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ORIGINAL ARTICLE

Comparison of cone-beam and conventional multislice computed tomography for image-guided dental implant planning

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Abstract
Objectives To compare the accuracy of cone-beam CT (CBCT) and multislice CT (MSCT) with regard to its use in image-guided dental implant surgery in a prospective model based study.
Material and methods Ten photopolymer-acrylate mandibula models, each with four precise metal reference markers, were scanned with MSCT and CBCT. The six reference distances between the markers were measured by a three-axis milling machine first. The distances were then measured by (1) navigation with the Medtronic StealthStation® TREON™ image-guided surgery system, (2) with the Medtronic planning-tool and (3) on the PC with the Mimics® software. Mean values were calculated for all three methods for CBCT and MSCT and were compared for statistical significance.
Results Of all measurements, 83% of the arithmetic mean values were within the ±0.5 mm range (MSCT 88% and CBCT 78%) and 17% within the ±1.0 mm range (MSCT 12% and CBCT 22%). The absolute difference of the arithmetic mean values showed no statistically significant difference between MSCT and CBCT. The difference of the overall mean values to the reference was 0.43 mm for MSCT and 0.46 mm for CBCT.
Conclusions The data of our study prove that the application of CBCT for the indicated purpose yielded good results comparable to those of MSCT. All three measuring methods were feasible and accuracy was statistically not different between the data acquired by MSCT and CBCT within the setting of this study.

Keywords Cone-beam · Navigation · Image-guided surgery · Dental implants

Clinical relevance CBCT is a valid alternative to MSCT for image guided surgery.

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Introduction

Multislice computed tomography (MSCT) is the gold standard for preoperative implant position planning and navigation in maxillofacial surgery today. Accurate imaging is mandatory for proper planning and implant placement prior to surgery. Of course, this is feasible and proven with conventional CT (MSCT). Nevertheless, the growing impact of three-dimensional (3D) imaging led to the introduction of cone-beam computed tomography (CBCT), also known as Digital Volume Tomography (DVT) in maxillofacial and oral surgery [1]. Based on the cone-beam technology it is possible to obtain high-quality 3D pictures with only short scanning times and reduced radiation dosages [2]. Another advantage may be a reduction of metal artefacts due to prosthetic dental restorations [2, 3]. Due to the compact design of most CBCT systems and the lower costs compared to conventional CT, it has developed a valuable alternative which is worth considering. Because of these known benefits, we conducted a comparative prospective model-based study concerning the accuracy of CBCT and MSCT with regard to its use in image-guided dental implant surgery.

Material and methods

Model production

For the purpose of our study, a total of ten mandibula models were produced on the basis of pre-existing DICOM data of a conventional CT scan. Data were processed via the special Objet Studio Software™ of Eden 3D Printing system. The device for the production of the models was an Eden 350™ printer using the PolyJet Photopolymer-Jetting technology. The material used for the models was Full Cure Transparent™, a transparent photopolymer acrylate, which was applied in 0.016-mm-thick layers and cured by ultraviolet light immediately, layer by layer. The models can then be used immediately after production.

Creating reference points

In order to create reference markers in the models for reproducible distance measurements 0.8 mm thick steel wires were fixed in the models with acrylate glue after drilling holes with a standard 0.8 mm drilling machine (Hahn& Kolb Inc., Type: Flott SB 32 V). The position of the reference markers were below the mandibular canal at the region of the second molar and in the region of the canines at the level of the crestal bone.

Creating reference distances

After fixation of the reference markers the distances between the tip of the markers were measured for each model in order to create reference distances. For this purpose a three-axis milling machine (Bridgeport Inc., type: Serie I 2HP) with three glass rulers and digital display (Heidenhain, Type: VRZ 754B; Traunreut, Germany) was used. The models were fixed on the machine vice with a paraffin mass to avoid accidental movements during the measuring procedure. The first reference marker was the point below the right second molar. When the measuring instrument touched this first point the coordinates of all three axes on the display were set to zero. The next point was the right canine, then the left canine and at the end the left second molar point. All coordinates were recorded and the six distances between the points were then measured and served as reference distances A to F (Fig. 1a).

Model scanning

All models were scanned by MSCT and CBCT.

Conventional CT (MSCT)

The conventional CT scans were done by a Philips Brilliance 64 channel scanner™ (Philips Electronics N.V., Eindhoven, the Netherlands). The models were fixed on the patient positioning table with the occlusonal plane orientated vertically like in real patients. After acquisition of the

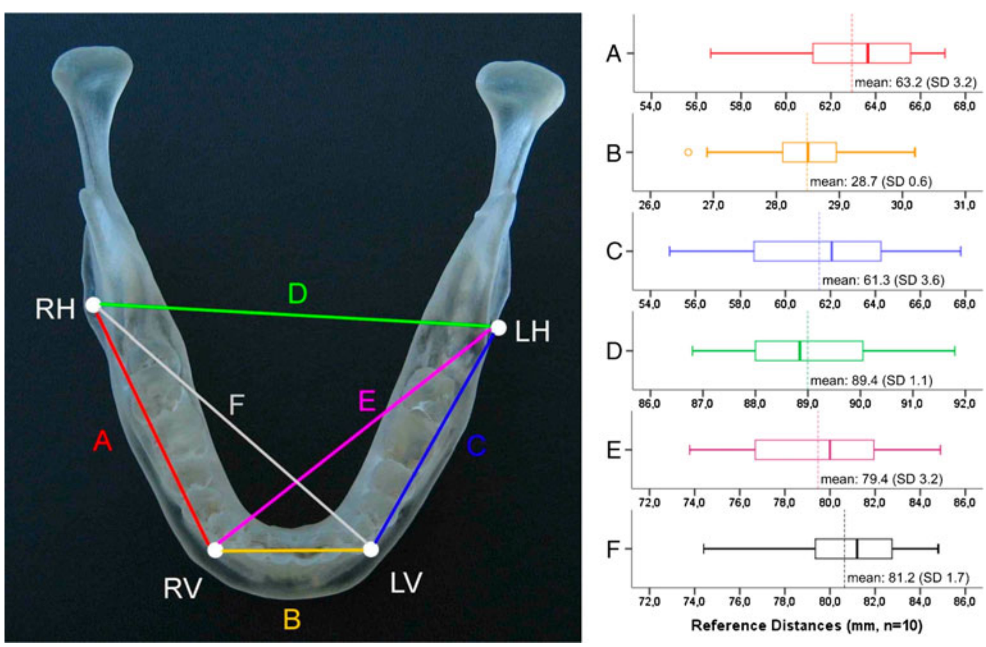

Fig. 1 **a** Reference points (1–4) and distances (A–F). **b** Distribution of reference values as boxplots

topogram, the scans were started. Scan parameters are shown in Table 1. The reconstructed images were then created based on the acquired data.

Cone beam CT

For DVT, we used the KaVo 3D eXam system™ (KaVo Dental GmbH, Biberach, Germany). The models were fixed on the chin rest in a central position. With the laser beam the position was checked and the topogram was accomplished. The scanning procedure was started and after 1 min the first overview of the scanned model was displayed in three dimensions on the screen. The used scan parameters are shown in Table 2.

Distance measuring

After data acquisition by MSCT and CBCT, the distances between the reference markers were measured by three different methods. All measurements in this study were performed by the same person. Since the main purpose of this study was the comparison of the accuracy of MSCT and CBCT for computer-assisted dental implantology two different types of distance measuring were performed with the aid of a commercially available Navigation system. The third method comprised measuring with a PC-based software without navigation. The three methods used were the following (Figs. 2 and 3):

(1) With the planning-tool of the Medtronic StealthStation® TREON™ system
(2) By navigation with the Medtronic StealthStation® TREON™ image-guided surgery system (Medtronic Inc., Minneapolis, MN, USA)
(3) On the PC with the Mimics® medical image processing software (Materialise NV, Leuven, Belgium)

Ad (1) 'Planning Tool': For measurements with the planning tool, the already imported and reconstructed data were used. Each reference marker was selected and its position checked on the CT scan. The distances were measured step by step by linking each reference point with the next. The distances were displayed in color codes as arrows and the distance was calculated.

Ad (2) 'Navigation': Raw DICOM data were exported to the Medtronic Stealth Station® TREON™ system and processed by the Software version 3.14, program 'spine 4'. Distance measuring was done on the models as 'real patient' to simulate the process of image-guided dental implantology. On each model a sensor was fixed by two screws in order to perform the registration of the model and link it with the 3D data in the software. The registration process was done by the pointer after definition of anatomically clear and reproducible points on the model. When the root mean square error (RMSE) was below 1.5 after registration of all points the accuracy of the registrated volume (spheres of accuracy) was tested. Two different spheres were present. Within the yellow sphere the accuracy for navigation is within a 2-mm range, within the green sphere it is within 1 mm. I our study all reference markers (fixed wires) were within the green sphere. After this procedure the measurements were started by touching the tip of the reference markers with the pointer. Each point was then marked in the navigation system. After marking of all four reference points, the distance measurements were performed with the software.

Ad (3) 'Mimics': Independently from the measurements on the navigation system, the distances were calculated on a PC with the software Mimics®, too. Data from the CT scans were transferred to the PC and 3D models were created with this program. By a special segmentation technique the models could be displayed without disturbing background artefacts or irrelevant structures. On the CT scans, the reference markers (fixed wires) were marked separately and reconstructed as 3D model. Now, distance measurements were possible. This was accomplished by connecting the tips of the wires with the integrated measuring function. For this

Table 1 Scan parameters of the MSCT

Parameter	Value
Collimation	20×0.625
Voltage (kV)	140
Current (mA s)	100
Thickness (mm)	0.625
Increment	1.25
Window	800/3000
Reconstruction	Value
Thickness (mm)	1.25
Window	800/3,000
Enhancement	−0.25

Table 2 Scan parameters of the CBCT

Parameter	Value
Center of volume	Vorne
Voltage (kV)	120
Current (mA s)	18.54
Scanning time (s)	8.9
resolution	0.4 voxel
FOV	60
Reconstruction	Value
Volume size (cm)	Landscape, 6×6×6
Projection image matrix	400×400
Voxel size (mm)	0.4×0.4×0.4
Reconstruction time (min)	1

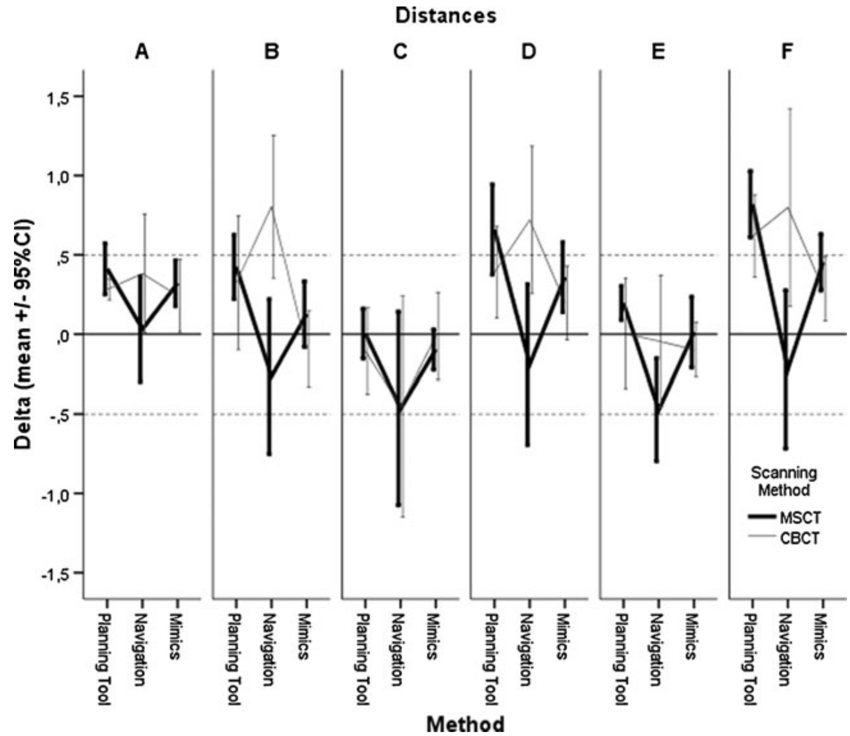

Fig. 2 Graph depicts deviation of scanning methods combined with measurement methods for all six distances

reason, the wires had to be enlarged and the exact position of the tips was determined in all three dimensions. Then the tips of the four reference wires were connected and the distances calculated by the software.

Statistical evaluation

The results of the measurements of each distance measured in mm from all ten mandibula models for each scanning and navigation method were documented in an Excel™ file (Microsoft, Redmond, USA) and statistically evaluated by the Program R™ (Version 2.11.1, The R Foundation for Statistical Computing, Vienna, Austria) and SPSS™ (Version PASW Statistics 18; SPSS Inc., IBM corporation, Somers, USA). Mean values and 95% confidence intervals were calculated as summarized in Table 3. Univariate ANOVA was applied for each distance A–F to test for significant differences between differences of measured and reference values (=delta) of MSCT and CBCT combined with all three distance measurement methods. According to the results of the Levene's test for equality of variances, more than one distance group showed unequal variances. Therefore critical significant level was set to $p<0.01$. Differences between measured and reference values, 95% confidence intervals results of the Shapiro–Wilk test for normality results are summarized in Table 4 together with the numbers of means within and outside the ±0.5 mm range of accuracy. ANOVA results for each distance, scanning method and measurement method are depicted in Table 5.

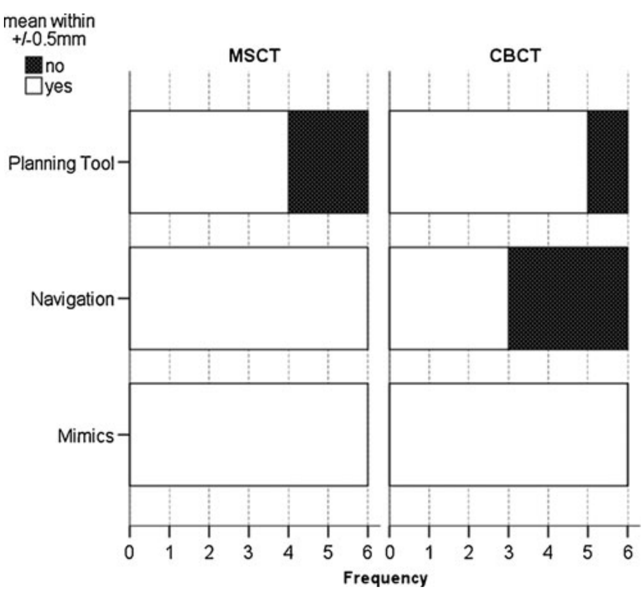

Fig. 3 Frequencies of means within and outside the ±0.5 mm range of accuracy: the vast majority (i.e., 30 of 36) of the values remains within the 0.5-mm limit

Results

The distribution of reference values are displayed as additional boxplots in Fig. 1b. The detailed results of the differences of measured and reference values are displayed for each distance as diagrams including both scanning methods, the reference line and all three methods of measuring in

Table 3 Survey of the measurement characteristics for both modalities

Measuring method	Scanning method	
	MSCT Mean (95% CI)	CBCT Mean (95% CI)
Planning tool		
A (*n*=10)	62.8 (60.5–65.1)	62.9 (60.7–65.2)
B (*n*=10)	28.3 (27.9–28.7)	28.4 (27.8–29.0)
C (*n*=10)	61.3 (58.7–63.9)	61.4 (58.8–64.0)
D (*n*=10)	88.7 (87.8–89.6)	89.0 (88.0–89.9)
E (*n*=10)	79.2 (76.9–81.5)	79.4 (77.0–81.8)
F (*n*=10)	80.3 (78.3–82.3)	80.5 (78.5–82.5)
Navigation		
A (*n*=10)	63.2 (60.8–65.6)	62.8 (60.6–65.1)
B (*n*=10)	29.0 (28.5–29.4)	27.9 (27.4–28.5)
C (*n*=10)	61.8 (59.2–64.4)	61.8 (59.4–64.1)
D (*n*=10)	89.5 (88.5–90.6)	88.6 (87.9–89.4)
E (*n*=10)	79.9 (77.6–82.1)	79.4 (77.2–81.7)
F (*n*=10)	81.3 (79.4–83.3)	80.3 (78.1–82.5)
Mimics		
A (*n*=10)	62.9 (60.6–65.2)	63.0 (60.8–65.2)
B (*n*=10)	28.6 (28.2–29.0)	28.8 (28.4–29.2)
C (*n*=10)	61.4 (58.8–64.0)	61.3 (58.7–63.9)
D (*n*=10)	89.0 (88.1–89.9)	89.2 (88.4–89.9)
E (*n*=10)	79.4 (77.0–81.8)	79.5 (77.2–81.8)
F (*n*=10)	80.7 (78.7–82.6)	80.8 (78.9–82.7)

MSCT multislice computed tomography=conventional CT; *CBCT* cone-beam computed tomography

order to perceive the differences easily are shown in Fig. 2. Spheres of accuracy within the 1-mm range (±0.5) are displayed, too, because they are important for the navigation process (Table 4). The frequency of mean values of each scanning and the navigation method within or outside the ±0.5 mm range are depicted in Fig. 3.

However, the results of ANOVA suggest no significant influence on deviations of scanning methods (MSCT, CBCT) combined with measurement methods (Planning Tool, navigation and Mimics; Table 5). Further Scheffé's post-hoc analysis for comparison of pairwise differences was passed due to the main ANOVA results.

Discussion

CBCT gained a lot of popularity during the last years, resulting in its increased use in many indications within Oral and Maxillofacial Surgery [2, 4, 5]. It uses a rotating pyramidal shaped X-ray beam with detector in order to reconstruct axial images based on the defined volume by a single rotation. The cone-shaped beams are very similar to conventional 2D X-ray units. Its popularity is mainly based on its known advantages like small size, low radiation dose, short scanning times and low acquisition costs compared to MSCT [2]. Besides applications in orbital surgery [6], impacted teeth surgery [7, 8], periodontology [9, 10] and even radiotherapy [11] the main indication for its use are dental implant procedures including 3D imaging of the facial bony structures [1, 4, 12]. Further applications include virtual implantation, preoperative planning procedures including the production of drill guides and intraoperative navigation for ideal implant placement [5, 13]. The success of navigated dental implant surgery strongly depends on the accuracy of the imaging method used. Several studies compared the accuracy of CBCT and MSCT and found it to be metrically similar [14–17]. In a study by Mischkowski et al. [1], the accuracy of the data for intraoperative navigation in high-contrast structures like bone was compared. No statistical differences were detected regarding handling, time exposure and surgical results. Nevertheless the authors emphasize the consideration of some special CBCT properties like smaller field of view (FOV) and lower image contrast. Furthermore, the registration procedure has to be adapted due to the limited FOV with its small scan volume. It is a well-known fact that the registration method based on anatomical landmarks is inferior to fiducial based registration. Nevertheless, we decided to apply the anatomical landmark-based registration method in this study, because we intended to follow a study protocol close to clinical 'reality', where actually anatomical based registration is still frequently used in order to minimize the expenditure for preparation. According to clinical workflows, we strictly adhered to an upper limit of the RMSE of each registration.

Within the setting of our study, the differences regarding accuracy compared to the reference (milling machine) were statistically not significant, too, but however there are some remarkable differences.

When looking at the diagrams of the overall mean value, it can easily be noticed that both scanning methods (MSCT and CBCT) are very accurate. However, the results from both scanning methods obviously differ depending on the measuring method used.

MSCT

Measurements by the aid of navigation tend to overestimate the reference distance. The curve of the diagram is always the same for all six distances. This might indicate a systematic error of the measuring method. For the daily surgical routine, this error means no impaired performance of the navigation process due to the mandatory intraoperative registration and accuracy checking on anatomical landmarks prior to the surgical procedure. Care has to be taken, too, that all reference markers are within the 1-mm spheres of

Table 4 Statistical analysis of differences between measurement and reference values

Measuring method	Delta: difference of measured value to reference				Accuracy	
	MSCT		CBCT		Means within ±0.5-mm range	
	Mean (95% CI)	SWT	Mean (95% CI)	SWT	MSCT	CBCT
Planning tool						
A (*n*=10)	0.4 (0.3 to 0.6)	0.67	0.3 (0.2 to 0.3)	0.48	Yes	Yes
B (*n*=10)	0.4 (0.2 to 0.6)	0.90	0.3 (−0.1 to 0.7)	0.55	Yes	Yes
C (*n*=10)	0.0 (−0.2 to 0.2)	0.28	−0.1 (−0.4 to 0.2)	0.11	Yes	Yes
D (*n*=10)	0.7 (0.4 to 0.9)[a]	0.52	0.4 (0.1 to 0.7)	0.97	No	Yes
E (*n*=10)	0.2 (0.1 to 0.3)	0.23	0.0 (−0.3 to 0.4)	0.52	Yes	Yes
F (*n*=10)	0.8 (0.6 to 1.0)[a]	0.28	0.6 (0.4 to 0.9)[a]	0.79	No	No
Navigation						
A (*n*=10)	0.0 (−0.3 to 0.4)	0.77	0.4 (0 to 0.8)	0.44	Yes	Yes
B (*n*=10)	−0.3 (−0.8 to 0.2)	0.84	0.8 (0.4 to 1.3)[a]	0.14	Yes	No
C (*n*=10)	−0.5 (−1.1 to 0.1)	0.82	−0.5 (−1.2 to 0.2)	0.40	Yes	Yes
D (*n*=10)	−0.2 (−0.7 to 0.3)	0.98	0.7 (0.3 to 1.2)[a]	0.60	Yes	No
E (*n*=10)	−0.5 (−0.8 to −0.2)	0.59	0.0 (−0.5 to 0.4)	0.79	Yes	Yes
F (*n*=10)	−0.2 (−0.7 to 0.3)	0.66	0.8 (0.2 to 1.4)[a]	0.49	Yes	No
Mimics						
A (*n*=10)	0.3 (0.2 to 0.5)	0.87	0.2 (0.0 to 0.5)	0.23	Yes	Yes
B (*n*=10)	0.1 (−0.1 to 0.3)	0.81	−0.1 (−0.3 to 0.1)	0.16	Yes	Yes
C (*n*=10)	−0.1 (−0.2 to 0)	0.78	0.0 (−0.3 to 0.3)	0.08	Yes	Yes
D (*n*=10)	0.4 (0.1 to 0.6)	0.32	0.2 (0.4 to 0.4)	0.89	Yes	Yes
E (*n*=10)	0.0 (−0.2 to 0.2)	0.03	−0.1 (−0.3 to 0.1)	0.65	Yes	Yes
F (*n*=10)	0.5 (0.3 to 0.6)	0.17	0.3 (0.1 to 0.5)	0.25	Yes	Yes

MSCT multislice computed tomography = conventional CT, *CBCT* cone-beam computed tomography, *SWT* Shapiro–Wilk test (*p* value)

[a]Delta value outside the ±0.5-mm range

accuracy and RMSE values are below 1.5. All mean values are within the ±0.5 mm range around the reference value. The deviations are therefore negligible for the clinical application.

When using the planning tool or Mimics®, the reference distance is always underestimated. This may be due to the layer thickness and size of the FOV and the voxel size of the reconstructions. But almost all mean values are within the ±0.5 mm range around the reference value, too, except for two values from the planning tool within the ±1.0 mm range (Fig. 3). Nevertheless, the accuracy is therefore acceptable.

Table 5 Results of ANOVA: critical *p* value — $p<0.01$

Distance	ANOVA (*p* values)	
	Measuring method	Scanning method
A	0.431	0.591
B	0.074	0.056
C	0.046	0.974
D	0.178	0.214
E	0.021	0.678
F	0.026	0.109

CBCT

Mean value diagrams are always different and the scattering of the values is low. This might indicate a random error in the measurements. Three values calculated by navigation were within the ±0.5 mm range around the reference value and three values were within the ±1 mm range. Therefore, the accuracy is sufficient for image guided dental implantology. Before starting navigation, an additional accuracy check with determined anatomical landmarks is always mandatory as described in the MSCT section.

The values calculated by the planning tool or Mimics® were closer to the reference values. This can be explained by the smaller FOV and the smaller voxel size. Only one value from the planning tool was not in the ±0.5 mm range (Fig. 3).

It is known from the literature that the background noise is increased while image contrast is reduced when calculating axial slices out of CBCT raw data [18]. This is mainly due to the complex algorithms necessary compared to the direct acquisition of axial data from MSCT. The identification of very fine anatomical structures and the differentiation between cortical and cancellous bone is hampered [7, 19]. Obviously, the accuracy of imaging skeletal structures with

CBCT is controversially discussed in the literature [14, 15, 20, 21], and there exist variations between different devices [21]. Nevertheless, the accuracy of the CBCT unit used in our study (KaVo 3D eXam system™) yielded satisfying results and image quality.

When regarding the differences in effective radiation dose values, it can be seen that CBCT means less radiation for the patient with values ranging from 27 (low dose) to 1,073 μSv compared to 474 (low dose) to 1,410 μSv for MSCT [12]. Whenever possible, the aim has to be the use of special low-dose protocols in order to reduce effective radiation dose values without significantly impairing image quality [12, 22]. The wide range of reported CBCT dose values has mainly device specific reasons and therefore a comparison is difficult [1]. Although the comparison of different radiation dose values was not the purpose of his study, its impact in the daily routine has to be considered. Generally, the ALARA principle (as low as reasonably achievable; International Commission on Radiation Protection, ICRP 2007 [23]) has to be respected and the image parameters for both MSCT and CBCT have to be optimized to achieve sufficient image quality at the lowest possible radiation exposure [24]. When using low dose protocols, the radiation dose values of CBCT are only approximately 10% of the lowest MSCT values [1, 25, 26]. But recently, progress has been achieved in dose reduction also for MSCT and dose levels similar to CBCT values without a decrease in image quality seem to be possible in the future [27].

Against this background, the routine application of CBCT for dental implant planning and intraoperative navigation seems to be a valid alternative to the established gold standard MSCT [28].

In general, two main 'factors' have to be considered in context with navigation accuracy in image guided dental implantology: On one hand, the quality of the imaging data per se, on the other hand the registration method. The influence of the imaging data quality was subject of the presented study, while in a recently published report, Widmann et al. [29] focus on the registration method in CBCT and MSCT protocols.

Concerning CBCT significantly lower radiation exposure, reasonably short scanning times, compact design together with adequate accuracy are the main advantages. The data of our study prove that the application of CBCT for the indicated purpose yielded good results comparable to those of MSCT. All three measuring methods were feasible, and accuracy was adequate with the data acquired by CBCT within the setting of this study.

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Conflict of interest None declared.

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