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EFFECT OF VOXEL SIZE ON THE ACCURACY OF NERVE TRACING MODULE OF CONE BEAM COMPUTED TOMOGRAPHY IMAGES

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ABSTRACT

Introduction: Cone beam computed tomography (**CBCT**) has been used for preoperative treatment planning for dental implants, one of the major advantages is its accurate linear measurements. But when it comes to automatic detection of voxel intensity values as in automatic nerve detection, little evidence in the literature was found. Thus; in order to examine the accuracy of this automatic process, this study was performed in vitro.

Methods: A dry edentulous mandible was imaged using i-CAT next generation (Imaging sciences international, Hatfield, PA, USA) using gutta percha markers at certain areas of interest, the reconstructed panoramic image was evaluated and nerve tracing was done for both sides, then linear measurements was performed from the edge of the inferior alveolar nerve canal (IANC) to the inferior border of mandible, buccal, lingual and crest of the ridge. These measurements were compared to actual physical measurements performed by using a digital caliber after sectioning of the mandible at the gutta percha sites.

Results: Intra-observer agreement was good to very good regarding all measurements for both observers, while inter observer agreement was weak to very good regarding all measurements for both observers. There was no statistically significant difference between the CBCT scans (0.2 mm, 0.3 mm, and 0.4 mm voxel size) regarding all measurements except one measurement at the 0.4 mm voxel size CBCT scan showed a statistically significant high mean error.

Conclusion: The choice of FOV and voxel size should be made by clinicians based on the clinical task at hand, keeping in mind that their choices not only affect the diagnostic quality of images but also the amount of radiation exposure that their patients receive.

INTRODUCTION

Dental implants have evolved over the years and turned into a predictable treatment for replacement of missing teeth.[1,2] Precise preoperative planning and assessment of the recipient site is essential for a successful implant osseointegration and successful treatment outcome.[3] This requires a comprehensive knowledge of various anatomic structures and variations.[4]

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While the number of dental implants have increased, the numbers of neurosensory disturbances and haemorrhages have increased even in locations which was considered safe before as the anterior mandible.[5,6] Therefore, preoperative planning must be done to identify the inferior alveolar nerve canal (**IANC**) to prevent damage to the neurovascular bundle that passes inside the mandibular canal, the course of which varies within the mandibular body as well as the shape and dimensions of the bone.[7]

Several authors investigated the mandibular canal position using cone beam computed tomography (**CBCT**), IANC proved to run near the lingual cortical side from its entrance in the ramus to the mental foramen, and that it is positioned about 1 cm above the inferior border of the mandible. [8-10] On the other hand other researches found that IANC position may vary from one patient to the other according to the degree of alveolar ridge resorption.[10,11]

Although CBCT has gained increased popularity in many indications, its main indication is dental implant procedures [12], specially providing a superior display of the IANC and its variations which is critical to perform a more expected surgical procedures, avoiding possible sensory disturbances and complications.[13]

Viewing CBCT images using the software viewer is considered essential during implant planning either by the oral radiologist or the oral surgeon. All CBCT systems have their viewing software supplied on a compact disk (**CD**); each software is different in its task specific reconstruction capabilities provided by the manufacturer. Although these features may include panoramic reconstructions, implant planning reconstructions with 2-dimensional (**2D**) and 3- dimensional (**3D**) windows, temporomandibular joint reconstructions, airway reconstructions. Almost any CBCT software has a nerve tracing application. This allows for the identification and colour coding of IANC, thereby assisting its recognition. [4,15]

Up to our knowledge, few researches were focusing on the accuracy of the nerve tracing tool in order to provide sufficient scientific information for the dental community, so the aim of the current study is to determine the accuracy of using IANC tracing technique on CBCT images in precisely locating the IANC using different voxel sizes.

MATERIALS AND METHODS

For the purpose of our study, one edentulous mandible, randomly selected, was borrowed from the Anatomy Department, Faculty of Medicine, Ain Shams University. The study design was expedited from review by the Faculty's Research Ethics Committee. The mandible was anonymous and not identified by age, gender, or ethnic group.

Mandible preparation:

The alveolar crest of the mandible in both sides at the molar, premolar areas was plateaued using a diamond bur mounted on straight hand piece. The buccal and lingual cortical plates came to be nearly on the same horizontal level in order to facilitate reference points determination.

Creating reference points:

In order to create reference markers in the mandible, small pieces of gutta percha were fixed on the mandible with glue in a five predefined locations to yield 5 dentoalveolar specimens (**Fig. 1**). The position of the reference markers were at the level of the crestal bone between the sockets of the premolar and molar teeth. Other reference markers were positioned along a perpendicular line drawn to the inferior border of the mandible from the previous reference markers at each location. This was done to ensure reproducible measurements. Individual sections were assigned a numeric value of 1 through 5, starting anteriorly in a posterior direction. R and L letters were used to discriminate the two sides.

Radiographic Scanning:

The mandible was wrapped with thin plastic wrapping (in order not to disturb the dryness of the mandible) and placed in a thin, clear plastic container which was filled with water to simulate soft tissue attenuation. Then, the mandible was scanned using the i-CAT next generation (Imaging Sciences International, Hatfield, PA, USA) at the Oral Radiology Department, Faculty of dentistry, Ain shams university. (**Fig.** 2)

The assembly was adjusted on the machine's platform in a central position which was checked with the three laser beam. Images were obtained at 3 different voxel sizes 0.2 mm, 0.3 mm and 0.4 mm. All the three scans were performed at 120 kVp, 5 mA. The field of view (**FOV**) was adjusted in order to cover the sigmoid notch superiorly and the mandibular inferior border inferiorly in order to easily locate the mandibular foramen and inferior mandibular border respectively on the resultant image.

Fig. (1) Gutta percha markers fixed on the dry mandible

Fig. (2) Positioning of the mandible on the platform during CBCT acquisition

Nerve tracing and radiographic measurements

After volume acquisition, images were examined by two oral and maxillofacial (**OMF**) radiologists with ten and fourteen years of experience. Images were examined using i-CAT Vision® software (Imaging Sciences International, Hatfield, PA, USA). The examiners separately reviewed the volumes in ideal dimly lit viewing conditions using the same computer monitor (15.6 inch HD LED) at full size, 1:1. They were allowed to handle the volumes freely with the software and use all available tools to identify the IANC. They were also allowed to change contrast and brightness.

IANC tracing and measurements:

On the implant screen, panoramic reconstruction was centrally adjusted along an intermediate level between the crest of the ridge and mandibular inferior border. Manual IANC tracing was performed using the "estimate nerve canal" tool provided by the software; right and left IANCs were traced separately based on four points starting from the mandibular foramen down to the mental foramen as displayed on cross-sectional images. The border of the color coded tracing was used as the starting measurement point as shown in **(Fig. 3)**

Then cross sectional images were reoriented in order to pass through gutta percha markers in order to precisely standardize measurements' locations. On each section passing through gutta percha markings, four linear measurements were performed using the "distance" tool. The distance from IANC superior, inferior, buccal and lingual edges to the alveolar crest, inferior, buccal and lingual mandibular borders respectively were measured at each section using a perpendicular line as shown in **(Fig. 3)**. Each observer performed the measurements twice separated by two weeks interval using the same protocol.

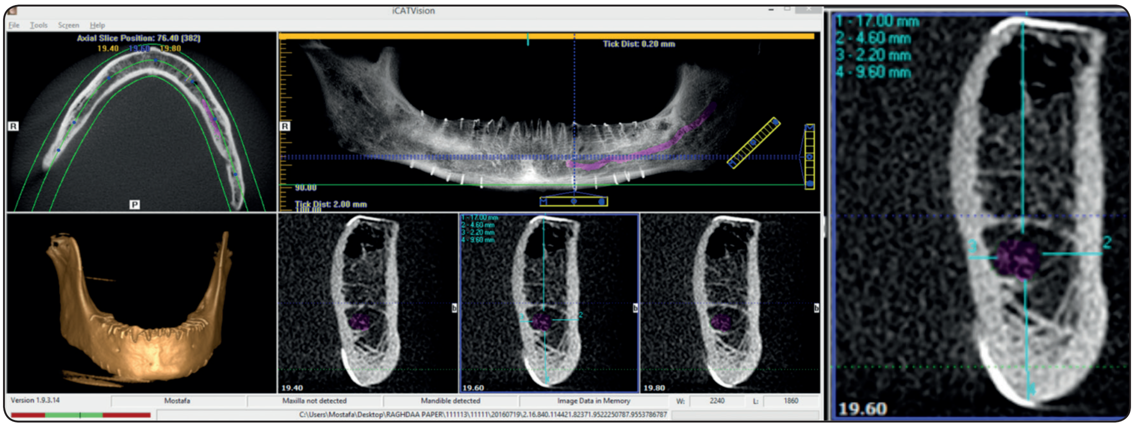

Fig. (3) Implant screen on i-CAT VisionR showing the color coded nerve tracing on both cross sectional and panoramic images

Physical Measurements

After scanning, the dry mandible was sectioned using a Stryker saw (Stryker Model 810 Autopsy Saw, Azusa, CA) at the 5 predefined locations along the lines joining the reference markers from the alveolar crest to the inferior boarder of the mandible on each side as shown in **(Fig. 4)**. For each section, the distance from the IANC border to the alveolar crest, inferior, buccal and lingual mandibular borders was measured by the caliber using the gutta percha markers as a guide for measurement. These measurements were recorded for further comparison with CBCT measurements.

Statistical Analysis

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). Measurement error data showed non-parametric distribution. Data were presented as mean, median, standard deviation (SD), minimum, maximum and 95% Confidence Interval (95% CI) values. Intra- and inter-observer agreement was assessed using Cronbach's alpha reliability coefficient. Friedman's test was used to compare between measurement error with the three CBCT scans (0.2, 0.3, and 0.4 mm voxel size). Wilcoxon signed-rank test with Bonferroni's adjustment was used for pair-wise comparisons when Friedman's test is significant. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics Version 20 for Windows (SPSS, Inc., an IBM Company, NY, USA).

Fig. (4): A) Dento-alveolar specimens after cutting and B) Physical measurement of the mandibular sections

RESULTS

Reliability analysis

As the two observers performed the measurements twice using the same protocol, both showed good to very good intra-observer agreement regarding all measurements with Cronbach's alpha values ranging from 0.685–0.994 and 0.764–0.999 for the first and second observers respectively. Comparing both readings by both observers showed weak to very good inter-observer agreement regarding all measurements with Cronbach's alpha values ranging from 0.074–0.985 and 0.066–0.990 for the first and second readings respectively.

Error measurement

The difference between the actual physical measurements obtained by the digital caliber and CBCT measurements was considered as the measurement error and by comparing this error between the CBCT scans (0.2 mm, 0.3 mm, and 0.4 mm voxel size), there was no statistically significant difference between these CBCT scans regarding all measurements **(Fig. 5)** except one measurement at the 0.4 mm voxel size CBCT scan showed a statistically significant high mean error; while all other measurements showed no statistically significant difference between the CBCT measurements and actual physical measurements as shown in **Table (1)**.

TABLE (1) The mean, standard deviation (SD) values and results of Friedman's test and Wilcoxon signed-rank test for comparison between error measurements with different Voxel sizes

Side	Distance Measured	0.2 mm Voxel		0.3 mm Voxel		0.4 mm Voxel		*P*-value
		Mean	SD	Mean	SD	Mean	SD	
Left IANC	IANC/Alveolar crest	0.69	0.75	0.67	0.98	-0.11	0.32	0.071
	IANC/Inferior border	1.15	1.66	0.73	0.65	0.87	1.02	0.779
	IANC/Buccal border	0.56	1.49	-0.40	1.15	-0.75	0.86	0.127
	IANC/Lingual border	-0.20	0.29	0.00	0.45	0.28	0.47	0.607
Right IANC	IANC/Alveolar crest	1.46	1.89	2.14	2.78	0.49	0.98	0.779
	IANC/Inferior border	-0.65 ^{B}	1.86	-0.81 ^{B}	3.01	1.55 ^{A}	1.41	0.022*
	IANC/Buccal border	-0.25	0.49	0.52	0.47	0.16	1.74	0.165
	IANC/Lingual border	-0.49	0.28	-0.53	0.63	-0.68	0.39	0.331

: Significant at $P \leq 0.05$, Different superscripts in the same row are statistically

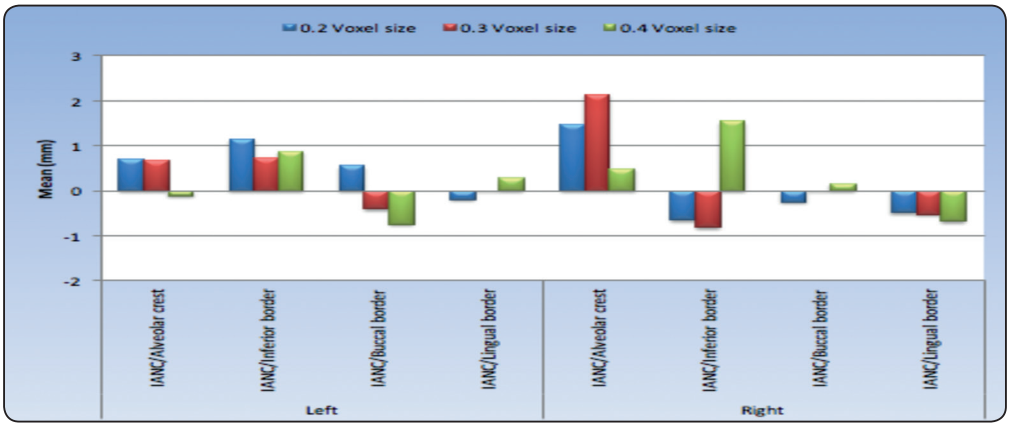

Fig. (5) Bar chart representing comparison between mean error measurements with different Voxel sizes

DISCUSSION

IANC is one of the most important anatomical structures in the mandible taking into consideration the variation in its course in both vertical and horizontal planes[4]. Moreover, the visibility of the canal varies between patients and in different locations in the mandible being more easily identified in posterior areas and more difficult towards the mental foramen[13]. Therefore, precise identification of the IANC for accurate preoperative planning is a challenging process[16].

This points out the precious contribution of 3D CBCT technology as an ideal imaging modality owed to its sub-millimeter resolution and high image quality which allows mandibular canal tracing to determine its exact location [16,17].

Clinically, the quality of the CBCT image and its capability to demonstrate the anatomical structures and pathology depend on settings used during acquisition or reconstruction, one influencing factor is the voxel size which has a huge impact on the image details and the diagnostic outcome[18].

Therefore, the aim of this study was to investigate the impact of using three different voxel sizes in detecting the accuracy of IANC tracing in vitro. To the authors' knowledge, no published studies assessed the use of isolated voxel size variation in CBCT images on the visualization of IANC specially by using the nerve tracing tool. Although other authors investigated the effect of changing the voxel size on detection of periapical bony lesions[19], detection of external root resorption[20], accuracy of linear measurements[21-23], accuracy of 3D reconstruction[24], accuracy of mandibular cortical thickness measurements[25] and temporomandibular joint osseous changes [26].

In the present study we used a dry mandible for testing CBCT linear measurements by comparing these measurements with the actual physical measurements as the gold standard. The imaging of a dry mandible is a challenge regarding proper positioning and choosing the best FOV. Also we have chosen to immerse the mandible in water to simulate soft tissues during image acquisition. This was in accordance with several authors who imaged a dry mandible for different purposes regarding CBCT [19,23,24,27,28].

We have chosen to use gutta percha markers to reorient the CBCT cross sectional images and to identify measurement areas in order to accurately standardize measurement areas; Gutta percha is widely used as a radiographic marker in several CBCT studies[29,30,31]; on the other hand Damstra et al[23] used glass sphere markers, Hekmatian et al[25] used aluminum foil strips and Ludlow et al[27] used orthodontic wires in their studies. In our study we have chosen gutta percha to avoid possible metal artefacts which may result from metallic markers that may affect image quality.

In our study we compared the effect of changing the voxel size during image acquisition on the accuracy of nerve tracing and we found that there was no statistically significant difference between 0.2, 0.3 and 0.4 mm voxel sizes.

The same results were proved by Aktan et al[21] and sherrard et al.[32] who compared accuracy of endodontic working length by using different voxel sizes ranging from 0.1 to 0.5 mm and 0.2 to 0.4 respectively, they concluded that there is no statistically significant difference between the CBCT scans regarding endodontic working length measurement.

Damstra et al[23] and Vieira et al[33] showed the same results regarding the accuracy of CBCT linear measurements when they compared 0.25, 0.4 mm and 0.125, 0.25 mm voxel sizes respectively. The same results were obtained by Hekmatian et al[25] regarding mandibular thickness measurements as they found no significant difference between 0.15 and 0.3 mm voxel sizes. Our results were also in accordance with Lukat et al[26] who investigated the visualization of TMJ osseous structures by 0.076 and 0.3 voxel sizes and Ozer[34] who compared 0.125, 0.2, 0.3 and 0.4 mm voxel size in detection of simulated vertical root fracture.

Despite that all our measurements showed no statistically significant mean error, only one measurement showed statistically significant mean error and this could possibly be due to bone marrow spaces present at this specific area (right side from the inferior border of IANC to the mandibular inferior border) causing difficulty for the software to accurately determine the exact border of IANC at that area; as the software identifies the IANC by searching for high-contrast gaps in the mandible, so similarity between the voxel value of IANC and a large marrow space (probably larger than 0.4 mm) might be the cause of this difference in mean error.

While our results showed no effect on the image accuracy when changing the voxel size, we have to stress on the fact that our study focused on linear measurements while other authors investigated the accuracy of 3D volumetric measurements and showed different results as Maret et al[24] who compared between 0.2 and 0.3 mm voxel size in 3D volumetric measurements and found a statistically significant underestimation of the volume in 0.3 mm CBCT images. Also Dalili et al.[35] concluded in their study regarding detection of external root resorption that 0.25 mm was more accurate than 0.5 mm voxel size.

The increased demand on CBCT for implant planning and the convenient tools provided by various software, increased dentists' referral for CBCT scans. This should be an alarming sign for oral radiologists to investigate the effect of increased patient absorbed dose and provide recommendations for patients exposure to radiation. Several parameters can be varied during image acquisition according to the diagnostic task but still no protocols have been established for specific diagnostic tasks in dentistry[18]. In our study we proved that changing the voxel size will not affect the accuracy of the nerve tracing tool, and so using larger voxel size will not affect the clinical outcome and decrease the patient absorbed dose according to Nikneshan et al[36].

This would be following the ALARA concept and in accordance with the American academy of oral and maxillofacial radiology **(AAOMR)**[37] and the European academy of dental and maxillofacial radiology **(EADMFR)**[38] as both stated that when using CBCT, the smallest field of view should be used in order to decrease patient absorbed dose.

On the other hand, using a larger voxel size will decrease the scanning time, thus decreasing motion artefacts which may cause a dramatic effect on image quality[39].

CONCLUSION

The choice of voxel size should be made by clinicians based on the clinical task at hand, keeping in mind that their choices not only affect the diagnostic quality of images but also the amount of radiation exposure that their patients receive.

RECOMMENDATIONS

The objectives of this study did not include the assessment of diagnostic accuracy, the performance of the imaging software, or the resolution of the computer monitor. Future studies should be performed assessing the diagnostic accuracy of CBCT Images using varying imaging protocols. So further clinical studies in this area are needed in order to examine the accuracy of nerve tracing tools.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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