Available online at www.giornaleitalianoendodonzia.it

ORIGINAL ARTICLE

Investigation on the frequency of streak artifacts resulted from different sealers in cone-beam computed tomography images

ABSTRACT

Aim: *This ex-vivo study aimed to investigate streaking artifacts produced by three different sealers to prevent false-positive diagnosis of vertical root fractures (VRF) in clinical settings using cone-beam computed tomography (CBCT).*
Materials and Methods: *The present experimental study included 60 mandibular teeth, single-rooted premolars prepared using a Protaper F3 file and randomly classified into 4 groups, which were obturated using gutta-percha F3 cones alone (control group) or with one of the sealers: MTA Fillapex (FA), Sealapex, and AH26. The teeth underwent CBCT scan with a 5×8 cm field of view (FOV), and the images were qualitatively evaluated in axial sections by two observers and were coded as follows: Code 1: absence of dark streaks, Code 2: slight dark streaks, Code 3: pronounced dark streaks not extending to the root surface, Code 4: dark streaks extending to the root surface, resembling a fracture.*
Data were analyzed using SPSS software version 20. Chi-square test was used for artifact frequency comparison at P≤0.05 level of significance.
Results: *According to both observers, there was no significant inter-group difference in artifact frequency (P>0.05), while Code 3 was the most common artifact observed in all groups.*
Conclusions: *Dark streaks not extending to the root surface (code 3) were the most common artifact in the teeth obturated using gutta-percha cones alone or with sealers MTA Fillapex (FA), Sealapex, and AH26.*

Vida Maserrat[1]

Heshmat Allah Shahraki Ebrahimi[2]

Maryam Dalaei Moghadam[2]*

Forough Khodadadnejad[3]

Hanane Jami Al Ahmadi[4]

[1]Department of Radiology, Faculty of Dentistry, Zahedan University of Medical Science, Zahedan, Iran

[2]Department of Endodontic, Faculty of Dentistry, Zahedan University of Medical Science, Zahedan, Iran

[3]Department of Endodontic, Faculty of Dentistry, Arak University of Medical Science, Arak, Iran

[4]Private practice in Zahedan, Iran

Received 2021, April 17
Accepted 2021, July 24

KEYWORDS *Cone-Beam Computed Tomography, sealer, streak artifact*

Corresponding Author
Maryam Dalaei Moghadam | Bozorgmehr Boulevard, 24st, Zahedan, Sistan and Baluchestan | Iran
Phone:+989120407133 | Email: maryam.dalaei@yahoo.com

Peer review under responsibility of Società Italiana di Endodonzia

10.32067/GIE.2021.35.02.37

Introduction

Root canal treatment is performed for apical periodontitis prevention and treatment (1, 2). Complete elimination of bacteria from the root canal system, selection of filling material (2), and the quality of root canal filling (3) are the important factors effective in achieving this goal.

Radiography play an important role in evaluating the root treatment outcomes and the etiology of the endodontic failures (4, 5). One of the main challenges of dental procedures is the Correct diagnosis of root fracture because early VRF detection prevents extensive damage to the dental supporting tissues.

In most cases, accurate diagnosis is only possible after evaluating the clinical signs and features and symptoms of the periapical radiographs and CBCT images (6, 7). Two-dimensional (2D) radiographs have some limitations in VRF diagnosis. these radiographs can only detect VRFs if the plane of fracture line is parallel to the radiation direction (8).

Recently, application of cone-beam computed tomography (CBCT) imaging has become common in endodontic treatments, overcoming the limitations of 2D imaging modalities. Some applications of CBCT include detection of strip perforation (5), VRF detection, root canal filling evaluation and detection of periapical lesions and evaluation of their healing course (3).

Most root filling materials such as gutta-percha and sealers cause different forms of artifacts (9, 10). These linear artifacts can lead to the false-positive misdiagnosis of dental root fractures (11). Root canal sealers can be classified according to their composition: calcium hydroxide, glass-ionomer, resin, silicone-based sealers, zinc oxide eugenol (12) and mineral trioxide aggregate(MTA)-based sealers (13, 14).

All sealers should have sufficient radio-opacity to allow evaluating the quality of root canal filling by radiography. Therefore, radio-opaque materials are added to sealers to help differentiate between the sealer and dental tissue or even gaps within the root canal filling (15, 16). Considering the differences in radiopacity between the sealers, these filling materials also have different atomic composition and interaction with X-rays. The scattered radiation combined with the lower milliamperage of CBCT can compromise the quality of the scan, inducing image artifacts and leading to inaccurate or false diagnoses (15).

These artifacts in CBCT images are due to the beam-hardening effect, in which there is a preferential absorption of lower-energy photons compared to higher-energy photons in an X-ray beam, leading to the creation of lines that mimic the appearance of a root fracture (4) beam hardening may occur in two forms. Cupping artifacts and white streaks associated with dark bands may be appear near of dense materials. Dark bands may mimic root fracture in the CBCT images, thus reducing its accuracy of this modality in root fracture detection (17).

According to the studies, small FOV provides images with higher resolution and lower artifacts than large FOV. Moreover, smaller voxel sizes improve the quality of CBCT images (4, 18).

However, streak artifacts can still be present in CBCT images even if small FOVs and various voxel sizes are used because of the radio-opaque materials, such as metals, gutta-percha, and sealers (16, 18-24).

In some studies, authors have evaluated the dark bands in the root canal-treated teeth CBCT images.

Gholampour et al. (25) investigated the artifacts caused by three different sealers, including zinc oxide-eugenol (ZOE)-based sealer, ceramic-based sealer, and resin in CBCT with two different resolutions. They concluded that Gutta-percha alone produced more artifacts than gutta-percha with sealers; moreover, ZOE-based sealer induced more artifacts than other sealers.

Brito-Junior et al (15) investigated the streak artifacts caused by various root canal sealers (Endofill, Sealer 26, Fill apex, AH Plus) in CBCT images with variable voxel resolution. They concluded that the type of sealer and voxel resolution can influence the presence of streaking artifacts observed in CBCT images.

Freitas-e-Silvae et al. (26) investigated the

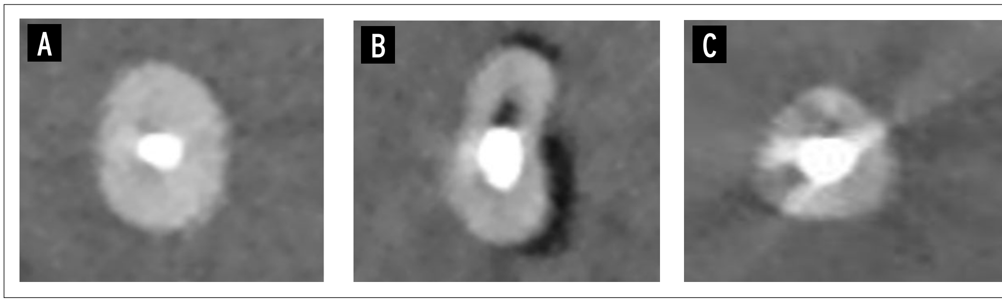

Figure 1
Axial slices showing streaking artifacts on cervical root sections according 4 codes that were studied **A)** Code 2: slight dark streaks, **B)** Code 3: pronounced dark streaks not extending to the root surface, **C)** Code 4: dark streaks extending to the root surface, resembling a fracture from left to right respectively.

effect of three different sealers (fill canal, sealer 26, AH plus) in the VRF diagnosis and concluded that endodontic sealers do not influence the detection of VRF. There is little information available on detecting streak artifacts resulted from sealers. Therefore, such information can be helpful in decreasing the potential risk of false-positive VRF detection.

Therefore, the present experimental study intended to evaluate the frequency of artifacts resulted from sealers containing calcium hydroxide, epoxy resin, and MTA in small-volume CBCT images of obturated teeth. The null hypothesis was no significant difference exists between the artifacts resulted from different sealers.

Materials and Methods

The present study was an ex vivo study including 60 single-rooted mandibular premolars (from humans aged 18-50) with mature apexes and similar lengths that were recently extracted due to periodontal or orthodontic indications. Exclusion criteria included teeth with internal or external root resorption, cracks, fractures, extensive restorations (beyond the CEJ), root canal obstruction, dilaceration, and other anomalies. All the samples were evaluated and confirmed to fulfill the inclusion and exclusion criteria using digital radiography in mesiodistal and buccolingual dimensions. For surface disinfection, the teeth were immersed in 5.25% sodium hypochlorite solution (Chloraxid, Cerkamed, Poland) for 2 hours (3). Then, they were kept in distilled water until imaging. They were re-evaluated using an operating microscope (Pico, Zeiss Co., Jena, Germany) to ensure the absence of any crack or fractures. Moreover, those with round root canals were the only teeth selected (3, 8).

All teeth were prepared by a postgraduate student in endodontics (last year resident). Anatomical crowns of all samples were cut off in CEJ perpendicular to the longitudinal axis of the teeth using a carborundum disc and air turbine (KaVo Dental, Biberach, Baden-Württemberg, Germany). To determine the working length, the #10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) was introduced into the canal until its tip was visible at the apex; 1 mm was subtracted from this length to determine the working length. Instrumentation was performed by the same operator that prepared the teeth.

All the canals were prepared using ProTaper rotary files (Dentsply Maillefer, Ballaigues, Switzerland) until the F3 size. During preparation, root canals were irrigated using 2 ml of 5.25% sodium hypochlorite solution for 1 minute. Following preparation, 2 ml of a 17% EDTA solution (Aria Dent, Tehran, Iran) was applied for 1 minute, followed by 3 ml 5.25% sodium hypochlorite solution and 3 ml distilled water to eliminate residues of the smear layer. Then, the root canals were dried with paper points (Diadent, Chongiu, Korea).

Root canal filling

The roots were randomly divided into 4 groups (n 15).

Table 1
Frequency distribution of artifact types observed by all groups (n=60)

		Code 2	Code 3	Code 4
Control	Frequency	2	8	5
	Percentage	13.3%	53.3%	33.3%
Sealapex	Frequency	2	7	6
	Percentage	13.3%	46.7%	40%
MTA Fillapex	Frequency	1	10	4
	Percentage	6.7%	66.7%	26.7%
AH26	Frequency	1	9	5
	Percentage	6.7%	60%	33.3%

The sealers were prepared according to the manufacturer's instructions and were inserted into the canals using a Lentulo spiral until reaching the working length. Then, the obturation was performed using the single-cone technique and the gutta-percha F3 cones (Maillefer, Ballaiges, Switzerland). The sealer used in each group was different from other groups in composition. Study groups were as follows.
Group 1: Gutta-percha without sealer (Control group)
Group 2: Gutta-percha and Sealapex (SybronEndo, Orange, CA, USA)
Group 3: Gutta-percha and MTA Fillapex (Angelus, Londrina, PR, Brazil)
Group 4: Gutta-percha and AH26 (Denstply, De Trey, Konstanz, Germany)
After obturation, the samples were kept in distilled water until mounting for CBCT acquisition.

CBCT acquisition

The teeth were numbered from 1 to 60 and were randomly mounted in four putty molds along their longitudinal axis. For CBCT acquisition, the molds were placed in a container with water to simulate soft tissue. CBCT images were obtained using NewTom Giano extraoral imaging system (Vila Silverstrini, Verona, Italy) with the following settings in high-resolution exposure conditions: 0.3 mm voxel size, 90 kVp, 0.6 mA, and 10 s exposure time (pulsed). The samples were placed in the center of the FOV (5×8 cm). The images were reconstructed and saved using the NNT software. Axial images were obtained from the coronal to the apical areas of the teeth with slices thickness being 0.15 mm.

CBCT image evaluation

CBCT images were displayed on a 19-inch screen, colour, 1366x768 pixels resolution (Samsung, Seoul, Korea) and were evaluated by two blinded observers, including a maxillofacial radiologist with 10 years' experience and an endodontist with 8 years' experience. Streak or linear artifacts were in axial sections detected and were coded as follows. Code 1: absence of dark streaks; Code 2: slight dark streaks that were not obvious; Code 3: pronounced dark streaks not extending to the root surface; Code 4: dark streaks extending to the root surface that resembled a fracture. Finally, the data were recorded on a computer and used for statistical analysis.
The Chi-square test was used to compare the frequency (ratio) of artifacts in the 4 groups. The intra-and interobserver degree of agreement in artifact detection was measured using the κ agreement coefficient. The significance level was considered 5% ($p<0.05$) for all tests, and the statistical analysis was performed using SPSS version 20.

Results

The highest frequency of artifacts was observed in relation to Code 2 in the control group (13.3%) and sealapex sealer group (13.3%), in relation to Code 3 in MTA fillapex group (66.7%) and in relation to Code

4 in sealapex sealer (40%). Code 3 was the most common artifact in all the groups. Due to the presence of artifacts in all groups, Code 1 was not included in the analysis.
According to the Chi-square test no statistically significant difference was observed in the frequency of different types of artifacts in the experimental groups. The intraobserver (kappa 0.83 [95% CI 0.82, 0.89]; and interobserver agreement (Kappa 0.70 [95% CI: 0.72, 0.74] respectively, were good.

Discussion

CBCT imaging is the technique indicated for VRF diagnosis when 2D images do not provide adequate information, especially in the root canal-treated teeth (26).
Studies have demonstrated that artifacts caused by root fillings materials may reduce the accuracy, sensitivity, and specificity of CBCT imaging in VRF diagnosis. Thus, an attempt to identify CBCT artifacts related to different filling materials seems to be important for diagnosing root fractures (15).
The presence of radiopacifiers and other chemical substances in the formulation of different sealers such as bismuth oxide, bismuth subcarbonate, barium sulfate, and zinc oxide can lead to differences in density (26).
Root canal filling materials, such as gutta-percha cones and sealers, can make obvious streak artifacts that mimic the lines of root fracture. Therefore, a definite diagnosis of VRF has always been questionable due to the artifacts resulted from various materials in the root canal, leading to a false-positive diagnosis (11).
According to some studies, sealers are the main material causing artifacts mimicking root fractures in CBCT (15, 26) which is contrary to the present study. The present study showed that gutta-percha alone or in combination with sealers (sealapex, MTA fillapex, and AH26) causes obvious streak artifacts, which are mostly seen as pronounced dark streaks not extending to the root surface in the axial CBCT images (Code 3). Some studies have shown that root canal filling materials do not influence on VRF diagnosis (21, 26, 28). For instance, Melo SL et al. (21) showed that longitudinal root fractures diagnostic ability using CBCT was not influenced by the presence of posts or gutta-percha. Additionally, Dutra Kl et al. (28) showed that the presence of gutta-percha caused a low beam hardening artifact which did not hinder the VRF diagnosis.
Several studies have evaluated influence of root fillings on the detection of VRFs using CBCT images, although the filling material used had been restricted to only gutta-percha (19, 24).
Gutta-percha and metallic posts are frequently used, and they are responsible for beam-hardening artifacts because of their high density, which reduces the ability to diagnose root cracks and fractures, obscuring root canal morphology (29).
Gutta-percha cones created distinct streaking artifacts on CBCT axial slices, which are consistent with the present findings (15). Freitas-e-Silva et al. (26) showed that due to the high amount of intra-canal gutta-percha, the use of different sealers does not affect on the vertical root fracture diagnosis. Gholampour et al. (25) concluded that gutta-percha alone produced more artifacts compared with gutta-percha and sealer (resin sealers, ceramic sealers, and ZOE-based sealers). They suggested that the higher number of artifacts created by gutta-percha could be due to the higher density of gutta-percha compared to the density of the gutta-percha and sealer combination.
Using a 0.076 mm voxel size, Brito-Junior et al. (15) found no significant difference in the frequency of streak artifacts in root canals filled with sealers AH26, AH plus, and Fillapex. However, the findings of the mentioned study in a larger voxel size (0.2 mm), which was close to the voxel size used in the present study (0.3 mm), were not compatible with ours. Voxel size of CBCT imaging is related to contrast and resolution (22). According to Brito-Junior et al. (15), it seems that smaller voxel size decreases the artifacts, thereby increasing the diagnostic accuracy of root fracture detection in root-filled teeth. Another difference of the present study with the study by Brito-Junior et al. was the larger sample size of the present study and different image evaluation methods used in the two studies. Brito-Junior et al. only investigated the absence

or presence of the artifacts, while we classified artifacts into 4 codes, which allowed more precise and detailed evaluation and subsequent higher accuracy of the potential results.

Iikubo et al. (11) investigated the pure effect of voxel size and FOV on the artifacts created by gutta-percha-filled root canals. They evaluated the artifacts on CBCT images obtained using two modes: I-mode (FOV: 102 mm, voxel size: 0.2 mm) and D-mode (FOV: 51 mm, voxel size: 0.1 mm). The artifacts were more common in I-mode, which had a larger voxel size and FOV. Therefore, it was shown that a smaller voxel size and FOV could decrease artifacts in CBCT images. However, the present study used a fixed FOV and voxel size while it investigated three types of sealers. Obviously, lower FOV and voxel size increase the image resolution by decreasing the radiation scattering (4).

However, smaller size voxels can increase background noises, reducing the quality of CBCT images (20). Also, root canal filling removal before imaging can increase the diagnostic accuracy of CBCT (30).

According to Celikten et al. (3), the CBCT device and associated software play an important role in streak artifact reduction. They evaluated the artifacts resulted from the three different sealers using different brands of CBCT devices and found that the NewTom VGi EVO and Accuitomo 170 devices seemed to perform equally and significantly better than the other machines tested. However, the present study used the same CBCT device to evaluate the artifacts from three sealer types. Also, Rabelo et al. (31) investigated different parameters related to exposure and reported that different exposure conditions did not affect the frequency of artifacts.

Neves et al. (6) investigated the effects of four different modes in the Accuitomo 170 CBCT device on the artifacts and the accuracy of VRF detection in unfilled teeth and teeth root-filled with gutta-percha, metal posts, and fiber posts. They reported that CBCT modes had no effects on the VRF diagnosis, while gutta-percha and metal posts had adversely affected the VRF diagnosis. Our study used a fixed, high-resolution mode; however, our findings on the ability of gutta-percha in causing artifacts were compatible with those of Neves et al. because we found artifacts even in the control group, which contained gutta-percha without sealer.

Despite all these studies, little information is available on detecting the streak artifacts resulted from sealers. Such information can be helpful in decreasing the potential risk of false-positive detection of VRF. Therefore, it is recommended to conduct further studies with larger sample sizes and different voxel sizes.

Conclusions

In the present study, we found no significant difference between the Sealapex, MTA Fillapex, AH26, and control groups in the frequency of streak artifacts in CBCT images.

Clinical Relevance

The result of this study showed that endodontic sealers do not influence the detection of VRFs.

Conflict of Interest

The authors deny any conflict of interest related to this study.

Acknowledgements

This study was supported and funded by Zahedan University of Medical Sciences.

References

1 *Siqueira J, Rôças I, Ricucci D, Hülsmann M. Causes and management of post-treatment apical periodontitis. British dental journal. 2014;216(6):305-12.*

2 *Lim M, Jung C, Shin D-H, Cho Y-b, Song M. Calcium silicate-based root canal sealers: a literature review. Restorative Dentistry & Endodontics. 2020;45(3).*

3 *Celikten B, Jacobs R, de Faria Vasconcelos K, Huang Y, Shaheen E, Nicolielo LFP, et al. Comparative evaluation of cone beam CT and micro-CT on blooming artifacts in human teeth filled with bioceramic sealers. Clinical oral investigations. 2019;23(8):3267-73.*

4 *Durack C, Patel S. Cone beam computed tomography in endodontics. Brazilian dental journal. 2012;23(3):179-91.*

5 *Abdinian M, Moshkforoush S, Hemati H, Soltani P,*

Moshkforoushan M, Spagnuolo G. Comparison of cone beam computed tomography and digital radiography in detecting separated endodontic files and strip perforation. Applied Sciences. 2020;10(23):8726.
6 Neves FS, Freitas DQ, Campos PSF, 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. Journal of Endodontics. 2014;40(10):1530-6.
7 Tamse A, Kaffe I, Lustig J, Ganor Y, Fuss Z. Radiographic features of vertically fractured endodontically treated mesial roots of mandibular molars. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology. 2006;101(6):797-802.
8 Mohammadpour M, Bakhshalian N, Shahab S, Sadeghi S, Ataee M, Sarikhani S. Effect of titanium and stainless steel posts in detection of vertical root fractures using NewTom VG cone beam computed tomography system. Imaging Science in Dentistry. 2014;44(2):89-94.
9 Ardakani FE, Razavi SH, Tabrizizadeh M. Diagnostic value of cone-beam computed tomography and periapical radiography in detection of vertical root fracture. Iranian endodontic journal. 2015;10(2):122.
10 Helvacioglu-Yigit D, Kocasarac HD, Bechara B, Noujeim M. Evaluation and reduction of artifacts generated by 4 different root-end filling materials by using multiple cone-beam computed tomography imaging settings. Journal of endodontics. 2016;42(2):307-14.
11 Iikubo M, Osano T, Sano T, Katsumata A, Ariji E, Kobayashi K, et al. Root canal filling materials spread pattern mimicking root fractures in dental CBCT images. Oral surgery, oral medicine, oral pathology and oral radiology. 2015;120(4):521-7.
12 ØRstavik D. Materials used for root canal obturation: technical, biological and clinical testing. Endodontic topics. 2005;12(1):25-38.
13 Scarparo RK, Haddad D, Acasigua GAX, Fossati ACM, Fachin EVF, Grecca FS. Mineral trioxide aggregate–based sealer: analysis of tissue reactions to a new endodontic material. Journal of Endodontics. 2010;36(7):1174-8.
14 Assmann E, Scarparo RK, Böttcher DE, Grecca FS. Dentin bond strength of two mineral trioxide aggregate–based and one epoxy resin–based sealers. Journal of endodontics. 2012;38(2):219-21.
15 Brito-Júnior M, Santos L, Faria-e-Silva A, Pereira R, Sousa-Neto M. Ex vivo evaluation of artifacts mimicking fracture lines on cone-beam computed tomography produced by different root canal sealers. International endodontic journal. 2014;47(1):26-31.
16 Decurcio DA, Bueno MR, Alencar AHGd, Porto OCL, Azevedo BC, Estrela C. Effect of root canal filling materials on dimensions of cone-beam computed tomography images. Journal of Applied Oral Science. 2012;20(2):260-7.
17 Salineiro FCS, Talamoni IP, Velasco SK, Barros FM, Cavalcanti MdGP. Artifact induction by endodontic materials: a CBCT analysis. Clinical and Laboratorial Research in Dentistry. 2019.
18 del Carpio-Perochena A, Kishen A, Felitti R, Bhagirath AY, Medapati MR, Lai C, et al. Antibacterial properties of chitosan nanoparticles and propolis associated with calcium hydroxide against single-and multispecies biofilms: an in vitro and in situ study. Journal of endodontics. 2017;43(8):1332-6.
19 Hassan B, Metska ME, Ozok AR, van der Stelt P, Wesselink PR. Detection of vertical root fractures in endodontically treated teeth by a cone beam computed tomography scan. Journal of endodontics. 2009;35(5):719-22.
20 Hassan B, Metska ME, Ozok AR, van der Stelt P, Wesselink PR. Comparison of five cone beam computed tomography systems for the detection of vertical root fractures. Journal of endodontics. 2010;36(1):126-9.
21 Melo SLS, Bortoluzzi EA, Abreu Jr M, Corrêa LR, Corrêa M. Diagnostic ability of a cone-beam computed tomography scan to assess longitudinal root fractures in prosthetically treated teeth. Journal of endodontics. 2010;36(11):1879-82.
22 Costa FF, Gaia BF, Umetsubo OS, Cavalcanti MGP. Detection of horizontal root fracture with small-volume cone-beam computed tomography in the presence and absence of intracanal metallic post. Journal of endodontics. 2011;37(10):1456-9.
23 Costa FF, Gaia BF, Umetsubo OS, Pinheiro LR, Tortamano IP, Cavalcanti MGP. 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. Journal of endodontics. 2012;38(6):856-9.
24 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. International endodontic journal. 2012;45(11):1004-9.
25 Gholampour A, Soleymani A, Bijani A, Haghanifar S. A comparison of image artifacts with gutta-percha and different sealers on root filled teeth using cone beam computed tomography: An in vitro study. Caspian Journal of Dental Research. 2020;9(2):42-9.
26 Freitas-e-Silva A, Mármora B, Barriviera M, Panzarella FK, Raitz R. CBCT Performance and Endodontic Sealer Influence in the Diagnosis of Vertical Root Fractures. The journal of contemporary dental practice. 2019;20(5):553.
27 Patel S, Wilson R, Dawood A, Foschi F, Mannocci F. The detection of periapical pathosis using digital periapical radiography and cone beam computed tomography–Part 2: a 1-year post-treatment follow-up. International endodontic journal. 2012;45(8):711-23.
28 Dutra KL, Pachêco-Pereira C, Bortoluzzi EA, Flores-Mir C, Lagravère MO, Corrêa M. Influence of intracanal materials in vertical root fracture pathway detection with cone-beam computed tomography. Journal of Endodontics. 2017;43(7):1170-5.
29 Vasconcelos KdF, Nicolielo L, Nascimento M, Haiter-Neto F, Bóscolo F, Van Dessel J, et al. Artefact expression associated with several cone-beam computed tomographic machines when imaging root filled teeth. International endodontic journal. 2015;48(10):994-1000.
30 Hekmatian E, Fathollahzade H, Sheikhi M. Detection of vertical root fractures using cone-beam computed tomography in the presence and absence of Gutta-Percha. The Scientific World Journal. 2018;2018.
31 Rabelo KA, Cavalcanti YW, de Oliveira Pinto MG, Sousa Melo SL, Campos PSF, de Andrade Freitas Oliveira LS, et al. Quantitative assessment of image artifacts from root filling materials on CBCT scans made using several exposure parameters. Imaging Science in Dentistry. 2017;47(3):189-97.