RESEARCH

Reliability and reproducibility of linear mandible measurements with the use of a cone-beam computed tomography and two object inclinations

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Objective: The aim of this study was to assess the influence of inclination of the object on the reliability and reproducibility of linear measurements of anatomic structures of the mandible on images obtained using cone-beam CT (CBCT).

Methods: Ten linear dimensions between anatomical landmarks were measured in a dry mandible. The measurements were performed with a manual calliper three times by three observers. The mandible was scanned with Planmeca Promax 3D cone-beam CT (Planmeca Oy, Helsinki, Finland) with the base of the mandible parallel as well as tilted 45° to the horizontal plane. Computer measurements of the linear dimension were performed by three observers. The radiographic measurements were performed four times for each experimental setting. A total of 240 measurements were performed. Reproducibility was evaluated through comparison of standard deviation (SD) and estimation of intraclass correlation coefficient (ICC). The error was estimated as the absolute difference between the radiographic measurements and the mean manual calliper measurements.

Results: The mean SD for the radiographic measurements was 0.36 mm for the horizontally positioned mandible and 0.48 mm for the inclined mandible. The ICC between examiners was 0.996 mm, between sessions was 0.990 mm and between CBCT measurements and calliper was 0.992 mm. The overall absolute mean measurement error was 0.40 mm (SD 0.39 mm). The percentage of errors that exceeded 1 mm was 6.7%.

Conclusion: The results revealed high reliability of measurements performed on CBCT images independently from object position, examiner's experience and high reproducibility in repeated measurements settings.

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Keywords: cone beam computed tomography; image reconstruction; reliability of results

Introduction

In the field of dentistry and oral surgery, there are various indications for radiographic examinations with three-dimensional (3D) imaging for both diagnosis and treatment planning.^{1–4} In addition to panoramic and intraoral radiography, CT has frequently been used for implant surgery planning. However, the additional 3D information provided by CT does not always balance

the increase in radiation dose. The introduction of cone-beam CT (CBCT), also called cone-beam volumetric tomography (CBVT), provides 3D images with a considerable reduction of the radiation dose compared with CT examinations,^{5,6} but with an image quality that is equivalent to CT images, particularly regarding hard tissues.⁷

The use of CBCT examinations in various clinical situations has increased in recent years.^{8–12} This includes the planning of implant therapy,¹³ computer-guided implant insertion^{14,15} and intraoperative navigation in maxillofacial surgery.¹⁶

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Table 1 List of the linear distances selected for the study

Molar BL width	Buccolingual width of the crown of the first molar
Molar MD width	Mesiodistal width of the crown of the first molar
Mental foramen	Lower margin of mental foramen—mesial crest of 45 alv.
Alv. 34 MD width	Mesiodistal width of the marginal portion of alv. 34
Parasymphysis	Width of the mandible at midline
Alv. 33 depth	Depth of 33 alv. referred to the distal crest
Alv. 44 depth	Depth of 44 alv. referred to the mesial crest
Alv. 41 BL width	Buccolingual dimension of the marginal portion of alv. 41
Alv. 41 MD width	Mesiodistal dimension of the marginal portion of alv. 41
Alv. 41 depth	Depth of alv. 41 referred to the mesial crest

BL, buccolingual; MD, mesiodistal; alv., alveolus

Prerequisites for the use of sectional images in implant pre-surgical planning are (i) dimensional accuracy of the images by absence of spatial distortions and (ii) reproducibility of linear measurements obtained from bidimensional images derived from the examination. A crucial issue in evaluating reformatted CT scan images is the possibility of spatial distortions owing to the anisotropic nature of the voxel composing the images.^{17–19} CBCT is characterized by isotropic voxels composing the image; reformatting should not cause any distortion and the position of the subject in the scanning device should not affect the accuracy of recording linear measurements on the reformatted images.²⁰

The main objective of the present study was to assess the influence of inclination of the object on the reliability and reproducibility of linear measurements of anatomic structures of the mandible on images obtained with a CBCT device. An additional objective was to assess the reproducibility of measurements performed by examiners with various clinical experience.

Material and methods

Ten different linear distances between defined anatomical points were identified on a dry anonymous human mandible (Table 1). Three examiners (two dental students and one dentist) participated in the study. They measured the defined distances with a manual calliper (Leone, Firenze, Italy) with a precision of 0.1 mm. Prior to the measurements, the observers were trained in the use of the manual calliper. The measurements were performed three times by each observer and the mean of the measurements served as the dimensional truth (Table 2).

The mandible was positioned in a Planmeca Promax 3D unit (Planmeca Oy, Helsinki, Finland) with the mandibular base parallel to the floor as well as at an angle of 45° to the horizontal scanning plane (Figure 1). The mandible was placed and fixed by a silicon-based material on a plastic plate on a custom adapted support that was also inclined at the desired angle. The Planmeca Promax 3D is a multifunctional maxillofacial radiography unit that can perform conventional digital panoramic and cephalometric images in addition to the

3D volumetric tomography images. The CBCT scan is obtained by using a pulsed short X-ray and a CsI-coated complementary metal oxide semi-conductor (CMOS) flat panel digital sensor with a field of view (FOV) dimension of 80 × 80 mm. The total scanning time was 18 s at 56 kVp and 3 mA while an actual exposure time of only 6 s was used. The scan resulted in the production of 300 bidimensional raw images from a shortened rotation of 194° around the subject. The 3D volume consisted of 0.16 mm cubical voxels reconstructed from the bidimensional images by a proprietary 3D algorithm.

Prior to the measurements of the anatomical landmarks on the CBCT images, the observers were trained in the use of the Romexis® software measurement tools (Planmeca Oy, Helsinki, Finland). No calibration was performed. The observers independently performed their registrations without access to any previously recorded measurements. The person responsible for the data analysis did not participate in the measurement sessions.

The radiographs were viewed on a PC workstation (Hewlett Packard Limited, London, UK) with a professional screen (AG Neovo Technology B.V., LL Capelle a/d IJssel, Netherlands). To perform the radiographic assessments of the defined distances, each examiner had to explore the 3D model (Figure 2). The model was re-oriented in order to find the best orientation to generate a two-dimensional (2D) image for the measurement of a specific distance. The defined distances were measured on the 2D images on the computer screen utilizing the measurement tool of the given software.

Table 2 Length in mm obtained for the different linear distances on the dried skull measured with a manual calliper

Segment	Mean	SD
Molar BL width	10.30	0.19
Molar MD width	10.97	0.14
Mental foramen	15.62	0.42
Alv. 34 MD width	4.57	0.21
Parasymphysis	10.98	0.04
Alv. 33 depth	16.67	0.65
Alv. 44 depth	14.26	0.47
Alv. 41 BL width	4.48	0.37
Alv. 41 MD width	2.51	0.21
Alv. 41 depth	10.00	0.00

SD, standard deviation; BL, buccolingual; MD, mesiodistal; alv., alveolus

Figure 1 The experimental setting with horizontal and 45° inclined mandible

The measurements on the dried mandible were performed 1 month prior to the radiographic assessments. The radiographic measurements were repeated four times during 2 days. The time interval between the two measurement days was 3 weeks. Each day consisted of two measurement sessions, one in the morning and one in the afternoon. In order to minimize the potential bias of repeated measurements, the sequence of measurements was randomly assigned between and within examiners. The total number of measurements recorded was 240.

Data analysis

Mean values and standard deviations (SDs) were calculated for descriptive purposes. A reliability analysis was performed between groups of measurements identified by the examiner, repeated measures and type of measurement (scanning of horizontal and inclined mandible) by calculating the intraclass correlation coefficient (ICC) for the single measurement.²¹ In order to evaluate measurement error, the mean value of the manual calliper measurements on the dried mandible was considered as the reference value ("dimensional truth"). The absolute error (AbsErr) between measurements on the dried mandible (*D*) and computer measurements (*C*) was calculated as:

$$\vec{\text{AbsErr}} = |C - D|$$

The relative error (RelErr) was calculated by dividing the AbsErr by the mean measurement on the dried mandible and multiplying by 100:

$$\text{RelErr} = \frac{|C - D|}{D} \times 100$$

All statistical analysis was performed with SPSS 16 software (SPSS Inc., Chicago, IL).

Results

The mean and SD values of linear distances measured by using a calliper on the dried mandible are summarised in Table 2. The mean value ranged from approximately 2.5 mm to 16.7 mm.

The mean linear distance measurements obtained from the radiographic images are reported in Table 3. No significant differences were detected between measurements obtained by the CBCT scanned with 2 different inclinations of the mandible (0° and 45°

Figure 2 The three-dimensional model and two-dimensional sections for distance measurement

Table 3 Radiographic measurements in mm obtained for the different segments on the cone beam CT (CBCT) images

Segment	CBCT 0°		CBCT 45°	
	Mean	SD	Mean	SD
Molar BL width	10.49	0.18	10.65	0.28
Molar MD width	11.23	0.30	10.97	0.44
Mental foramen	16.19	0.52	15.78	0.29
Alv. 34 MD width	4.35	0.62	4.17	0.77
Parasymphysis	11.23	0.27	11.21	0.58
Alv. 33 depth	16.18	0.43	16.48	1.04
Alv. 44 depth	13.93	0.39	13.99	0.29
Alv. 41 BL width	4.76	0.42	4.48	0.24
Alv. 41 MD width	2.46	0.12	2.33	0.19
Alv. 41 depth	9.87	0.38	9.34	0.72

BL, buccolingual; MD, mediobuccal; alv., alveolus; SD, standard deviation

angulations). The average SD was 0.36 mm for the horizontal CBCT and 0.48 mm for the 45° CBCT.

The degree of correlation between the measurements recorded from different examiners as testified from the ICC was significant ($P < 0.001$) and amounted to 0.996 (95% confidence interval (CI) 0.995–0.997) (Table 4).

The ICC between the measurements recorded at repeated sessions (reproducibility) was significant ($P < 0.001$) and amounted to 0.99 (95% CI 0.985–0.993) (Table 5).

The ICC between the measurements recorded on the dried skull by the use of the manual calliper and the measurements obtained on the radiographic images was significant ($P < 0.001$) and amounted to 0.992 (95% CI 0.988–0.994) (Table 6).

The absolute measurement errors based on the difference between the CBCT (0° and 45° angulations of the jaw) and the mean anatomical measurements for the different segments are reported in Table 7. The magnitude of the mean error ranged from 0.09 mm for the mesiodistal dimension of the alveolus of 41 elements to 0.98 mm for the height of a bone septum between two alveoli. The overall mean absolute error

was 0.40 mm (SD 0.39 mm). The percentage of errors that exceeded 1 mm was 6.7%. The relative error ranged from 1% to 19% according to the different segment.

The mean of all the absolute differences between the measurements obtained from the CBCT of the mandible horizontally positioned and the anatomical measurements was 0.36 mm (SD 0.34 mm), whereas the corresponding figure for the CBCT of the mandible projected at 45° angulation to the horizontal plane was 0.45 mm (SD 0.42 mm).

To allow a visual evaluation of the dispersion of the radiographic measurements around the anatomical value, the values are plotted in a graph (Figure 3).

Discussion

The findings of the present study demonstrated a high reproducibility and reliability of measurements performed on CBCT images.

The use of only one sample limited the possibility of variation in anatomical features but this potential weakness of the study was partly compensated for by defining ten different measurement locations on the mandible with different distances from the centre of rotation.

The observations of the current study correspond to what other authors have recently reported regarding the accuracy of CBCT measurements.^{22–27} However, while in the referenced studies the distances measured were marked by a radiopaque material or an artificial cavity, in our study no such reference was used in order to simulate, as closely as possible, the clinical situation when radiographs are used for clinical measurements or implant treatment planning. Moreover, none of the previous studies have compared different inclination of the same object examined to test the possible dimensional distortions in the reformatted image.

Table 4 Intraclass correlation coefficient for interexaminer radiographic assessment reliability

	Intraclass correlation	95% confidence interval		Significance
		Lower bound	Upper bound	
Single measures	0.996	0.995	0.997	$P < 0.001$
Average measures	0.999	0.998	0.999	$P < 0.001$

Table 5 Intraclass correlation coefficient for intraexaminer radiographic assessment reliability

	Intraclass correlation	95% confidence interval		Significance
		Lower bound	Upper bound	
Single measures	0.990	0.985	0.993	$P < 0.001$
Average measures	0.997	0.996	0.998	$P < 0.001$

Table 6 Intraclass correlation coefficient between anatomical and radiographic measurements

	Intraclass correlation	95% confidence interval		Significance
		Lower bound	Upper bound	
Single measures	0.994	0.992	0.996	$P < 0.001$
Average measures	0.997	0.996	0.998	$P < 0.001$

Table 7 Mean, standard deviation (SD), range of absolute measurement error and mean relative error (MRE) between mean radiographic and mean calliper measurements (mm)

Segment	CBCT 0°					CBCT 45°				
	Mean	SD	Min.	Max.	MRE	Mean	SD	Min.	Max.	MRE
Molar BL width	0.19	0.18	0.00	0.50	2%	0.35	0.28	0.00	0.90	3%
Molar MD width	0.28	0.25	0.00	0.70	3%	0.35	0.25	0.00	1.00	3%
Mental foramen	0.59	0.52	0.00	1.20	4%	0.23	0.25	0.00	0.90	1%
Alv. 34 MD width	0.55	0.35	0.00	1.20	14%	0.68	0.54	0.10	1.60	19%
Parasymphysis	0.27	0.24	0.00	0.70	2%	0.41	0.45	0.00	1.30	4%
Alv. 33 depth	0.54	0.40	0.00	1.10	3%	0.98	0.31	0.30	1.50	6%
Alv. 44 depth	0.41	0.35	0.00	1.00	3%	0.33	0.27	0.00	0.90	2%
Alv. 41 BL width	0.36	0.33	0.00	1.10	7%	0.18	0.14	0.00	0.40	4%
Alv. 41 MD width	0.09	0.08	0.00	0.30	4%	0.20	0.15	0.00	0.40	9%
Alv. 41 depth	0.32	0.24	0.00	0.80	3%	0.79	0.55	0.00	2.00	9%

CBCT, cone beam CT; min., minimum; max., maximum; BL, buccolingual; MD, mesiodistal; alv., alveolus

No significant difference was detected in terms of SD of the radiographic measurements when the mandible was angulated at 45° compared with the horizontal orientation during the scanning procedure. This finding confirms that the spatial distortions of the scanning cylinder is small as the voxels that are composing the image are isotropic.⁶ From a clinical point of view, this means that the positioning of the patient is not crucial in CBCT given that all structures of interest are included in the scanned volume.

The results of this study also showed that the reliability of the measurements was not dependent on

the experience of the operator. This may be attributed to a high image quality in terms of resolution and contrast that allowed the examiner to easily identify the various anatomical structures used as reference points for the measurements.

The software employed allowed the examiners to easily obtain desired 2D sections based on the initial evaluation of the 3D models and to measure the linear distances on the computer screen. The absence of distortions in the 3D model generated from the CBCT is essential when the data are exported to software designed for planning of dental implant placements and

Figure 3 Plot graph of cone beam CT (CBCT) measurements with anatomical mean value as reference. BL, buccolingual; MD, mesiodistal; alv., alveolus

proper positioning of the implants in relation to vital anatomical structures is mandatory.

Compared with CT scans, the radiation dose given to the patient is considerably lower for CBCT examinations.⁵ In CBCT examinations the region of interest is scanned with a single semi-circular pyramid-shaped beam read out in a flat panel detector. The flat panel detector ensures a high spatial resolution imaging with isotropic voxels, obviously unaffected by changes in the inclination of the subject. Furthermore, the low contrast resolution of CBCT does not affect the imaging of high-contrast osseous structures.²⁸ Thus, the combination of high quality images with reliable measurements and comparatively low radiation doses has the potential to broaden the application of CBCT imaging in the dental and oral maxillofacial fields, both for diagnostic and treatment planning purposes. However, for proper planning of implant therapy,

traditional radiographic techniques sometimes provide the necessary information,^{29,30} calling for a careful evaluation of the benefits of additional radiographic examinations in relation to the dose of radiation.

Conclusion

The results of the present study revealed high reliability of measurements performed on CBCT images independently from object position, examiner's experience and high reproducibility in repeated measurements settings.

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