same software without segmentation abilities (Simplant Planner, Materialise Dental). An experienced clinician (V.A.) examined the images and planned the final positions of the implants with the help of the axial and sagittal cross sections with reference to the three-dimensional model of the jaw bone and the scan prosthesis. Care was given to establish the best possible implant location with respect to the prosthetic outline known as the "backwards planning"[12] (Figure 1). A total of 108 implants (consisting of 64 in the maxilla and 44 in the mandible) were planned (Figure 2). The final positions of the implants were confirmed and the plan was saved and sent to production facility (Materialise Dental). Following the arrival of the guides, they were checked intraorally for the proper fit using the previously prepared bite registration.

Implant Surgery

The SLA guide was seated over the mucosa, and the proper fit was confirmed using the silicone bite registration. As noticed in a previous study,[1] exact positioning of the mucosa-supported SLA guide can be hampered because of injection-related swelling after infiltration anesthesia. Thus, the anesthetic was administered slowly

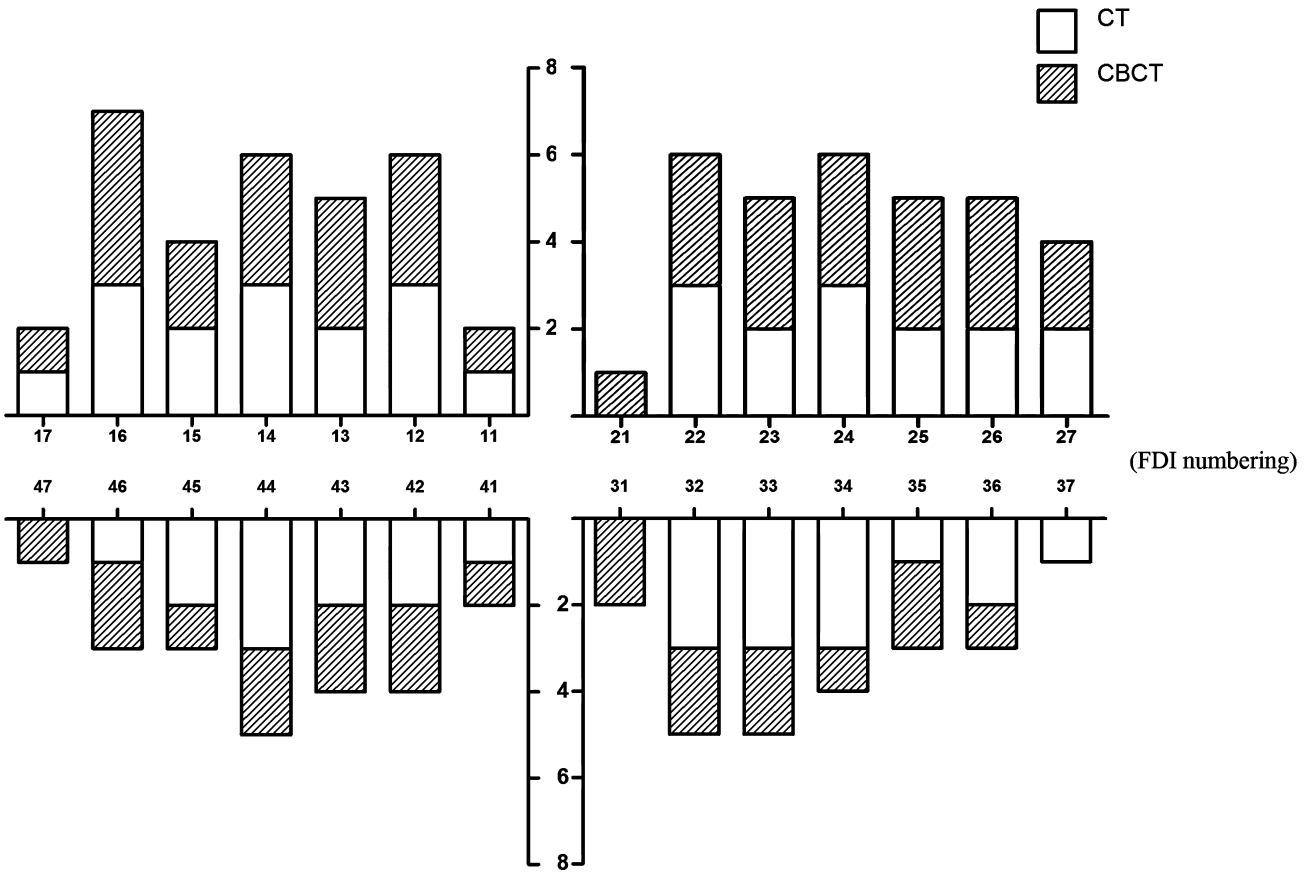

Figure 2 Number and location of implants planned in CT and CBCT groups according to FDI (World Dental Federation) numbering system.

through the holes on the SLA guide, and the numbness was checked. The guide was carefully fixed by the osteosynthesis screws (OBL, Chatillon, France) through the designated opening on the SLA guide while in full occlusion with the opposing jaw. The bite registration was removed and additional anesthesia was administered from the mucosal border in the buccal or lingual/palatinal aspect of the SLA guide, as required. The mucotomy and osteotomy was completed using the special drill kit (Simplant SAFE drill kit, Materialise Dental), which consisted of a mucotome and two consecutive drills with depth-controlling physical stoppers (Figure 3). Following the removal of the overlying mucosa in the recipient area, the metal sleeves controlling the direction and depth of the drills was mounted on the metal tubes on the guide. Care was given to initiate the osteotomy in parallel with the guides' metal sleeves because a nonparallel start has been shown to increase the deviations dramatically because of rotational tolerance of the drills in the sleeves.[13] The length of the drills was preassigned by the manufacturer according to the planned implant length and operational limitations. Care was taken to prevent overheating of the bone during the osteotomy by providing copious saline irrigation. The guide sleeves were removed and the mucotome was once again used in all osteotomy sites to ensure the

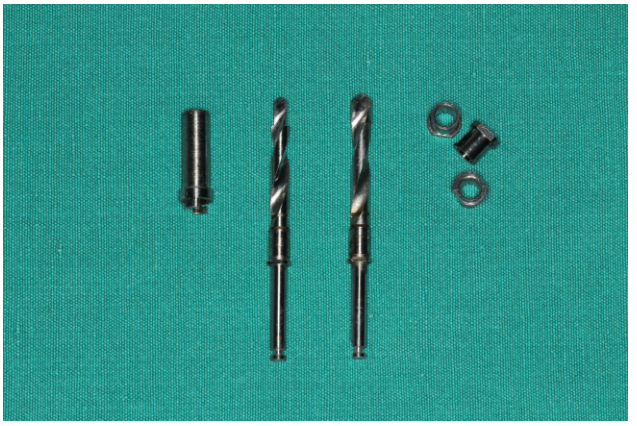

Figure 3 The special kit used for the mucotomy and osteotomy. From left to right: mucotome; pilot and twist drills with physical stoppers to control the depth of the osteotomy; metal guide sleeves providing vertical and horizontal control for the drills.

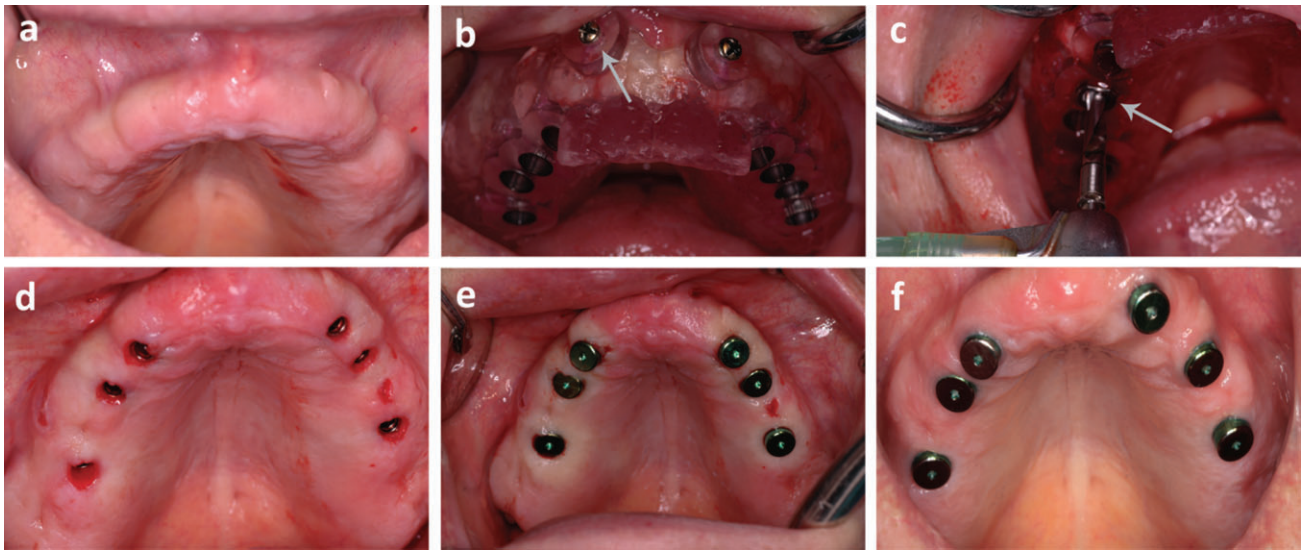

Figure 4 Implant surgery using mucosa-supported SLA guides. *A*, Edentulous maxilla with sufficient attached mucosa width. *B*, The mucosa-supported SLA guide was fixed by osteosynthesis screws (*arrow*). *C*, Osteotomy was performed using the special drill kit and metal guide sleeves (*arrow*). *D*, Clinical view of the surgical site following the implant placement and removal of the SLA guide. *E*, Gingival formers were fastened and implants were left to osseointegration. *F*, Clinical view of healing after 3 months.

removal of soft tissues in the implant recipient areas. All prepared osteotomy holes were rinsed by saline, and the implants (SPI Element, Thommen Medical, Waldenburg, Switzerland) were inserted through the guide via a torque-controlled handpiece (W&H, Salzburg, Austria). Following the removal of transfer mounts, the osseosynthesis screws were removed, and the guide was dismounted. The primary stability of the implants (described in the first part of this study) was measured. All implants were healed in a nonsubmerged manner with the proper gingival formers attached. Implants were left to an osseointegration period of 2 months in the mandible and 3 months in the maxilla (Figure 4). At the end of the healing period, patients were scanned once again by the same CT or CBCT device with exposure parameters unchanged.

Image Fusion and Deviation Measurement

The image fusion and deviation measurement process was performed as described in a previous study.[11] Measurements were done by an independent prosthodontist (B.P.) who was unaware of which group each patient belonged to. The planning data were retrieved from the production facility in the raw file format. Then, using a special software (Analyze, AnalyzeDirect, Lenexa, KS, USA), surface volumes of the planned and placed implants were fused in the three-dimensional environment by using a semi-automated fusion procedure, which utilizes a mapping protocol of the FOV in both images. By using the segmentation, surface extractor, and volume render feature of the software, the bone encircling the planned and placed implants was removed, and the implants were left superimposed on the identical three-dimensional spatial image. The use of different colors during the volume rendering allowed identification of the planned and placed implants. Two points (in the x, y, and z coordinates) in the center of the shoulder and the apex of the implants were determined. These two lines were connected by a line which constituted the "axis" of the implants. The deviations in the implant shoulder and tip (distance between the center points of the implant tip and shoulder) was measured in millimeters. The angle between the axis of the planned and the placed implants was measured in degrees. Measurements were taken on two separate days, and the averages were recorded as final (Figure 5).

Statistical Analysis

Descriptive statistics of measured values consisting of mean, standard deviation, minimum–maximum, and 95% confidence interval (CI) were calculated with the help of a statistical software (Graphpad Prism 5.0, Graphpad Software Inc.). Distribution was not normal in some data sets as determined by the D'Agostino Pearson Omnibus Normality test. Therefore, Mann-Whitney *U* test was used to analyze the deviations of

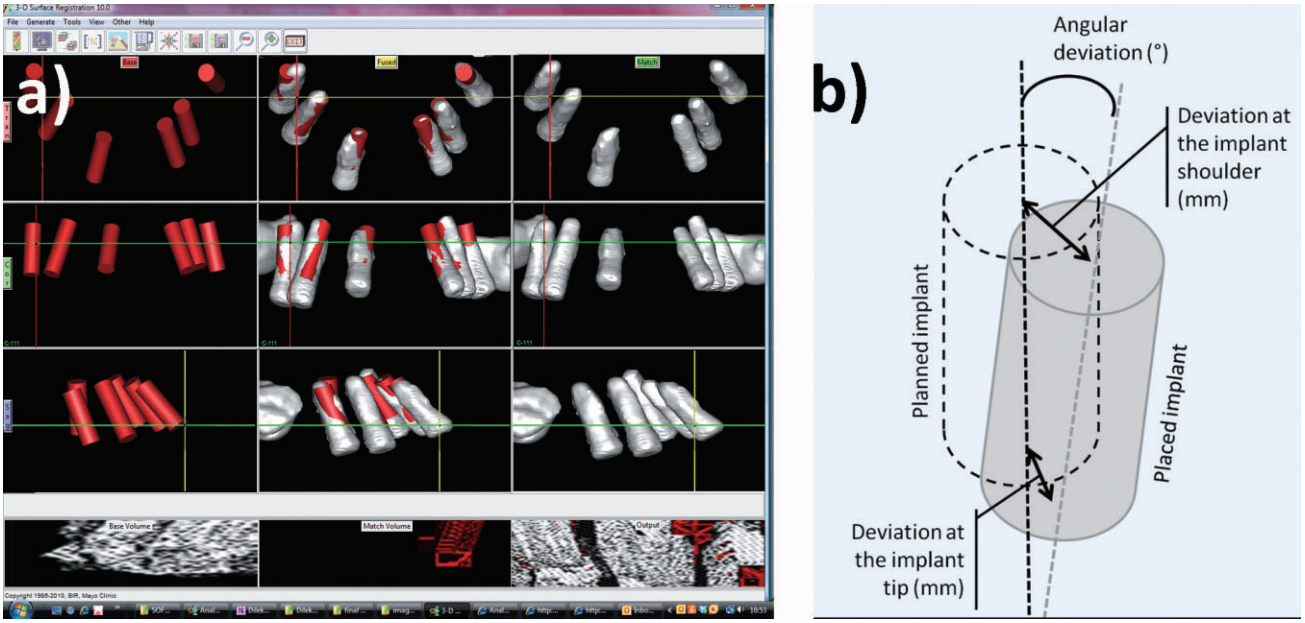

Figure 5 Measurement of the deviations between the planned and placed implants. *A*, Special three-dimensional image analysis software was used for the fusion of the presurgical planning with the new tomographic data taken at the stage of loading. Planned and placed implants are depicted by red and gray colors, respectively. *B*, Angle difference between the axis of the implants (°) and linear deviations between the center shoulder and tip points (mm) were measured.

implants according to scanning method (CT or CBCT), anatomic location (maxilla and mandible), and gender (male and female). The statistical power of the completed experiment (linear and angular deviations) was also determined using a dedicated software (Statmate).

Multiple regression analysis was used to reveal any possible relation of the measured implant deviations and corresponding implant dimensions (length and diameter), radiographic gray density values (inside and outside the planned implants), insertion torque value (ITV) and resonance frequency analysis (RFA), as well as with the perceived subjective bone quality (BQC) of each implant osteotomy.[14] In order to satisfy the assumptions of the multiple regression analysis, logarithmic transformations (square root) were performed on the non-normal data sets: linear deviation of the implants in the CT (tip) and the CBCT (shoulder and tip) group, angular deviation of implants in the CT group, VV (outside the implants), HU (inside the implants), and radiographic BQC. Implants and the corresponding data in CT and CBCT groups were analyzed on separate models using the enter method, and deviations in the shoulder and tip and angular deviations were attained as the fixed factors (criterion variable); implant length and diameter, HU–VV inside and outside the implants, radiographic and perceived subjective BQC, ITV, and RFA were attained as the independent variables (predictor variables). The absence of multicollinearity was confirmed in those models that were found acceptable. Statistical software (SPSS 16, Chicago, IL, USA) was used for the multiple regression analysis. Any p level below .05 was accepted as statistically significant.

RESULTS

The technician responsible for the segmentation and the preparation of the raw CT and CBCT data reported that the processing of CBCT data were challenging because of high resolution and noise, and therefore, the volume rendering process took longer in the CBCT group. The adjustment of the threshold values for the segmentation of bone and scan prosthesis was also complicated in the CBCT group because in contrast to the CT, the preset threshold of the software values did not comply. This was elucidated by manual adjustment in most of the cases. Nevertheless, no areas or any cross sections demonstrated a poor or inferior image quality either in CT or in CBCT groups.

All 108 implants were placed uneventfully as planned on the software, and there were no damage-related complications in any critical anatomy. Two implants failed (one was due to postoperative infection

TABLE 1 Deviations between the Planned and Placed Implants in CT and CBCT Groups

	CT		CBCT	
	Implant Shoulder	Implant Tip	Implant Shoulder	Implant Tip
Linear deviations (mm)				
Mean (SD)	0.75 (0.32)	0.80 (0.35)	0.81 (0.32)	0.87 (0.32)
Min–max	0.08–1.26	0.13–1.34	0.11–1.31	0.28–1.33
95% CI	0.66–0.84	0.70–0.90	0.72–0.90	0.78–0.96
Angular deviations (°)				
Mean (SD)	3.30 (1.085)		3.47 (1.144)	
Min–max	0.46–4.98		0.78–5.12	
95% CI	3.07–3.63		3.17–3.78	

and the other one was found mobile at the end of the healing period). Because of titanium-related heavy beam-scattering around four implants (three in the CT and one in the CBCT image), deviation measurement was possible only at 102 implants (50 in the CT and 52 in the CBCT group). The linear and angular deviations of implants placed by CT- and CBCT-derived guides are presented in Table 1. Highest linear deviation in the implant shoulder (1.31 mm) was measured in the CBCT group and highest linear deviation in the implant tip (1.34 mm) was measured in the CT group. The lowest linear deviation (0.08 mm in the shoulder and 0.13 mm in the implant tip) was measured in the CT group. Also, the highest angular deviation (5.12°) was measured in the CBCT group and the lowest angular deviation (0.46°) was measured in the CT group. Mean linear deviation in the CT group was 0.75 (range 0.08–1.26, SD 0.32) and 0.80 mm (range 0.13–1.34, SD 0.35) at the implant shoulder and tip, respectively. In the CBCT group, the mean linear deviation was 0.81 (range 0.11–1.31, SD 0.32) and 0.87 mm (range 0.28–1.33, SD 0.32) at the implant shoulder and tip, respectively. Mean angular deviation was 3.30 (range 0.46–4.98, SD 0.36) and 3.47° (range 0.78–5.12, SD 0.37) in CT and CBCT groups, respectively. The differences of linear and angular deviations between the implants in the CT and CBCT group were statistically not significant (implant shoulder: Mann-Whitney U: 1,212, $p = .551$; implant tip: Mann-Whitney U: 1,064, $p = .113$; angular deviation: Mann-Whitney U: 1,095, $p = .169$; Figure 6). In the maxilla, mean linear deviation at the implant shoulder was 0.73 (range 0.12–1.26, SD 0.33) and 0.82 mm (range 0.18–1.31, SD 0.33), and mean linear deviation in the implant tip was 0.81 (range 0.19–1.34, SD 0.36) and 0.88 mm (range 0.37–1.30, SD 0.32) in CT and CBCT groups, respectively. In the mandible, mean linear deviation at the implant shoulder was 0.74 (range 0.08–1.12, SD 0.30) and 0.80 mm (range 0.11–1.29, SD 0.34), and mean linear deviation in the implant tip was 0.77 (range 0.13–1.31, SD 0.35) and 0.89 mm (range 0.28–1.32, SD 0.34) in CT and CBCT groups, respectively. The differences between the linear and angular differences of implants placed in the maxilla or mandible were statistically not significant in both CT ($p = 0.12$ and $p = .22$

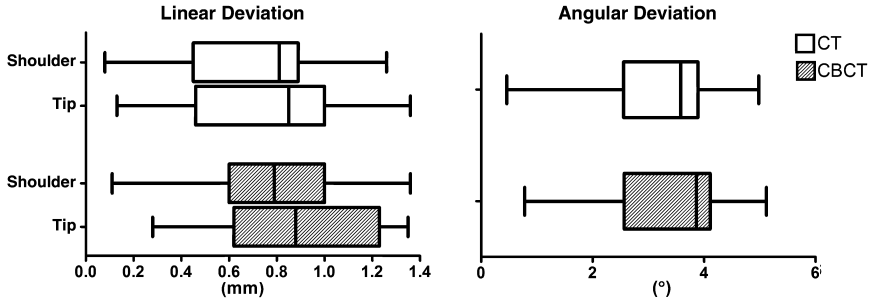

Figure 6 Box plots depicting median, quartile, and minimum–maximum deviation values of implants placed by CT- and CBCT-derived SLA guides.

TABLE 2 Emerged Multiple Regression Model (Linear Deviation in the Implant Tip [mm]) in the CT Group

Variables	Coefficient	SE	*t* Ratio	*p*
Model 1 in the CT group*				
Linear deviation in the implant tip (mm); (criterion variable)	3.336	8.45	0.32	.032
HU outside the implant	–2.233	0.231	3.231	.0011
Implant length	2.012	1.453	1.987	.028

*Adjusted $r^2 = 0.4819$; sum of squares, 226.65; SD of residuals, 7.815; F = 3.938; $p = .022$. Predictor variables HU inside the implant ($p = .12$), perceived subjective BQC[14] ($p = .067$), and implant diameter ($p = .46$) were not significant in this model.

for deviations in the implant shoulder and tip, $p = .34$ for the angular deviation) and CBCT groups ($p = .22$ and $p = .33$ for deviations in the implant shoulder and tip, $p = .23$ for the angular deviation). Also, the deviation differences of implants placed to males and females were statistically not significant in the CT ($p = .31$) and CBCT group ($p = .28$).

The measured gray density values inside and outside the implants were reported in the first part of this study. In relation to those values, a significant model emerged in the CT group for the linear deviation at the implant tip (mm) ($F_{2.655} = 3.938$, $p = .022$, adjusted $r^2 = 0.4819$) in which the gray density (HU) outside the implant ($p = .0011$) and the implant length ($p = .028$) was significant (Table 2). No significant models were found for the rest of the variables.

According to the standard deviation values, the statistical power regarding the difference of linear deviations (0.06 and 0.07 mm) was 87.4 and 88.4% for implant shoulder and tip, respectively. The difference of the angular deviations between the CT and CBCT groups (0.017°) resulted with a statistical power of 89.9%.

DISCUSSION

Reliability of CT- and CBCT-derived mucosa-supported SLA guides in terms of linear and angular deviations between the planned and placed implants was analyzed in this study. Deployment of multiple regressions modeling in conjunction with the gray density values inside and outside the planned implants (as explored in the first part of this study) allowed further clarification of any possible relevant dependents.

In CT, the imaging of the designated area is performed by a continuous turn of the tube-detector assembly emitting a linear ray of radiation (fan beam) while the patients' table moves in a continuous synchronized manner. Upon completion of the data acquisition by a full 360° turn of the tube-detector assembly (an axial slice), the patient is moved incrementally (according to the desired slice thickness), and a new X-ray beam is emitted up until the volume of the corresponding anatomy has elapsed. Segmentation and reconstruction of a three-dimensional object from the CT images therefore requires a narrow slice interval, which consequently raises the total X-ray dose depending on the desired resolution level. The images are computed directly from a set of raw data by the set of X-rays attenuated for all points of the entire cross-sectional image.[15] Gray density depiction of the images is therefore on a linear scale, and by the attenuation of air as –1,000 HU and water as 0 HU, the anatomy in the FOV could be rendered in absolute values. Segmentation and three-dimensional reconstruction out of CT data are based on a stack of images in planes other than the original stack (reformat), and volume elements need to be averaged between the two consecutive slices, which was referred to as "non-isotropic." The effect of averaging becomes prominent with the increase of the slice thickness in CT.[16]

In the CBCT, however, no averaging is needed as the information, not of one layer but of the whole volume of the scanned object (volumetric), is acquired through a pyramid or cone-shaped beam of X-rays (cone beam) focused in the detector.[17] In contrast to the CT, the patient remains stationary in a seated position while the tube-detector arm of the CBCT device makes the turn,[18] and as a result of volumetric data acquisition, the images are "isotropic." The volumetric information is then converted to reformatted sections (or three-dimensional reconstructions) by custom software on the basis of a

factory-defined gray intensity attenuation. The algorithms used during this conversion were also adapted from the CT technology and not specific to the CBCT. Accordingly, the gray density of the CBCT images are not absolute and subject variability owing to various confounding factors such as the presence of radiopaque objects in the area, position of the scanned object, and the type of the detector.[19] As compared with the CT, the dynamic contrast is limited (gray density values are in a smaller range) and image artifacts are more common.[6] Nevertheless, the radiation exposure for the patient is relatively low and corresponds to a threefold digital panoramic X-ray dose and almost one-tenth of a limited-zone multidetector CT.[20]

As the SAL guide itself is a digital copy of the scan prosthesis, a high resolution combined with accurate gray intensity attenuation would be idealized for any imaging modality. In this respect, the small voxel size (a volume element, representing the value on a regular grid in three-dimensional space) provided by the CBCT (80–400 μm) may appear as an advantage as compared with the CT (300 and 1,000 μm).[21] Despite these features, CBCT did not surpass CT for any of the investigated parameters in this study. Increased noise and variable intensity of the CBCT images were visible in most of the patient images, which required manual tuning of the gray intensity thresholds and deletion of the scatter noise. Also, implants in the CBCT group yielded slightly lower accuracy than those of the CT group, although the differences were statistically not significant.

The transfer error of SLA template-guided implants was investigated by many previous studies, but this was the first in comparing the clinical effect of the scanner type. When compared with the multiple-type guides used sequentially, matching the drill diameters (hold in place by hand),[22] single-type guides yielded lower deviation values as a result of rigid fixation provided by the osteosynthesis screws or bone-anchor pins.[5,11] Among other studies examining the accuracy of the presently used guides, ex vivo and cadaver studies yielded the best results; Van Assche and colleagues[23] used a flat-panel CBCT device to produce similar SLA guides. They placed a total of 12 implants to the human cadaver jaws and reported a mean 2° (SD 0.8) angular and 1.1 (SD 0.7) and 2.0 mm (SD 0.7) linear deviation in the implant shoulder and tip, respectively. Another cadaver and human study utilized a conventional CT scanner to produce SLA guides for the insertion of 16 implants, which revealed 0.8° (SD 0.3) angular and 0.3 (SD 0.1) and 0.9 mm (SD 0.3) linear deviation at implant shoulder and tip, respectively.[24] In both of the studies, instability of the guide during instrumentation was shown to be inducing deviations.

Possibly because of the intrusion of additional confounding factors such as restricted mouth opening and visibility and physiological motions during the execution of the actual surgery, clinical studies revealed higher deviation values.[25] Furthermore, the accuracy of the deviation measurements was shown to be compromising by patient-related factors such as movement during tomographic scan.[26] Highest values were reported by a preliminary study (mean 7.25° [SD 2.67] angular and 1.45 [SD 1.42] and 2.99 mm [SD1.77] at the implant shoulder and tip, respectively), which utilized the CT-derived SLA guides applied without any fixation.[27] Indeed, the accuracy of the SLA template-guided implants improved by providing rigid screw fixation. In a prospective clinical study, D'haese and colleagues[28] investigated the accuracy of 78 implants placed by multi-slice CT-based mucosa-supported SLA guides. They reported a mean of 2.60° (SD 1.61) angular and 0.91 (SD 0.44) and 1.13 mm (SD 0.52) linear deviation at the implant shoulder and tip, respectively. These data are congruent with the results from the present study. However, because of differences of the employed tomographic scanner and image fusion procedure, the results are hardly comparable in respect to the effect of the scanner. It should also be emphasized that the post-imaging processing (or so known segmentation) is prone to a number of operator-dependent errors such as incorrect setting of the gray density thresholds yielding gross deformation of an SLA guide.[29] In a previous study that employed the same CBCT scanner and SLA guides, almost identical deviation values were found (2.9° [SD 0.39] angular and 0.7 [SD 0.13] and 0.76 mm [SD 0.15] linear deviation at the implant shoulder and tip, respectively).[11] The result of the present study taken together with the previous investigations may also highlight the fact that the clinical accuracy of the presently utilized SLA guides can be minimized no further than a certain level because of various technical and physiological factors such as mucosal resiliency,[30] tolerance within the SLA guide,[14] and radiographic distortion.[18] Yet, no complications were reported as a result of drill or implant body collision to any critical anatomy in any of the

discussed studies. Accordingly, it can be concluded that both CT- or CBCT-based SLA guides can be used for the safe placement of implants.

The emerged regression model pointed out that in the CT group, the linear deviation of the implant tip was related with the length of the implant and was inversely related to the gray density value around the planned implant. The location of the implant shoulder is limited within the guidance tube, whereas the tip of the implant has relatively more freedom. Furthermore, the amount of deviation will become more pronounced with the added length in the implant tip. Increased linear deviation at the tip of the zygomatic implants may be explanatory to this occasion.[31] A recent study analyzed the deviations of implants placed by CT-based mucosa-supported SLA guides to smoker and non-smoker patients.[30] Implants placed to smokers yielded significantly higher deviation values (2.64° angular and 1.04 and 1.26 mm linear deviation at the implant shoulder and tip, respectively). Increased mucosal thickness and decreased alveolar bone density was suggested to be a cause of increased deviation values in smokers. Based on these findings, clinicians should be advised to be aware of potential deviations at the implant tip in low-density alveolar bone.

It should also be noted that, all of the patients in this study were totally edentulous at least in one jaw and the absence of highly radiopaque objects such as teeth or metallic crowns, bridges in the CBCT group may have also contributed to achieving similar deviations as of in the CT group. There is no blurring from out-of-focus structures in the CT images whereas such objects were shown to be distorting the CBCT images with beam-hardening or halation effects.[32] Results of this study should be judged cautiously for the extrapolation of conclusions to the clinical practice. The employed sample-size estimation (Part I) designating all implants as independent units, underestimates the fact that the group of implants placed through an individual guide are subject to synchronous deviations, which could occur as a result of a technical (i.e., movement of the patient during tomographic scan) or an iatrogenic error (i.e., improper positioning of the guide on the edentulous mucosa). Nevertheless, for the larger confirmatory studies, data from the present study may constitute a basis for a patient-level, sample-size calculation. Also, regarding the amount of deviations, mean values should be apprehended only as a mathematical expression and clinicians must account for the maximal deviation values for any potential worst-case scenario.

In this study, implants placed by CT- and CBCT-based mucosa-supported SLA guides revealed similar deviation values. A deviation-free implant placement was possible in neither of the groups, and the amount of linear deviation at the implant tip seemed to ascend with the implant length and low gray density. The use of CBCT could be easily justified because of its lower radiation dose and involved costs. However, because of their diverse detector and software technology, alternative CBCT scanners require further comparative studies to warrant the present outcome.

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