Institute of Experimental Morphology, Pathology and Anthropology with Museum
Bulgarian Anatomical Society

Acta morphologica et anthropologica, 24 (1-2)
Sofia ● 2017

Accuracy of Linear Measurements on Polygonal Models of Dry Mandibles Generated from Industrial CT Data

Diana Toneva[1], *Silviya Nikolova*[1], *Ivan Georgiev*[2,3]

[1] *Institute of Experimental Morphology, Pathology and Anthropology with Museum, Bulgarian Academy of Sciences, Sofia, Bulgaria*
[2] *Institute of Information and Communication Technologies, Bulgarian Academy of Sciences, Sofia, Bulgaria*
[3] *Institute of Mathematics and Informatics, Bulgarian Academy of Sciences, Sofia, Bulgaria*

*Corresponding author: e-mail: ditoneva@abv.bg

The aim of the study was to assess the accuracy of linear measurements taken on surface models of dry mandibles generated from industrial CT data compared to the corresponding measurements taken directly on the mandibles. Ten mandibles were scanned through computed tomography. The CT scanning was performed on a Nikon XTH 225 system. The polygonal models were generated using VGStudioMax 2.2. Ten linear measurements were taken on both dry mandibles and 3D models. The conventional measurements were taken with a digital caliper. The digital measurements were obtained using Geomagic Verify Viewer. All parameters were measured twice by two observers. Almost perfect intra- and interobserver reliability was obtained for all digitally and directly taken measurements. The repeated measures ANOVA did not establish statistically significant differences between both measuring methods for any of the metric parameters. The overall absolute error was 0.37 mm and the overall relative error was 1.00%.

Key words: mandible, CT, polygonal model, measurements, accuracy

Introduction

Industrial computed tomography (CT) is an appropriate method for data acquisition of complex objects. It gives accurate representation of shape at high resolution, but the accessibility to this kind of CT scanners is limited. The very large file size of the 3D volume-rendered images is another shortcoming. The surface models generated from CT data enable a reduction of the size of the file maintaining an acceptable level of details. However, one of the most critical factors influencing the CT process for metrology applications and causing loss of accuracy during CT measurements is the edge detection also called surface extraction or image segmentation, which is the process of surface formation from the CT volume data [17]. Thus, the precise surface determination is essential for nearly all kinds of CT analyses [21], since size and shape differences could appear in the process of segmentation.

The accuracy of linear measurements of the mandible and maxillofacial region has been assessed using different imaging technologies, because of their significance in the maxillofacial surgery and orthodontic practice. Nowadays, cone-beam CT (CBCT) is widely used in dental practice, because of its advantages over conventional CT, including higher resolution, short scanning time and reduced radiation exposure. Thus, it has been increasingly reported recently. The accuracy of CBCT measurements of the mandible has been assessed on 2D tomographic slices and 2D virtual cephalographic images [7, 8, 9, 10, 11, 13, 24], 3D volume-rendered CBCT images [1, 7, 10, 16, 18, 23], and 3D surface-rendered CBCT images generated through segmentation and thresholding method [3, 4, 5, 8, 20, 22]. Some of the authors showed a tendency for the CBCT measurements to underestimate the direct ones [1, 3, 4, 23]. Glover and Pelc [6] have explained the underestimation and overestimation in the CBCT measurements with so-called partial volume effect, which occurs when a voxel is occupied by two structures with different densities, and the voxel reflects an average density value. However, Ye et al. [26] have suggested that the choice of the threshold value during the segmentation procedure was a more acceptable reason for underestimation of the measurements. Engelbrecht et al. [5] have also noticed that when threshold-based methods were used, the 3D surface models produced by CBCT were accurate but slightly inferior to reality. Although there have been a lot of studies about the accuracy of mandibular measurements, it was not tested on virtual models generated through industrial CT.

The aim of this study was to assess the accuracy of linear measurements taken on polygonal models of dry mandibles generated from industrial CT data in comparison to the directly taken mandibular measurements.

Materials and Methods

The study was conducted on a sample of 10 dry mandibles from the Military Mausoleum with Ossuary, National Museum of Military History, Bulgaria. The mandibles were scanned through computed tomography. The scanning was performed on an industrial CT system Nikon Metrology XT H 225 with reflection head and a voltage of 85 kV and 95 μA tube current. To generate a 3D CT volume, a series of sequential 2D X-ray images (projections) were captured as the object was rotated through 360°. For each scan 3000 projections were registered, as each projection was taken with an exposure time of 500 ms. The polygonal models in STL format were generated from voxel data by automatic surface determination and surface extraction using VG Studio Max 2.2 software. Automatic surface determination is suitable for volumes containing object with only one material. Usually in such cases the histogram consists of two peaks - the background peak and the material peak. The isosurface value is calculated as an average of the two gray values corresponding to two peaks.

Ten linear measurements between definite landmarks described according to Martin and Saller [14] were taken on both dry mandibles and polygonal models (**Table 1**).

The conventional measurements of the mandibles were obtained using a digital caliper (Würth, Germany) with accuracy to 0.03 mm. The digital measurements were accomplished on the 3D models using the free software Geomagic Verify Viewer (3D Systems, Inc). All parameters were measured twice by two observers. The 1st and 2nd measurements of all samples were taken on separate days.

The intra- and interobserver reliability was estimated using intraclass correlation coefficient (ICC), two-way mixed model. The absolute and relative errors were calcu-

Table 1. Mandibular measurements

Measurements		Definition
M1	kdl (R) – kdl (L)	The direct distance between the left and right kondilion laterale (kdl)
M2	kdm (R) –kdm (L)	The direct distance between the left and right kondilion mediale (kdm)
M3	kr (R) – kr (L)	The direct distance between the left and right koronion (kr)
M4	go (R) – go (L)	The direct distance between the left and right gonion (go)
M5	ml (R) – ml (L)	The direct distance between both landmarks mentale (ml)
M6	id-gn	The direct distance from infradentale (id) to gnation (gn)
M7	kdl (L) -kdm (L)	The direct distance between left kondilion laterale and left kondilion mediale
M8	id-kr (L)	The direct distance from infradentale to the left koronion
M9	id-kdl (L)	The direct distance from infradentale to the left kondilion laterale
M10	id-kdm (L)	The direct distance from infradentale to the left kondilion mediale

(R) – right; (L) – left

lated. The absolute error represented the difference between digital and direct measurements. The relative error was calculated as an index of the absolute error related to the direct measurements multiplied by 100. The comparison between both digital and conventional measurements was performed using with repeated measures ANOVA. Values of $p < 0.05$ were considered significant.

Results

Reliability

Almost perfect intra- and interobserver reliability (> 0.8) was found for all digitally and directly taken measurements. The intraobserver ICCs for the digital measurements ranged from 0.932 to 0.999 for the first observer and from 0.961 to 0.999 for the second one. The intraobserver ICCs for the direct measurements ranged from 0.974 for the first observer and from 0.966 for the second one up to 0.999. Interobserver ICC values were within 0.917-0.999 for the digital measurements and 0.969-0.999 for the direct ones. The most reliable measurement was M1 and the measurement with lower ICC values was M10.

Accuracy

The means and SD of the digital and direct measurements are presented in **Table 2**. Because of the high agreement in the measurements within and between the observers, the assessment of the differences between digital and direct measurements was based on the combined repeated measurements of both observers for each measuring method.

The overall absolute error was 0.37 ± 0.96 mm, as 7 of the 10 distances had lower values on polygonal models. The smallest error was observed for the M9 and the grea-

Table 2. Means and SD of the digital and direct measurements. Comparison of the measurements using repeated measures ANOVA

Measurements	**Digital measurements**		**Direct measurements**		***F*-value***	***p*-value**
	Mean	**SD**	**Mean**	**SD**		
M1	116.16	7.12	116.96	7.09	0.060	0.810
M2	80.33	5.80	79.70	5.87	0.054	0.819
M3	93.09	3.79	92.45	4.35	0.115	0.738
M4	99.38	4.58	100.48	4.63	0.266	0.613
M5	44.72	2.67	44.88	2.54	0.018	0.894
M6	30.95	2.14	32.65	1.82	3.487	0.078
M7	18.79	2.22	19.53	2.34	0.499	0.489
M8	82.51	3.57	82.67	3.98	0.008	0.929
M9	107.56	2.54	107.49	2.89	0.004	0.953
M10	103.18	2.12	103.51	2.31	0.112	0.742

*Degrees of freedom (df) for each *F*-ratio are (1.18).

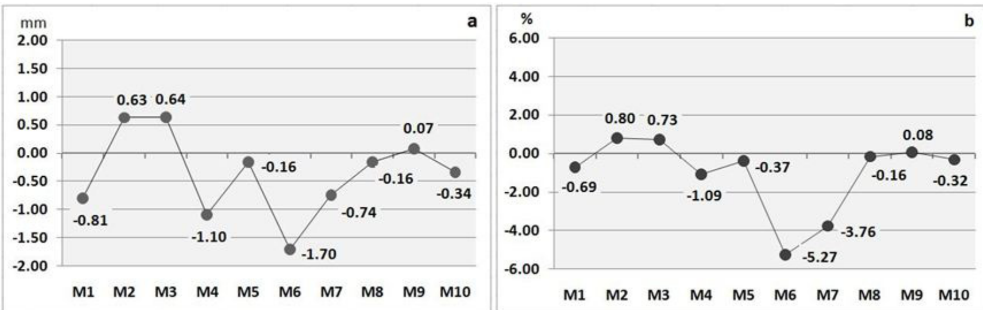

Fig. 1. Measurement errors: a) Absolute measurement errors; b) Relative measurement errors

test one for the M6 (**Fig. 1a**). The overall relative error was 1.00 ± 1.97%. The biggest relative errors (> 3%) were obtained for the measurements M6 and M7 (**Fig. 1b**).

The factorial repeated measures ANOVA did not show statistically significant size differences between polygonal models and dry mandibles (**Table 2**).

Discussion

The comparison between linear measurements taken on polygonal models derived from industrial CT data and dry mandibles did not show statistically significant differences. Statistically non-significant differences have been also established between the 3D CBCT and direct measurements by Baumgaertel et al. [1], Gribel et al. [7], Kamburoglu et al. [10], Tarazona-Álvarez et al. [23]. However, Periago et al. [18] and Brown et al. [3] have found that most of the 3D measurements differed significantly from those on dry skulls. Rieth-Hoerst et al. [21] have established that the conversion from voxel data into STL resulted in a measurement deviation ≥ 1/10 of a voxel for 20% of the measurements and some deviations added a measurement uncertainty of more than 5% compared to the voxel data. In our study, a relative measurement error > 5% in relation to the direct measurements was established only for the mandibular height (M6), which was the most differing variable between both measuring methods. Pinsky et al. [19] have also found the largest error in height measurements on the mandible. However, because of the lack of other vertical measurements in our study, it could not be assessed if this difference was due to the concrete measurement or was a result affecting the mandibular heights as a whole.

The 3D measurements on surface models are susceptible to errors connected with the landmark location on the virtual models as well as with the choice of the operator or software on the threshold in the process of segmentation. Some studies are conducted on objects marked with different kind of fiducial markers [2, 7, 12, 20]. Gribel et al. [7] have noticed that the use of fiducial markers leads to higher accuracy, but their size, material, and shape in combination with the scan resolution can influence the results. Brown et al. [3] have suggested that the landmark identification on the 3D rendering without the aid of radiopaque fiducial markers is a more representative simulation of the clinical situation and provides a combined assessment of 3D landmark identification error and error due to imaging procedure. In the present study, similar to these of Baumgaertel et al. [1], Hilgers et al. [9] and Periago et al. [18], such markers were not used, so the differences could be referred to the landmark location and segmentation error. The agreement in the measurements of both observers indicated that measurements were reliable with almost perfect intra- and interobserver reliability. In other studies with and without use of fiducial markers, the intra- and interobserver reliability was also found to be almost perfect [1, 7, 10, 16, 18]. In our previous study [25], the technical error of measurement was reported on the same sample and results showed that the largest total relative technical error was observed for the measurements demonstrating the largest relative measurement errors (M6 and M7) in the present study. Actually, landmarks of reference such as gnathion located on a prominence or curvature have been previously reported as difficult for identification [15]. However, it should be noticed that the measurement imprecision in our study was in the acceptable limits, so the landmark location could have led to greater inaccuracy but to a certain degree.

Concerning the segmentation process, Periago et al. [18] have summarized that it could be influenced by the software algorithm, the contrast resolution of the scan, the thickness and degree of calcification of the bony structure, and the technical skills of the operator. It should be taken into account that results obtained in our study were derived from scanning of dry mandibles with an industrial CT scanner and the bone surface was extracted from high-resolution 3D CT data (**Fig. 2**), unlike the segmentation performed on patients CT scans. The image quality could severely affect the segmentation results. Periago et al. [18] have noticed that the image quality from medical CT scanners decreases because of soft tissue attenuation, patient motions, number of basis projection images, voxel size, etc. Although Periago et al. [18] have assessed the accuracy on 3D surface-rendered images of dry skulls, 50% of the measurements had a mean difference between 1 mm and 2 mm and 10% differed with more than 2 mm. Measurement errors up to 1 mm have been reported as clinically acceptable for diagnosis and planning [4]. In our study, four of the 10 measurements differed with less than 0.5 mm, four of them had measurement errors between 0.5 mm and 1 mm and the measurement errors for the other two measurements (M4 and M6) were between 1 mm and 2 mm.

According to Poleti et al. [20], the 3D surface models segmented from CBCT data have been reported as accurate models of the real objects with reliable and accurate

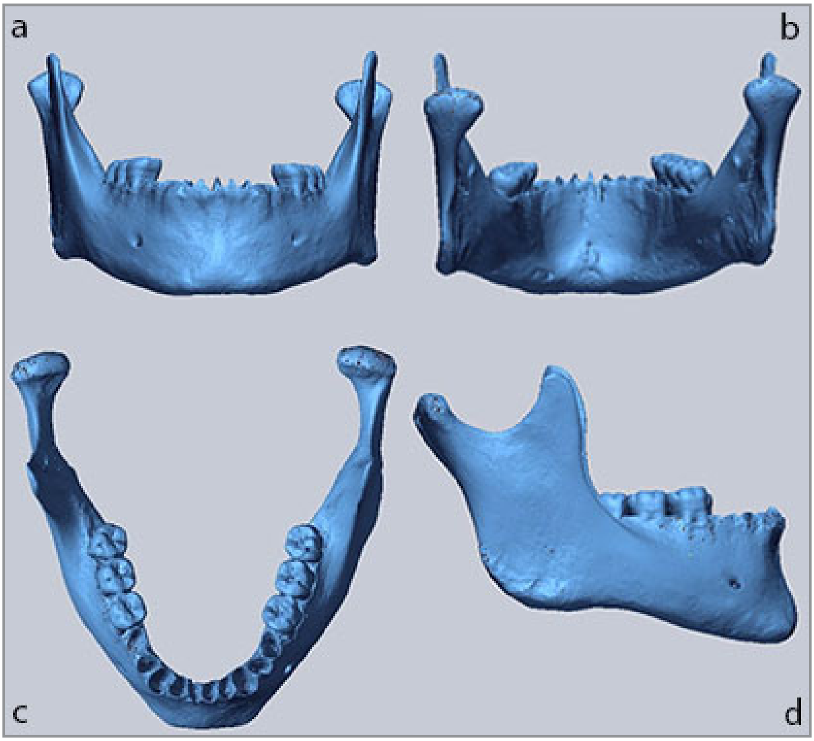

Fig. 2. Polygonal model of a dry mandible generated from industrial CT data: a) Anterior view; b) Posterior view; c) Superior view; d) Lateral view

Fig. 3. Anterior view of the polygonal model of the left mandibular condyle after surface extraction from industrial CT data

linear measurements compared to the physical ones. However, Engelbrecht et al. [5] have suggested the need of a more advanced segmentation technique especially at the condylar region and the lingual side of the mandible. According to our observations, the condyle was also affected by the surface extraction process, but it did not lead to statistically significant differences from the direct measurements (**Fig. 3**).

Conclusion

As a whole, the polygonal models generated from industrial CT data were established to represent accurate copies of the scanned objects. The linear measurements obtained from the polygonal models were reliable and accurate compared to the directly taken ones.

Acknowledgement: This study was supported by the "Program for Support for Young Scientists in Bulgarian Academy of Sciences", research grant DFNP – 75/27.04.2016. The authors would like to acknowledge the kind assistance given by the staff of the National Museum of Military History, Bulgaria.

References

1. **Baumgaertel, S., J. Martin, L. Palomo, M. G. Hans.** Reliability and accuracy of cone-beam computed tomography dental measurements. – *Am. J. Orthod. Dentofacial. Orthop*., **136**, 2009, 19-28.
2. **Berco, M., P. H. Rigali Jr, R. M. Miner, S. DeLuca, N. K. Anderson, L. A. Will**. Accuracy and reliability of linear cephalometric measurements from cone-beam computed tomography scans of a dry human skull. – *Am. J. Orthod. Dentofacial. Orthop*., **136**, 2009, 11-19.
3. **Brown, A. A., W. C. Scarfe, J. P. Scheetz, A. M. Silveira, A. G. Farman.** Linear accuracy of cone beam CT 3D images. – *Angle Orthod*., **79**, 2009, 150-157.
4. **Damstra, J., Z. Fourie, J. J. Huddleston Slater, Y. Ren.** Accuracy of linear measurements from cone-beam computed tomography-derived surface models of different voxel sizes. – *Am. J. Orthod. Dentofacial. Orthop*., **137**, 2010, 1-7.
5. **Engelbrecht, W. P., Z. Fourie, J. Damstra, P. O. Gerrits, Y. Ren.** The influence of the segmentation process on 3D measurements from cone beam computed tomography-derived surface models. – *Clin. Oral Investig*., **17**, 2013, 1919–1927.
6. **Glover GH, Pelc NJ.** Nonlinear partial volume artefacts in X-ray computed tomography. – *Med Phys*., **7**, 1980, 238-248.
7. **Gribel, B. F., M. N. Gribel, D. C. Frazäo, J. A. McNamara Jr, F. R. Manzi.** Accuracy and reliability of craniometric measurements on lateral cephalometry and 3D measurements on CBCT scans. – *Angle Orthod*., **81**, 2011, 2635.
8. **Hassan, B., P. van der Stelt, G. Sanderink.** Accuracy of three dimensional measurements obtained from cone beam computed tomography surface-rendered images for cephalometric analysis: influence of patient scanning position. – *Eur. J. Orthod*., **31**, 2009, 129–134.
9. **Hilgers, M. L., W. C. Scarfe, J. P. Scheetz, A. G. Farman.** Accuracy of linear TMJ measurements with cone beam computed tomography and digital cephalometric radiography. – *Am. J. Orthod. Dentofacial. Orthop*., **1278**, 2005, 803-811.
10. **Kamburoğlu, K., E. Kolsuz, H. Kurt, C. Kiliç, T.** Özen**, C. S. Paksoy.** Accuracy of CBCT measurements of a human skull. – *J. Digit. Imaging*, **24**, 2011, 787-793.
11. **Kumar, V., J. B. Ludlow, A. Mol, L. Cevidanes.** Comparison of conventional and cone beam CT synthesized cephalograms. – *Dentomaxillofacial Radiology*, **36**, 2007, 263-269.
12. **Lagravere, M. O., J. Carey, R. W. Toogood, P. W. Major.** Threedimensional accuracy of measurements made with software on cone-beam computed tomography images. – *Am. J. Orthod. Dentofacial. Orthop*., **134**, 2008, 112-116.
13. **Ludlow, J. B., W. S. Laster, M. See, L. J. Bailey, H. G. Hershey.** Accuracy of measurements of mandibular anatomy in cone beam computed tomography images. – *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod*., **103**, 2007, 534-542.
14. **Martin, R., K. Saller.** Kraniometrische Technik. – In: *Lehrbuch der Anthropologie* (Eds R. Martin, K. Saller), Band I, Stuttgart, Gustav Fischer, 1957.
15. **Medelnik, J., K. Hertrich, S. Steinhäuser-Andresen, U. Hirschfelder, E. Hofmann.** Accuracy of anatomical landmark identification using different CBCT- and MSCT-based 3D images. An in vitro study. – *J. Orofac. Orthop*., **72**, 2011, 261-278.

16. **Moreira, C. R., M. A. Sales, P. M. Lopes, M. G. Cavalcanti.** Assessment of linear and angular measurements on three-dimensional cone-beam computed tomographic images. – *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod*., **108**, 2009, 430-436.
17. **Ontiveros-Zepeda, S., J. A. Yagüe-Fabra, R. Jiménez Pacheco, F. J. Brosed-Dueso**. A Comparative of 3D Surface Extraction Methods for Potential Metrology Applications. – *Key Engineering Materials*, **615**, 2014, 15-21.
18. **Periago, D. R., W. C. Scarfe, M. Moshiri, J. P. Scheetz, A. M. Silveira, A. G. Farman.** Linear accuracy and reliability of cone beam CT derived 3-dimensional images constructed using an orthodontic volumetric rendering program. – *Angle Orthod*., **78**, 2008, 387-395.
19. **Pinsky, H. M., S. Dyda, R. W. Pinsky, K. A. Misch, D. P. Sarment.** Accuracy of three-dimensional measurements using cone-beam CT. – *Dentomaxillofac. Radiol*., **35**, 2006, 410-416.
20. **Poleti, M. L., T. M. Fernandes, O. Pagin, M. R. Moretti, I. R. Rubira-Bullen.** Analysis of linear measurements on 3D surface models using CBCT data segmentation obtained by automatic standard pre-set thresholds in two segmentation software programs: an in vitro study. – *Clin. Oral Invest*., **20**(1), 2016, 179-185.
21. **Rieth-Hoerst, S., C. Reinhart, T. Günther, T. Dierig, J. Fieres.** Methods to ensure accuracy and reliability of analyses and measurements done on CT data-sets. – *Proceedings of 11th European Conference on Non-Destructive Testing*, Prague, Czech Republic, 2014.
22. **Stratemann, S. A., J. C. Huang, K. Maki, A. J. Miller, D. C. Hatcher.** Comparison of cone beam computed tomography imaging with physical measures. – *Dentomaxillofac. Radiol*., **37**, 2008, 80-93.
23. **Tarazona-Álvarez, P., J. Romero-Millán, D. Peñarrocha-Oltra, M. Á. Fuster-Torres, B. Tarazona, M. Peñarrocha-Diago.** Comparative study of mandibular linear measurements obtained by cone beam computed tomography and digital calipers. – *J. Clin. Exp. Dent*., **6**(3), 2014, e271-e274.
24. **Tomasi C., E. Bressan, B. Corazza, S. Mazzoleni, E. Stellini, A. Lith.** Reliability and reproducibility of linear mandible measurements with the use of a cone-beam computed tomography and two object inclinations. – *Dentomaxillofac. Radiol*., **40**, 2011, 244-250.
25. **Toneva D., S. Nikolova, I. Georgiev, A. Tchorbadjieff.** Intra- and interobserver measurement error of linear measurements on three-dimensional computed tomography models of dry mandibles. – *Acta Morphologica et Anthropologica*, **23**, 2016, 102-110.
26. **Ye, N., F. Jian, W. Lai.** Effect of voxel size and partial volume effect on accuracy of tooth volumetric measurements with cone beam CT. – *Dentomaxillofac. Radiol*., **42**, 2013, 20130070.