RESEARCH ARTICLE

Contrast-to-noise ratio with different settings in a CBCT machine in presence of different root-end filling materials: an *in vitro* study

¹Husniye Demirturk Kocasarac, ²Dilek Helvacioğlu Yigit, ³Boulos Bechara, ¹Alper Sinanoglu and ³Marcel Noujeim

¹Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Kocaeli University, Basiskele, Kocaeli, Turkey;

²Department of Endodontics, Faculty of Dentistry, Kocaeli University, Basiskele, Kocaeli, Turkey; ³Department of Comprehensive Dentistry, The University of Texas Health Science Center, San Antonio, TX, USA

Objectives: To compare the contrast-to-noise ratio (CNR) of multiple acquisition settings for four types of retrograde filling materials in CBCT images taken for endodontic surgery follow-up.

Methods: 20 maxillary central incisors were endodontically treated and obturated with 4 different root-end filling materials: amalgam, mineral trioxide aggregate, SuperEBA™ (Harry J Bosworth Company, Skokie, IL) and Biodentine™ (Septodont, Saint-Maur-des-Fossés, France). Teeth were placed in a skull and scanned, one by one, with the Planmeca ProMax® 3D Max (Planmeca, Helsinki, Finland); at different voltages: 66, 76, 84 and 96 kVp; with low, normal and high resolution and high definition (HD); with and without metal artefact reduction (MAR). Images were analyzed using ImageJ software (National Institutes of Health, Bethesda, MD) to calculate the CNR. The dose–area product was registered, and the effective dose calculated.

Results: No statistically significant difference was noted between the four materials. 84 and 96 kVp with low resolution and the use of MAR-generated images that have statistically better CNR than 66 and 76 kVp with HD, normal and high resolutions and without MAR. The use of low resolution also generated the smallest value of effective dose.

Conclusions: The best setting for radiographic follow-up in an endodontic surgery with retrograde filling on the Planmeca ProMax is 96 kVp with low resolution and high MAR; this setting produced one of the lowest effective doses.

Dentomaxillofacial Radiology (2016) **45**, 20160012. doi: [10.1259/dmfr.20160012](https://doi.org/10.1259/dmfr.20160012)

Cite this article as: Demirturk Kocasarac H, Helvacioğlu 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**: 20160012.

Keywords: cone beam computed tomography; contrast-to-noise ratio; root-end filling material; endodontics; root canal filling materials

Introduction

Radiographic examination is an essential tool for successful management of endodontic problems from diagnosis to planning and treatment and finishing by assessment of healing and follow-up if needed. Until recently, radiographic evaluation in endodontics was mainly made using conventional periapical radiography which gives two-dimensional representation of three-

dimensional anatomical structures, thus the image may demonstrate some errors due to overlapping structures and the possibility of distortion.^{1,2}

The development of CBCT has highlighted the shortcomings of conventional radiography when assessing the anatomy of the maxillofacial structures.³ CBCT plays a crucial role in visualizing anatomical complexities and diseases affecting dental and osseous tissues. CBCT is indicated when a low-radiation or no-radiation method is not able to answer a clinical

Correspondence to: Dr Husniye Demirturk Kocasarac. E-mail: husniyedemirturk@gmail.com

Received 10 January 2016; revised 20 February 2016; accepted 7 March 2016

question asked by the clinician, indications include detection of a pathology, root fracture, root resorption, endodontic surgery or follow-up for previously performed procedure. The purpose is always to overcome the drawbacks of intraoral radiography, which was for a long time the primary radiographic method used in endodontics.⁴ The degree to which the image quality changes between the available settings on the CBCT machine is not known yet. It is the radiologist's duty to decide which acquisition setting is the most appropriate for what the referring practitioner needs, to provide the best dental care for their patient; this decision depends on many factors such as the age, sex and clinical needs of the patients, and it directly affects image properties such as resolution and field of view.

An endodontic surgery may be necessary when periapical inflammation cannot be treated by conventional root canal treatment and orthograde obturation. Besides providing a tight apical seal to prevent passage of micro-organisms or their products into periradicular tissues, being dimensionally stable and inducing healing of periradicular tissue,⁵ an ideal root-end filling material, placed at the time of surgery, must also be clearly visible on radiographs to differentiate materials from root dentin and the adjacent bone.⁶

Several root-end filling materials have been currently in use. Among them, amalgam has been and still is a widely used material.⁷ SuperEBA™ (Harry J Bosworth Company, Skokie, IL) is a modified zinc oxide eugenol cement with increased physical properties such as high strength and adhesion to dentin.⁸ Mineral trioxide aggregate (MTA) is also commonly used due to high biocompatibility, sealing ability and low solubility.⁹ MTA-Angelus (Angelus, Londrina, Paraná, Brazil) is produced from Portland cement with addition of bismuth oxide with higher radio-opacity. Recently, Biodentine™ (Septodont, Saint-Maur-des-Fossés, France), a new calcium silicate-based material, has extensively been started to be used due to its enhanced handling characteristics and mechanical properties.¹⁰

The evaluation of bone healing following endodontic surgery is often judged radiographically in follow-up examinations.¹¹ CBCT scan can be useful to check and identify the reasons of failure of previous surgical procedure due to missed canals, recesses, isthmuses or undetectable apical cracks and to provide critical information about the teeth under investigation and their surrounding anatomy. However, the artefacts caused by root-end filling materials and resulting low image quality might compromise this task.

CBCT, as with any technology, has known limitations, including a possible higher radiation dose, artefact generation, scatter, noise and variations in dose distribution within a volume of interest that affects the image quality.¹² Image quality, conveyed as the contrast-to-noise ratio (CNR),⁴ can be enhanced by changing some parameters during scanning procedure such as the scanning field of view,¹³ electric current (mAs),¹⁴ tube voltage (kVp)^{15,16} and number of basis

images.¹⁷ However, high-density materials such as metals can cause beam hardening and streak artefacts^{16,18} which leads to a decrease in the CNR. Generally, a lesion-to-background contrast is related to the CNR. The CNR is one of the main factors, among many, that influences image quality in CBCT; it has been considered to be more closely related to image quality than image noise.¹⁹

Pauwels *et al*¹⁵ stated that a higher mAs decreases image noise by increasing the signal at the detector. The influence of kVp on dose and image quality is more complicated due to a combination of several energy-dependent X-ray interactions. It has always been a challenge to optimize exposure settings in radiology practice. The influence of changing exposure settings on image quality and dose is not straight and should be appropriately balanced, assuring that an acceptable image quality is acquired at the lowest conceivable dose level. The analysis of technical image quality (*e.g.* CNR) gives an objective method to examine this balance.

Planmeca CBCT machine (ProMax® 3D Max; Planmeca, Helsinki, Finland) has the option of applying an algorithm to decrease the metal artefact. Additionally, the same machine offers 16 different kVp (66–96) options, 12 mAs (1–12), 4 resolutions from which the operator may choose when acquiring the data to obtain an optimum image quality.

Presently, the effect of different CBCT settings on the CNR of images with different root-end filling materials is still unknown. This information could be helpful to reduce potential risks of misdiagnosing pathology or compromising a follow-up. The objective of this study was to determine whether the images, in the presence of four different root-end filling materials, obtained from different kVps with varying resolutions and varying metal artefact reduction (MAR) algorithms, differ in CNR and to determine the optimal settings for Planmeca ProMax 3D Max CBCT machine, taking in consideration the effective dose generated by these settings.

Methods and materials

Sample selection and preparation

20 freshly extracted single-rooted maxillary central incisors were used for this study. The ethical approval of this *in vitro* study was obtained from The Ethics Committee of Kocaeli University (KOU KAEK 2015/161), Kocaeli, Turkey. The inclusion criteria were: straight single roots with mature apices and similar lengths. Teeth presenting with apical curvature, root caries, resorption, previous root canal treatment or restorations were discarded.

After access preparation, the root canals were prepared with nickel–titanium rotary files (ProTaper® Universal; Dentsply Tulsa Dental Specialties, Tulsa,

OK) up to size 40 (F4). Root canals were then filled using the lateral condensation technique with gutta-percha and AH-Plus® (Dentsply-DeTrey, Kontanz, Germany). All teeth were kept at 37° and 100% humidity for 1 week. Each root-end was resected perpendicularly to its long axis at 3 mm from the apex with a high-speed instrument and a diamond-coated cylindrical bur (Mani; MANI Inc., Tokyo, Japan). A 3-mm deep root-end cavity was prepared with a thin fissure bur (#330, Mani). The samples were randomly distributed to four experimental groups (five for each group) of which cavities were filled with four different root-end filling materials: amalgam (Tytin®, Kerr Manufacturing Co., Romulus, MI), white MTA-Angelus, SuperEBA cement and Biodentine. Periapical radiographs were taken to verify the quality of the root-end fillings. Teeth were then stored at 37 °C with 100% humidity. The same operator performed all root canal preparations, obturations and root-end fillings.

CBCT imaging

The root sample was placed in an empty maxillary anterior socket of a dried human skull taken from the Department of Anatomy, Faculty of Dentistry, Kocaeli University. Intact anterior teeth collected from different individuals were also fixed in their respective empty locations in the maxilla. The maxilla was covered with 4-mm-thick pink wax layer to simulate alveolar soft tissue during exposure. A round plastic box was used to position the skull in the machine; it was also filled with water to cover the area of interest. Coloured markers were made at the periphery to help replacing the skull in the same position after changing the tooth (Figure 1).

CBCT scan of teeth filled with different root-end filling materials were acquired using Planmeca CBCT machine (Planmeca ProMax 3D Max). The settings were: 66, 76, 84 and 96 kVp with no MAR–high resolution, no MAR–normal resolution, high MAR–low resolution and high MAR–high definition. These were the most frequently used settings based on different diagnostic tasks. Voxel sizes of 100, 150, 200 and 400 µm were used in the scans. Exposure time (approximately 4, 12, 15 s) and mA (6–10) were automatically adjusted by the machine according to the settings chosen. The imaging settings were adjusted so that there would be images differing in only one of the parameters: kVp, resolution and MAR algorithm for each of the four root-end filling materials. Therefore, it would be possible to ensure that fluctuations in the CNR are solely an effect of changes in one of these parameters.

320 volumes were exported using multislice digital imaging in communications in medicine format (DICOM) with 0.16 mm thickness. Identical slices were chosen at the same level from different scans, the analysis was performed using ImageJ software (National Institutes of Health, Bethesda, MD). In each image, two areas were selected, and a mean gray value and standard deviation were obtained. The first

Figure 1 Skull placed in a round plastic container with wax covering the maxillary crest.

area was chosen on the wax located buccal to the filling material; the control area was selected at the edge of the volume where the artefact is minimal (Figure 2). The CNR was calculated using the formula:^{4,15,16,18}

$$CNR = \frac{|\text{Mean}_{\text{Wax}} - \text{Mean}_{\text{Control}}|}{\sqrt{SD_{\text{Wax}}^2 + SD_{\text{Control}}^2}}$$

where mean is the mean gray value in the area of interest and SD is the gray value standard deviation in the same area.

For every setting, the effective dose was calculated from the measured dose–area product (DAP) value, multiplied by a conversion coefficient and expressed in millisieverts (Figure 3). The DAP is automatically calculated and provided by the machine prior to exposure. We used the same conversion formulas as Shin *et al*²⁰ did in their study, suggested by Helmrot and Alm Carlsson²¹ and Batista *et al*,²² taking into consideration the kVp.

The effective dose from CBCT with voltages of 60–75 kV was calculated with the conversion formula suggested by Helmrot and Alm Carlsson:²¹

$$E = 0.08 \text{ mSv Gy}^{-1} \text{ cm}^{-2} \times P_{KA}$$

where *E* is the effective dose and *P_{KA}* is the DAP.

The effective dose with voltages >75 kV was calculated using the formula suggested by Batista *et al*.²²

Figure 2 Areas of interest used for contrast-to-noise ratio calculation.

$$E = [0.00145 \times (\text{kV}) + 0.0118] \times P_{KA}$$

where kV is the tube voltage, E is the effective dose and P_{KA} is the DAP.

Validation (root sectioning and observation)

Following the root-end filling, periapical radiographs were taken for all teeth using photostimulable phosphor plate (Digora® Optime, Soredex Medical Systems, Helsinki, Finland) to justify the quality (*e.g.* void, gap). Then, the teeth were placed in self-cured acrylic (Orthoplast; Vertex, Zeist, Netherlands) blocks. Resin

blocks were sliced on an IsoMet® 1000 precision saw (Buehler®, Lake Bluff, IL) equipped with a 0.3-mm water-cooled low-speed diamond disc (Buehler). Each root was horizontally cut at 1–3 mm starting from the root-end to obtain three slices of 1 mm thickness. Slices were viewed in a stereomicroscope (Leica MZ75; Leica Imaging Systems Ltd, Cambridge, England, UK) at a magnification of $\times 24$, and then digital photographs were taken with an Olympus X-835 camera (Olympus Optical Co. Ltd, Tokyo, Japan). Radiographic and microscopic cross-sectional images were validated, and the quality of the root-end fillings was confirmed (Figure 4).

Statistical analysis

The CNR was calculated for each material at four different kVp settings (66, 76, 84 and 96 kVp), four resolution settings (high, normal, low and high definition) and two MAR settings (high and no). This experiment was repeated on 5 different teeth, for a total of 80 readings per material.

The CNR was calculated using the standard ANOVA, with all two-way and three-way interactions between the three machine settings and the four materials, and with the tooth as a blocking factor (assumed not to interact with material or any of the machine settings). For identifying the setting combinations which have sufficient evidence to be considered different from the others, Tukey's multiple comparison adjustment technique was used. $p < 0.05$ was taken to state statistical significance.

Results

ANOVA analysis showed that at the 95% confidence level, each of the machine settings (kVp, resolution and MAR setting) and tooth have a statistically significant

Figure 3 Calculated effective doses by settings measured in millisieverts. HD, high definition; HR, high resolution; LR, low resolution; MAR, metal artefact reduction; NR, normal resolution.

Figure 4 Axial image at the level of the mid-height of the root-end filling materials. (a) Amalgam, (b) white mineral trioxide aggregate angelus, (c) Biodentine™ (Septodont, Saint-Maur-des-Faussés, France) and (d) SuperEBA™ (Harry J Bosworth Company, Skokie, IL).

effect on the mean value of the CNR but the material used does not, given all other factors held constant. There are also small but significant two-way interactions between material and MAR, material and resolution, kVp and resolution, kVp and MAR, and resolution and MAR as well as their three-way interactions between material, resolution and MAR and kVp, resolution and MAR ($p < 0.05$). The other two-way and three-way interactions are not statistically significant ($p > 0.05$).

Tukey's multiple comparison adjustment analysis was used for the CNR to determine the factor combinations that have enough evidence to be considered different from the others. The most meaningful comparisons, starting with the highest mean value of the CNR for that comparison group, are shown in Figure 5. Regarding the effect of material alone, despite that Biodentine had the highest CNR, no statistically significant difference was found between the materials ($p > 0.05$). Comparing different CNR values by kVp, we found that 66 and 76 kVp were inferior to 84 and 96 kVp because of the lower mean value of the CNR ($p < 0.05$), but 84 and 96 kVp were found equal to each other ($p > 0.05$). When we compared CNR by resolution and MAR setting, a significant difference was seen between the different resolutions, with the low resolution showing better CNR than normal and high resolutions and high definition. High MAR showed higher CNR comparing with no MAR setting ($p < 0.05$).

All the comparisons were integrated; it is apparent that the best choice to obtain a high CNR is to use low resolution, high MAR and either 84 or 96 kVp (Table 1, Figure 5).

Measured DAP values for every setting were converted into effective doses using a conversion formula and comparison between the different doses showed that the low resolution generated the least amount of radiation, and increasing the resolution is increasing the dose. From another hand, increasing the kVp gradually increases the radiation dose but with a slower pace (Figure 3).

Discussion

CBCT settings can be modified in several ways. Therefore, exposure settings should be adjusted according to the diagnostic task to deliver the best image with the least possible amount of dose to the patient.

It is known that high-density materials (*e.g.* metal) cause beam hardening and streak artefacts which often obscure areas of diagnostic importance within the image causing interpretation challenges and interfering with the diagnostic quality.^{17,18} These artefacts decrease the contrast between adjacent objects and limit clear examination of areas of interest. Multiple studies showed that artefacts and low CNR cause misdiagnosis of root fractures, voids and false-positive observations, especially in

Figure 5 The contrast-to-noise ratio (CNR) comparison by metal artefact reduction (MAR) and resolution. Biodentine™ obtained from Septodont, Saint-Maur-des-Faussés, France and SuperEBA™ from Harry J Bosworth Company, Skokie, IL. High, high resolution; Low, low resolution; Off, no MAR; On, MAR. Note that the figure shows only the most meaningful comparisons.

the presence of gutta-percha and root canal sealers.^{17,23–26} However, to our knowledge, the image quality and interpretation challenges related to root-end filling materials using CBCT have not been shown till now. The current study evaluated the influence of different root-end filling materials and multiple settings on image quality in Planmeca ProMax 3D Max CBCT machine.

In this study, we used the most preferred settings as clinical routine: 66, 76, 84 and 96 kVp with and without MAR and different resolutions. By modifying these settings individually, it was possible to explain how the image quality can be optimized while keeping the radiation dose within acceptable limits. We also used four types of root-end filling material in the search of the material that can give an image with the least number of negative factors affecting its quality. The CNR was used to assess the effect of these settings on image quality because it is a commonly used image quality parameter and can be easily interpreted.¹⁵

Higher kVp value increases the signal at the X-ray detector by increasing the photon energy and reducing the absorption ratio. The results obtained in this study showed that increasing the kVp affected the CNR significantly and positively. This finding is in agreement with the findings of Bechara et al¹⁶ and Kim et al.²⁷ However, in the machine we used, the CNR did not vary significantly between the 84 and 96 kVp. Thus, with less radiation exposure, the same image quality was obtained (Table 1, Figure 3). This result is consistent with the study by Pauwels et al¹⁵ which aimed to

determine the optimal kVp in CBCT while balancing the CNR and radiation dose. They measured the CNR in a phantom containing four materials (air, aluminium, polytetrafluoroethylene and low-density polyethylene) with the kVp/mA ranging from 60/1 to 90/8. They concluded that the highest kVp value (*i.e.* 90 kVp) results in the highest CNR at a fixed radiation dose, especially at low dose levels.

The use of MAR algorithm increased the CNR significantly in the presence of all four root-end filling materials. The MAR algorithm lowered the influence of

Table 1 Contrast-to-noise ratio (CNR) comparison by kVp, resolution (res.) and metal artefact reduction (MAR)

kVp/res./MAR	Mean value of CNR	p-value
96, low res., high MAR	2.39	–
84, low res., high MAR	2.28	0.9999
76, low res., high MAR	1.37	<0.0001
84, high res., high MAR	1.36	<0.0001
84, low res., no MAR	1.25	<0.0001
76, high res., high MAR	1.14	<0.0001
66, high res., high MAR	1.04	<0.0001
96, high res., high MAR	1.00	<0.0001
76, low res., no MAR	0.95	<0.0001
66, low res., no MAR	0.87	<0.0001
66, low res., high MAR	0.85	<0.0001
96, low res., no MAR	0.81	<0.0001
76, high res., no MAR	0.68	<0.0001
96, high res., no MAR	0.65	<0.0001
84, high res., no MAR	0.64	<0.0001
66, high res., no MAR	0.56	<0.0001

Statistically significant difference on the mean value of CNR. Note that the table shows only the most meaningful comparisons.

the beam hardening and scattering artefacts caused by filling materials, resulting in an increase in the CNR. Bechara *et al*^{16,18} reported similar observations using a phantom where metal was present in all scans. Clinically, the algorithm can be utilized to minimize artefacts and noise and to maximize the CNR if a root-end filling material is present, providing the endodontist and the radiologist with a limited artefact image yielding the way to a better comparison with pre-op images. However, it should be considered that the reconstruction time is increased when MAR is used.

The increased CNR values are clearly seen when MAR is used, but how the images might look like if root-end filling material was not within the field of view is not demonstrated. It is not clear if the parameters used or the application of the MAR can restore the content of the surrounding structures within the image to provide a closer presentation of the “reality” or all what these settings are doing is a matter of interpolation or iteration aiming at reducing the effect of the high density material.

In current study, the use of low resolution resulted in a higher CNR increasing the accuracy of the images to assess bone healing in the area where an endodontic surgery with retrograde filling was performed. Klintstrom *et al*²⁸ assessed how imaging parameters (current, voltage, rotation degree, voxel size, imaging area and rotation time) in CBCT affect the accuracy in quantifying trabecular bone structures, CNR and radiation dose. They concluded that differences in resolution mode did not have any significant effect on the CNR and that a fair CNR can be obtained with a low radiation dose which conforms with one of the results of our study. Neves *et al*²⁹ assessed the effect of CBCT resolution modes (high-resolution, high-fidelity, high-speed and standard) in diagnosis of vertical root fractures with different intracanal (gutta-percha, metal post and fibre post) materials. They stated that differences among resolution do not improve the image quality significantly in terms of diagnosing root fractures. The reason of the discrepancy in conclusions between the study by Neves *et al*²⁹ and our study might be due to the different filling materials used.

Although the highest CNR was seen in Biodentine, statistically significant difference was not found between Biodentine, SuperEBA, MTA and amalgam when all other given factors held constant. Bechara *et al*¹⁸ showed that metal artefacts cause a decrease in the CNR. It was clear in our study that when high MAR was used, the CNR did not change significantly between

root-end filling materials (Figure 5) which suggests that MAR can be used to counteract the effects of beam hardening and streak artefacts, and that high MAR optimizes the CNR in the presence of root-end filling materials (amalgam, MTA, Biodentine and SuperEBA). Although CBCT is still lacking an objective criteria considering diagnostic acceptability of an image, several studies showed that CBCT doses can be reduced remarkably with image quality remaining sufficient.^{14,15} Thus, corroborating the present study, it can be concluded that dose optimization using exposure parameters below manufacturers’ default setting should always be investigated, especially for children. Siegel *et al*³⁰ examined combinations of exposure settings for paediatric CT, concluded that the increase in noise at low-dose settings is minimum in smaller phantoms or patients. Pauwels *et al*¹⁵ stated that this can be expected in CBCT as well. Further studies using small-size phantoms or jaws in several settings will elucidate this issue and give precious addition to the current study.

This *in vitro* study looked only at one aspect of image quality and assessed how the CNR differs between CBCT settings (kVp, resolution and MAR algorithm) using the manufacturers’ recommendations for mA, voxel size and exposure time when root-end filling material is present. It may be interesting to evaluate diagnostic accuracy difference between these settings for a given task. This is important, particularly MAR algorithm, because it is being marketed on the assumption that it will decrease artefacts resulting in higher image quality.

Conclusion

The results of the study provided important insights related to dose and image quality. The use of high MAR and low resolution produced the least amount of radiation with the highest CNR given by 96 kVp. The best clinically applicable setting for evaluation of an area where an endodontic surgery with retrograde filling on the Planmeca ProMax is 96 kVp with high MAR and low resolution, especially that this setting produced low dose levels.

Although the best CNR was seen when Biodentine was used for a retrograde obturation, statistically significant difference was not found between Biodentine, SuperEBA, MTA and amalgam when all other factors were held constant.

References

1. Special Committee to Revise the Joint AAE/AAOMR Position Statement on use of CBCT in Endodontics; Fayed MI, Nair MK, Levin MD, Benavides E, Rubinstein RA, Barghan S, *et al*. AAE and AAOMR joint position statement: use of Cone Beam Computed Tomography in endodontics 2015 update. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2015; **120**: 508–12. doi: <http://dx.doi.org/10.1016/j.oooo.2015.07.033>
2. Gröndahl HG, Huuonen S. Radiographic manifestations of periapical inflammatory lesions. *Endod Top* 2004; **8**: 55–67.
3. Patel S, Dawood A, Whaites E, Pitt Ford T. New dimensions in endodontic imaging: part 1. Conventional and alternative radiographic systems. *Int Endod J* 2009; **42**: 447–62. doi: <http://dx.doi.org/10.1111/j.1365-2591.2008.01530.x>
4. 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: <http://dx.doi.org/10.2334/josnusd.54.227>

5. Johnson BR. Considerations in the selection of a root-end filling material. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1999; **87**: 398–404. doi: [http://dx.doi.org/10.1016/S1079-2104\(99\)70237-4](http://dx.doi.org/10.1016/S1079-2104(99)70237-4)
6. Shah PM, Chong BS, Sidhu SK, Ford TR. Radiopacity of potential root-end filling materials. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1996; **81**: 476–9. doi: [http://dx.doi.org/10.1016/S1079-2104\(96\)80028-X](http://dx.doi.org/10.1016/S1079-2104(96)80028-X)
7. Kim S, Kratchman S. Modern endodontic surgery concepts and practice: a review. *J Endod* 2006; **32**: 601–23. doi: <http://dx.doi.org/10.1016/j.joen.2005.12.010>
8. Aqrabawi J. Sealing ability of amalgam, super EBA cement, and MTA when used as retrograde filling materials. *Br Dent J* 2000; **188**: 266–8.
9. Torabinejad M, Hong CU, McDonald F, Pitt Ford TR. Physical and chemical properties of a new root-end filling material. *J Endod* 1995; **21**: 349–53. doi: [http://dx.doi.org/10.1016/S0099-2399\(06\)80967-2](http://dx.doi.org/10.1016/S0099-2399(06)80967-2)
10. Grech L, Mallia B, Camilleri J. Investigation of the physical properties of tricalcium silicate cement-based root-end filling materials. *Dent Mater* 2013; **29**: e20–8. doi: <http://dx.doi.org/10.1016/j.dental.2012.11.007>
11. Chong BS, Ford TR, Wilson RF. Radiological assessment of the effects of potential root-end filling materials on healing after endodontic surgery. *Endod Dent Traumatol* 1997; **13**: 176–9. doi: <http://dx.doi.org/10.1111/j.1600-9657.1997.tb00034.x>
12. Suomalainen A, Esmaili EP, Robinson S. Dentomaxillofacial imaging with panoramic views and cone beam ct. *Insights Imaging* 2015; **6**: 1–16. doi: <http://dx.doi.org/10.1007/s13244-014-0379-4>
13. Bechara B, McMahan CA, Moore WS, Noujeim M, Geha H. Contrast-to-noise ratio with different large volumes in a cone-beam computerized tomography machine: An in vitro study. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2012; **114**: 658–65. doi: <http://dx.doi.org/10.1016/j.oooo.2012.08.436>
14. 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**: 483–8. doi: <http://dx.doi.org/10.1016/j.ejrad.2010.09.018>
15. Pauwels R, Silkosessak O, Jacobs R, Bogaerts R, Bosmans H, Panmekiate S. A pragmatic approach to determine the optimal kVp in cone beam ct: balancing contrast-to-noise ratio and radiation dose. *Dentomaxillofac Radiol* 2014; **43**: 20140059. doi: <http://dx.doi.org/10.1259/dmfr.20140059>
16. Bechara BB, Moore WS, McMahan CA, Noujeim M. Metal artefact reduction with cone beam ct: an in vitro study. *Dentomaxillofac Radiol* 2012; **41**: 248–53. doi: <http://dx.doi.org/10.1259/dmfr/80899839>
17. Bechara B, McMahan CA, Nasseh I, Geha H, Hayek E, Khawam G, et al. Number of basis images effect on detection of root fractures in endodontically treated teeth using a cone beam computed tomography machine: an in vitro study. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2013; **115**: 676–81. doi: <http://dx.doi.org/10.1016/j.oooo.2013.01.026>
18. Bechara B, McMahan CA, Geha H, Noujeim M. Evaluation of a cone beam ct artefact reduction algorithm. *Dentomaxillofac Radiol* 2012; **41**: 422–8. doi: <http://dx.doi.org/10.1259/dmfr/43691321>
19. Kalender WA, Deak P, Kellermeier M, van Straten M, Vollmar SV. Application and patient size-dependent optimization of X-ray spectra for CT. *Med Phys* 2009; **36**: 993–1007. doi: <http://dx.doi.org/10.1118/1.3075901>
20. Shin HS, Nam KC, Park H, Choi HU, Kim HY, Park CS. Effective doses from panoramic radiography and CBCT (cone beam CT) using dose area product (DAP) in dentistry. *Dentomaxillofac Radiol* 2014; **43**: 20130439. doi: <http://dx.doi.org/10.1259/dmfr.20130439>
21. Helmrot E, Alm Carlsson G. Measurement of radiation dose in dental radiology. *Radiat Prot Dosimetry* 2005; **114**: 168–71. doi: <http://dx.doi.org/10.1093/rpd/nch502>
22. Batista WO, Navarro MV, Maia AF. Effective doses in panoramic images from conventional and CBCT equipment. *Radiat Prot Dosimetry* 2012; **151**: 67–75. doi: <http://dx.doi.org/10.1093/rpd/ncr454>
23. Bechara B, Alex McMahan C, Moore WS, Noujeim M, Teixeira FB, Geha H. Cone beam CT scans with and without artefact reduction in root fracture detection of endodontically treated teeth. *Dentomaxillofac Radiol* 2013; **42**: 20120245. doi: <http://dx.doi.org/10.1259/dmfr.20120245>
24. Brito-Júnior M, Santos LA, Faria-e-Silva AL, Pereira RD, Sousa-Neto MD. Ex vivo evaluation of artifacts mimicking fracture lines on cone-beam computed tomography produced by different root canal sealers. *Int Endod J* 2014; **47**: 26–31. doi: <http://dx.doi.org/10.1111/iej.12121>
25. Khedmat S, Rouhi N, Drage N, Shokouhinejad N, Nekoofar MH. 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* 2012; **45**: 1004–9. doi: <http://dx.doi.org/10.1111/j.1365-2591.2012.02062.x>
26. Vasconcelos K, Nicolielo LF, Nascimento MC, Haiter-Neto F, Bóscolo FN, Van Dessel J, et al. Artefact expression associated with several cone-beam computed tomographic machines when imaging root filled teeth. *Int Endod J* 2015; **48**: 994–1000. doi: <http://dx.doi.org/10.1111/iej.12395>
27. Kim S, Yoo S, Yin FF, Samei E, Yoshizumi T. Kilovoltage cone-beam CT: comparative dose and image quality evaluations in partial and full-angle scan protocols. *Med Phys* 2010; **37**: 3648–59. doi: <http://dx.doi.org/10.1118/1.3438478>
28. Klintstrom E, Smedby O, Klintstrom B, Brismar TB, Moreno R. Trabecular bone histomorphometric measurements and contrast-to-noise ratio in CBCT. *Dentomaxillofac Radiol* 2014; **43**: 20140196.
29. Neves FS, Freitas DQ, Campos PS, Ekestubbe A, Lofthag-Hansen S. Evaluation of cone-beam computed tomography in the diagnosis of vertical root fractures: the influence of imaging modes and root canal materials. *J Endod* 2014; **40**: 1530–6. doi: <http://dx.doi.org/10.1016/j.joen.2014.06.012>
30. Siegel MJ, Schmidt B, Bradley D, Suess C, Hildebolt C. Radiation dose and image quality in pediatric ct: effect of technical factors and phantom size and shape. *Radiology* 2004; **233**: 515–22. doi: <http://dx.doi.org/10.1148/radiol.2332032107>