Dentomaxillofacial Radiology (2008) 37, 10–17
© 2008 The British Institute of Radiology
http://dmfr.birjournals.org

RESEARCH

Accuracy of linear measurements using dental cone beam and conventional multislice computed tomography

A Suomalainen*[,1], T Vehmas[2], M Kortesniemi[3], S Robinson[1] and J Peltola[1,4]

[1]Department of Radiology, Helsinki University Central Hospital, Finland; [2]Department of Occupational Medicine, Finnish Institute of Occupational Health, Helsinki, Finland; [3]HUS Helsinki Medical Imaging Centre, University of Helsinki, Finland; [4]Department of Oral Radiology, Institute of Dentistry, University of Helsinki, Finland

Objectives: The aim of this study was to evaluate the accuracy of linear measurements obtained with dental cone beam CT (CBCT) and multislice CT (MSCT) by altering radiation doses using pre-operative planning of the placement of oral implants as a model.
Methods: A human cadaver mandible was examined in two edentulous areas and one dentate area using CBCT and MSCT. The mandible was examined both dry and immersed in sucrose solution isointense with soft tissue. Two readers measured four linear distances twice from each section. The mandible was cut into 4 mm thick slices at three marked places. These slices were microradiographed and used as the gold standard for measurements from each section.
Results: The intraclass correlations between the intra- and interobserver readings obtained with the different methods showed almost perfect matches. The measurement error (ME) showed significant differences between the methods studied ($P = 0.022$): the mean ME was 4.7% for CBCT and 8.8% for MSCT of the dry mandible, 2.3% and 6.6%, respectively, for the mandible immersed in sucrose solution and 5.4% for low-dose MSCT. Lowering the MSCT radiation dose to less than a quarter of its conventional original value did not significantly affect the ME.
Conclusions: CBCT is a reliable tool for implant-planning measurements when compared with MSCT. In this study, a considerable radiation dose reduction could be achieved with low-dose MSCT examinations without a major loss of measurement accuracy.
Dentomaxillofacial Radiology (2008) **37,** 10–17. doi: 10.1259/dmfr/14140281

Keywords: radiology; computed tomography; cone beam; dental implant

Introduction

Neither intraoral nor panoramic radiographs give the three-dimensional (3D) information of the imaged area needed for optimal pre-operative planning of dental implant placement. Different cross-sectional tomograms, CT and, more recently, special dental cone beam CT (CBCT) examinations have been used for this purpose.[1,2]

Helical CT involves simultaneous translatory movement of the patient while the X-ray tube and the detector rotate around the gantry axis. This permits continuous data acquisition, image reconstruction and archiving as the entire volume of interest is scanned. Special algorithms allow multiplanar computer-reformatted two-dimensional (2D), 3D and panoramic reconstructions. For example, DentaScan software (GE Medical Systems, Global Center, Milwaukee, WI) allows 2D orthoradial multiplanar reformatted images to be reconstructed in addition to axial and panoramic images. The plane of the images is perpendicular (orthogonal) to the curvature of the dental arch.[3] Depending on the imaging settings used, the effective dose of a dental CT examination is 15–74 times higher than that of a panoramic radiograph.[4] Conventional CT produces relatively high radiation exposure, particularly without low-dose settings, and is therefore only recommended in anatomically difficult cases or in connection with extensive implant treatment.[5]

---

*Correspondence to: Anni Suomalainen, Department of Radiology, Helsinki University Central Hospital, PO Box 263 (Kasarmikatu 11-13), FI–00029 HUS, Finland; E-mail: anni.suomalainen@hus.fi
Received 21 August 2006; revised 26 January 2007; accepted 18 February 2007

Recently, CBCT devices have been developed for dentomaxillofacial imaging.[6–10] CBCT uses a cone-shaped X-ray beam and a scan range with a more restricted field of view (FOV) in the axial dimension than in multislice CT (MSCT). Pre-operative bone volume and structure can be evaluated with CBCT.[11–14] The benefits of CBCT are lower costs, smaller device size and lower radiation dose than MSCT.[6,7,15] However, low dose-settings can almost reduce the radiation dose in conventional single-slice or MSCT examination to that of CBCT.[4]

The aims of the present study were: (i) to evaluate the accuracy of linear measurements in the posterior mandible using CBCT (3D Accuitomo) and MSCT; (ii) to evaluate the accuracy of low-dose examinations; and (iii) to assess the intra- and interexaminer reproducibility of these evaluations.

Materials and methods

The CBCT study was performed with a 3D Accuitomo device (3D Accuitomo, J Morita MFG. Corp., Kyoto, Japan). The function of the Ortho-CT, which is the prototype of the 3D Accuitomo CBCT, is described in detail in Arai et al.[7] Imaging values of 80 kVp, 3 mA and 17 s exposure time, together with a 0.25 mm copper (Cu) filter and 1 mm reconstructed slice thickness were used in the CBCT examination.

The MSCT study was performed with a four-slice scanner (LightSpeed Plus, GE Medical Systems). DentaScan software (GE Medical Systems) was used to reconstruct 2 mm thick 2D orthoradial multiplanar reformatted images. A comprehensive data analysis was performed for scanning parameters of the MSCT SE 759–SE 905 (Table 1). Radiation exposures of the scans were further reduced, but exact measurements then became uncertain or impossible to make.

The cadaver mandible was imaged with the CBCT and MSCT devices (i) dry and, in order to better resemble the clinical situation concerning the radiation attenuation and scattering properties of the region examined in patients, (ii) immersed in sucrose liquid isointense with soft tissue (ICRU-44; 53.3 HU) placed in a 15 × 15 × 9 cm plastic box. Low-dose MSCT examinations were performed only with the cadaver mandible immersed in sucrose solution. The position of the mandible in the sucrose solution was maintained at a constant during the examinations. The same human cadaver mandible was used in a previous study to evaluate the accuracy of cross-sectional tomograms obtained with four panoramic radiographic units in the assessment of implant site measurements.[16]

The cadaver mandible was fixed with a horizontal plate to the 3D Accuitomo CBCT device and images were reconstructed perpendicular to the inferior border of the mandible. In MSCT, the cadaver mandible was imaged with the median sagittal plane perpendicular to the horizontal plane and the inferior border of the mandible parallel to the axial slice plane, as recommended by the DentaScan protocol, and 2D orthoradial multiplanar reformatted images were reconstructed.

The linear distances in the mandibular area in the first and second molar regions (edentulous regions) on the right and in the second premolar region (dentate region) on the left were measured in millimetres. In

Table 1 The scanning parameters used in multislice CT (MSCT) and the corresponding radiation and effective doses. Automatic milliampere modulation (AutomA) was used in three protocols (SE 910, SE 915 and SE 920)

Protocol	*Tube current (mA)*	*Voltage (kV)*	*Pitch/table feed (mm)*	*Rotation time (s)*	*Radiation dose, $CTDI_{vol}$ (mGy)*	*Radiation dose, DLP (mGy cm)*	*Effective dose, E (mSv)*
SE 759	80	140	0.75/3.75	0.8	27.4	153.0	0.45
SE 815	60	140	0.75/3.75	0.8	20.5	114.8	0.34
SE 820	40	140	0.75/3.75	0.8	13.7	76.5	0.22
SE 825	80	140	1.5/7.5	0.8	13.7	79.1	0.23
SE 830	60	140	1.5/7.5	0.8	10.3	59.4	0.17
SE 835	40	140	1.5/7.5	0.8	6.8	39.6	0.12
SE 840	80	120	0.75/3.75	0.8	20.1	112.2	0.31
SE 845	60	120	0.75/3.75	0.8	15.1	84.2	0.23
SE 850	40	120	0.75/3.75	0.8	10.0	56.1	0.15
SE 855	80	120	1.5/7.5	0.8	10.0	58.0	0.16
SE 860	60	120	1.5/7.5	0.8	7.5	43.5	0.12
SE 865	40	120	1.5/7.5	0.8	5.0	29.0	0.08
SE 870	80	100	0.75/3.75	0.8	12.9	72.2	0.19
SE 875	60	100	0.75/3.75	0.8	9.7	54.2	0.15
SE 880	40	100	0.75/3.75	0.8	6.5	36.1	0.10
SE 885	80	100	1.5/7.5	0.8	6.5	37.3	0.10
SE 890	60	100	1.5/7.5	0.8	4.8	28.0	0.08
SE 895	40	100	1.5/7.5	0.8	3.2	18.7	0.05
SE 900	100	80	0.75/3.75	1.0	11.3	63.1	0.17
SE 905	100	80	1.5/7.5	1.0	5.6	32.6	0.09
SE 910	78.9	140	0.75/3.75	0.8	27.0	150.9	0.44
SE 915	122.5	120	0.75/3.75	0.8	30.7	171.8	0.47
SE 920	154.1	100	0.75/3.75	0.8	24.9	139.1	0.37

CTDI, CT dose index; DLP, dose–length product edentulous regions cross-sectional sites were marked by gluing an orthodontic tube onto the alveolar crest. A second tube was glued onto the buccal aspect of the mandible, on a line drawn from the first tube perpendicular to the inferior border of the mandible. In the dentate region, only one tube glued to the buccal aspect was used. The marks were used to verify the correct sites for the slices used for the measurements.

The radiographs were evaluated blind and separately by two specialists in oral and maxillofacial radiology (AS and JP), who chose the image slice with the orthodontic tubes best visible. The adjacent slices were used as complementary images if the structures used for measurements could be identified more clearly in them. The measurements were made twice, with a 2 week interval between. The measurements were: A, total height of the mandible; B, distance of the alveolar crest from the mandibular canal; C, thickness of cortical bone at the most inferior aspect of the mandible; D, thickness of mandible at the height of the superior bony crest of the mandibular canal (Figure 1). On the left in the second premolar region, the total height of the mandible was greater than the radiation field height at the centre of the rotation of the CBCT. For this reason two examinations were performed in this region with CBCT and the total height of the mandible was measured using two cross-sectional images.

The mandible was cut into 4 mm slices at the positions marked by the orthodontic tubes. These slices were microradiographed, measured from the film using a slide gauge and used as the gold standard for measurements as described previously.[16] The magnification factor for the microradiographs was 1.0. Programs of the CBCT and MSCT equipment automatically take into consideration their magnification factors.

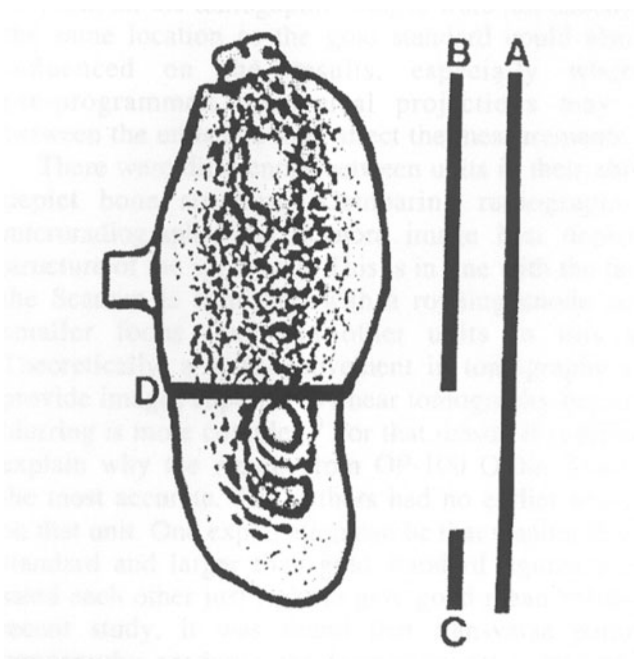

Figure 1 The four measurements taken from each cross-sectional radiograph: A, total height of the mandible; B, distance of the alveolar crest from the mandibular canal; C, thickness of the cortical bone at the most inferior aspect of the mandible; D, thickness of the mandible at the height of the superior bony crest of the mandibular canal

Radiation doses for the MSCT examinations were recorded as dose-length product (DLP) values (mGy cm) displayed at the scanner console. The displayed DLP could be calculated as the product of the pitch-corrected weighted CT dose index ($CTDI_{vol}$) value also displayed at the console and the effective length of the helical CT scan. Different DLP values from consecutive MSCT scans with adjusted imaging parameters but identical scan lengths thus correspond directly to the differences in $CTDI_{vol}$ values within the scanned area. $CTDI_{vol}$, DLP and effective doses were also calculated with the CT-EXPO (v1.5.1(E)) program.[17] Effective doses were determined according to the ADAM mathematical male model, whereas the EVA female model was also used to test the difference in similar radiation exposure between genders.[18] The position of the 5 cm scan length in the effective dose calculation was according to the actual scans performed with the MSCT. The dose display for MSCT was evaluated by measuring the radiation output using a standard pencil ionization chamber with an effective length of 10 cm in the CTDI head phantom (PMMA cylinder of 16 cm diameter). The radiation output in CBCT was assessed with a similar measurement set-up, including measurements in the scan FOV and in peripheral regions of the head phantom (outside the scan FOV). The resulting doses were compared with the published values.[4]

Statistical methods

4 points in the phantom were evaluated from 3 tomographic slices, thus making 12 measurements per observer for each tomographic method. Observer action was assessed by calculating the single measures intraclass correlation for intra- and interobserver performance for the distances measured in the phantom.[19] The measurement error (ME) was defined as:

$$\text{ME} = \text{absolute value}\,[(X_i - GS)/GS], \qquad (1)$$

where X_i is the measured actual length with a particular method and GS indicates its gold standard measurement. X_i was the mean value of two measurements performed by two observers (four measurements altogether) in each particular tomographic method. Due to its right-skewed frequency distribution, the ME was square-root transformed to facilitate the statistical calculations. The ME was correlated with the estimated radiation dose using the Pearson correlation. The mean ME in CBCT, CBCT in which the cadaver mandible was embedded in sucrose solution, MSCT and MSCT in which the cadaver mandible was embedded in sucrose solution using scanning parameters as in SE 759 and 905, were compared with the analysis of variance, repeated measures design (sphericity assumed, deviation contrast). To further explore the technical parameters (*i.e.* tube voltage (kV), current (mA), rotation time (s) and the pitch factor), multiple regression was used. These parameters were simultaneously set as independent variables and thus adjusted for their mutual effects, while ME was the outcome variable. SPSS 12.0 (SPSS Inc, Chicago, IL) software was used. P-values of less than 0.05 were considered significant.

The number of measurements successfully performed in two sessions and by two radiologists (theoretically ranging from 0 to 48) was correlated with radiation dose using the Spearman correlation. Individual contributors given above were related to this number of successful measurements for each method with ordinal regression.

Results

The mean ME for the material as a whole was 6.5%. This varied according to the imaging method (Figure 2). Radiation dose had a significant negative correlation with ME ($r = -0.159$, $P = 0.008$, Figure 3) as well as with its transformed value ($r = -0.171$, $P = 0.004$). ME showed significant differences between the methods studied ($P = 0.022$) (Table 2, Figure 4). CBCT with cadaver mandible embedded in sucrose solution was thus the best method. Of the potential determinants of ME, only the pitch factor was significantly related. These relationships remained fairly constant even when the measurement site was added to the model as a categorical covariant (SPSS general linear model). The model with milliampere and tube voltage settings, rotation time and pitch factor as independent variables explained 5.3% of the variation in ME. The intraclass correlations between intra- and interobserver readings for the different methods showed an almost perfect match with some of the values presented in Table 2.

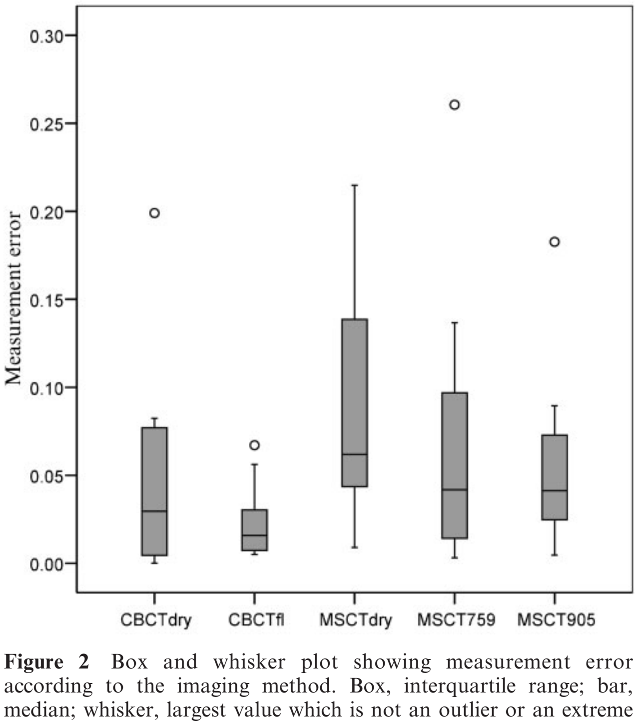

Figure 2 Box and whisker plot showing measurement error according to the imaging method. Box, interquartile range; bar, median; whisker, largest value which is not an outlier or an extreme score; outlier, more than 1.5 box lengths above the box; CBCT dry, cone beam CT of dry mandible; CBCT fl, CBCT of mandible in sucrose solution; MSCT dry, multislice CT of dry mandible; MSCT759, MSCT of mandible in sucrose solution using conventional scanning parameters SE 759; MSCT905, low-dose MSCT of mandible in sucrose solution using scanning parameters SE 905. For scanning parameters in MSCT see Table 1

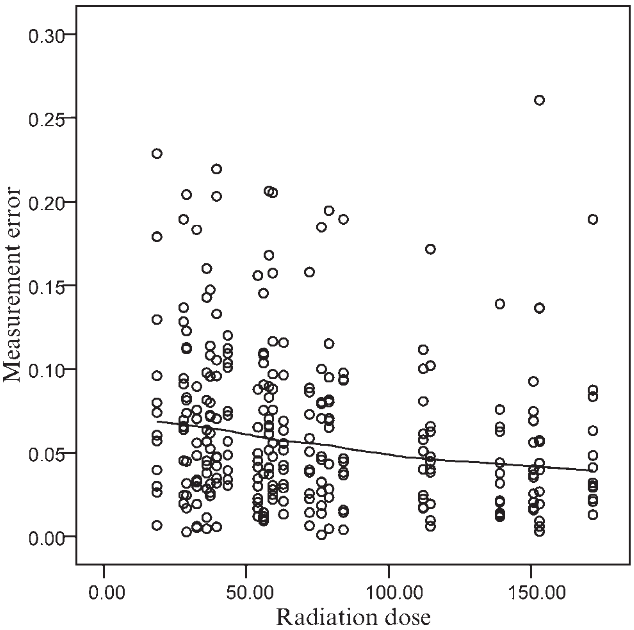

Figure 3 Locally smoothed scatter plot indicating the association between radiation dose (dose-length product (mGy cm)) and measurement error. Analysis performed using MSCT SE 759–SE 920, see Table 1

There was a good correlation between the number of successful measurements and the radiation dose ($r_S = 0.620$, $P < 0.001$) (Figure 5). This analysis was performed using all data, including the measurements with further reduced radiation exposure. In the multiple ordinal regression model, the pitch factor was negatively associated with the number of successful measurements ($P < 0.001$) as opposed to the tube voltage, which was a positive contributor ($P < 0.001$). The effect of the milliampere settings was positive but not significant ($P = 0.120$).

The $CTDI_{vol}$ and DLP radiation dose values recorded from the console display in MSCT scans were within the ranges of 3.2–30.7 mGy and 18.7–171.8 mGy cm, respectively. The calculated radiation doses were in agreement with the recorded doses within the limits of dosimetric uncertainty. The effective doses from the MSCT scans were from 0.05 mSv to 0.47 mSv, calculated according to the ADAM mathematical male model.

Table 2 Intraclass correlations: Intrareader agreement (AS 1 *vs* AS 2), interreader agreement (AS 1 *vs* JP 1) and measurement errors (ME). For scanning parameters in MSCT, see Table 1

Imaging method	*AS measurement 1* vs *2*	*AS measurement 1* vs *JP measurement 1*	*Mean ME (%)*
CBCT (dry mandible)	0.999	0.999	4.7
CBCT (mandible in sucrose solution)	1.000	0.999	2.3
MSCT (dry mandible)	0.999	1.000	8.8
MSCT SE 759 (mandible in sucrose solution)	0.999	0.999	6.6
MSCT SE 905 (mandible in sucrose solution)	0.999	0.997	5.4

CBCT, cone beam CT; MSCT, multislice CT

Effective doses calculated according to the EVA female model were 33% larger. The recorded physical doses ($CTDI_{vol}$ and DLP) and calculated effective doses in MSCT scans are presented with relevant scan parameters in Table 1. The dose values measured in CBCT were 2 mGy in the central scan region and 1 mGy in the peripheral region of the head phantom. The obtained values agreed satisfactorily with the published values, taking into account the differences between the dose assessment methods.[4]

Discussion

Conventional CT is generally accepted as an accurate tool for measuring bony structures. In the present study, we demonstrated that the error of linear measurements is even smaller with CBCT than with MSCT when using pre-operative planning of the placement of oral implants as a model.

With the DentaScan program used in MSCT in this study, the slices are produced in a predetermined angle to the object. This angle depends on the position of the object during the examination. In mandible it is desirable to produce cross-sectional slices perpendicular to the mandibular canal. In clinical practice, however, the mandibular canal is not visible. The orientation of the inferior border of the mandible coincides reasonably well with the orientation of the plane of the mandibular canal. The aim was to place the cadaver mandible in a position which results in cross-sectional slices perpendicular to the inferior

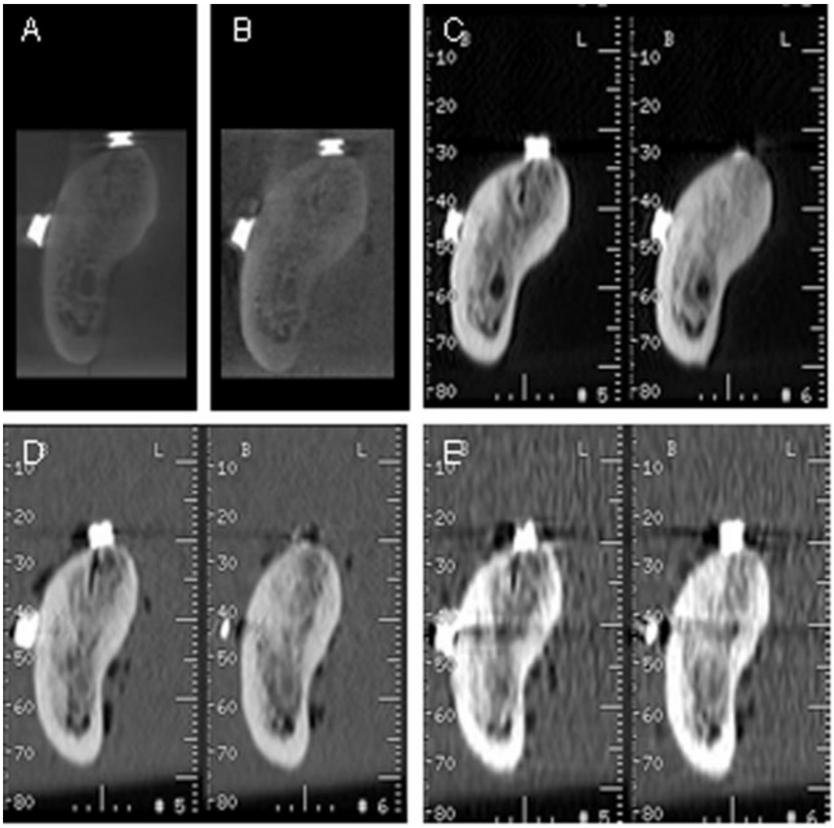

Figure 4 Cross-sectional images on the right side in the second molar region. A, cone beam CT (CBCT) image of dry mandible; B, CBCT image of mandible in sucrose solution; C, multislice CT (MSCT) images of dry mandible; D, MSCT images of mandible in sucrose solution using conventional scanning parameters SE 759; E, low-dose MSCT images of mandible in sucrose solution SE 905. For scanning parameters in MSCT, see Table 1. The images have been digitally enhanced

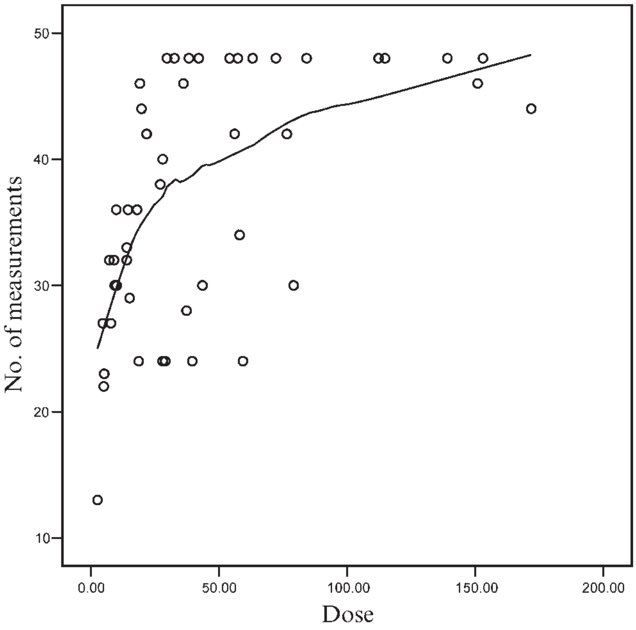

Figure 5 Number of successful measurements related to the radiation dose (dose-length product (mGy cm)). Analysis performed using all data, including measurements with further reduced radiation exposure

border of the mandible. The orthodontic brackets used as landmarks for orientation and measurements of the object were always visible in the same slice of the region of interest. However, because of the orientation of the object, the brackets were not always optimally situated for the measurements. This merely mimics the difficulties faced in optimal placement of patients in clinical situations. The region(s) of interest may be situated in such a way that it may be impossible to produce satisfactory images for accurate measurements with a single scan. With CBCT this disadvantage can be overcome, because slicing can be done in arbitrary planes for optimal orientation of the region of interest.

There was little difference in intra- and interexaminer repeatability between these methods. With the limited material available in this study, low-dose MSCT examinations, with radiation dose less than a quarter of conventional values, produced images with a quality sufficient to make reliable linear measurements for the pre-operative planning of placement of oral implants. For sufficient image quality the acceptable threshold values for scanning parameters varied. There were substantial variations in different regions of the mandible. The MSCT scan protocol can be further optimized by adjusting the pitch factor. The number of images with insufficient quality increased along with decreasing radiation dose. It seems that experienced readers are able to exclude examinations with poor image quality, and thus avoid major measurement errors. Automatic milliampere modulation (AutomA) protocols resulted in relatively high radiation doses with the measurement set-up and noise index settings used here. However, in clinical scans the AutomA settings could be optimized for low-dose examinations as appropriate to the clinical indications.

Kobayashi et al[20] compared the accuracy of measurement of distance using limited CBCT (LCBCT) and helical CT (HCT). The vertical distance from a reference point to the alveolar ridge was measured in five cadaver mandibles. A significantly smaller measurement error was also observed in their study for LCBCT than for HCT, 1.4% and 2.2%, respectively ($P < 0.0001$). Our figures for measurement errors are higher than in the study of Kobayashi et al.[20] This can be explained at least in part by the thickness of the cortex of the inferior border of the mandible. Even a minor measurement error leads to a considerable relative difference from the gold standard. This, however, is not a problem in clinical dental practice because the main interest focuses on the dimensions of the alveolar crest cranial to the mandibular canal. One explanation for the poorer result in the mandibular left premolar area in our study is that the total height of the crest had to be measured from two CBCT images. In the dentate region, the difficulty of selecting the exact level of the alveolar crest might also explain the higher ME. In the edentulous regions, an orthodontic tube fixed onto the alveolar crest as well as onto the buccal aspect of the mandible made it easier to define the correct measurement points than in the dentate region. It is noteworthy that the values representing the gold standard also contain a source of error. Although anatomical structures were clearly seen in microradiographs, the measurement agreement was not perfect.[16]

The pixel size of the 3D Accuitomo is 0.125 × 0.125 mm and, due to the isotropic volume data of CBCT examination, the voxel size of the 3D Accuitomo is 0.125 mm per side. The calculated pixel size of the MSCT used in this study is approximately 0.25 × 0.25 mm. Thus, a one pixel error in our MSCT measurements is larger than in our CBCT measurements. It is obvious that measurements of images with a better resolution are prone to a smaller measurement error. It should be noted, however, that CBCT devices are not all alike. When using a CBCT device with a larger FOV and a pixel size corresponding to that of a MSCT device, similar measurement accuracy for CBCT and MSCT may be expected.

Good geometric accuracy has been reported for the NewTom 9000 CBCT (Quantitative Radiology, Verona, Italy).[6,21] Mozzo et al[6] evaluated geometric accuracy with reference to various reconstruction modalities and different spatial orientation. The reported difference between the true value and general mean value was 0.8–1% for width measurements and 2.2% for height measurements. A phantom with two circular inserts was used in this study together with the automatic option for measurements. With this option it is possible to select a segment across the two bone soft tissue edges of interest. The software then analyses the corresponding densitometric profile, automatically setting the bone borders at half the height of the edges.

This may explain the good results reported in this phantom study. According to Lascala et al,[22] the NewTom 9000 CBCT image underestimates the actual distances between skull sites. However, the differences are only significant for the skull base. The NewTom 9000 CBCT is reliable for linear evaluation measurements of other structures more closely associated with dentomaxillofacial imaging. In addition, certain image artefacts have been reported with the 3D Accuitomo CBCT scanner, depending on the object material and X-ray tube voltage, probably due to the properties of the image detector (image intensifier).[23] No such image deformations were observed in this study.

Ekestubbe et al[24] demonstrated that low-dose CT performs as well as high-dose CT for tomographic imaging for dental implant planning in the posterior parts of the mandible. This was shown in a study in which CT examinations with low milliampere-second settings were compared with conventional values and the images were graded visually (40 mAs to 280 mAs). The visibility of the alveolar crest and the mandibular canal were evaluated. Rustemeyer et al[25] also concluded that a considerable dose reduction without a loss of diagnostic information is achievable in dental CT. Our results are in accordance with those of Ekestubbe et al[24] and Rustemeyer et al.[25] High-contrast structures such as the jawbone and teeth can be imaged using radiation doses significantly lower than those recommended by the manufacturers for implant planning measurements. According to Cohnen et al,[4] in conventional CT, low-dose examinations can reduce the radiation dose nearly to that of CBCT.

Depending on the CT scan settings, the effective dose from a dental CT examination is 15 to 74 times higher than that from a panoramic radiograph.[4] The effective doses calculated for MSCT in this study were of the same magnitude, but still slightly lower than the doses reported by Cohnen et al.[4] However, it should be noted that effective doses are by definition statistical values concerning the carcinogenetic and hereditary risk of ionizing radiation to a particular population. Thus effective dose should not be used to evaluate the risk to individual patients. Ekestubbe et al[24] showed that the radiation doses absorbed by most organs were three to ten times higher than for conventional tomography when ordinary CT protocols were used. Dula et al[26] have reported that a series of four conventional tomograms of a single-tooth gap in the molar region corresponds to 13% of the biological risk from CT of the maxilla. In addition to the higher radiation dose, the cost of a CT examination is also higher than that of conventional tomography. For these reasons, conventional CT is recommended only in anatomically difficult cases or in connection with extensive implant treatment.

On the other hand, the radiation dose from CBCT is lower than that from conventional CT. Reported reductions range from two to three times, to as much as six times lower than that of conventional CT.[4,6,27] However, there is a wide variation in doses between different CT scan protocols with different diagnostic targets. In low-dose dental CT the dose can be reduced to less than a quarter of that from conventional CT and, as such, the difference in effective dose will not be significant when compared with the dose reported in CBCT.[4] The differences in applicable scan ranges in CBCT and MSCT should also be taken into account when overall radiation exposures are considered or scan protocol optimization is performed in order to minimize radiation exposure in CBCT or MSCT.

It has been reported that the effective dose from CBCT is from three to ten times higher than that from a panoramic radiograph.[4,28] Varying the FOV of the CBCT affects the effective dose as the primary physical absorbed dose distribution in the scanned and surrounding tissue regions due to the primary and scattered radiation changes with adjustments to beam collimation and overall beam geometry.

The intraclass correlations between the intra- and interobserver readings for the different methods showed an almost perfect match. However, the same measurements were evaluated continuously, which may have strengthened the apparent reliability of the measurements. The 2 week interval between the measurements contributes positively to the reliability.

Even though the cadaver mandible was immersed in sucrose solution isointense with soft tissue, the missing cervical vertebra and skull base may have influenced the results. The study design would have been more representative if a cadaver mandible with soft tissues, skull base and cervical vertebra had been available.

The slice thickness of the gold standard used in this study was 4 mm. In a 4 mm thick slice, an anatomical structure such as a lateral groove in the alveolar process, possibly hampering successful implantation, may remain undetected. In clinical practice, thinner slices help to overcome this problem. In the cadaver mandible used in this study no such defects were present. To mimic typical imaging protocols adopted in daily clinical praxis, we selected reconstructed slice thicknesses of 1 mm in CBCT and 2 mm in MSCT. It can be assumed that no major false notion was caused by differences in slice thickness.

Further studies are needed to evaluate in more detail the suitability of low-dose protocols for dental implant planning in clinical practice. In an osteopenic mandible the observation of the mandibular canal is often difficult and reduction of radiation dose may make it virtually impossible. In addition, the possible differences in imaging maxilla and mandible as well as the suitability of low-dose CT data for stent fabrication in connection with dental implant treatment should be studied.

In conclusion, CBCT is a reliable tool for implant planning measurements compared to MSCT. In this study, a considerable radiation dose reduction could be achieved in MSCT with low-dose settings compared with values obtained for conventional MSCT protocols without adversely affecting measurement reliability.

References

1. Abrahams JJ. Dental CT imaging: a look at the jaw. *Radiology* 2001; **219**: 334–345.
2. Gahleitner A, Watzek G, Imhof H. Dental CT: imaging technique, anatomy and pathologic conditions of the jaws. *Eur Radiol* 2003; **13**: 366–376.
3. Yanagisawa K, Friedman C, Vining E, Abrahams J. DentaScan imaging of the mandible and maxilla. *Head Neck* 1993; **15**: 1–7.
4. Cohnen M, Kemper J, Möbes O, Pawelzik J, Mödder U. Radiation dose in dental radiology. *Eur Radiol* 2002; **12**: 634–637.
5. Tyndall DA, Brooks SL. Selection criteria for dental implant site imaging: A position paper of the American Academy of Oral and Maxillofacial Radiology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2000; **89**: 630–637.
6. Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. *Eur Radiol* 1998; **8**: 1558–1564.
7. Arai Y, Tammisalo E, Iwai K, Hashimoto K, Shinoda K. Development of a compact computed tomographic apparatus for dental use. *Dentomaxillofac Radiol* 1999; **28**: 245–248.
8. Linsenmaier U, Rock C, Euler E, Wirth S, Brandl R, Kotsianos D, et al. Three-dimensional CT with a modified C-arm image intensifier: feasibility. *Radiology* 2002; **224**: 286–292.
9. Heiland M, Schmelzle R, Hebecker A, Schultze D. Intraoperative 3D imaging of the facial skeleton using the SIREMOBIL Iso-C^{3D}. *Dentomaxillofac Radiol* 2004; **33**: 130–132.
10. Araki K, Maki K, Seki K, Sakamaki K, Harata Y, Sakaino R, et al. Characteristics of a newly developed dentomaxillofacial X-ray cone beam CT scanner (CB MercuRay™): system configuration and physical properties. *Dentomaxillofac Radiol* 2004; **33**: 51–59.
11. Terakado M, Hashimoto K, Arai Y, Honda M, Sekiwa T, Sato H. Diagnostic imaging with newly developed ortho cubic super-high resolution computed tomography (Ortho-CT). *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2000; **89**: 509–518.
12. Ito K, Gomi Y, Sato S, Arai Y, Shinoda K. Clinical application of a new compact CT system to assess 3-D images for the preoperative treatment planning of implants in the posterior mandible. A case report. *Clin Oral Implant Res* 2001; **12**: 539–542.
13. Ziegler CM, Woertche R, Brief J, Hassfeld S. Clinical indications for digital volume tomography in oral and maxillofacial surgery. *Dentomaxillofac Radiol* 2002; **31**: 126–130.
14. Sato S, Arai Y, Shinoda K, Ito K. Clinical application of a new cone-beam computerized tomography system to assess multiple two-dimensional images for the preoperative treatment planning of maxillary implants: case reports. *Quintessence Int* 2004; **35**: 525–528.
15. Hashimoto K, Arai Y, Iwai K, Araki M, Kawashima S, Terakado M. A comparison of a new limited cone beam computed tomography machine for dental use with multidetector row helical CT machine. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2003; **95**: 371–377.
16. Peltola JS, Mattila M. Cross-sectional tomograms obtained with four panoramic radiographic units in the assessment of implant site measurements. *Dentomaxillofac Radiol* 2004; **33**: 295–300.
17. Stamm G, Nagel HD. [CT-expo – a novel program for dose evaluation in CT]. *Rofo* 2002; **174**: 1570–1576.
18. Zankl M, Panzer W, Drexel G. The calculation of dose from external photon exposures using reference human phantoms and Monte Carlo methods Part VI: Organ doses from computed tomography examinations. GSF-Bericht 30/91. Oberschleißheim: GSF-Forschungszentrum, 1991.
19. Norman GR, Streiner DL. Repeated-measures ANOVA and reliability of measurement. Relation between kappa and the intraclass correlation. In: Norman GR and Streiner DL. *Biostatistics: the bare essentials* (2nd edn). Hamilton, Canada: BC Decker Inc., 2000, pp 100, 221–222.
20. Kobayashi K, Shimoda S, Nakagawa Y, Yamamoto A. Accuracy in measurement of distance using limited cone-beam computerized tomography. *Int J Oral Maxillofac Implants* 2004; **19**: 228–231.
21. Marmulla R, Wörtche R, Mühling J, Hassfeld S. Geometric accuracy of the NewTom 9000 Cone Beam CT. *Dentomaxillofac Radiol* 2005; **34**: 28–31.
22. Lascala CA, Panella J, Marques MM. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). *Dentomaxillofac Radiol* 2004; **33**: 291–294.
23. Katsumata A, Hirukawa A, Noujeim M, Okumura S, Naitoh M, Fujishita M, et al. Image artifact in dental cone-beam CT. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2006; **101**: 652–657.
24. Ekestubbe A, Thilander A, Gröndahl K, Gröndahl H-G. Absorbed doses from computed tomography for dental implant surgery: comparison with conventional tomography. *Dentomaxillofac Radiol* 1993; **22**: 13–17.
25. Rustemeyer P, Streubühr U, Suttmoeller J. Low-dose dental computed tomography: significant dose reduction without loss of image quality. *Acta Radiol* 2004; **45**: 847–853.
26. Dula K, Mini R, van der Stelt PF, Buser D. A radiographic assessment of implant patients: decision-making criteria. *Int J Oral Maxillofac Implants* 2001; **16**: 80–89.
27. Schulze D, Heiland M, Thurmann H, Adam G. Radiation exposure during midfacial imaging using 4- and 16-slice computed tomography, cone beam computed tomography and conventional radiography. *Dentomaxillofac Radiol* 2004; **33**: 83–86.
28. Ludlow JB, Davies-Ludlow LE, Brooks SL. Dosimetry of two extraoral direct devices: NewTom cone beam CT and Orthophos Plus DS panoramic unit. *Dentomaxillofac Radiol* 2003; **32**: 229–234.