Effect of cone-beam computed tomography voxel size on detection of vertical periodontal bone defects

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ABSTRACT

Objectives: Finding the best voxel size for the detection of vertical periodontal bone defects with minimum patient radiation dose is a priority. This study sought to assess the effect of cone-beam computed tomography (CBCT) voxel size on the detection of vertical bone defects.

Materials and Methods: In this in vitro, experimental study, 31 vertical defects including 2 one-wall, 12 two-wall, and 17 three-wall defects were randomly created in the maxilla and mandible of four sheep skulls with the associated soft tissue using round and needle burs. Forty sound sites were considered as the control group. The CBCT scans were obtained from the skulls with 0.150 and 0.300 mm^3 voxel sizes and 8 x 11 cm^2 field of view (FOV). The images were randomly evaluated by two oral and maxillofacial radiologists and two periodontists, and their findings were recorded. The inter-rater observer agreement (weighted kappa), sensitivity and specificity values were calculated for each voxel size. Comparisons were made using paired t-test.

Results: The two voxel sizes had no significant difference in detecting one-wall and two-wall defects (P>0.05). But the smaller voxel size was significantly superior for detecting three-wall defects (P=0.001). The inter-rater observer agreement was unfavorable (kappa < 0.6) for the detection of all three defect types.

Conclusion: In general, increasing the image resolution by decreasing the voxel size increased the sensitivity and reduced the specificity of CBCT for detection of vertical bone defects, and is only recommended for detection of three-wall defects.

Keywords: Cone-Beam Computed Tomography; Vertical Bone Defects; Resolution; Voxel Size

INTRODUCTION

Periodontitis is a highly prevalent condition that results in the loss of tooth-supporting structures and can lead to eventual tooth loss. Detection of periodontal defects is often challenging for dental clinicians since they are usually masked by soft tissue. However, early detection of periodontal defects such as vertical bone defects is imperative for early management and good prognosis (1-3).

Vertical or angular bone defects are obliquely-oriented defects in the bone surrounding the teeth, which create an empty space along the root. These defects are often located in the apical segment and are often associated with infra-bony pockets. Goldman and Cohen (4) classified vertical bone defects based on the number of bony walls into one-wall, two-wall, and three-wall defects. The number of walls in the apical region of some defects may be higher than that in the occlusal region; such defects are referred to as combined osseous defects. Vertical defects formed in the interproximal areas can be usually detected by radiography. However, thick bone plates may mask them and complicate their radiographic detection. Vertical defects formed in the facial, lingual, or palatal plates may remain undetected on radiographs, and surgery is the only reliable method for the detection of such defects (5).

Diagnostic radiography associated with comprehensive clinical examination is the cornerstone of the detection of periodontal bony defects (6). The conventional 2D radiographic modalities provide 2D images of 3D structures, which results in the superimposition of anatomical structures, image distortion, and blurring, causing the loss of diagnostically valuable data (7). On the other hand, underestimation of the size and severity of periodontal defects leads to inadequate treatment and subsequent progression of periodontal destruction; while, overestimation of the size of periodontal defects can lead to unnecessary aggressive and invasive treatments such as periodontal surgery (8, 9). Thus, 3D radiographic modalities may be employed to overcome the limitations of 2D radiography.

Cone-beam computed tomography (CBCT) is particularly used for more accurate diagnosis in dentistry due to its advantages such as lower patient radiation dose, occupying a smaller space, lower cost, and higher resolution than medical computed tomography (10). However, the diagnostic quality of CBCT is influenced by the voltage (kVp), amperage (mAs), size of the field of view (FOV), and voxel size (11-13). Of the aforementioned parameters, voxel size has a significant effect on image resolution. Smaller voxel sizes yield images with higher resolution. However, the patient radiation dose also increases with the use of a smaller voxel size, which is not favorable (14, 15). The CBCT voxel sizes are isotropic, ranging from 0.075 to 0.4 mm (14, 16, 17). Evidence shows that 0.150 mm^3 voxel size is the cutoff point for detection of periodontal defects such that images obtained with higher resolutions have no significant difference from those obtained with 0.150 mm^3 voxel size in terms of diagnostic quality (2, 18, 19). On the other hand, it has been demonstrated that voxel sizes smaller than 0.300 mm^3 have significantly superior efficacy for the detection of periodontal defects, compared with larger voxel sizes (20, 21). Thus, 0.150 mm^3 and 0.300 mm^3 voxel sizes appear to be suitable for the detection of periodontal defects.

Considering all the above, this study aimed to compare the efficacy of 0.150 mm^3 and 0.300 mm^3 CBCT voxel sizes for detection of one-wall, two-wall and three-wall vertical periodontal bone defects to find the best voxel size for detection of each defect type with minimum patient radiation dose.

MATERIALS AND METHODS

This in vitro experimental study that evaluated 4 sheep skulls with both the maxilla and mandible accompanied by the surrounding soft tissues, was approved by the ethics committee of our school. The sample size was calculated to be 31 assuming alpha= 0.05, beta= 0.20, and a study power of 80%.

The teeth in both jaws underwent scaling and root planing with manual instruments. Next, a #15 surgical scalpel was used to elevate a full-thickness mucoperiosteal flap in each quadrant for direct visualization of the surgical site. A total of 31 vertical defects including 2 one-wall, 12 two-wall, and 17 three-wall defects were randomly created in the maxilla and mandible of the four sheep skulls with the associated soft tissue using 1/4, and 1/8 round, needle, and fissure burs and high-speed handpiece under water coolant, according to the method described by Goldman and Cohen(4). The flap was then returned and sutured with the sling, the figure of eight, or simple sutures using non-absorbable silk suture thread (3/0 USP). Forty sound sites were also considered as the control group.

Next, each skull underwent CBCT in a NewTom Giano CBCT scanner (Verona, Italy) with 0.150 and 0.300 mm^3 voxel sizes and 8 x 11 cm^2 FOV with 90 kV voltage, and 55.10 mA amperage for 9 s for the 150 mm^2 voxel size, and 22 mA amperage for 3.6 s for the 0.300 mm^3 voxel size. The axial view (Figure 1) and sagittal view CBCT scans were then randomly evaluated by four observers including two oral and maxillofacial radiologists and two periodontists, and their findings were recorded. Their opinion regarding the presence/absence of defects and their types was recorded in a checklist designed for this purpose.

To assess the intra-observer agreement, the observers evaluated 50% of the images again after a 3-week interval, and the kappa value was calculated. Also, due to the presence of four observers in this study, the kappa[1] value for the inter-observer agreement was calculated using the STATA software(22). Inter-rater observer agreement Kappa[2] value with merging 4 observer data was also calculated using SPSS. According to Cohen(23), the kappa values ≤ 0 indicate no agreement, values between 0.01-0.20 indicate none to slight, 0.21-0.40 indicate fair, 0.41-0.60 indicate moderate, 0.61-0.80

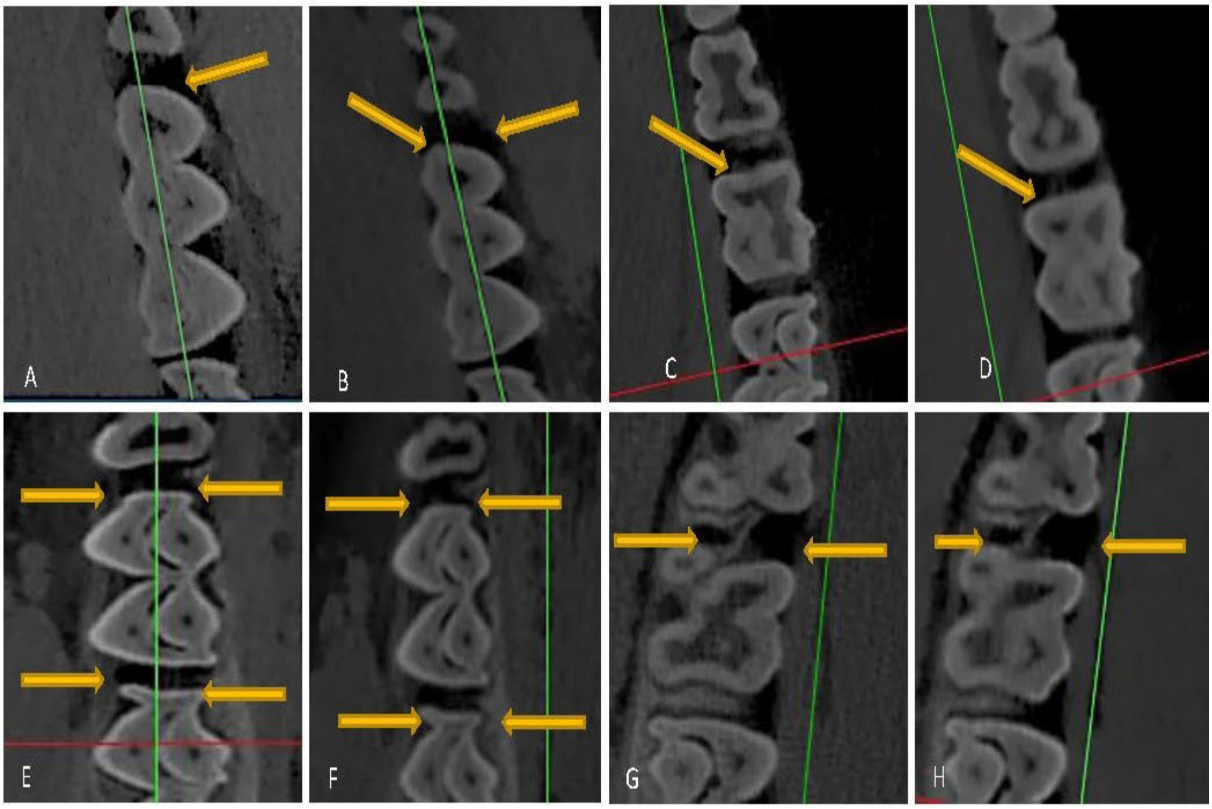

Fig. 1 – Axial view of one-wall vertical defects (**A**: 0.150 mm^3 voxel size, **B**: 0.300 mm^3 voxel size), two-wall vertical defects (**C**: 0.150 mm^3 voxel size, **E**: 0.150 mm^3 voxel size, **D**: 0.300 mm^3 voxel size, **F**: 0.300 voxel size), and three-wall vertical defect (**G**: 0.150 mm^3 voxel size, **H**: 0.300 mm^3 voxel size).

indicate substantial, and 0.81-1.00 indicate perfect agreement. For further simplification in this study, the kappa values ≥0.60 indicated favorable agreement between the observers in the detection of defects while smaller values indicated unfavorable agreement. The sensitivity, specificity, positive (PPV) and negative predictive values (NPV), positive (LR+) and negative likelihood ratios (LR-), false positivity, false negativity, and weighted kappa were calculated and reported for the two voxel sizes. Paired t-test was applied to compare the two voxel sizes. All statistical analyses were carried out using SPSS version 20 and STATA version 14 software programs. The level of significance was set at 0.05.

RESULTS

Table 1 presents the kappa[1] inter-observer agreement value and kappa[2] value for inter-rater observer agreement between the 4 observers as described, sensitivity, specificity, false positivity, false negativity, PPV, NPV, LR+, and LR- for detection of one wall, two-wall, and three-wall vertical defects by using the two voxel sizes.

The inter-observer and inter-rater observer agreement for detection of one-wall, two-wall, and three-wall defects was higher using a 0.15 mm^3 voxel size than a 0.300 mm^3 voxel size. However, the kappa[2] coefficient for inter-rater observer agreement for both voxel sizes were < 0.6 (unfavorable), and the difference between the two voxel sizes for detection of one and two wall vertical defects was not significant (P=0.083) (P=0.251), while for detection of three-wall defects was statistically significant, and the smaller voxel size was significantly superior for this purpose (P=0.001).

Table 2 shows the weighted kappa values for validity (agreement with the gold standard) and reliability of observes for detection of vertical bone defects. The weighted kappa values for assessment of inter-observer agreement (reliability) increased with an increase in image resolution and reduction of voxel size

Table 1 – Kappa[1] value and merged data Kappa[2] for the inter-observer agreement, sensitivity (SN.), specificity (SP.), false positivity (FP.), false negativity (FN.), positive predictive value (PPV), negative predictive value (NPV), positive likelihood (LR+) and negative likelihood ratio (LR-) for detection of one-wall, two-wall and three-wall vertical defects using the two voxel sizes in comparison with the gold standard.

Voxel	Defect	Kappa[1]	Kappa[2]	SN.	FN.	SP.	FP.	PPV	NPV	LR+	LR–
0.30	I wall	0.16	0.280	45.2	54.8	81.9	18.1	65.9	65.8	2.49	0.67
0.15		0.24	0.428	62.9	37.1	79.4	20.6	70.3	73.4	3.05	0.47
0.30	II wall	0.09	0.271	45.8	54.2	81.9	18.1	43.1	83.4	2.53	0.66
0.15		0.17	0.328	56.3	43.8	79.4	20.6	45.0	85.8	2.73	0.55
0.30	III wall	0.81	0.213	38.2	61.8	81.9	18.1	47.3	75.7	2.11	0.75
0.15		0.14	0.374	58.8	41.2	79.4	20.6	54.8	81.9	2.85	0.52

Kappa[1]: Inter-observer agreement between the 4 observers using STATA Software (22); Kappa[2]: inter rater Observer Agreement using Merged Data between 4 Observer and analyzed with SPSS software; SN: Sensitivity; FN: False Negativity; SP: Specificity; FP: False Positivity; PPV: Positive predictive value; NPV: Negative predictive value: LR+: Positive likelihood ratio: LR-: Negative likelihood ratio.

(P<0.001). Also, the weighted kappa values for assessment of the agreement of the opinion of the observers with the gold standard (validity) increased with an increase in image resolution and reduction of voxel size (P<0.001).
Table 3 shows pairwise comparisons of the two voxel sizes for each type of vertical defect by using paired t-test. The difference between the two voxel sizes was only significant for the three-wall defects (P=0.001).
Considering the fact that the number of one-wall defects was only 2, and paired t-test showed no significant difference between the two voxel sizes for detection of one-wall defects (P=0.083), pairwise comparisons were not performed for one-wall defects.
Table 4 shows pairwise comparisons of the two voxel sizes for each observer regarding the sensitivity, specificity, false negativity, and false positivity of detection of two-wall defects.
Table 5 presents pairwise comparisons of the two voxel sizes for each observer regarding the sensitivity, specificity, false negativity, and false positivity of detection of three-wall defects.

Table 2 – Weighted kappa values for validity (agreement with the gold standard) and reliability (inter-observer agreement) of the observes for detection of vertical defects

Voxel size	Validity			Reliability		
	Weighted kappa	Standard error	P-value	Weighted kappa	Standard error	P-value
0.30	0.391	0.099	0.001>	0.168	0.099	0.001>
0.15	0.390	0.097	0.001>	0.266	0.100	0.001>

Table 3 – Pairwise comparisons of the two voxel sizes for each type of vertical defect by using paired t-test

Defect	Voxel Size	Mean	S.D.	S.E.	t	Df.	P-value
One-wall	0.300 vs. 0.150	-.038	.194	.022	-1.755	70	.083
Two-wall	0.300 vs. 0.150	-.051	.391	.044	-1.157	70	.251
Three-wall	0.300 vs. 0.150	-.167	.439	.050	-3.354	70	.001

SD: Standard deviation; SE: Standard error of the mean

Table 4 – Pairwise comparisons of the two voxel sizes for each observer regarding the sensitivity, specificity, false negativity and false positivity of the detection of two-wall defects

Observer	Voxel size	Kappa*	Sensitivity	False negativity	Specificity	False positivity
Periodontist 1	0.300	0.264	33.3	66.7	90	10
	0.150	0.421	58.3	41.7	85	15
Periodontist 2	0.300	0.102	41.7	58.3	70	30
	0.150	0.224	50	50	75	25
Radiologist 1	0.300	0.181	41.7	58.3	77.5	22.5
	0.150	0.283	50	50	80	20
Radiologist 2	0.300	0.567	66.7	33.3	90	10
	0.150	0.385	66.7	33.3	77.5	22.5

*Kappa values indicate intra-observer agreement.

Table 5 – Pairwise comparisons of the two voxel sizes for each observer regarding the sensitivity, specificity, false negativity and false positivity of the detection of three-wall defects

Observer	Voxel size	Kappa*	Sensitivity	False negativity	Specificity	False positivity
Periodontist 1	0.300	0.287	35.3	64.7	90	10
	0.150	0.497	64.7	35.3	85	15
Periodontist 2	0.300	0.215	52.9	47.1	70	30
	0.150	0.322	58.8	41.2	75	25
Radiologist 1	0.300	0.073	29.4	70.6	77.5	22.5
	0.150	0.275	47.1	52.9	80	20
Radiologist 2	0.300	0.287	35.3	64.7	90	10
	0.150	0.402	64.7	35.3	77.5	22.5

*Kappa values indicate intra-observer agreement.

DISCUSSION

The quality of CBCT images depends on parameters such as the tube voltage, FOV, and voxel size. Voxel size has a critical effect on the quality of CBCT scans, frequency of scanning, and reconstruction of CBCT images. The effect of voxel size on the resolution has been extensively studied, particularly with regard to the detection of different defect types (14). Evidence shows that smaller voxel sizes provide higher resolution and better visualize the details (24). Despite the presence of numerous studies regarding the effect of voxel size on the detection of root fracture, internal and external root resorption, and occlusal caries, studies regarding the effect of voxel size on vertical periodontal defects are limited (2). Thus, this study compared the efficacy of 0.150 mm^3 and 0.300 mm^3 CBCT voxel sizes for detection of one-wall, two-wall and three-wall vertical periodontal bone defects to find the best voxel size for detection of each defect type with minimum patient radiation dose.

In the present study, the results showed that with an increase in image resolution (reduction of voxel size), the sensitivity of detection of vertical defects increased but the specificity decreased, which can be due to increased false-positive cases in the use of higher resolution, compared with lower resolution images. Accordingly, Eftekhar et al.(25) evaluated the detection of fenestration, dehiscence, and furcation defects using similar voxel sizes and FOV to our study, they reported that with an increase in image resolution, diagnostic sensitivity increased while specificity was increased. Moreover, they concluded that reduction in voxel size significantly improved the detection of dehiscence, grade I and II furcation defects but not for fenestration or grade III furcation defects. In the present study, the three types of vertical defects were separately evaluated. However, Icen et al. (26) evaluated the detection of vertical periodontal bone defects, in general, using 0.125 and 0.160 mm^3 voxel sizes with 8 x 8, and 8 x 10 cm FOVs. Similar to our study, they reported that a reduction in voxel size increased the diagnostic sensitivity and accuracy of detection of defects. Dong et al. (27) evaluated the efficacy of CBCT with 0.125, 0.2, and 0.4 mm^3 voxel sizes for the detection of alveolar bone defects and to find the best voxel size for clinical use. They found no significant difference between 0.125 and 0.200 mm^3 voxel sizes in this respect. However, 0.4 mm^3 voxel size had a significantly lower diagnostic value than the other two. They stated that considering the diagnostic value and minimizing the patient radiation dose, 0.200 mm^3 voxel size would probably be the best choice for the detection of periodontal defects by CBCT. However, their conclusion regarding the significant difference of 0.400 mm^3 voxel size with 0.125 and 0.200 mm^3 voxel sizes for detection of bone defects cannot be well generalized to the clinical setting or compared with our results since they did not separately assess each type of vertical defect. However, their results were in agreement with our findings regarding three-wall defects. Kolsuz et al. (2) assessed the detection of tunnel defects by CBCT using 5 different voxel sizes (all smaller than 0.2 mm^3). They found significant differences in detection of these defects between the voxel sizes > 0.150 mm^3 and those ≤ 0.150 mm^3. Their results were in agreement with our findings regarding three-wall defects. Enhos et al. (28) reported more accurate detection of defects by using 0.3 mm^3 voxel size compared with 0.4 mm^3, and 0.2 mm^3 voxel size compared with 0.3 mm^3. However, they explained that this higher efficacy was not cost-effective, and did not recommend the smaller voxel size for routine use in patients with normal conditions. Their results regarding higher diagnostic accuracy by an increase in resolution and reduction in voxel size were in agreement with ours.

It is noteworthy that CBCT provides high-resolution images with valuable diagnostic information regarding periodontal defects. However, an increase in resolution requires increase in patient radiation dose. Thus, it is only recommended for suspected cases and when the early diagnosis can significantly affect the treatment plan of patients. Thus, clinicians should select a voxel size with optimally high accuracy while minimizing the patient radiation dose according to the ALARA principle.

This study had some limitations. The long shape of the sheep jaw is different from the human jaw. Also, the bone density of sheep skulls is lower than that of human skulls. Moreover, the sheep skull has higher porosities, which could have led to a false diagnosis of sound areas, and a reduction of specificity. On the other hand, it should be noted that this study had an in vitro design. Detection of periodontal defects in the clinical setting is often less accurate and more difficult than in vitro setting due to factors such as the presence of artifacts of metal restorations. Moreover, only two one-wall vertical defects were evaluated in this study, which compromised the quality of statistical analysis in this group. Future studies are required on an equal number of different types of vertical defects to obtain more reliable results. Also, the size of created defects should be precisely measured and compared with their size on CBCT images to determine the dimensional accuracy of CBCT. Furthermore, clinical studies are recommended on patients suspected of periodontal defects who are candidates for periodontal surgery to obtain more accurate results.

CONCLUSION

In general, increasing the image resolution by decreasing the voxel size increased the sensitivity and reduced the specificity of CBCT for the detection of vertical bone defects. In conclusion, there would be no need to use 0.150 mm^3 voxel size for detection of one-wall and two-wall vertical defects since they can be accurately detected by 0.300 mm^3 voxel size (with lower patient radiation dose). For three-wall defects, however, considering the significant difference between the two voxel sizes and the importance of their correct detection for early treatment and bone grafting, the use of a 0.150 mm^3 voxel size is recommended for their detection. However, it should be noted that the final decision regarding the most appropriate voxel size must be made by the periodontist based on individual patient conditions.

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