Dental Communication

BBRC Bioscience Biotechnology Research Communications

Biosc.Biotech.Res.Comm. Vol 13 (3) July-Aug-Sep 2020 Pp-1362-1368

Quantitative Comparison of the Artifact of Six Cone-Beam Computed Tomography Systems in Endodontically Treated Teeth with Gutta Percha and AH26

Mohammad Sheikh Ali, Mohammad Saleh Parsaee, Shahryar Shahab, Zeynab Azizi* and Hosein Mosaferi and Hanieh Nazarinia

Department of Restorative Dentistry, Faculty of Dentistry, Shahed University, Tehran, Iran

Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Shahed University, Tehran, Iran,

ABSTRACT

Artifacts are among the most important limitations of cone-beam computed tomography (CBCT). In different CBCT systems, the exposure options or the machine geometry might affect the diagnostic validity. This study aimed to compare the artifact rate in 6 CBCT systems in endodontically treated teeth with AH26. The effects of different voxel sizes on the artifacts in one of CBCT units was evaluated too.Twenty single-rooted teeth were randomly divided into 2 groups (n=10) and were instrumented up to the apical size of 25. The control group was left empty with no obturation, but case group were filled with gutta percha and AH26. Both groups were scanned by using 6 CBCT systems including NewTom VG, Planmeca, Kodak, Soredex, Vatech, NewTom Giano. CBCT scanning was performed via Vatech with 3 different voxel sizes (0.125, 0.2, and 0.3 mm^3.) OnDemand 3D software was used for analysis. Any deviation from the control group gray values was considered as artifact. The maximum, minimum, average and standard deviation of grey value in 4 points were measured. One-way ANOVA, independent t-test and Tukey's HSD post hoc test were used for statistical analyses of the data ($P<0.05$). Significant artifact was observed in Soredex, Planmeca, Kodak, and NewTom VG. While, NewTom Giano and Vatech showed no significant artifact. ($P<0.05$). artifact's presence was significant in images obtained with 0.3 mm3 voxel size, followed by 0.2 and 0.125 mm3, respectively. Different CBCT units have variations in artifacts. Even in units with fewer artifacts, it is critical to use a mode with small voxel size to reduce the artifacts.

KEY WORDS: ARTIFACT, CONE¬ BEAM COMPUTED TOMOGRAPHY, SEALER, VOXEL SIZE.

ARTICLE INFORMATION

**Corresponding Author: Dr_azizi_mp@yahoo.com*
Received 5th July 2020 Accepted after revision 17th Sep 2020
Print ISSN: 0974-6455 Online ISSN: 2321-4007 CODEN: BBRCBA

Thomson Reuters ISI Web of Science Clarivate Analytics USA and Crossref Indexed Journal

NAAS Journal Score 2020 (4.31) SJIF: 2020 (7.728)
A Society of Science and Nature Publication,

Online Contents Available at: http//www.bbrc.in/
DOI: http://dx.doi.org/10.21786/bbrc/13.3/57

INTRODUCTION

The accuracy of cone-beam computed tomography (CBCT) has been investigated in several studies (May, et al 2013, Bernardes, R.A. et al. 2009, Kamburoglu, K., et al. 2009, Ozer, S.Y. 2010). The artifacts and noises sometimes interfere with clear vision of minor changes in CBCT images and consequently decrease the diagnostic accuracy of images. These artifacts are attributed to the high x-ray absorption by the objects of high density (Pauwels, et al. 2015) and results in two types of artefacts; 1) cupping artifact and 2) streaks and dark bands (White SC, 2014). When there is a radiopaque object in the canal, the produced artifacts negatively affect the diagnostic accuracy of details like vertical root fracture (VRF) (Kambungton, et al . 2012, Hassan, et al. 2010, Ozer, 2011). The effect of different materials on CT images has been investigated since 1970. Research revealed that different materials created different rates of artifact in images. Likewise, different rates of artifact have been reported in CBCT systems due to the several contributing factors (Wenzel, et al. 2005, Julia et al. 2004, Eliliwi et al. 2020).

There are various CBCT systems available for assessment of the dentofacial area. They differ in detector design, patient scanning settings, and data reconstruction parameters [Mozzo, et al.,1998, Kobayashi, et al. 2004, Araki, et al.,2004, Sukovic, 2003, Arai, et al., 1999, de Lima 2019]. The quality of CBCT images are significantly influenced by a number of scanning and reconstructing factors such as the field of view (FOV), voxel size, the number of basis projections used for reconstruction, and the image artifacts. CBCT systems are different in terms of image quality and ability of displaying the anatomic structure [Loubele, M., et al 2007, Loubele, M., et al., 2006, Loubele, M., et al.2008, Mischkowski, R.A., et al. 2008, Kwong, J.C., et al., 2008, Bryant, J.A., 2008, Liang, X., et al.].

The differences are more prominent and important in tiny anatomical structures such as periodontal ligaments and trabecular bone[Liang, X., et al.2010]. Several studies compared the diagnosis accuracy of various CBCT systems in VRF, or just compared a limited number of CBCT systems (Esmaeili et al.2012 , Safi et al.2015, Pauwels, et al 2013, Bamba, et al. 2013). Most of these studies evaluate the artifacts subjectively (Kamburoglu, et al. 2010, Hassan, et al.,2010, Ozer, 2011, Esmaeili et al. 20120) which can be influenced by the observer's situation. In order to overcome this limitation, the current study was conducted to quantitatively compare the artifact rate in six CBCT systems in endodontically-treated teeth with AH26 sealer and gutta percha and also the effect of voxel size on producing artifacts.

MATERIAL AND METHODS

This experimental study was performed on 20 single-rooted single-canal teeth. They were subjected to proximal radiography to confirm that the roots were quite healthy with no calcification, filling, or obvious fractures. The crowns were sectioned at the cementoenamel junction by using fissure diamond bur (D+Z; Germany). The samples were rinsed with NaOCl, and the length of the roots was adjusted to 13 mm. The sample teeth were randomly divided into case and control group (n=10 per group).The teeth preparations were performed by using Reciproc files on 1:6 reduction hand piece operated by a torque-controlled motor (VDW Silver reciproc motor). The files, speed, and torque were set according to the manufacturer's instruction. The R25 file with a tip size of 25 and a taper of 0.06 over the first 3 mm was used in a reciprocating, slow in- and out- pecking motion according to the manufacturer's instruction.

The samples in the study group were filled with AH26 sealer along with 0.04 tapered size 25 master gutta percha, followed by 0.02 taperd size 15 accessory gutta percha. The samples in the control group were left unfilled with no obturation. The upper surface of all canals were sealed with SE Bond Clearfil (Kuraray; NY, USA) and light-cured to prevent water penetration when placed in water during imaging. The samples in each group were mounted on a putty block at a minimum distance of 10 mm. The block dimensions were set according to the FOV adopted for imaging. The CBCT images of the samples were taken by using six CBCT systems including NewTom VG (QR SRL Company; Verona, Italy), Planmeca (Planmeca OY; Helsinki, Finland), Kodak (Trophy; Croissy-Beaubourg, France), Soredex (Soredex; Tuusula, Finland), Vatech (PaX-Flex3D; Vatech Co., Hwasung, Korea), and NewTom Giano (QR SRL Company; Verona, Italy). The CBCT images were taken with KvP and mAs set by operator of each device to gain the best quality with less effect of the two factors and the largest FOV (Table 1). By selecting the largest FOV, effect of the location on FOV has reduced.

Table 1. The characteristics of CBCT systems and imaging conditions

Imaging conditions / CBCT Systems	Kvp	mA	Time (ms)	FOV	Voxel size (mm)	Detector type
NewTom VG	110	3.9-5.6	3.5	20×25	0.125	FPD*
NewTom Giano	90	3	3.6	11×8	0.5	FPD
Vatech	85	5	4	10×8.5	0.2	FPD
Planmeca	80	8	5	10×8	0.4	FPD
Scanora	90	13	4	13×15	0.135	FPD
Kodak	85	5	4	17×13.5	0.2	CCD+

* Flat Panel Detector
\+ Charge-coupled device

The images were transferred to OnDemand software (Version 1.0; Cybermed Inc., 2010, UAS). As displayed in Table 1 and 2, four ROIs (Region of Interest) of 2-mm2 were selected in the mid axial plane (Hassan, et al. 2009). 1-mm out of the center of the teeth in four directions (north, south, east, and west)(totally 40 samples in each group). The minimum, maximum, mean and standard deviation of the grey value was measured. The observations and calculations were done by an undergraduate dentistry student under the supervision of two experienced radiologists. Any deviation from the control group mean gray value was considered as artifact. After giving first stage results, Cone-beam computed tomography scanning by Vatech (as one the units with less artifacts in this study) was performed on automatic mode(85 kVp, 5 mA, and 0.6 seconds) with three voxel sizes of 0.125 mm3 and 5×5 cm FOV, 0.2 mm^3 and 5×9 cm FOV, and 0.3 mm3 and 14×9 cm FOV. Observation and evaluation was done as explained before.

The data were statistically analyzed by using SPSS software (version 16). Kolmogorov-Smirnov test was used to determine the normality of data. The descriptive features were measured including the central tendency and index of dispersion (mean and standard deviation). Analysis of variance of the groups was calculated regarding the studied features; the mean values of the groups were compared by using Duncan's test. The qualitative and ordinal parameters were analyzed by using nonparametric methods. Independent t-test was used to compare the case and control groups in terms of the mean rate of artifact. One-way ANOVA was used to compare the mean values among the six CBCT systems.

RESULTS AND DISCUSSION

Table 2 shows that the mean grey value was different among the six CBCT systems. The highest and lowest mean grey values were observed in images taken by Planmeca and Vatech systems, respectively. The independent t-test compared the mean grey values of the case and control group according to the imaging system (Table 2). The artifact value (The absolute numerical value of the mean grey value difference between the study group and the control group) in different systems was ordered as following, Scanora> Planmeca> NewTom VG> Kodak> Vatech> NewTom Giano. The difference was significant in Soredex, Planmeca, NewTom VG and KodaK ($P<0.05$) but insignificant in tow latter. Also the results revealed no significant difference in the grey value between case and control group with0.125 and 0.2 mm3 voxel sizes ($P>0.05$). But, at 0.3 mm3 voxel size, the grey value was significantly different ($P<0.05$); i.e., significantly more artifacts were observed at 0.3 voxel size.

Table 2. Comparison of the mean grey value and standard deviation (SD) in the case and control group according to the CBCT system

CBCT Systems	Case group Mean(SD)	Control group Mean(SD)	Difference between the case and control group
Planmeca	1707.5(519/72)	1177.9(221/69)	529.6
Scanora	1631.1(1314/88)	1075.6(162/79)	555.5
NewTom	1616.7(170/13)	1268.7(166/59)	348.08
NewTom Giano	1558.3(342/61)	1451.1(242/23)	107.02
Kodak	1419.9(403/89)	1144.1(271/03)	275.8
Vatech	949.8(637/76)	815.7(121/86)	134.1

The CBCT images can be negatively affected by the artifacts from the root filling materials, which decreases the accuracy, sensitivity, and specificity of this imaging technique in identifying the image details (White 2014, Khedmat, et al. 2012, Wanget al. 1998, Hassan, et al 2009). The current results revealed that despite the different mean grey value, the CBCT devices created different rates of artifact. Among the six studied systems, the highest and lowest artifacts were seen in Scanora and NewTom Giano, respectively. An artifact is any distortion or error in the image that is unrelated to the subject being study (White et al. 2014). Evaluation of gray value in the images as the presenter of X-ray attenuation pattern is a way to assess the non- uniformity and artifacts (Rabelo et al.2017). Artifact is sometimes due to the beam hardening phenomenon, in which the material absorbs more low-energy photons than the high-energy ones (Arai, et al 1999). This phenomenon creates two different types of artifact including cupping artifact and streaks and dark bands (White 2014). These lines lead to misdiagnosis of extra canals or VRFs, and false positive results(Araki, et al. 2004). The higher the atomic number of the material, the more artifacts would be observable (May et al.2013).

In several researches artifacts are studied subjectively (Kamburoglu, et al. 2010, Hassan, et al., 2010, Ozer, 2011, Esmaeili 2012) which can be affected by observing situation so in current study, artifacts were evaluated quantitatively by considering the difference between the numerical values of gray level in case and control group. Hassan et al. evaluated 80 extracted teeth placed in a dry mandible (Hassan, et al. 2009). Similar to some other studies, they found that the artifacts caused by the root filling such as sealer, gutta percha, metals, and silver cones drastically decreased the specificity of CBCT images; however, it did not affect the sensitivity (Kamburoglu, et al. 2010, Hassan, et al., 2009, Rabelo et al. 2017, Talwar, et al. 2016, Moudi et al. 2015 Shokri et al 2019).

Presencce of the sealer and gutta percha in the root canal reduce the specificity (Moudi et al. 2015). It is worth mentioning that the sealer per se causes more artifacts than the gutta percha per se (Decurcio et al. 2012). Since AH26 contains bismuth oxide, all the samples in the present study showed artifact and decreased the quality of CBCT images. Limited number of studies directily addressed the artifact in CBCT images, and most of them were focused on details such as root fractures and resorption (Hassan, et al. 2009, Melo, et al 2010, Karaçaylı, 2013, Patel, et al., 2013).The nature of artifacts is reported to be similar in different systems. Iikubo et al. compared 3D Accuitomo, Alphard VEGA, and CB Throne systems, and found no significant difference in the characteristics of the artifacts (Iikubo, et al. 2015). This similarity was attributed to the dependency of the artifacts on factors such as the position and size of the FOV and spatial resolution of the device. In any case, the quality of CBCT images is directly related to the imaging conditions.

The rate of artifacts and diagnosis accuracy of CBCT images are influenced by several factors such as the characteristics of the device and the imaging conditions. The device characteristics are the detector type, FOV, voxel size, and system-related artifacts. The imaging conditions are KVp, mA, position of the object in the FOV, and duration of radiation. The systems might also be different according to the amount of basis radiation for each image, data reconstruction parameters (algorithm), and device-related artifacts [8]. Accordingly, different studies employed different CBCT systems. Based on the detector technology, the general CBCT devices are divided into image intensifier tube/charged coupled device (IIT/CCD) and flat panel detectors (FPDs). Reports indicate that the IIT/CCD has increased pixel noise and higher image artifact than the FPDs, results in lower contrast and spatial resolution (Hassan, et al., 2010).

The FOV contributes to creating artifact as much as the detector does. Based on the adopted FOV, the CBCT devices are divided into three types of small, medium, and large. The FOV is directly related with the voxel size, and affects the spatial resolution and contrast. Larger FOV creates lower resolution and contrast, which directly influences the observation of anatomical structures (Hassan et al. 2010, Durack, et al. 2012, Kajan, 2012). The smaller the FOV, the higher the image quality and the lower artifact[Wang 1999, Costa, et al. 2012]. Regarding the direction of the object in the FOV, the more the distance between the object and centre of FOV, the more the radial-shaped artifacts (Lee, et al. 2002). Moudi et al. evaluated the effect of metal artifacts in different field of views, and found that in smaller FOVs, the sensitivity and specificity of the NewTom 5G system was 100%. In higher FOV, the sensitivity was decreased by 14% and specificity decreased by 11% (Moudi 2015). The present study investigated the general conditions of the systems; therefore, to create similar conditions, the highest FOV in each system was used which covered the object thoroughly. By using high number of samples and their distribution all over the FOV, and considering average of all samples, we aimed to reduced the effect of object position in the FOV. Yet, the present study reported high artifacts in Scanora (FOV= 15×13) or NewTom VG (FOV= 25×20), which could be due to the large FOV.

Voxel size is another factor that affects the quality of CBCT images [Muhammad, A.M.A. et al. 2020]. In this study there was no focus on FOV or voxel size in controlled condition, and interestingly different results were found; Planmeca and NewTom Giano units had nearly similar FOV and voxel sizes but showed completely different amount of artifacts. As several studies show the smallest voxel size increases the resolution and consequently the quality of images and diagnosis accuracy of VRF (Hassan, et al., 2010, Melo, et al. 2010, Iikubo, et al. 2015, Durack, C. et al. 2012). However, artifacts are still observed in small voxel sizes due to the presence of radiopaque materials such as gutta, sealer, or metal (Durack, et al. 2012). The present findings showed that the radiopaque content of AH26 sealer such as sulfate barium, bismuth oxide, and zinc oxide, caused this sealer to create artifacts on CBCT images in all three voxel sizes.

The present study used single software to eliminate the plausible effect of software in image reconstruction and consequently the artifact rate. Although Melo et al. studied four CBCT softwares and observed that presence of metal post in the canal significantly decreased the diagnosis accuracy in all the four softwares (Melo, et al. 2010). Hassan et al. compared five CBCT systems in detection of VRF at different voxel sizes. They concluded that iCAT at 0.25 mm3 voxel size showed the best diagnostic ability, followed by Scanora 3D at 0.2 mm3 voxel size, Accuitomo XYZ at 0.25 mm3 voxel size, and NewTom at 0.2 mm3 voxel size. The lowest quality was related to the Galileos at 0.3 mm3 voxel size. They attributed the differences among the results of different devices to factors such as the detector type, FOV, and voxel size (which affects the contrast and resolution), as well as the inherent artifacts of each system. However, Wenzel et al. reported that iCAT functioned better with 0.125 mm rather than 0.25 mm voxel size (Wenzel, et al. 2009).

Melo et al. evaluated the diagnostic ability of CBCT images in detecting the longitudinal root fractures in prosthetically-treated teeth. They observed better image quality and sensitivity in 0.2 than 0.3 mm3 voxel size (Melo, et al. 2010). Likewise, Ozer found that 0.2 mm3 voxel size was superior to 0.125, 0.3, and 0.4 voxel sizes because of its lower exposure and proper image properties (Ozer, 2011). Valizadeh et al. assessed the diagnostic accuracy of CBCT images in detection of VRF in presence of casting posts. They noted that 0.2 and 0.125 mm3 voxel sizes were not different in sensitivity, specificity, positive and negative predictive values. Therefore, 0.2 mm3 voxel size was recommended based on ALARA principle (Valizadeh, et al. 2015). Aligned with current study, Janqueira et al. reported no difference between 0.125 and 0.25 mm3 voxel sizes (Junqueira, et al. 2013). Whereas, Wenzel et al.

announced that Icat system functioned better in 0.125 mm3 voxel size than in 0.25 mm3 voxel size (Wenzel, et al. 2009). Comparing three voxel sizes, Kamburoglu et al. observed that 0.19 and 0.1 mm3 voxel sizes offered better quality than 0.3 mm3; however, the imaging took longer and the patient was exposed to higher radiation dose (Kamburoglu, et al. 2010). Similarly, Liedke et al. noted higher diagnostic quality at 0.2 and 0.3 mm3 voxel sizes compared with 0.4 mm3 voxel size in detecting external root resorption (Liedke, et al. 2009).

The present study announced the group with larger voxel size (0.3 mm3) to have the highest rate of artifacts, than the groups with smaller voxel sizes (0.2 and 0.125 mm3) with no significant artifact. This was in line with the studies carried out by Kamburoglu , Ozer and Melo (Kamburoglu et al 2010, Ozer 2011, Melo, et al. 2010). Artifacts were also observed in smaller voxel sizes due to the presence of radiopaque materials like gutta, sealer, or metal (Durack, et al. 2012). Presence of noise in small voxel sizes degrades the image quality (Karaçaylı, . 2013). It seems that more attention should be paid to the signal-to-noise ratio (SNR). Decreasing the voxel size would reduce the S/N in each voxel (Spin-Neto, 2013), which should be compensated with mAs and kVp; otherwise, it would reduce the image quality. Presumably, this can be the reason for the presence of artifact and low image quality in the group with 0.125 and 0.2 mm3 voxel sizes in the present study. Accordingly, considering ALARA, 0.2 mm^3 voxel size is suggested for more accurate evaluation of images and higher quality to investigate the details. Regarding the KVp, Esmaeili et al. evaluated the artifact caused by titanium implants and concluded that increasing the KVp resulted in decreased artifact in images (Esmaeili et al. 2012).

Having surveyed the imaging parameters, Jadu et al. concluded that the KVp was directly related with signal difference to noise ratio (SDNR) and adversely related with the mA (Jadu et al. 2011). Regarding the mAs, Scarfe pointed out that the ideal imaging parameters to reduce the artifact in CBCT was small FOV, small voxel size, short time, and low mA (Scarfe et al. 2009). However, Decurcio declared that decreasing the mAs resulted in increased artifact (Decurcio et al. 2012). In the present study, the most artifacts were created by Scanora and Planmeca, which had the highest mA. Withal, this factor was not directly and independently evaluated. Moreover, due to the proximity of the KVp values in all devices, except for the NewTom VG (110), no specific effect could be studied. Solutions have been suggested to reduce the artifact in images (Hassan, et al. 2009, Bechara et al. 2012), one of which is the use of softwares which can decrease the artifact caused by metals through reducing the beam hardening phenomenon (Bechara et al. 2012). However, the use of these methods is still controversial and requires extensive studies.

CONCLUSION

Within the limitations of this study it can be concluded that artifacts were observed in images taken by all the studied CBCT systems. Although units with less artifacts are suggesting. Besides that, artifacts were observed in all images with any voxel size, smaller voxel sizes were found to reduce the artifact. However, they are accompanied by more patient radiation dose. Hence, a balance should be considered in selection of voxel size.

Declaration: Authors declare that they have no conflict of interest. No identifying information about patients is included in the article.

REFERENCES

Arai Y, Tammisalo E, Iwai K, Hashimoto K, Shinoda K. (1999) Development of a compact computed tomographic apparatus for dental use. Dentomaxillofac Radiol. Jul;28(4):245-8. doi: 10.1038/sj/dmfr/4600448.

Araki, K, Maki K, Seki K, Sakamaki K, HarataY, Sakaino R, Okano T, Seo K. (2004) Characteristics of a newly developed dentomaxillofacial X-ray cone beam CT scanner (CB MercuRay): system configuration and physical properties. Dentomaxillofac Radiol. Jan;33(1):51-9. doi: 10.1259/dmfr/54013049.

Avsever H, Gunduz K, Orhan K, et al.(2014) Comparison of intraoral radiography and cone-beam computed tomography for the detection of horizontal root fractures: an in vitro study. Clin Oral Investig. 18(1):285-292. doi:10.1007/s00784-013-0940-4

Bamba J, Araki K, Endo A, Okano T. (2013) Image quality assessment of three cone beam CT machines using the SEDENTEXCT CT phantom. Dentomaxillofac Radiol. 42(8):20120445. doi: 10.1259/dmfr.20120445.

Bechara BB, Moore WS, McMahan CA, Noujeim M, (2012) Metal artefact reduction with cone beam CT: an in vitro study. Dentomaxillofac Radiol., 41(3): p. 248-253.

Bernardes, R.A. de Moraes IG, Húngaro Duarte MA, Azevedo BC, de Azevedo JR, Bramante CM.(2009) Use of cone-beam volumetric tomography in the diagnosis of root fractures. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 108(2):270-7. doi: 10.1016/j.tripleo.2009.01.017. Epub 2009 Mar 9.

Bryant, J.A., N.A. Drage, and S. Richmond (2008) Study of the scan uniformity from an i-CAT cone beam computed tomography dental imaging system. Dentomaxillofac Radiol. 37(7):365-74. doi: 10.1259/dmfr/13227258.

Costa, F.F., Gaia BF, Umetsubo OS, Pinheiro LR, Tortamano IP, Cavalcanti MG.(2012) Use of large-volume cone-beam computed tomography in identification and localization of horizontal root fracture in the presence and absence of intracanal metallic post. J Endod. 38(6):856-9. doi: 10.1016/j.joen.2012.03.011. Epub 2012 Apr 26.

De Lima ED, de Farias Freitas APL, Suassuna FCM, Melo SLS, Bento PM, de Melo DP (2019). Assessment of Cone-beam Computed Tomographic Artifacts from

Different Intracanal Materials on Birooted Teeth. Journal of endodontics. 45(2):209-13. e2.
Decurcio DA, Alencar H, Porto OCL, Azevedo BC, Estrela C,(2012) Effect of root canal filling materials on dimensions of cone-beam computed tomography images. J Appl Oral Sci, 20(2): p. 260-267.
Durack, C. and S. Patel (2012) Cone beam computed tomography in endodontics. Braz Dent J. 23(3)179-91.
Eliliwi M, Bazina M, Palomo JM (2020) kVp, mA, and voxel size effect on 3D voxel-based superimposition. The Angle Orthodontist. 90(2):269-77
Esmaeili F, M.J. Pezhman Haddadi, and Mehdi Vatankhah (2012) Beam Hardening Artifacts: Comparison between Two Cone Beam Computed Tomography Scanners. J Dent Res Dent Clin Dent Prospects 6(2): p. 49- 53.
Hassan B, Metska ME, Ozok AR, van der Stelt P, Wesselink PR.(2010) Comparison of five cone beam computed tomography systems for the detection of vertical root fractures. J Endod. 36(1):126-9. doi: 10.1016/j.joen.2009.09.013.
Hassan B, Metska ME, Ozok AR, van der Stelt P, Wesselink PR.(2009) Detection of vertical root fractures in endodontically treated teeth by a cone beam computed tomography scan. J Endod. 35(5):719-22. doi: 10.1016/j.joen.2009.01.022.
Ingle JI, Bakland LK, Baumgartner JC.(2008) Ingle's endodontics/John I. Ingle, Leif K. Bakland, J. Craig Baumgartner: Hamilton, Ont.: BC Decker; 2008.
Jadu FM, Yaffe MJ, Lam EWN (2011) Optimization of exposure parameters for cone beam computed tomography sialography. Dentomaxillofac Radiol 40(6): p. 362- 368.
Julia F. Barrett, N.K (2004) Artifacts in CT: Recognition and Avoidance. RadioGraphics, 24(6): p. 1679- 1691.
Junqueira RB, Verner FS, Campos CN, Devito KL, do Carmo AM.(2013) Detection of vertical root fractures in the presence of intracanal metallic post: a comparison between periapical radiography and cone-beam computed tomography. J Endod. 39(12):1620-4. doi: 10.1016/j.joen.2013.08.031. Epub 2013 Oct 13.
Kajan, Z.D. and M. Taromsari, (2012) Value of cone beam CT in detection of dental root fractures. Dentomaxillofac Radiol 41(1):3-10. doi: 10.1259/dmfr/25194588.
Kamburoglu K, Murat S, Yüksel SP, Cebeci AR, Horasan S. (2009)Detection of vertical root fracture using cone-beam computerized tomography: an in vitro assessment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod109(2):e74-81. doi: 10.1016/j.tripleo.2009.09.005.
Kambungton J, Janhom A, Prapayasatok S, Pongsiriwet S.(2012) Assessment of vertical root fractures using three imaging modalities: cone beam CT, intraoral digital radiography and film. Dentomaxillofac Radiol.41(2):91-5. doi: 10.1259/dmfr/49798768.
Katharina Alves Rabelo, Y.W.C., Martina Gerlane de Oliveira Pinto, Saulo Leonardo Sousa Melo, Paulo Sérgio Flores Campos, Luciana Soares de Andrade Freitas Oliveira, and Daniela Pita de Melo (2017) Quantitative assessment of image artifacts from root filling materials on CBCT scans made using several exposure parameters. Imaging Sci Dent,. 47(3) p. 189-197.
Khedmat S, Rouhi N, Drage N, Shokouhinejad N, Nekoofar MH(2012). Evaluation of three imaging techniques for the detection of vertical root fractures in the absence and presence of gutta-percha root fillings. Int Endod J 45(11):1004-9. doi: 10.1111/j.1365-2591.2012.02062.x. Epub 2012 May 2.
Kobayashi K, Shimoda S, Nakagawa Y, Yamamoto A. (2004) Accuracy in measurement of distance using limited cone-beam computerized tomography. Int J Oral Maxillofac Implants. 19(2):228-31.
Kwong JC, Palomo JM, Landers MA, Figueroa A, Hans MG.(2008) Image quality produced by different cone-beam computed tomography settings. Am J Orthod Dentofacial Orthop. 133(2):317-27. doi: 10.1016/j.ajodo.2007.02.053.
Lee KW, Williams MC, Camps JJ, Pashley DH.(2002) Adhesion of endodontic sealers to dentin and gutta-percha. J Endod. (10):684-8. doi: 10.1097/00004770-200210000-00002.
Liang X, Jacobs R, Hassan B, Li L, Pauwels R, Corpas L, Souza PC, Martens W, Shahbazian M, Alonso A, Lambrichts I. (2010)A comparative evaluation of Cone Beam Computed Tomography (CBCT) and Multi-Slice CT (MSCT) Part I. On subjective image quality. Eur J Radiol. 75(2):265-9. doi: 10.1016/j.ejrad.2009.03.042. Epub 2009 May 1.
Liedke GS, da Silveira HE, da Silveira HL, Dutra V, de Figueiredo JA. (2009) Influence of voxel size in the diagnostic ability of cone beam tomography to evaluate simulated external root resorption. J Endod. 35(2):233-5. doi: 10.1016/j.joen.2008.11.005.
Iikubo M, Osano T, Sano T, Katsumata A, Ariji E, Kobayashi K, Sasano T, Wakoh M, Seki K, Kojima I, Sakamoto M.(2015) Root canal filling materials spread pattern mimicking root fractures in dental CBCT images. Oral Surg Oral Med Oral Pathol Oral Radiol. 120(4):521-7. doi: 10.1016/j.oooo.2015.06.030. Epub 2015 Jul 9.
Loubele M, Guerrero ME, Jacobs R, Suetens P, van Steenberghe D. (2007) A comparison of jaw dimensional and quality assessments of bone characteristics with cone-beam CT, spiral tomography, and multi-slice spiral CT. Int J Oral Maxillofac Implants. ;22(3): 446-54.
Loubele M, Maes F, Schutyser F, Marchal G, Jacobs R, Suetens P.(2006) Assessment of bone segmentation quality of cone-beam CT versus multislice spiral CT: a pilot study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 102(2):225-34. doi: 10.1016/j.tripleo.2005.10.039. Epub 2006 Apr 21.
Loubele M, Maes F, Jacobs R, van Steenberghe D, White

SC, Suetens P.(2008) Comparative study of image quality for MSCT and CBCT scanners for dentomaxillofacial radiology applications. Radiat Prot Dosimetry. 129(1-3):222-6. doi: 10.1093/rpd/ncn154. Epub 2008 Jun 26.
May, J.J., N. Cohenca, and O.A. Peters,(2013) Contemporary management of horizontal root fractures to the permanent dentition: diagnosis--radiologic assessment to include cone-beam computed tomography. Pediatr Dent. 35(2):120-4.
Melo SL, Bortoluzzi EA, Abreu M Jr, Corrêa LR, Corrêa M.(2010) Diagnostic ability of a cone-beam computed tomography scan to assess longitudinal root fractures in prosthetically treated teeth. J Endod ;36(11):1879-82. doi: 10.1016/j.joen.2010.08.025. Epub 2010 Sep 19.
Mischkowski RA, Scherer P, Ritter L, Neugebauer J, Keeve E, Zöller JE.(2008) Diagnostic quality of multiplanar reformations obtained with a newly developed cone beam device for maxillofacial imaging. Dentomaxillofac Radiol.37(1):1-9. doi: 10.1259/dmfr/25381129.
Moudi E, Madani Z, Bijani A, Nabavi Z (2015) The effect of metal artifacts on the identification of vertical root fractures using different fields of view in cone-beam computed tomography. Imaging Sci Dent 45(3): p. 147-151.
Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA.(1998) A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. Eur Radiol. 8(9):1558-64.
Muhammad, A.M.A., Ibrahim, N., Ahmad, R. et al.(2020) Effect of reconstruction parameters on cone beam CT trabecular bone microstructure quantification in sheep. BMC Oral Health 20, 48 https://doi.org/10.1186/s12903-020-1035-7
Ozer, S.Y.(2010) Detection of vertical root fractures of different thicknesses in endodontically enlarged teeth by cone beam computed tomography versus digital radiography. J Endod. ;36(7):1245-9. doi: 10.1016/j.joen.2010.03.021. Epub 2010 Apr 24.
Ozer, S.Y.(2011) Detection of vertical root fractures by using cone beam computed tomography with variable voxel sizes in an in vitro model. J Endod.37(1):75-9. doi: 10.1016/j.joen.2010.04.021. Epub 2010 Nov 5.
Pauwels R, Araki K, Siewerdsen JH, Thongvigitmanee SS.(2015)Technical aspects of dental CBCT: state of the art. Dentomaxillofac Radiol. 44(1):20140224. doi: 10.1259/dmfr.20140224.
Pauwels R, Stamatakis H, Bosmans H, Bogaerts R, Jacobs R, Horner K, Tsiklakis K (2011) Quantification of metal artifacts on cone beam computed tomography images. Clin Oral Implants Res. Suppl A100:94-9. doi: 10.1111/j.1600-0501.2011.02382.x. Epub 2011 Dec 15.
Patel S, Brady E, Wilson R, Brown J, Mannocci F. (2013) The detection of vertical root fractures in root filled teeth with periapical radiographs and CBCT scans. Int Endod J 46(12):1140-52. doi: 10.1111/iej.12109. Epub 2013 Apr 26.
Safi Y, Aghdasi MM, Ezoddini-Ardakani F, Beiraghi S, Vasegh Z.(2015) Effect of Metal Artifacts on Detection of Vertical Root Fractures Using Two Cone Beam Computed Tomography Systems. Iran Endod J 10(3): p. 193- 198.
Spin-Neto, R., E. Gotfredsen, and A. Wenzel (2013) Impact of voxel size variation on CBCT-based diagnostic outcome in dentistry: a systematic review. J Digit Imaging. 26(4):813-20. doi: 10.1007/s10278-012-9562-7.
Shokri A, Jamalpour MR, Khavid A, Mohseni Z, Sadeghi M.(2019) Effect of exposure parameters of cone beam computed tomography on metal artifact reduction around the dental implants in various bone densities. BMC medical imaging. 19(1):34.
Sukovic, P.(2003) Cone beam computed tomography in craniofacial imaging. Orthod Craniofac Res. 6 Suppl 1:31-6; discussion 179-82.
Talwar S, Utneja S, Nawal RR, Kaushik A, Srivastava D, Oberoy SS.(2016) Role of Cone-beam Computed Tomography in Diagnosis of Vertical Root Fractures: A Systematic Review and Meta-analysis. J Endod;42(1):12-24. doi: 10.1016/j.joen.2015.09.012.
Valizadeh, S., E.M. Rabie, and Z. Azizi, (2015) Diagnostic Accuracy of Different Resolutions of Cone Beam Computed Tomography imaging System for Detection of Vertical Root Fractures In Presence of Casting Posts Journal of Dental School 33(3): p. 225-232.
Wang P, Lui DG, Zhang, Y Zhang, and XC Ma,(1999) Detection of dental root fractures by using cone-beam computed tomography. Dentomaxillofac Radiol. 28(4):245-8. doi: 10.1038/sj/dmfr/4600448., 2011. 40(5): p. 290-298.
Wenzel, A. and L.L. Kirkevang (2005) High resolution charge-coupled device sensor vs. medium resolution photostimulable phosphor plate digital receptors for detection of root fractures in vitro. Dent Traumatol. 21(1):32-6. doi: 10.1111/j.1600-9657.2004.00258.x.
Wenzel A, Haiter-Neto F, Frydenberg M, Kirkevang LL. (2009) Variable-resolution cone-beam computerized tomography with enhancement filtration compared with intraoral photostimulable phosphor radiography in detection of transverse root fractures in an in vitro model. Oral Surg Oral Med Oral Pathol Oral Radiol Endod.108(6):939-45. doi: 10.1016/j.tripleo.2009.07.041. Epub 2009 Oct 28.
White SC, P.M.(2014) ed. Oral Radiology principles and interpretation. 7 ed. 2014, Elsevier: New Delhi.
William C. Scarfe, Martin D. Levin, David Gane, and Allan G. Farman (2009) Use of Cone Beam Computed Tomography in Endodontics. Int J Dent, 2009.