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The Effect of Different Field of View Sizes on Contrast-to-Noise Ratio of Cone-Beam Computed Tomography Units: An In-Vitro Study

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ABSTRACT

Objectives: 'Field of view (FOV) size' affects the quality of radiographic images and the radiation dose received by patients. In cone-beam computed tomography (CBCT) FOV should be selected according to therapeutic purposes. While aiming for the highest diagnostic image quality, the radiation dose should be kept to a minimum to reduce the risk for patients. The purpose of this study was to assess the effect of different sizes of FOV on contrast-to-noise ratio (CNR) in five different CBCT units.

Materials and Methods: In this experimental study, CBCT scans were taken from a dried human mandible containing a resin block fixed to the lingual cortex and a resin ring was used to simulate soft tissue during scans. Five CBCT units including, NewTom VGi, NewTom GiANO, Soredex SCANORA 3D, Planmeca ProMax, and Asahi Alphard 3030 were evaluated. Each unit had 3 to 5 different FOVs. Images were obtained and analyzed with ImageJ software and CNR was calculated in each image. ANOVA and T-test were used for statistical analysis (P<0.05).

Results: Comparison among different FOVs of each unit showed significant CNR reductions in small FOVs (P<0.05). Similar FOV sizes of different CBCT devices were also compared and demonstrated significant differences (P<0.05).

Conclusion: A direct relationship between FOV size and CNR was observed in all five CBCT units, but differences in exposure parameters of these units led to variable CNR in FOVs with similar sizes.

Keywords: Artifacts; Cone-Beam Computed Tomography; Phantoms, Imaging, Radiographic Image Enhancement

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INTRODUCTION

Cone Beam Computed Tomography (CBCT) is currently known as an accurate imaging modality in dentistry for diagnostic and therapeutic purposes [1]. Many CBCT devices are available in the market and each of them claims to provide the best image quality. There is a wide range of exposure parameters such as tube voltage, tube current, exposure time, and rotation arc, which varies among different units [2,3]. Finding a device with the best parameters that offer minimum radiation doses to patients while being cost-effective, is of great importance to practition-ers. It is the radiologist's responsibility to determine which unit to use and which exposure parameters to select to achieve the best image quality, even though this decision is related to many factors [1-5]. Therefore, it is important to assess image quality by standard methods. The level to which the image quality changes according to varying parameters of CBCT units is unknown Proper adjustments should be determined by the radiologist and if disregarded, patient's dosage and image quality will be affected [2,3]. Assessment of the diagnostic quality of images has been performed using different methods in various articles [4-9].

One of the aspects of image quality in CBCT is contrast resolution, which denotes the ability to detect different contrast levels in an image [4,5]. Contrast-to-noise ratio (CNR) is one of the factors that can affect image quality in CBCT. CNR is a quantitative criterion for expressing image quality [2].

This ratio has been assessed in various articles using different methods [1, 10-14]. For the first time in 2012, Bechara et al. [1] evaluated the CNR in the images obtained by one CBCT device. The importance of assess-ment of this issue becomes more clear bearing in mind that CBCT has been widely welcomed in various dentistry treatments. Voxel size and field of view (FOV) also affect image quality and patient's dose. FOV in CBCT imaging should be selected according to therapeutic purposes, in a way that diagnostic needs can be properly satisfied [1].

The dimensions of the scan field vary depending on the type of the radiographic device. Usually, this size is selected based on the size of the assessed area. Most of the previous studies in this regard have some shortcomings [1-3]. Moreover, the majority of these studies have not directly evaluated the effect of FOV, and its effect has been implied as a sidelong finding. Since larger FOVs result in higher radiation dose, correct selection of FOV size in each device is of utmost importance [1-3].

The purpose of the present study was to assess the CNR of raw images in various sizes of FOV in five different CBCT units. The results could be used to optimize the application of this imaging modality

MATERIALS AND METHODS

The phantom used in this study was comprised of a dried human mandible, and a 2×1×1cm epoxy resin block was fixed to the lingual side of right mandibular molars using wax. During imaging, the mandible was placed inside an epoxy resin ring to simulate soft tissue (Figure 1).

Fig. 1. The phantom used for imaging

The scan fields were adjusted so that the right side of the mandible which contained the resin block was imaged in all the scans (Figures 2,3).

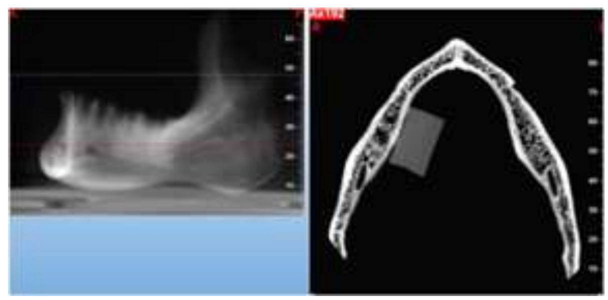

Fig. 2. Axial view in the 15×15 cm FOV of NewTom VGi CBCT unit

Fig. 3. Geometric depiction of the detector in relation to the object and projection, when the detector or the source has an angular orientation

In each unit, the standard exposure parameters recommended by the manufacturer were used. Overall, the scans were made in a single session without moving the phantom (Figure 3). The five evaluated CBCT units and the applied exposure parameters are listed in Table 1.

Table 1. Exposure parameters of the five cone-beam computed tomography units

Unit	Kilovoltage peak	Milliamperage	Exposure Time (s)	Scan Time (s)	Milliampere-seconds
NewTom VGi	110	0.55	3.6	18-26	1.99
NewTom GiANO	90	3	3.6	17	10.8
Asahi Alphard 3030	80	4-10	-	17	-
Planmeca ProMax	78 -80	9	12.3	9-37	110-123
Soredex SCANORA 3D	85	15	2.4-6	10-13	30-45

In this study, five CBCT units were assessed: NewTom Giano (GiANO, NewTom, Verona, Italy) with five FOVs, NewTom VGi (NewTom, Verona, Italy) and Scanora 3D (Scanora, Soredex, Helsinki, Finland) each with four, and Alphard 3030 (Alphard, Asahi, Kyoto, Japan) and Planmeca Promax (ProMax, Planmeca, Helsinki, Finland) each with three FOVs.

FOV characteristics of each CBCT unit and their voxel sizes by scan field are shown in Table 2. Hence there were 19 different FOVs and the scans and measurements were repeated 4 times for each FOV. Accordingly, the sample size was comprised of 76 measurements.

Table 2. Voxel size separated by scan field in each cone-beam computed tomography unit

Unit	Field of vision (cm)	Voxel Size (μm)
NewTom VGi	15×15	250
	12×15	200
	12×8	
	8×8	
NewTom GiANO	11×8	300
	11×5	
	8×8	
	8×5	
	5×5	
Asahi Alphard 3030	20×18	390
	15×15	200
	5×5	100
Planmeca ProMax	3×5	160
	5×8	
	8×8	
Soredex SCANORA 3D	13×14.5	350
	7.5 ×14.5	
	7.5 ×10	300
	6×6	200

Image analysis:

In the axial view, the image related to the central area of the resin block was selected (Figure 2). The obtained images were analyzed using ImageJ software: 1.4.2 bundled with 32-bit Java 1.6.0-10 (26 MB). For data analysis, segments of the air area and resin block were selected as control and sample, respectively. Subsequently, the histogram related to these segments was drawn by the software. The mean and standard deviation (SD) values were used to calculate CNR according to the following formula:

$$CNR = \frac{Mean_{block} - Mean_{control}}{\sqrt{SD^2_{block}+SD^2_{control}}} [2]$$

The SDs of the air and resin block histograms were used to calculate noise, and the mean difference values were employed for contrast assessment. Data were analyzed using ANOVA ($P<0.05$).

RESULTS

In this study, the five CBCT units had three to five FOVs. Their CNR based on different FOV sizes are summarized in Table 3.

ANOVA and Post hoc tests were used for comparing the CNRs in different scan fields. First, the related fields in each unit were compared (Table 4) and then the fields with similar dimensions in the five units were classified into five groups, and comparisons were made in each group. The classifications are presented in Table 5.

Table 3. Contrast-to-noise ratio (CNR) in different field of view (FOV) sizes assessed for five cone-beam computed tomography (CBCT) units

CBCT unit	FOV (cm)	CNR		
		Minimum	Maximum	Mean±Standard Deviation
NewTOM VGi	15×15	30	32	30.85±0.85
	12×15	25.5	27.5	26.65±0.85
	12×8	23.6	24.5	23.92±0.39
	8×8	19	22.8	21.1±1.5
NEWTOM GiANO	11×8	59.6	60.6	60.12±0.45
	11×5	56.5	58	57.37±0.63
	8×8	53.8	55.5	54.77±0.75
	8×5	50.5	52	51.37±0.63
	5×5	47.1	48.7	48.15±0.73
Alphard 3030	20×18	33.7	35.2	34.5±0.64
	15×15	27	29.6	28.72±1.2
	5×5	20.1	22.2	21.37±0.91
Planmeca ProMax	8×8	22.9	24.6	23.60±0.72
	8×5	18.5	20.2	19.40±0.70
	5×3	12.5	13.8	13.17±0.58
Soredex SCANORA 3D	13×14.5	22.5	24.1	23.42±0.69
	7×14.5	19.9	21.2	20.50±0.53
	7.5×10	16.9	18.3	17.62±0.72
	6×6	14.2	16.6	15.47±0.99

Table 4. Significant contrast-to-noise ratio values of each scan field compared to the other scan fields of the five cone-beam computed tomography (CBCT) units

CBCT unit	Field of view (cm)		Mean difference	Standard error	P
NewTom VGi	8×8	12×15	-5.55	0.71	<0.001
		12×8	-2.82	0.71	0.009
		15×15	-9.75	0.71	<0.001
	12×15	8×8	5.55	0.71	<0.001
		12×8	2.72	0.71	0.011
		15×15	-4.2±	0.71	<0.001
	12×8	8×8	2.82	0.71	0.009
		12×15	-2.72	0.71	0.011
		15*15	-6.92	0.71	<0.001
	15×15	8×8	9.75	0.71	<0.001
		12×15	4.2	0.71	<0.001
		12×8	6.92	0.71	<0.001
Alphard 3030	5×5	15×15	-7.35	0.67	<0.001
		20×18	-13.12	0.67	<0.001
	15×15	5×5	7.35	0.67	<0.001
		20×18	-5.77	0.67	<0.001
	20×18	5×5	13.12	0.67	<0.001
		15×15	5.77	0.67	<0.001
NewTom GiANO	5×5	8×5	-3.22	0.45	<0.001
		8×8	-6.62	0.45	<0.001
		11×5	-9.22	0.45	<0.001
		11×8	-11.97	0.45	<0.001
	8×5	5×5	3.22	0.45	<0.001
		8×8	-3.4	0.45	<0.001
		11×5	-6	0.45	<0.001
		11×8	-8.75	0.45	<0.001
	8×8	5×5	6.62	0.45	<0.001
		8×5	3.4	0.45	<0.001
		11×5	-2.59	0.45	<0.001
		11×8	-5.35	0.45	<0.001
	11×5	5×5	9.22	0.45	<0.001
		8×5	6	0.45	<0.001
		8×8	2.59	0.45	<0.001
		11×8	-2.75	0.45	<0.001
	11×8	5×5	11.97	0.45	<0.001
		8×5	8.75	0.45	<0.001
		8×8	5.35	0.45	<0.001
		11×5	2.75	0.45	<0.001
Planmeca ProMax	5×3	8×5	-6.22	0.47	<0.001
		8×8	-10.42	0.47	<0.001
	8×5	5×3	6.22	0.47	<0.001
		8×8	-4.2	0.47	<0.001
	8×8	5×3	10.42	0.47	<0.001
		8×5	4.2	0.47	<0.001
Soredex SCANORA	6×6	10×7.5	-2.15	0.53	0.008
		14.5×13	-7.95	0.53	<0.001
		14.5×7.5	-5.02	0.53	<0.001
	10 ×7.5	6×6	2.15	0.53	0.008
		14.5×13	-5.8	0.53	<0.001
		14.5×7.5	-2.87	0.53	0.001
	14.5×13	6×6	7.95	0.53	<0.001
		10×7.5	5.8	0.53	<0.001
		14.5×7.5	2.92	0.53	0.001
	14.5×7.5	6×6	5.02	0.53	<0.001
		10×7.5	2.87	0.53	0.001
		14.5×13	-2.92	-	0.001

Table 5. Classification of similar field of views of different cone-beam computed tomography units in five groups

Units and field of views						Significance
1	8×5 NewTom GiANO	8×5 Planmeca ProMax	-	-	-	-
2	8×8 NewTom VGi	8×8 NewTom GiANO	8×8 Planmeca ProMax	-	-	Significant
3	15×15 NewTom VGi	15×15 Alphard 3030	12×15 NewTom VGi	14.5×13 Soredex SCANORA	20×18 Alphard 3030	Significant
4	11×8 NewTom GiANO	12×8 NewTom VGi	10×7.5 Soredex SCANORA	-	-	Significant
5	5×5 NewTom GiANO	5×5 Alphard 3030	5×3 Planmeca ProMax	6×6 Soredex SCANORA	-	Significant

DISCUSSION

The results of the present study show that with reducing the size of FOV in each of the five CBCT imaging units, the CNR decreases significantly. Moreover, the differences in the CNR were significant when similar FOVs in different units were compared. The kilovolt peak (kVp) and milliampere-second (mAs) were fixed in all FOVs of NewTom VGi and NewTom GiANO units and standard parameters were applied for scans. Voxel sizes in each unit related with FOV are summarized in Table 2.

According to the CNR values in the present study, it is obvious that irrespective of the type of imaging modality and considering the different parameters of exposure in each unit, the CNR increased with larger FOVs. This is especially noticeable in NewTom GiANO CBCT unit as the voxel size and exposure parameters were identical in all FOVs and only the size of FOV was changing.

In a research by Bechara et al. [8] in 2012, that evaluated the differences in the CNR in large FOVs of a CBCT unit, the phantom was scanned during a single session with three large FOVs. They concluded that with increased exposure time in each FOV, the CNR did not change significantly, while in larger FOVs the CNR decreased. The results of this study are in accordance with our findings.

However, it has been stated that scattered radiation decreases the contrast and increases the noise, and that the amount of scattered radiation is generally proportionate with the total tissue mass exposed to the primary radiation, and it increases with increasing the thickness of the object and FOV size. Improved image quality is expected in smaller FOVs due to decreased scattered radiation [4, 15].

On the other hand, local tomography phenomenon occurs in small FOVs when FOV only encompasses part of the object. In this phenomenon, the assessed area is surrounded by a tissue that is absent in image reconstruction but receives radiation. In these cases, ray sum is calculated from the total radiation that has passed through the object.

Therefore, in local tomography, the objects outside of the FOV are in angular ranges in the direction of x-rays; however, back projection process does not apply to them [15,16].

The other reasons are related to hardware limitations and high expenses of flat panel detectors that are necessary for large FOVs. Due to high costs of these detectors, the manufacturing companies use a technical solution encountered frequently in CBCT units. Usually, a smaller flat panel detector is used which its source-detector axis has an angular orientation relative to the center of rotation.

As a result, the central area of the object is reconstructed from a 360 degrees scan, while the peripheral areas are scanned in a 180 degrees rotation, and therefore ring artifact is formed in the axial view [15].

In comparing the large FOVs summarized in group 3 of Table 5, the maximum level of CNR in this group is related to the largest FOV in Alphard 3030 unit, because the voxel size of this filed is 390 µm and it is the largest field in the study. But overall, the CNR values of NewTom GiANO unit were higher than that of the other units, which may be due to the voxel size. Nevertheless, when the largest field (18×20 cm) and the largest voxel size (390 µm) were selected in Alphard 3030 unit, the CNR was significantly lower than that of NewTom GiANO unit. Therefore, it can be concluded that the factors that affect the CNR are not necessarily limited to FOV and voxel size, but exposure parameters and specifications of the unit and detector also have a role. However, it has been mentioned in some articles that when a high spatial resolution is needed to depict fine details on the image, smaller voxel sizes are recommended [8].

Partial volume averaging is one of the characteristics of imaging with fan-shaped projection and CBCT. This artifact is resulted when the selected voxel size is larger than the size of the object. In this case, the pixel represents a mean value of different brightness levels. This artefact can be resolved by selecting smaller voxel sizes [4].

Tanimoto and colleagues [6] assessed the effect of changes in voxel size on resolution and noise. The voxel sizes were 40, 80 and 160 µm and the scans were performed by 3D Accuitomo CBCT unit. The results showed that smaller voxel size causes increased noise, which is in accordance with our results. But the mentioned study has only compared small voxel sizes. However, voxel sizes up to 160 µm are used clinically for evaluation of fine details such as vertical root fractures and smaller voxels are either nonexistent in units or have no clinical application. In the present study, voxel sizes ranging from 160 to 390 µm were evaluated.

In a study by Hassan et al. [9] in 2010, the effect of factors such as scan field, degree of mouth opening and voxel size on 3D image quality was assessed. The results showed that in large FOVs, the resolution of 3D images was low in dental and interproximal areas. In addition, large voxel size and scan with closed mouth also decreased image resolution. This result contradicts our results in terms of voxel size. The differences can be attributed to the study design or the manner of image evaluation which was through eye observation in the mentioned study.

Maloul et al. [17] concluded that voxel size directly affects image resolution and noise. Generally, small voxel size renders higher spatial resolution, but due to the pixel fill factor in a specific flat panel detector, higher radiation dose may be necessary [4]. Considering that the exposure parameters including the kVp and mAs were different among these groups, and that the kVp varied from 80 to 110 in the fields, it is obvious that the CNR changes are more closely influenced by voxel size rather than by changes in the kVp.

According to Table 1 which shows the kVp of different units, the highest kVp was detected in NewTom VGi unit (110), and the lowest value was related to Planmeca ProMax unit (78). Contrariwise, the lowest mAs value was related to NewTom VGi unit (1.99), and the highest level was detected in Planmeca ProMax unit (110 to 123). Since scattered radiation degrades contrast and is controlled by the kVp (4), it seems that low kVp results in higher CNR. Comparison of 8×8 cm FOVs between these two units shows that the CNR value is significantly higher in Planmeca ProMax, even though the voxel size was smaller in this unit (160 µm). In a study by Bechara et al. [8] in 2012, it was concluded that the CNR increases with decreasing kVp, which confirms our results.

When the 8×11 cm FOV of NewTom GiANO unit and 7.5×10 cm FOV of Soredex SCANORA 3D unit with voxel size equal to 300 µm were compared, the CNR value was higher for NewTom GiANO unit with exposure parameters of 90 kVp/10.8 mAs, while the parameters equaled 85 kVp/30-40 mAs in Soredex SCANORA 3D.

This issue has been confirmed in a study by

Pauwels and colleagues [14] in 2014, which assessed the optimal kVp in a CBCT unit and calculated the CNR. They found that in the CBCT unit the highest kVp (90) was optimal. Therefore, they recommended lowering the mAs instead of the kVp in low dose protocols to maintain image quality. Higher kVp values increase the average photon energy and x-ray penetration and cause less interference between the projection and the object, and also increase the number of photons. This lowers the differences in ray attenuation in tissues with different densities. Therefore, high kVp results in low contrast.
Lofthang-Hansen et al. [13] in 2011 stated that exposure parameters should be adjusted according to diagnostic needs.
All the assessed factors in the present study affected the CNR. However, their degree of influence is a matter of discussion, since some factors have a higher coefficient of effectiveness. Also, risk-benefit should be considered in each diagnostic case, in a way that the highest diagnostic image quality can be achieved with minimum risks for patients.

CONCLUSION

The results of the present study show that with decreasing the FOV size in each of the five CBCT units, the CNR decreases significantly. Moreover, differences in the CNR were significant when similar FOVs of different CBCT units were compared.

CONFLICT OF INTEREST STATEMENT

None declared.

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