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ACCURACY OF ULTRA LOW DOSE AND STANDARD DOSE CBCT PROTOCOLS IN VOLUMETRIC MEASUREMENTS OF SIMULATED BONE DEFECTS VERSUS REAL MEASUREMENTS: EXPERIMENTAL STUDY

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ABSTRACT

Aim: To assess the accuracy of ultra-low dose and standard dose CBCT protocols in volumetric measurements of simulated bone defects in comparison with the real physical measurements.

Methodology: A number of 58 defects mimicking periapical lesions were prepared on the ribs of sheep. Actual physical volumetric measurements of the defects were obtained by water displacement method; samples were scanned by ultra-low dose and standard dose CBCT protocols(90 KVP,8 MA &13 SEC and 90 KVP,5.6 MA& 9 SEC) respectively . Volumetric measurements were done in each scan by two calibrated oral radiologists, with different experience, who were blinded to the parameters of the scans and to the physical measurements. The values of the CBCT volumetric measurements were compared to the physical measurements and statistically analyzed.

Results: The results of this study showed that ultra-low dose had smaller Dahlberge error, smaller Relative Dahlberge error,tighter limits of agreement and higher concordance correlation coefficient than standard dose which means better accuracy of the segmentation procedure using this protocol. A strong positive correlation was found between the two protocols and the physical measurement.

Conclusion: Ultra-low dose CBCT is a suitable protocol in volumetric measurements. As both ultra-low dose protocol and standard dose protocol had a strong correlation with physical measurement, CBCT is a reliable tool in volumetric measurements.

KEY WORDS: CBCT – periapical lesions- volumetric measurements- ultra-low dose CBCT

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INTRODUCTION

Periapical lesions are the most common lesions of the jaw, the majority of these lesions are sequences of pulpal or periodontal diseases that if left untreated may spread to enamoring tissues including orbits, sinuses, deep fascial spaces of the neck and intracranial structures that may bring about serious complications and severe patient morbidity. Periapical radiographic radiolucency may be the only sign of asymptomatic apical lesion **(Kruse et al., 2015)**. Accurate diagnosis and determination of the volume of a bony lesion as cyst, abscess..etc. is a process of great importance that aid in conservative surgical treatment, comparing the lesion dimension with the radiographic follow-up, also provide precise estimation of bone graft when reconstructive surgery is planned. **(Espisito et al., 2015).**

Determining the volume of each separate lesion is a matter of great specificity; as the size of the lesion is considered the only radiographic character that differentiate cyst from granuloma and consequently decide the treatment plan where the cystic lesion must be surgically removed, but the granuloma should be allowed to self-heal without surgical intervention. Correct decision regarding the treatment plan save the patient from subjecting to unnecessary surgery with its associated infection and morbidity **(Alghurabi et al., 2019).**

Volumetric measurement of the periapical lesion before endodontic treatment has a valuable effect on the predicted success. Pre-existing periapical lesion of a size beyond 50 mm commonly followed by failure and the surgical treatment plan must involve the use of graft material. Also larger sized lesion related to endodonically treated teeth is less likely to heal because of the fibroblastic proliferation from the periostium into the osseous defect, leading to scar formation rather than bony fill **(Razavi et al., 2015).**

Radiographic examinations play an essential role in the diagnosis of the different periapical lesions through assessment of the radiographic features and establishment of differential diagnosis. They help in laying down the correct treatment plan, possible referral, prompt management and avoidance of undue intervention or additional imaging **(Liange et al., 2014)**

Regarding to Bender principles of detection of bone loss in local resorpitive lesion, large resorpitive lesion in cancellous bone may go undetected due to low mineral content of the medullary bone. Periapical lesion confined within cancellous bone is difficultly shown in the periapical radiographs because of the overlying cortical bone masking it. Periapical radiographs mostly fail to completely reveal the true nature, extension and progression of the periapical lesion and had a great limitation in the lesion detection which is a fundamental of radiographic interpretation **(Bender and Seltzer., 2003).**

Two-dimension radiographs not only incapable of detecting the incipient periapical lesion, but also cannot maintain the actual size of the lesion in the image, that is mostly showed smaller. They also have limitation in demonstrating the location of the lesion in the buccolingual plane and revealing surface characteristics (rough or smooth). The lesion also may be radiographically deformed by the anatomic noise, where it is obscured by the immediately adjacent anatomical features as maxillary tuberosity and posterior mandibular dense cortical bone **(Lo Giudice et al., 2018).**

Above all, it was found commonly a negative radiographic signs of a pre - existing lesion as in case of apical lesion in the bifurcation area, after tooth extraction where the trabeculae over the socket appear normal, hiding the periapical pathosis. Also a false periapical lesion may be diagnosed as in case of apical rarefaction induced by endodontic instrumentation as the instrument has displaced the apical bone tissues and produced radiographic radiolucency. Therefore; there is a demand need for an accurate, high resolution three- dimensional image **(Kruse et al., 2015).**

CBCT is able to detect not only incipient lesions, but also lesions within cancellous bone only. The image of the CBCT shows the lesion in three dimensions, allowing measuring the area of low bone density and also gives an accurate estimation of the actual lesion size. It has laid the foundation of the 3D reconstruction and volumetric measurements of the periapical lesion **(Mischkowski et al., 2009).**

CBCT can be directed to pre-surgical evaluation of a periapical lesion and intra-operative surgical control of the lesion margins where it provides scans of minimum thickness up to 0.1 mm and a submillemeteric resolution (2 line pair/mm). Volumetric measurements using CBCT of the periapical lesion can be considered a mean of dimensional changes assessment where these changes permits precise evaluation of healing, quantitative evaluation, comparison of the different pathological lesions and assessment of the treatment outcomes **(Nivesh & Pradeep., 2016).**

In case of surgical intervention, volumetric assessment is done pre surgically to localize the lesion's relation to adjacent important structures and to acquire a guidance support system by 3D reconstruction thus help the operator to continue the structural go on definitive phases of the designed treatment plane earlier with higher degree of confidence**. (Park et al., 2019).**

In CBCT, several software packages already supplied with a dedicated tool for measuring the volumes of the regions of interest in cubic millimeter. A computer based and time saving CBCT technology called segmentation is produced. It can be defined as the method of assigning labels to pixels in 2D images or voxels in 3D and is a virtual procedure for quantification of outlined structures and 3D visualization of correlated image data **(Vallaeys et al., 2015).**

Several segmentation techniques were provided, mainly: manual, semi-automatic and full automatic segmentation. Although being tedious and time consuming, manual segmentation is the straight forward technique where the user outlines the structures slice by slice. This is by defining the ROI in each slice; a volume of interest is composed after combining all successive ROI. Due to its high accuracy, manual segmentation is used as a reference to the results of automatic and semi-automatic segmentation **(Rana et al., 2015).**

In quest to interpretate the periapical region, which involve a small sized lesion, faint borders that may be ill defined and evaluation of advances in related periodontal tissues, these fine details require optimal image quality, obtained by proper dose adjustment. So the issue of argument nowadays is the optimization of CBCT parameters besides preserving the wanted diagnostic image. A systematic review done by **Kusnoto et al., 2015** found that the use of CBCT is principally hindered due to its associated high radiation dose that increase radiation hazard and endanger patient **(Lennon et al., 2011).**

Low dose CBCT protocols have been proposed and successfully managed in reducing radiation dose and satisfying the needed radiographic details, this have been achieved by hardware and software improvement through the use of more sensitive detectors, advanced reconstruction algorithm, reduction of the exposure time, using a limited field of view (FOV) and the implementation of additional copper filter **(Yeung et al., 2020).**

Inspite of the extended applications of CBCT in the various fields in dentistry; it hasn't been sufficiently evaluated in diagnosis of periapical lesions and measuring their volume, so this study was designed to assess the accuracy of the different CBCT protocols in volumetric measurements of stimulated periapical lesions.

MATERIAL AND METHODS

Study population

This study was conducted on ribs of sheep, obtained from a local butcher. They were deprived from any soft tissue, boiled in 30% hydrogen peroxide for two hours and left to dry for two weeks **(Hakulinen et al., 2004).**

Sample preparation

Each rib was segmented into a segment of 4-5 cm in length. Irregular cavities mimicking the periapical lesions were created in the buccal (convex) and lingual (concave) surfaces of the rib, where each rib had 3-4 defects. All defects were contained in the cortical and cancelleous bone. No through and through defects were included. These defects were done using a round diamond bur of a size 3-4 mm under a low speed handpiece. Each rib was recognized by naming it with an alphabetical letter (A,B,C,…) defining its buccal and lingual surfaces and marking its right and left sides. Each defect was given a numerical number (1,2,3,…) . **Figure (1).**

Soft tissue simulation was done using a softened dental pink wax (Cavex, Honland BV modeling wax), adapted till we get a thichness of a bout 13mm.

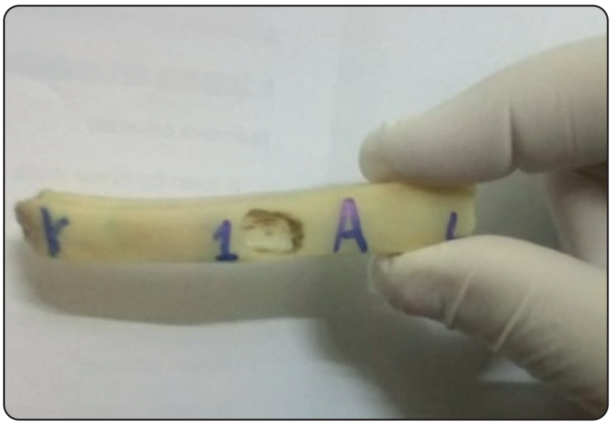

Fig. (1): Photograph of a rib sample with a defect prepared and numbered. The rib is identified by an alphabetical letter and its right and left sides are recognized.

Physical real measurements of the defects

The gold standard real volume of each defect was obtained by taking a precise impression using very high viscosity condensation silicon, the volume of this impression was calculated by Archimedes principle method **(Agbaje et al., 2004).**

Sample scanning using CBCT

Each bone sample was immobilized in a heavy –body silicon stent, seated in the horizontal plate of the PROMAX 3DMid CBCT device and the laser poisoning guide was used to guide placing the sample in the mandibular position. **Figure (2).**

Fig. (2): Mounting the rib in the CBCT machine for scanning.

Volumetric measurements in CBCT

The volumetric measurements of the defects were conducted using CBCT machine software (Planmecca Romexis viewer 3.8.1.R software). Volumetric segmentation was done manually as follow:

The intended defect was scrolled from its lowest point in the alveolar bone, through it reached the full size, till it disappeared to be fully recognized. When the most anterior part of the defect reached in the sagittal cut , the intersection of the longitudinal and transverse axis was drawn with the long axis of the rib to reconstruct the coronal cut where the defect 1st appear. Manual tracing was done using the coronal image with slice thickness of 1.2mm. Using the built-in volumetric measurement tool intended for manual segmentation (free region growing tool), the cortical boundaries of the defect were traced by that tool**. (Figure3).**

Fig. (3): Manual tracing of the defect in the 1st coronal cut, using the free region growing tool.

Manual tracing of the defect in each coronal cut sequentially, where the fit of the drawn line was checked for confirmation with the underlying cortical boundaries wherever possible. **Figure (4).**

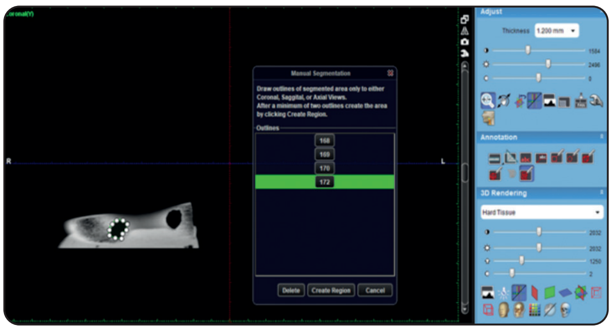

Fig. (4): Shows the value of manual tracing of the defect in each coronal cut sequentially.

After complete tracing of the defect in all cuts till reaching its full size, the function tool "create region" was activated to sum all traced volume together in a single segmented volume. The manually segmented volume was displayed with color coding and calculated in cm3 (**Figure5).**

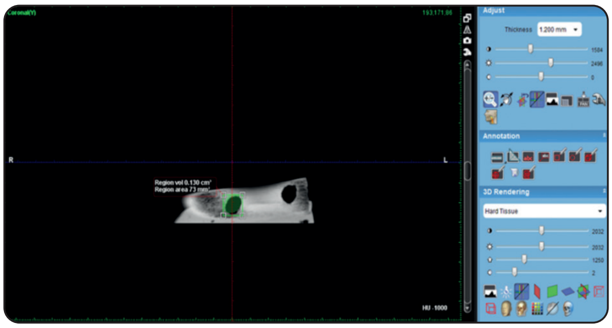

Fig. (5): The calculated volume of the manually segmented defect.

All measurements were conducted by two radiologists with experience of 15-20 years. Each radiologist conducted the measurements twice separated by two weeks interval. During CBCT measurements, each radiologist was blinded from CBCT protocols parameters, the readings of the other radiologist and the real measurements

Statistical methods

Numerical data were explored for normality by checking the data distribution and using Kolmogorov-Smirnov and Shapiro-Wilk tests. All data showed non-parametric (non-normal) distribution. Data were presented as mean, standard deviation, median and range values. Friedman's test was used to compare between defect volume measurements by standard, low doses and the physical measurement. Dunn's test was used for pair-wise comparisons when Friedman's test is significant. Wilcoxon signed-rank test was used to compare between errors of measurement as well as measurement error percentages by standard and low doses. Measurement error was assessed using Dahlberg's formula:

$$\text{Measurement error} = \frac{d2}{2n}$$

Where (d) is the difference between standard or low doses and the physical measurement, (n) is the sample size

For assessment of the agreement between low dose and standard dose measurements with the reference method Dahlberg error and Relative Dahlberg Error (RDE) are used together with Concordance Correlation Coefficients (CCC) including the 95% confidence limits.

RESULTS

I- Assessment of the error of the standard dose measurements

A small absolute Dahelberg error was found (0.0258mm) that indicates good accuracy of the segmentation measurements using this protocol. Mean difference is positive 0.0257 indicating that the standard dose is biased to smaller measurement value than the physical measurements. Concordance Correlation Coefficient CCC is 0.844 indicating excellent agreement of the two methods. **Table (1)**

II- Assessment of the error of the Ultra-low dose measurements

A small absolute Dahelberg error was found (0.0227) mm, smaller Dahelberg error means better accuracy of the segmentation using ultra-low dose protocol. Mean difference is positive 0.0207 indicating that the low dose is biased to smaller measurement value than the physical. Concordance Correlation Coefficient CCC is 0.881 indicated excellent agreement of the two methods. In general when comparing with the physical measurement the ultra-low dose has smaller Dahlberg error, smaller relative DE, tighter limits of agreement and higher CCC than standard dose. **Table (2)**

III- Comparison between standard, ultra-low doses and physical measurements (mm³)

There was a statistically significant difference between defect volume measurements in the three methods (P-value <0.001, Effect size = 0.514). Pairwise comparisons between the methods revealed that there was no statistically significant difference between standard and ultra-low dose protocols both showed statistically significantly lower mean volume than physical measurement. **Figure (6).**

TABLE (1): Results of Wilcoxon signed –rank test for comparison between measurement errors in defect volume (mm3) measurements by standard dose.

							Bland & Altman Limits of Agreement (LOA) 95%confidence limits				
Measurements	**Mean**	**SD**	**Dahelberg error DE**	**Relative Dahelberg Error RDE**	**Mean of Difference (physical-standard dose)**	**SD of the Difference**	**Lower**	**Upper**	**CCC**	**95% confidence limits**	
Standard dose	0.15	0.06	0.0258	14.9%	0.0257	0.0261	-0.0255	0.0769	0.844	0.761	0.900
Physical	0.17	0.06									

TABLE (2): Results of Wilcoxon signed –rank test for assessment of errors in defect volume (mm3) measurements by ultra- low dose CBCT protocol.

							Bland & Altman Limits of Agreement (LOA) 95%confidence limits				
Measurements	**Mean**	**SD**	**Dahelberg error DE**	**Relative Dahelberg Error RDE**	**Mean of Difference (physical-standard dose)**	**SD of the Difference**	**Lower**	**Upper**	**CCC**	**95% confidence limits**	
Low dose	0.15	0.17	0.0227	13.2%	0.0207	0.0249	-0.0281	0.0695	0.881	0.815	0.924
Physical	0.07	0.06									

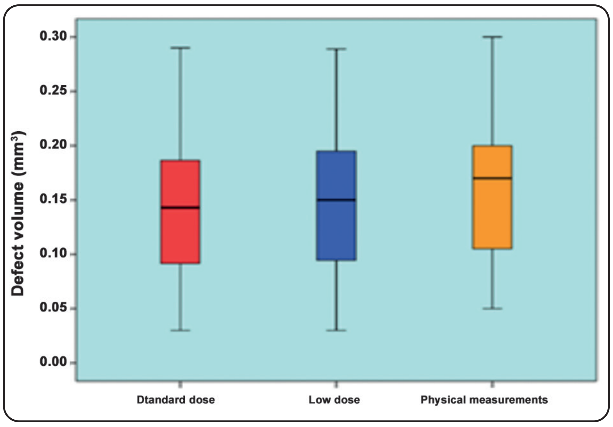

Fig. (6): Box plot representing median and range values for defect volume measurements.

IV- Correlation between CBCT protocols and gold standard physical measurement

Pearson correlation test showed a strong positive correlation was detected between the 2 CBCT protocols and the gold standard physical measurement (p=0.00), **(Table 3)**

V- Reliability of inter-and intra-examiner agreement

There was excellent inter-examiner agreement regarding all measurements with Cronbach's alpha values ranging from 0.847 to 0.912. and intra-examiner agreement regarding all measurements with Cronbach's alpha values ranging from 0.882 to 0.933. **Table (4)**

TABLE (3): Correlation of the recorded measurements using both CBCT protocols and physical measurement.

		Standard dose CBCT	Low dose CBCT	Physical
	Pearson Correlation		.976**	.914**
Standard dose CBCT	**P value**		.000	.000
	Interpretation		Strong positive	Strong positive
	Pearson Correlation	.976**		.932**
Low dose CBCT	**P value**	.000		.000
	Interpretation	Strong positive		Strong positive
	Pearson Correlation	.914**	.932**	
Physical	**P value**	.000	.000	
	Interpretation	Strong positive	Strong positive	

TABLE (4): Results of Cronbach's alpha reliability coefficient and Intra-class Correlation Coefficient (ICC. mnoyu) for inter- and intra-examiner agreement.

Measurement	Inter-examiner		Intra-examiner	
	Cronbach's alpha	ICC	Cronbach's alpha	ICC
Standard dose	0.847	0.822	0.879	0.856
Low dose	0.866	0.842	0.882	0.861
Physical measurement	**0.912**	**0.900**	**0.933**	**0.908**

DISCUSSION

Volumetric measurements in the field of dento-maxillofacial radiology plays an important role in the evaluation and determination of the size of various structures as maxillary sinus, sockets of teeth, pharyngeal space and also bony lesions including periapical pathosis as cysts, abscess and tumors. It is used for comparing the lesion dimensions during follow up procedure and determining the degree of healing of these lesions. It's also considered as a principal step in determining the success rate of endodontic treatment **(Park et al. 2017).**

Volumetric measurements in CBCT were presented as "segmentation" procedure that was investigated by several studies to be a reliable tool for volume calculation. The results of segmentation depends mainly on the quality of its image and the acquisition parameters which constitute the spatial and contrast resolution of these image, while a decrease in mill amperage leads to decreasing signal to noise ratio and lowering the contrast resolution, increasing the kilo voltage leads to an increase in the mean photon energy and lowering the contrast resolution **(Hassan et al., 2010 and Aoki et al., 2015).**

Hence treating a periapical lesion is a plan requires repeated frequency of radiographic examination in the same patient, so reducing the dose was a matter of concern to be implemented to save the patient from the biologic hazard of radiation exposure **(Kusnoto et al, 2015).**

The current study was conducted to assess the accuracy of CBCT standard dose and ultra-low dose protocols in volumetric measurements of bony lesion defects in comparison to the real measurements. CBCT volumetric measurement was performed using manual segmentation procedure and the real measurement was done by the ordinary used water displacement method. This experimental study was conducted on the ribs of sheep. Bovine bone –rib model was chosen because of the similarities in contour and dimension between this bone and human mandible and also it has cortical and cancellous bone of approximating thickness to the mandible **(Hakulinen et al., 2004).** Because of wide sample size and large number of bone defects are needed to assess the accuracy of CBCT protocols, so it was ethically to utilize such number of samples (58 defects) using bovine rib models in this study rather than human mandibles.

Exposure parameters (KVP, MA and Exposure time) were determined by the ultra-low dose and standard dose protocols as they were automatically adjusted in Planmecca Promax 3D Mid CBCT machine. The implementation of Ultra-low dose protocol reduces the MA and Exposure time which is the main factor in dose reduction from 8 MA and 13 sec in standard dose to 5.6 MA and 4.5 sec in ULD.

Manual segmentation was chosen for volumetric measurements instead of automatic, using its manual tool, it would be the best technique to fit the irregular shape of the defect. Automatic segmentation has not yet been adapted to fit the irregular shape and is more suitable for regular3D shapes. This was supported by, **Palamo et al. (2010)** who compared the manual segmentation with the semiautomatic and automatic segmentation and reported that manual segmentation was much more accurate than semiautomatic segmentation in measuring volumes using CBCT as it allowed the best operator control over tracing of the boundaries in each slice individually where the final volumetric calculation was made by the software.

Statistical analysis of the results of the current study showed that there was no statistical significant difference between standard dose and ultra-low dose protocols in defect volume measurements, where the mean defect volume for standard dose was (0.143) and the standard deviation was (0.066) and the mean defect volume for the low dose was (0.147) and the standard deviation was (0.069). The comparison between both protocols with the physical measurements showed that the ultra-low dose protocol has smaller Dahlberge error, smaller Relative Dahlberge error, and tighter limits of agreement and higher concordance correlation coefficient with physical measurement than standard dose

Up till now to our knowledge, there is no previous study in the literature has close resemblance to this study in methodology for comparing effect of scanning parameters in segmentation, However **Parket et al. (2017)** studied the effect of object shape and distance from the center of the image and different parameters (KVP and MA) on the accuracy of CBCT volumetric measurements. They used different geometric objects of pre calculated volumes and scanned them by CBCT machine. They used three different exposure settings (5 MA and 80KVP, 5MA and 100 KVP and 12 MA and 80 KVP). The minimum error obtained for objects imaged with 5MA and 100 KVP (-32-13%) and the maximum error obtained for objects imaged with 12MA and 80 KVP (39-3%). They thought the reason for these results was that image noise may be increased with the decrease in KVP, so a higher noise and presence of artifacts leads to image distortion that affects accuracy of segmentation. However they studied the effect of varying KVP and MA their results confirmed that lowering the milliamperage did not affect the volumetric measurements.

The current study showed that both standard dose and ultra-low dose parameters achieve higher segmentation procedure accuracy, Moreover, a strong positive correlation between the two CBCT protocols and the physical measurements was found, where the correlation value for the standard dose was 0.91and for the dose ultra-low dose was 0.93 which means that CBCT is a reliable tool for volumetric measurements.

Michetti et al. in 2015, designed a study for determining the optimal CBCT settings needed for an automatic segmentation used for root canal anatomy assessment. The results of segmentation were compared to the real histological assessment. The roots of 12 teeth were cut perpendicular to the root axis. These specimens were imaged using a combination of MA and KVP ranged from (2, 2.5, 3.2,4,5 and 6 MA) and (60, 65 and 70 KVP). They found that the best results of segmentation of the root canal was obtained at 3.2 MA and 60 KVP which means that a lower MA is suitable for segmentation. They stated that a strong correlation coefficient is present between the results of segmentation and the real measurements; which goes in agreement with the finding of the current study.

Inter-examiner reliability showed a very good agreement between all measurements ranged from0.847 to 0.912, while the intra-examiner reliability ranged from 0.882 to 0.933 between all measurements that support the accuracy of CBCT in volumetric measurement. Good inter and intra observer reliability may be justified by clinical experience and training of both examiners and standardization of the technique.

Excellent inter and intra-examiner reliability of CBCT volumetric measurements in this study was supported by the study of ***Alhowalia et al. (2012),*** they examined the volume of simulated bone lesions by CBCT, micro CT and compared their measurements with the real volumetric measurements. They found that CBCT volumetric measurements had 0.960 agreements in relation to the impression volume that indicates a strong positive agreement between them, parallel with the results of our study. They emphasized their high agreement to the fact that all examiners went through rigorous training program to assure that an appropriate strategy was employed.

CONCLUSIONS

From the results of the current study, can conclude that:

1- CBCT protocols provide a precise volumetric measurement of the periapical bony defects comparable to that of physical measurement.

2- There is a strong positive correlation between the CBCT volumetric measurements using both standard and low dose protocols and the physical measurements which proves that CBCT is a reliable tool for volumetric measurement.

3- Ultra -low dose protocol with its parameters is an appropriated CBCT protocol in the volumetric measurements of periapical bony defects as it showed less error percent than standard dose.

4- Inter and intra examiner reliability tests showed a very good agreement between all measurements which support the accuracy of CBCT in volumetric measurement.

5- CBCT volumetric measurement has a tendency for underestimation as the mean difference of error assessment in the two protocols was positive.

RECOMMENDATIONS

Recommendations for future work are as follow:

1- Further studies with larger sample size are needed to support the results of this study

2- Other ex-vivo studies should be performed to support the results of this experimental study which utilized bovine rib model rather than human mandible

3- Further in vivo studies should be performed to simulate the clinical situation in the patient's mouth as the presence of surrounding bone and teeth could increase the scatter radiation and beam hardening which in turn affects the facility of segmentation and volume measurement outcomes.

4- In this study defects were not completely enclosed in bone; instead, they include either the buccal or lingual plates that made analysis and segmentation easier, so defect totally enclosed in bone should be done and accuracy of volumetric measurements should be assessed.

5- Comparison between accuracy of the different CBCT softwares in volumetric measurement of bony defects and lesion size evaluation should be performed.

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