DOI: https://doi.org/10.17921/2447-8938.2023v25n3p129-136

Effect of Different Cone Beam Computed Tomography Devices and Protocols on Image Quality for the Evaluation of Periodontal Structures

Efeito de Diferentes Dispositivos e Protocolos de Tomografia Computadorizada deFeixe Cônico na Qualidade de Imagem para Avaliação de Estruturas Periodontais

Luciana Loyola Dantas*[a]; Janaína Araújo Dantas[a]; Luciana Soares de Andrade Freitas Oliveira[b]; Taruska Ventorini Vasconcelos[a]; Frederico Sampaio Neves[a]; Daniel Adrian Silva Souza[a]; Paulo Sérgio Flores Campos[a]; William C. Scarfe[c]; Iêda Margarida Crusoé Rocha Rebello[a]

[a]Universidade Federal da Bahia, School of Dentistry, Department of Propaedeutics and Integrated Clinic. BA, Brazil.
[b]Instituto Federal da Bahia, Department of Radiology. BA, Brazil.
[c]University of Louisville School of Dentistry, Department of Surgical/Hospital Dentistry. Louisville, Ky, USA.
*E-mail: lucianaloyola@yahoo.com.br

Abstract

The quality of Cone Beam Computed Tomography (CBCT) images is directly influenced by scanning and visualization protocols. Evaluate the subjective quality of the Cone Beam Computed Tomography (CBCT) image of different devices and protocols for diagnosing periodontal structures and correlate the findings with the contrast-to-noise ratio (CNR). One dry dentate mandible was scanned by six CBCT devices: Accuitomo 3D 170, CS 9000, CS 9300, Eagle 3D, i-CAT Classic, and Orthophos XG 3D. All CBCT devices were adjusted to provide a spatial resolution closest to 0.2 mm, and a FOV height limited to less than 100 mm. Cross-sectional images were evaluated randomly. The buccal bone coverage, the periodontal ligament space and the amount of image noise were assessed. The statistics were calculated based on a logistic regression model with the significance level set at 5%. Protocols with large FOVs demonstrated significantly lower image quality. No statistical differences were found regarding buccal bone coverage between the CBCT devices. The CNR showed the highest value for the Accuitomo 60mm x 60mm HiFi 180°, followed by the Accuitomo 60mm x 60mm HiFi 360°, and lower values for the i-Cat Classic and Orthophos XG 3D devices. Most protocols studied presented good image quality in evaluating the buccal bone coverage and periodontal ligament space. However, the exam with the lowest FOV of the Accuitomo 60mm x 60mm HiFi 180° device showed superiority concerning the others.

Keywords: Cone-Beam Computed Tomography. Technology, Radiologic. Radiography, Dental, Digital. Periodontics.

Resumo

A qualidade das imagens de tomografia computadorizada de feixe cônico (CBCT) é diretamente influenciada pelos protocolos de digitalização e visualização. Avaliar a qualidade subjetiva da imagem da Tomografia Computadorizada de Feixe Cone (CBCT) de diferentes aparelhos e protocolos para o diagnóstico de estruturas periodontais e correlacionar os achados com a razão contraste-ruído (RCR). Uma mandíbula dentada seca foi digitalizada por seis dispositivos CBCT: Accuitomo 3D 170, CS 9000, CS 9300, Eagle 3D, i-CAT Classic e Orthophos XG 3D. Todos os dispositivos CBCT foram ajustados para fornecer uma resolução espacial próxima a 0,2 mm e uma altura de FOV limitada a menos de 100 mm. Imagens transversais foram avaliadas aleatoriamente. A cobertura óssea vestibular, o espaço do ligamento periodontal e a quantidade de ruído da imagem foram avaliados. As estatísticas foram calculadas com base em um modelo de regressão logística com nível de significância de 5%. Protocolos com grandes FOVs demonstraram qualidade de imagem significativamente inferior. Não foram encontradas diferenças estatísticas em relação à cobertura óssea vestibular entre os dispositivos CBCT. O CNR apresentou o maior valor para o Accuitomo 60mm x 60mm HiFi 180°, seguido pelo Accuitomo 60mm x 60mm HiFi 360°, e valores menores para os dispositivos i-Cat Classic e Orthophos XG 3D. A maioria dos protocolos estudados apresentou boa qualidade de imagem na avaliação da cobertura óssea vestibular e do espaço do ligamento periodontal. Entretanto, o exame com menor FOV do aparelho Accuitomo 60mm x 60mm HiFi 180° apresentou superioridade em relação aos demais.

Palavras-chave: *Tomografia Computadorizada Cone-Beam. Tecnologia Radiológica. Radiografia Odontológica Digital. Periodontia.*

1 Introduction

There are numerous clinical applications for using Cone Beam Computed Tomography (CBCT) in Dentistry. CBCT provides multiplanar images with high spatial (sub-millimeter) and contrast resolution[1,2] with low radiation dose and cost, especially when compared to multi-slice computed tomography (MSCT). In periodontics, CBCT is used in the radiographic evaluation of the condition of the crestal alveolar bone coverage (BC) of the roots of the teeth relative to the cementoenamel junction (CEJ)[3-9] and periodontal attachment apparatus, including the periodontal ligament (PDL) space. While CBCT also allows for the assessment of intraosseous defects and visualization of the buccal and lingual bone levels, dehiscences, and fenestrations, measurement errors may be encountered in measuring the amount of bone loss or bone available[8,10.]

In clinical practice, the quality of the CBCT images and their ability to provide anatomical detail and demonstrate pathological characteristics are influenced by scanning and visualization protocols. Scanning protocols include considerations of exposure such as kilovoltage (kVp) and milliamperage (mA) and adjustment of acquisition parameters such as projection geometry (vertical and horizontal x-ray beam alignment (aligned or lateral off-set), field of view

(FOV), rotational arc (full 360° or partial) and acquisition time, which usually determines the number of basis projection images. Image visualization protocols are adjustments to the reconstruction process applied to the volumetric dataset to provide optimal visualization and type of reconstruction algorithm used, image resolution (voxel size), and application of algorithms to improve noise and reduce metallic artifacts[11-14]

CBCT acquisition and computer display technology have continually evolved since the first device's commercial introduction [15]. Numerous authors have investigated the purported advantages of these improvements for detecting, diagnosing, and measuring images by comparing specific CBCT devices for specific clinical scenarios. For example, Codari et al. evaluated the effect of FOV and high-density metallic material on the presence of metallic artifacts using three CBCT devices. They found significant differences between devices using a small FOV [16] . More recently, Dantas et al. evaluated observer detection of buccal BC on anterior teeth using six CBCT devices. They reported high diagnostic accuracy (75% to 94.4%) and observed the superiority of one CBCT unit over the others tested for this task[17].

The facto clinical standard for determining the diagnostic image quality of CBCT images has been a subjective assessment of various characteristics of specific anatomic or pathologic processes[5,9,11]. Performance of studies involving subjective assessment of CBCT image quality is difficult to perform and subject to a possible observer. Methodologic biases and measurements of various physical factors obtained from an image produce data that can support these subjective assessments. The images can be of a real skull or image quality phantom, and parameters include spatial resolution, contrast resolution, image noise, and contrast-to-noise ratio (CNR)[18].

Several authors have used CNR to evaluate and compare CBCT image quality using different scanning and visualization protocols[9,18-20]. The selection of protocols that produce images of acceptable diagnostic quality for specific clinical scenarios (task-specific) and sizes of patients is essential in that it minimizes radiation exposure to the patient. Recently, modifications to the ALARA (As Low as reasonably achievable) principle (United States Nuclear Regulatory Commission, UNC Title 10, Code of Federal Regulations, Section 20.1003, 2020) have been suggested in Dentistry to incorporate this ideology and defined as ALADAIP (As Low as Diagnostically Acceptable being Indication-oriented and Patient-specific)[21]. This concept aims to provide radiologic guidance for dental practitioners to obtain images with the lowest possible patient dose without undermining the diagnosis and with a patient-specific indication.

To the best of our knowledge, no investigator has yet proposed to evaluate multiple CBCT devices and scanning protocols to produce diagnostically acceptable image quality using minimal exposure to evaluate periodontal structures. Therefore, the objective of this study was to assess the subjective CBCT image quality of different devices and protocols for diagnosing periodontal structures and correlate the findings with CNR.

2 Material and Methods

The local Ethics Committee approved this research protocol (Opinion number: 2.558.466; CAAE: 68038117.7.0000.5024).

2.1 CBCT Imaging

Six CBCT devices were used to image a dry, dentate human skull, including the Accuitomo 3D 170 [J. Morita, Japan], CS 9000 and CS 9300 [Carestream Dental, France], Eagle 3D [Dabi Atlante, Brazil], i-CAT Classic [Imaging Sciences International, USA] and Orthophos XG 3D [Sirona Dental System, USA]). Scanning (FOV, Scan mode, Scan rotation) and visualization (nominal voxel size) protocols used are shown in Table 1. All units were adjusted to provide a spatial resolution (nominal voxel size) closest to 0.2 mm, and a FOV height limited to less than 100 mm (Range; 60 to 90), providing a region of interest restricted to a single dental arch and a 360° rotational arc. In addition, combinations of rotation scan, FOV, and scan mode were acquired using the Accuitomo 3D 170, comparing various scanning protocols for this unit to a control (60 x 60 mm, HiFi scan mode, and variable rotation scan). A total of 13 examinations were performed. After the acquisition, data were exported as a Digital Imaging and Communications in Medicine (DICOM) file with nominal thickness and saved for later retrieval and viewing.

Table 1 - Cone beam computed tomography devices and scanning protocols

	Protocol	Manufacturer	FOV (mm)	Scan Mode	kVp	mA	Scan Rotation	Voxel
1	Accuitomo 3D 170	J. Morita, Kyoto, Japan	60 x 60	HiFi	70	4	180°	0.125
2	Accuitomo 3D 170		60 x 60	HiFi	70	4	360°	0.125
3	Accuitomo 3D 170		60 x 60	Standard	70	4	180°	0.125
4	Accuitomo 3D 170		60 x 60	Standard	70	4	360°	0.125
5	Accuitomo 3D 170		170 x 120	HiFi	70	4	180°	0.250
6	Accuitomo 3D 170		170 x 120	HiFi	70	4	360°	0.250
7	Accuitomo 3D 170		170 x 120	Standard	70	4	180°	0.250
8	Accuitomo 3D 170		170 x 120	Standard	70	4	360°	0.250
9	CS 9000 3D	Carestream Dental, Trophy, France	80 x 90	-	60	8	360°	0.2
10	CS 9300		80 x 80	-	60	8	360°	0.18

	Protocol	Manufacturer	FOV (mm)	Scan Mode	kVp	mA	Scan Rotation	Voxel
11	i-CAT Classic	Imaging Sciences International. PA. EUA	160 x 80	-	120	36,12	360°	0.2
12	Eagle 3D	Dabi Atlante, Ribeirão Preto, Brazil	120 x 75	-	85	6,3	360°	0.2
13	Orthophos XG 3D	Sirona Dental System, Charlotte, NC, EUA	80 x 80	-	85	5	360°	0.16

Source: research data.

2.2 Subjective Image Quality

Image evaluation was carried out by three radiologists using a single display software (CS Dental Imaging Software 3D module, version v3.5.7, Carestream Health, Atlanta, USA) on a high-resolution LCD monitor (Eizo Radiforce MX300W, Eizo Corporation, Hakui, Japan) with a resolution of 2560 x 1600 pixels (4 megapixels), a pixel pitch of 0.2505 mm and 1000:1 contrast ratio. This monitor possesses In-Plane Switching (IPS) technology, which provides color uniformity regardless of the viewing angle, making it ideal for diagnosis. Available tools could be applied, such as the alteration of brightness and contrast and the approximation of images. Observers were blinded to the CBCT system used to acquire the images and the study's purpose. The evaluation took place weekly over 13 weeks, with one exam per week being analyzed.

The images were interpreted in a multiplanar window (axial, sagittal, and coronal) where the observer had unrestricted use of the image manipulations tools of the CS Dental Imaging Software. Observers were directed to assess image quality regarding specific anatomic features concerning periodontal diagnosis:

2.2.1 Buccal Bone Coverage (BC)

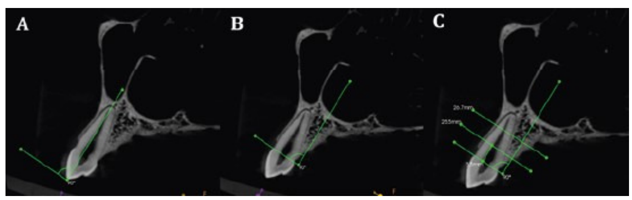
The methodology of Ferreira et al. was used to evaluate BC in three regions of the root surface: cervical third, middle third, and apical third[22]. Subjective assessments of confidence as to the presence or absence of BC on the root surface (Table 2) on four teeth of each exam. The orthogonal planes were adjusted such that the long axis of the tooth was perpendicular in both mid-sagittal and coronal planes with slice thickness corresponding to the acquisition resolution. Following the dataset's reorientation to the tooth's long axis, a line was constructed parallel to the long axis of the tooth in parasagittal reconstruction and perpendicular to a line drawn between the labial and palatal CEJ locations. Root divisions into thirds were then assigned based on the distance between the CEJ and apical terminus and assessed (Figure 1). Figure 2 shows the para-sagittal image reconstruction of the realigned dataset about the long axis of tooth 1.1 using different CBCT scanning and visualization protocols. An independent, trained observer examined the dry skull and recorded all absences of BC in the anterior region of the maxilla and mandible with the aid of an Odin digital caliper (Ortho-Pli, Philadelphia, PA, USA). The thirds were divided using previous measurements on the CBCT cross-sectional images.

Table 2 – Criteria used to detect buccal bone coverage.

Classification of Buccal Bone Coverage	
1	Absent
2	Possibly absent
3	Undefined (impossible to evaluate)
4	Possibly present
5	Present

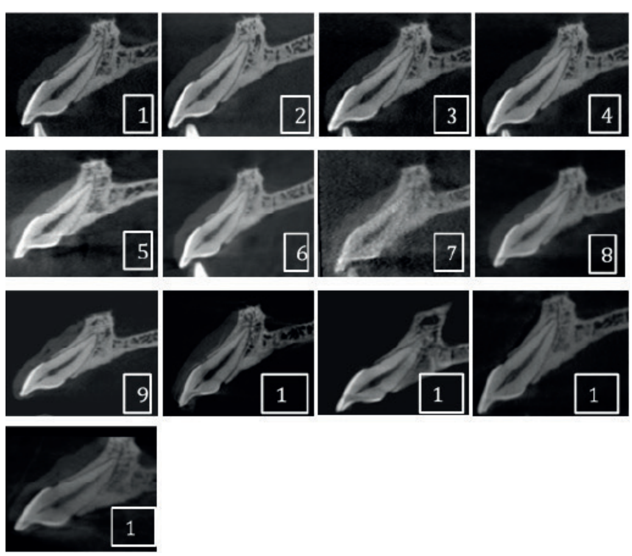
Source: research data.

Figura 1 - Measurement of thirds of tooth 2.3 through the construction of a perpendicular line along the long axis of the tooth in the parasagittal image (A); transferring the line to the cementoenamel junction and measuring the size of the root (B) and dividing the thirds (C)



Source: research data.

Figura 2 - Sagittal tomographic reconstruction of tooth 1.1 in different acquisition protocols: 1- Accuitomo 60mm X 60mm HIFI 180°; 2- 60mm X 60mm HIFI 360°; 3-60mm X 60mm STD 180°; 4- 60mm X60 mm STD 360°; 5- 170mm X 120mm HIFI 180°; 6- 170mm X 120mm HIFI 360°; 7- 170mm X120 mm STD 180°; 8- 170mm X 120mm STD 360°; 9- ICAT CLASSIC; 10- ORTHOPHOS XG 3D; 11- EAGLE 3D; 12-CS 9000; 13- CS 9300



Source: research data.

2.2.2 Classification of the periodontal ligament space

The observers' ability to distinguish the outline of the root surface from the adjacent BC is a function of the clarity of the periodontal ligament space. Image clarity is related to many factors, including spatial and contrast resolution and image noise. To subjectively assess resolution, observers were asked to rate image quality according to a 5-point scale (Table 3) for each of the four teeth, using the previously reformatted images.

Table 3 - Criteria used to classify image quality regarding buccal bone coverage.

Rating	Classification	Description
1	Excellent	High quality / definition / sharp image
2	Good	Good quality image
3	Satisfactory	Acceptable quality image
4	Poor	Poor quality image but still allows viewing
5	Very poor	Very poor-quality image that makes viewing impossible or insufficient

Source: research data.

2.2.3 Amount of image noise

The effect of perceived image noise on the observers' ability to distinguish the outline of the root surface from the adjacent BC was determined by observers rating image quality according to a 5-point scale (Table 4) for each of the four teeth, using the reformatted images generated previously.

Table 4 - Criteria used for subjective classification regarding the presence of noise

Noise Rating		
1	Mild	Without prejudice to the diagnosis
2	Mild to moderate	Acceptable without prejudice
3	Moderate	More attention to diagnosis
4	Moderate to severe	Diagnostic damage
5	Severe	Impossible to diagnose

Source: research data.

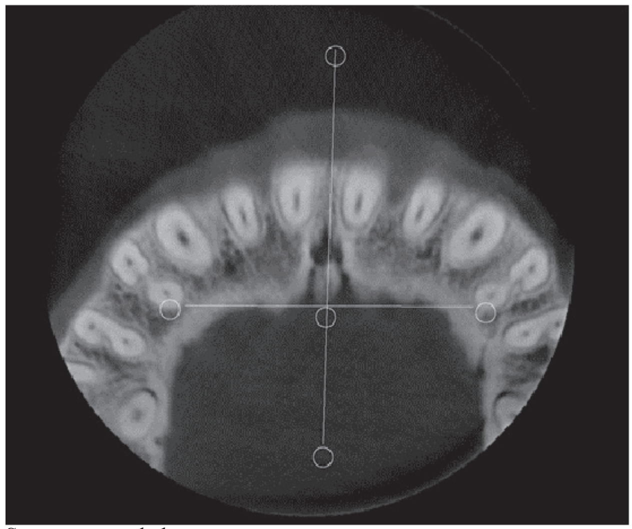
2.3 Objective Image Quality

The contrast-to-noise (CNR) was considered an objective measure of CBCT image quality[23,24]. Axial slices at the same level were chosen from each dataset. CNR was calculated in identical regions of interest (ROIs) using Image J software (National Institutes of Health, Bethesda, MD). This analysis was performed by an oral and maxillofacial radiologist with experience in this methodology.

Reoriented volumetric datasets were imported into Image J, and in the axial images, the level of the labial CEJ of the maxillary central incisors were identified. Circular ROIs (300x240 pixels) were selected at the exact locations in each image. Three regions in the mid-sagittal plane outside the anatomic area and distributed over the entire diameter of the FOV were considered as control. Two control ROIs were at the periphery of the scan, and the third was located at the intersection between the mid-sagittal and a line connecting the disto-palatal aspect of the palatal root of the left and right premolars. Two bilateral test ROIs were identified, one located in the palatal root of the first premolar (tooth) and a second located in the adjacent alveolar bone (Figure 3). Histogram analysis was applied in each ROI to provide the mean gray level and standard deviation (SD). The CNR was calculated, according to the methodology reported in a study by Vasconcelos et al.[20], based on the mean values for the test area and the control area, as follows:

$$\text{CNR} = \frac{|\,Average\ test - average\ control\,|}{\sqrt{Standard\ deviation\ test^2 + Standard\ deviation\ control^2}}$$

Figura - 3 Axial reconstruction shows the selection of regions of interest over the test area (tooth and bone) and the image's control area (upper, middle, and lower)



Source: research data.

2.4 Statistical Analysis

Statistical analyses were performed using the SAS system (SAS Institute Inc. The SAS System, release 9.4 [2012], SAS Institute Inc., Cary, NC, USA). Calculations of intra- and inter-observer reproducibility were determined using the weighted Kappa coefficient (kW) for qualitative measures and the intraclass correlation coefficient (ICC) for linear measurements.

A one-way ANOVA test with Tukey's post-hoc analysis was used to compare the absolute differences between mean values observed for subjective and objective indices for each examination and CBCT device. An *a priori* statistical significance level of $p \leq 0.05$ was used.

3 Results and Discussion

The inter-observer reliability was recorded twice for subjective evaluation and varied between reasonable (0.20 —| 0.40) and perfect (1.00) according to the Kappa coefficient. Intra-observer reproducibility was moderate (0.40 —| 0.60) to perfect (1.00) (Table 5).

Table 5 - Intra and inter-observer reliability

Variables / Evaluators	Intraobserver (k_w)				Interobserver (ICC)			
	R1	R2	R3	Mean	R1 / R2	R1 / R3	R2 / R3	Mean
BC image quality	0.853	0.931	0.68	0.821	0.557	0.448	0.735	0.58
BC Classification	1	0.778	0.486	0.754	0.99	0.304	0.375	0.556
Noise	1	1	0.833	0.944	0.833	1	0.833	0.888
Mean	0.951	0.903	0.666	0.839	0.793	0.584	0.647	0.674

Source: research data.

Table 6 shows the mean and standard deviation subjective assessment ratings for each CBCT examination. Protocols 5 and 7 (Accuitomo 3D F170), with large FOVs (170mm x 120mm), demonstrated significantly poorer image quality than all other protocols. About noise, these protocols, together with protocol 12 (Eagle 3D), were considered to present with substantially higher noise than all other protocols. For the evaluation of the BC classification, no statistical differences were found between the exams (Table 6). The accuracy in the detection of BC compared with the gold standard varied from 77.5% (observer 2) to 82.7% (observer 2) to 97.2% (observer 3). Each evaluator identified different protocols where they considered it impossible to evaluate BC in some isolated teeth (Observer 1, protocols 5 and 7); Observer 2, protocols 7 and 12; and Observer 3, protocol 12).

Table 6 - Means and standard deviation () of CBCT exams for subjective assessments

Exam	BC image quality	BC Classification	Noise
1	1.42 (0.66)	1.67 (1.55)	1 (0.00)
2	1.58 (1.16)	2 (1.80)	1.42 (0.99)
3	1.50 (0.52)	1.67 (1.55)	1 (0.00)
4	1.08 (0.28)	1.33 (1.15)	1 (0.00)
5	4.17 (0.57) *	1.17 (0.57)	4 (0.85) *
6	1.67 (0.88)	2 (1.80)	1 (0.00)
7	4.67 (0.49) *	1.83 (1.33)	4.33 (0.49) *
8	2.00 (0.85)	1.67 (1.55)	1.17 (0.57)
9	1.42 (0.79)	1.67 (1.55)	1 (0.00)
10	1.58 (0.66)	2 (1.80)	1.33 (0.49)
11	1.08 (0.28)	1.33 (1.15)	1 (0.00)
12	1.92 (1.08)	2 (1.59)	3 (0.85) *
13	1.33 (0.65)	1.67 (1.55)	1 (0.00)

*Statistical difference with other tests.
Source: research data.

Table 7 summarizes the objective measurements of image quality. Standard deviation results were higher for Accuitomo 3D exams with higher FOV (170mm x 120mm). The CNR showed a higher value for exam 1 (Accuitomo 60mm x 60mm HiFi 180°), followed by exam 2 (Accuitomo 60mm x 60mm HiFi 360°), and lower values for exams 11 and 13, iCat and Orthophos XG 3D.

Table 7- Contrast to Noise ratio according to exams for the control and test areas

Protocols	SD Control	SD Test	CNR
1	13.07	32.9	1.81$^{\infty}$
2	13.96	40.615	1.42$^{\infty}$
3	64.06	46.63	0.92
4	55.39	39.075	1.09
5	88.33	60.28	1.21
6	89.85	59.135	1.22
7	89.90	58.64	1.14
8	87.65	58.515	1.12
9	80.62	47.175	0.67
10	59.90	39.16	0.84
11	76.50	48.67	0.56$^{\times}$
12	97.21	41.69	1.33
13	89.35	56.03	0.54$^{\times}$

$^{\times}$ - lowest value / ∞- highest value.
Source: research data.

In this study, the quality of images obtained using different CBCT units and scan protocols were assessed qualitatively and quantitatively regarding depicting periodontal structures of a single phantom. We found that subjectively protocols using large FOVs produced images of inferior quality. No significant differences were found between protocols comparing CNR. However, the highest value was attributed to protocol 1 (small FOV, 180° rotation, and high image resolution).

The six CBCT units evaluated represent most brands present in Brazil and other countries, and among them, one of the most studied worldwide, the Accuitomo 3D 170. Due to the various characteristics of these tomographs, which influence the final quality of the image and, therefore, the diagnosis, several studies have been conducted to evaluate its limitations and benefits. Dantas et al.[17] found high accuracy in six different devices detecting buccal BC in anterior teeth. Hedeşiu et al.[25], when comparing three CBCT devices, found no influence of FOV in the diagnosis of simulated periapical lesions. Kamburoglu et al.[14] found similar performances in six devices with different FOVs and voxel sizes in detecting horizontal root fracture created artificially in extracted human teeth. Finally, Alqerban et al.[1] analyzed six devices and observed high precision, without significant differences, in detecting the severity of external root resorption caused by an impacted canine.

The present study revealed a slight superiority of the

Accuitomo 3D 170 over other devices. This corroborates the findings of Lofthag-Hansen et al.[5]. They stated that this device has been extensively studied, and its performance has proven slightly superior to the others on the market. Several studies have evaluated different types of protocols available on this device during image acquisition, such as that performed by Yadav et al. [26]. They found diagnostic efficacy in detecting degenerative changes associated with the ATM complex using the Accuitomo 3D 180° acquisition protocol compared to the 360° protocol.

For the subjective evaluation of the image quality of the BC on the buccal surface, this study showed that the lowest quality images were the Accuitomo 3D exams with large FOV (170mm x 120mm) and 180° rotation of the device. As the values of voxel, kVp, and mA were fixed for the protocols of this device, it is believed that this result is due to the large size of the FOV, which generates a worse spatial resolution, compromising the assessment of BC and minute periodontal structures. This result corroborates the findings of Molen[27], who concluded that the higher the FOV, the greater the beam spread. With this, the greater the noise generated, ideally using the lowest FOV capable of understanding the region of interest. Dillinger et al.[28] also stated that smaller FOVs should be used to evaluate minor injuries and structures such as root fractures and that large FOVs are more suitable for maxillary and/or mandibular injuries such as tumors or cysts, bone diseases (for example, osteonecrosis, osteomyelitis) and maxillary or mandibular fractures. Mayo et al.[29] reported the diagnostic accuracy of small FOV acquisitions in evaluating BC before paraendodontic surgery.

The degree of rotation of the device also influences the final image quality and can be changed on some devices. These settings can reduce radiation exposure doses, although they can degrade the image quality and should be adjusted according to the need for the desired diagnosis. Radiation measurements were not the direct object of this study; however, since the 360° scan obtains about twice as many images as the 180° scan, it would be safe to assume that the effective radiation dose would be twice as high for the 360° scan as for the 180° scan, thus, added to the smaller size of the FOV, the Accuitomo 60mm x 60mm HiFi 180° protocol was considered the closest to ideal for diagnosing periodontal structures. Neves et al[30] observed that both modes provide accurate measurements when evaluating the effect of the TCFC scan mode (180° or 360°) for preoperative measurements of dental implants. Since the 180° scan was used, lower exposure time and tube current values are associated with a lower radiation dose.

The CBCT device's scanning type is directly related to the number of base images (individual 2D images)[31,32]. According to Scarfe and Farman[31],a more significant number of base images provides more information in the reconstruction of the images (obtaining greater spatial and contrast resolution), increases the signal-to-noise ratio producing "smoother" images, and reduces the formation of beam hardening artifacts. However, the 180° rotation decreases the acquisition time of the images and allows the reconstruction of volumetric data with the disadvantage of increasing the noise and artifact. This justifies that this study found lower image quality for the protocols with 180° scanning associated with the large FOV. Therefore, it is plausible to encourage manufacturers to study a similar modality for their equipment, listing the factors so that quality loss does not occur.

Regarding the subjective evaluation of the buccal BC classification, the results obtained in this study did not reveal statistically significant differences between the protocols and CBCT devices, demonstrating that, although there is a difference about the final quality of the BC images among them, there is no significant loss due to its detection. However, statistical analysis revealed that there were significant differences between protocols 5 (Accuitomo 170mm x 120mm HiFi 180°), 7 (Accuitomo 170mm x 120mm Std 180°), and 12 (Eagle 3D 120mm x 75mm 360°) when the noise observed in each image was evaluated. These results are also related to the FOV size and degree of rotation for protocols 5 and 7. However, even though protocol 12 uses 360° rotation, smaller FOV than the other two protocols, and slightly smaller voxel (0.2mm), characteristics inherent to the manufacturer's technology may have interfered with the final image quality.

The highest CNR value was found for protocol 1 (Accuitomo 60mm x 60mm HiFi 180°), followed by protocol 2 (Accuitomo 60mm x 60mm HiFi 360°), which indicates that the size of the FOV and the resolution of the device (HiFi) provide better image quality. According to the manufacturer of the Accuitomo 3D, the HiFi protocol has less noise, with better contrast resolution, especially in the periphery of the image, as recorded here. The lowest value was found for protocol 13 (Orthophos XG 3D), which presented the worst image quality despite having used an 80mm x 80mm FOV. This indicates that the image quality may also be influenced by factors inherent in the manufacturer's technology.

The SD found from the development of this work was higher for protocol 5 (Accuitomo 170mm x 120mm HiFi 180°), showing the excessive variation of the gray value found in this protocol in the test area. In a study by Vasconcelos et al.[20], high SD values were found in regions where dental implants were installed, revealing the effect of metal on measurement. However, as in this study, no different types of materials were used; this gray variation appeared due to interferences of the image acquisition protocol, such as large FOV and 180° rotation degree, which eventually increase the image noise. This correlation is also accurate when evaluating the lowest SD found for protocol 1 (Accuitomo 60mm x 60mm HiFi 180°), which has a lower FOV, despite the 180° degree of rotation.

Due to the several factors that influence the final result of the image, it is essential to have a scanning protocol closer to ideal. This results in good image quality, aiming to reduce the patient's exposure dose and decrease the radiologist's working time since a long time can cause confusion and bias in the final diagnosis.

There are some limitations to an in vitro study such as this one. There is no interference from factors such as the patient's movement during the CBCT exam, for example, better image quality results. Another limitation found in this study was the number of evaluators. Further studies with a more significant number and more homogeneous levels of experience in CBCT should be performed.

4 Conclusion

It was observed that most of the studied protocols presented good image quality for the directed diagnosis of evaluation of the characteristics of the periodontium. However, considering the values of the means for the subjective assessment and the CNR in the objective evaluation, the examination with a lower FOV of the Accuitomo 60mm x 60mm HiFi 180° device showed superiority about the others.

Acknowledgements

The authors acknowledge the Coordination for the Improvement of Higher Education Personnel (Capes) contribution to this study.

References

1. Alqerban A, Reinhilde J, Steffen F, Nackaerts O, Guy W. Comparison of 6 cone-beam computed tomography systems for image quality and detection of simulated canine impaction-induced external root resorption in maxillary lateral incisors. Am J Orthod Dentofacial Orthop 2011;140(3):129-39. doi: https://doi.org/10.1016/j.ajodo.2011.03.021
2. Loubele M, Jacobs R, Maes F, Denis K, White S, Coudyzer W, et al. Image Quality vs Radiation Dose of Four Cone Beam Computed Tomography Scanners. Dentomaxillofac Radiol 2008;37(6):309-18. doi: https://doi.org/10.1259/dmfr/16770531
3. Scarfe WC, Farman AG. Cone beam computed tomography: A paradigm shift for clinical dentistry. Aust Dent Pract 2007;102-10.
4. Zoller JE, Neugebauer J. Cone-Beam volumetric imaging in dental, oral and maxillofacial medicine: fundamentals, diagnostics and treatment planning. Chicago: Quintessence Publishing; 2008.
5. Lofthag-Hansen S, Thilander-Klang A, Gröndahl K. Evaluation of subjective image quality in relation to diagnostic task for cone beam computed tomography with different fields of view. Eur J Radiol 2011;80(2):483-8. doi: https://doi.org/10.1016/j.ejrad.2010.09.018
6. Tetradic S, Anstey P, Graff-Radford S. Cone beam computed tomography in the diagnosis of dental disease. J Calif Dent Assoc 2010;38(1):27-32.
7. Patcas R, Muller L, Ullrich O, Peltomaki T. Accuracy of cone-beam computed tomography at different resolutions assessed on the bony covering of the mandibular anterior teeth. Am J Orthod Dentofacial Orthop 2012;141(1):41-50. doi: https://doi.org/10.1016/j.ajodo.2011.06.034
8. Jaju PP, Jaju SP. Clinical utility of dental cone-beam computed tomography: current perspectives. Clin Cosmet Investig Dent 2014;6:29-43. doi: https://doi.org/10.2147/CCIDE.S41621
9. Park HN, Min CK, Kim K, Koh KJ. Optimization of exposure parameters and relationship between subjective and technical image quality in cone-beam computed tomography. Imaging Sci Dent 2019;49:139-51. doi: https://doi.org/10.5624/isd.2019.49.2.139
10. Alamri HM, Sadrameli M, Alshalhoob MA, Sadra-Meli M, Alshehri MA. Applications of CBCT in dental practice: a review of the literature. Gen Dent 2012:60(5):390-400.
11. Liang X, Jacobs R, Hassan B, Li L, Pauwels R, Corpas L, et al. A comparative evaluation of Cone Beam Computed Tomography (CBCT) and Multi-Slice CT (MSCT) Part I. On subjective image quality. Eur J Radiol 2010;75:265-9. doi: https://doi.org/10.1016/j.ejrad.2009.03.042
12. Beledelli R, Souza PHC. What are artifacts and how they form in conical beam computed tomography images. Rev ABRO 2012:13(1):2-15.
13. Spin-Neto R, Gotfredsen E, Wenzel A. Impact of voxel size variation on CBCT-based diagnostic outcome in dentistry: a systematic review. J Digit Imaging 2012;26:813-20. doi: https://doi.org/10.1007/s10278-012-9562-7
14. Kamburoglu K, Onder B, Murat S, Avsever H, Yuksel S, Paksoy CS. Radiography detection of artificially created horizontal root fracture using different cone beam CT units with small fields of view. Dentomaxillofac Radiol 2013;42(4):20120261. doi: https://doi.org/10.1259/dmfr.20120261
15. Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. Eur Radiol 1998; 8(9):1558-64. doi: https://doi.org/10.1007/s003300050586
16. Codari M, Vasconcelos KF, Nicolielo LFP, Hayter Neto F, Jacobs R. Quantitative evaluation of metal artifacts using different CBCT devices, high-density materials and field of views. Clin Oral Implants Res 2017;28(12):1509-14. doi: https://doi.org/10.1111/clr.13019
17. Dantas LL, Ferreira PP, Oliveira LSAF, Neves FS, Campos PSF, Scarfe WC, et al. Cone beam computed tomography devices in the evaluation of buccal bone in anterior teeth. Aust Dent J 2019;64(2):161-6. doi: https://doi.org/10.1111/adj.12685
18. Choi JW, Lee SS, Choi SC, Heo MS, Huh KH, Yi WJ, et al. Relationship between physical factors and subjective image quality of cone-beam computed tomography images according to diagnostic task. Oral Surg Oral Med Oral Pathol Oral Radiol 2015; 119(3):357-65. doi: https://doi.org/10.1016/j.oooo.2014.11.010
19. Paul J. Effect of diagnostic cone-beam computed tomography protocols on image quality, patient dose, and lesion detection. Phys Med 2016;32(12):1575-83. doi: https://doi.org/10.1016/j.ejmp.2016.11.111
20. Vasconcelos TV, Bechara BB, Mcmahan CA, Freitas DQ, Noujeim M. Evaluation of artifacts generated by zirconium implants in cone-beam computed tomography images. Oral Surgery, Oral Med Oral Pathol Oral Radiol 2017;123(2):265-72. doi: https://doi.org/10.1016/j.oooo.2016.10.021
21. Opening AC, Jacobs R, Pauwels R, Stratis A, Hedesiu M, Salmon B. Cone-Beam CT in Paediatric Dentistry: DIMITRA Project Position Statement. Pediatr Radiol 2018;48(3):308-16. doi: https://doi.org/
22. Ferreira PP, Torres M, Campos PSF, Vogel CJ, De Araújo

TM, Rebello IMCR. Evaluation of buccal bone coverage in the anterior region by cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2013; 144(5):698-704. doi: https://doi.org/10.1007/s00247-017-4012-9

23. Bechara B, Mcmahan CA, Moore WS, Noujeim M, Geha H, Teixeira FB. Contrast-to-noise ratio difference in small field of view cone beam computed tomography machines. J Oral Sci 2012; 54:227-32. doi: https://doi.org/

24. Demirturk Kocasarac H, Helvacioglu Yigit D, Bechara B, Sinanoglu A, Noujeim M. Contrast-to-noise ratio with different settings in a CBCT machine in presence of different root-end filling materials: an in vitro study. Dentomaxillofac Radiol 2016;45(5):20160012. doi: https://doi.org/10.2334/josnusd.54.227

25. Hedeşiu M, Báciuţ M, Báciuţ G, Nackaerts O, Jacobs R. Comparison of cone beam CT device and field of view for the detection of simulated periapical bone lesions. Dentomaxillofac Radiol 2012;41(7):548-52. doi: https://doi.org/10.1259/dmfr/19322177

26. Yadav S, Palo L, Mahdian M, Upadhyay M, Tadinada A. Diagnostic accuracy of 2 cone-beam computed tomography protocols for detecting arthritic changes in temporomandibular joints. Am J Orthod Dentofacial Orthop 2015;147(3):339-44. doi: https://doi.org/10.1016/j.ajodo.2014.11.017

27. Molen AD. Considerations in the use of cone-beam computed tomography for buccal bone measurements. Am J Orthod Dentofacial Orthop 2010;137:130-5. doi: https://doi.org/10.1016/j.ajodo.2010.01.015

28. Dillenseger JP, Gros CI, Sayeh A, Rasamimanana J, Lawniczak F, Leminor JM, et al. Image quality evaluation of small FOV and large FOV CBCT devices for oral and maxillofacial radiology. Dentomaxillofac Radiol 2016;46(1):1-10. doi: https://doi.org/10.1259/dmfr.20160285

29. Mayo Jr CV, Replogle KJ, Marshall JG, Best AM, Sehgal HS, Sousa Melo S, et al. Accuracy of Presurgical Limited Field of View Cone-beam Computed Tomography in Predicting Intraoperative Buccal Cortical Bone. J Endod 2020;46(2):169-77. doi: https://doi.org/10.1016/j.joen.2019.10.026

30. Neves FS, Souza TDC, De-Azevedo-Vaz SL, Flores Campos PS, Bóscolo FN. Influence of cone-beam computed tomography milliamperage settings on image quality of the mandibular third molar region. Oral Radiol 2014;30(1):27-31. doi: https://doi.org/10.1007/s11282-013-0132-6

31. Scarfe WC, Farman AG. What is Cone-Beam CT and how does it work? Dent Clin North Am 2008;52(4):707-30. doi: https://doi.org/10.1016/j.cden.2008.05.005

32. Kiljunen T, Kaasalainen T, Suomalainen A, Kortesniemi, M. Dental cone beam CT: a review. Phys Med 2015;31(8):844-60. doi: https://doi.org/10.1016/j.ejmp.2015.09.004