Influence of different root canal obturation materials in CBCT imaging: an in vitro evaluation

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ABSTRACT

Objective: This study evaluated the influence of canal obturation materials in the production of cone beam computed tomography (CBCT) images artifact, by means of image density analysis and comparison between four materials in central incisors and monoradicular premolar teeth. **Materials and Methods:** The teeth were submitted to endodontic instrumentation and divided into 5 groups: one control group (no endodontic filling) and four test groups each one filled by a different endodontic sealer (PulpCanal Sealer, AHPlus, Sealer26 and BCSealer). After CBCT scanning, the images were assessed to determine grayscale variations in three root thirds (objective analysis). The second (subjective) analysis compared the control group with two of the test groups in a randomized process. **Results:** In the objective analysis, Sealer26 and BCSealer showed statistical difference for minimum values, in comparison with another sealers, for both anterior and posterior teeth. For maximum values, only control group differed statistically from test groups. When comparing premolars and central incisors grayscale values by ANOVA analysis, a statistically significant difference was found mainly for minimum values. At the subjective analysis, for both anterior and posterior teeth, PulpCanal Sealer was the filling most frequently appointed by the observers as the one that produced more artifact interference. **Conclusion:** Endodontic fillings at posterior teeth performed similar behavior. Only PulpCanal Sealer on apical third presented higher maximum values in relation to others groups, which could represent more white brands. For anterior teeth, BC Sealer performed higher minimum values in relation to other endodontic fillings, which could represent more dark bands.

Keywords: Tomography, X-Ray Computed. Endodontics. Root Canal Obturation. Diagnosis, Oral.

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Introduction

Cone beam computed tomography (CBCT) imaging is influenced by several factors such as different detector components, reconstruction algorithms provided by the software, focal point size at the X-ray tube, factors inherent to the CBCT machine (work regimens and wear of the X-ray generator) and its behaviour, number of X-ray projections (frames) and voxel size at the 3D image.[1,2] Each one of these aspects may interfere at the final quality and resolution of images generated by CBCT machines. CBCT machines and software improvements resulted in devices that provide better quality reconstruction and effortless manipulation of images.[1,2] Structures with higher density (e.g. teeth, cortical bone and restorative materials) may influence negatively at the quality of image obtained in CBCT, because these structures develop the "beam-hardening" effect.[3,4] This imaging interference is denominated artifact. Different CBCT software providers developed tools to minimize the artifact interference on CBCT images. However, artifacts are still a main influencing factor that negatively impacts the diagnosis accuracy of root fractures.[3,5]

Teeth that are submitted to endodontic treatment frequently require intracanal post and crown restoration. Intracanal materials hinder the x-ray beam to go through them, thus resulting in artifact production. In those cases, artifacts may appear in the form of streaks and bands that overlap the root, and could simulate root fracture images,[6] hence negatively influencing diagnostic tasks especially in cases of dental fractures or tooth perforations.

Based on these assertions, the objective of this study was to evaluate the influence of different endodontic filling materials in the production of CBCT images artifact, by means of image density analysis in central incisor and monoradicular premolar teeth, in their apical, medium and cervical root thirds independently.

Methodology

Preparation of Samples

After Ethics Committee approval (protocol 1.121.863), extracted single-rooted human premolar teeth (n = 100) and human central incisors (n=100) were selected for the study. In order to avoid sample problems, all teeth were pre-scanned by CBCT to exclude previous root cracks, fracture or dilacerations.

The anatomic crowns of all the selected teeth were sectioned on the cementoenamel junction by using a carborundum disc propelled by an air turbine (KaVo Dental, Biberach, Baden-Württemberg, Germany).

An endodontics specialist prepared all teeth for the study. A #10 K- file (Dentsply Maillefer, Ballaigues, Jura-Nord Vaudois, Switzerland) was placed inside the canal until its tip was visible at the apical foramen, in order to determine the working length. Endodontic instrumentation was performed by using Easy ProDesign rotary instruments (Easy equipment, Belo Horizonte, MG, Brazil) up to size #.25/06 and #.25/08. During preparation, each canal was irrigated with 5.25% NaOCl in between each successive instrument. The teeth were kept immersed in water during the entire process.

The premolars were divided into five groups of 20 teeth each, as follows:

» Control group: Instrumented root without endodontic filling;

» Pulp Canal Sealer (Kerr, Orange, CA, USA) Group: Instrumented root obturated with conventional gutta-percha points and Pulp Canal Sealer filling;

» AH Plus (Dentsply, York, PA, USA) Group: Instrumented root obturated with conventional gutta-percha points and AH Plus filling;

» Sealer 26 (Dentsply, York, Pennsylvania, USA) Group: Instrumented root obturated with conventional gutta-percha points and Sealer 26 filling;

» BC Sealer (Brasseler, Savvannah, GA, USA) Group: Instrumented root obturated with bioceramic gutta-percha points and BC Sealer filling;

» A similar division was performed to the central incisors teeth.

All sealers were manipulated according to manufacturers's instructions.

Image Acquisition

In order to standardize the teeth position during the imaging acquisition, a mandible model fabricated with dental stone (Durone, Dentsply, York, Pennsylvania, EUA) was made. Four cavities were manufactured, two in the anterior and two in the posterior region (one at the left side of the mandible, and the second one on the right side) to insert each tooth for the CBCT scan, 7 simulating the alveolar socket.

CBCT (3DMax, Soredex, Helsinki, Uusimaa, Finland) scans were performed for each tooth individually placed in the mandible stone model. The field of view (FOV) consisted of a 10 x 5 cm (height x diameter) cylinder with 0.15 mm voxel, 80 kVp and 8 mA - HD (high definition) protocol.

Image Assessment

All CBCT images were exported as Digital Imaging and Communications in Medicine (DICOM) files and imported into a workstation (iMac 27", Apple, Cupertino, CA, USA.). A DICOM viewer software (OsiriX MD 1.2 64-bit, Pixmeo, Geneva, Switzerland) was employed to assess the images. All observers were previously calibrated by analyzing similar images obtained at the pilot study and had not previous had contact with sample images.

Grayscale variables

Two examiners, who had experience in analyzing CBCT images, performed the first analysis by using the ROI (Region of Interest) tool provided by OsiriX MD. This tool allowed them to obtain grayscale values through measuring pixel density at each tooth segment area, which were categorized as:

» Cervical Third (CT): 2 mm from the cementoenamel junction;

» Middle Third (MT): median point from the root length, and Apical Third (AT): 2 mm up to the apical foramen.

» Following the determination of the segment area, the examiner selected the ROI area by inserting points around the root perimeter and manually drawing a line to form a closed polygon. This technique was repeated at the axial view of each root third. The inner region of this perimetrical line determined the area in which the grayscale values were obtained using the ROI tool.

The ROI tool provided minimum, maximum, mean and standard deviation of the pixel values, and area and perimeter from the selected area. The minimum and maximum pixel values were used to evaluate the grayscale in each third of the root.

Image Evaluation

Two professionals (one maxillofacial radiologist and one endodontist with 5 years of experience in analyzing CBCT images) performed a subjective analysis. For this purpose, an image of the same area in which the measurements were performed was exported in TIFF format to create the material for these comparisons. The images did not contain numeric data provided by the ROI tool. Images depicting each root third with the different endodontic filling materials as well as the control group, for both premolars and central incisors, are represented in Figures 1 and 2.

The randomization procedures were performed by an operator that was not involved in the images analyses. This process comprised two steps: in order to determine the teeth random sequence, www.random.org (Randomness and Integrity Services Ltd., Dublin, Ireland) was used. After that, the software "Randomness 1.5.2" (Andrew Merembach, Los Angeles, CA, USA) randomized the material groups (Pulp Canal Sealer Group, AH Plus Group, Sealer 26 Group or BC Sealer Group image) within each one of the pre-randomized teeth sequences assembled in a PowerPoint (Microsoft Corporation, Redmond, WA, USA) presentation slide format. The observers got access to the presentation and had to select which test image (A or B, corresponding to the position taken by the test group at each slide) represented a higher level of interference caused by artifact (presence of artifact interference, dark bands and white streaks), when compared to the control group image. When the observer concluded that the two images had produced similar levels of artifact in both test groups, the answer was "zero". The same images were analyzed again after a 2-week interval.

Statistical analysis

Objective and subjective analyses were performed. Objective analyses were conducted based on grayscale values, while subjective analyses were based on images evaluation at PowerPoint presentation. The reliability of this study was assessed based on the interexaminer measurements by using the interclass correlation coefficient (ICC), with a 95% confidence interval. Kappa coefficients were calculated to determine inter - and intraobserver agreements for the subjective analysis.[5,8]

The values obtained at each ROI, for control group and each one of the test groups measurements were submitted to descriptive statistics. Normalization linear function of data was conducted to analyze the groups. Then, ANOVA analysis was conducted to compare the groups. The minimum values were associated with darker images, while maximum values were associated with brighter images.

Reliability statistics, Kappa tests and descriptive statistics were performed at BioEstat software (Instituto Mamiraua, Belém, PA, Brazil).

Individual observer responses for test groups were collated, submitted to the frequency distribution analysis by the three outcomes in our sample (image A or image B represented a higher presence of artifact, or the images A and B represented equal presence of artifact) and data were presented in percentage for each outcome, independently for each root third. Numerical data were calculated using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). The percentages obtained by each group were compiled. Descriptive statistics and comparisons among each group were performed.

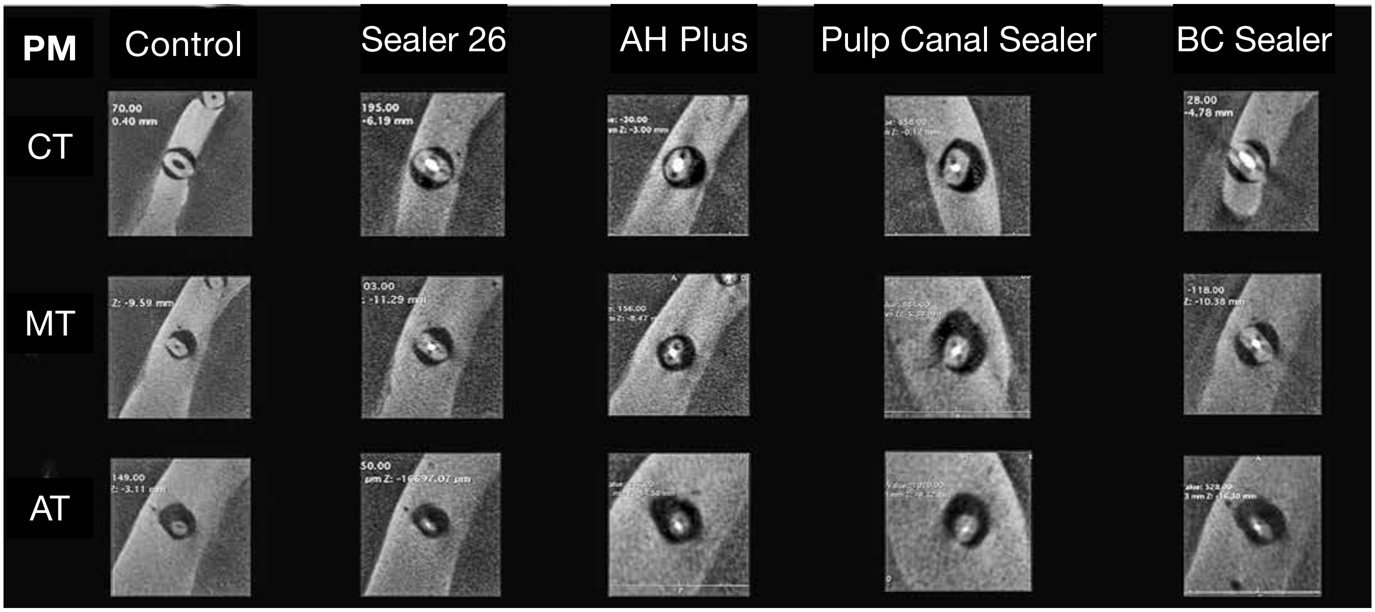

Figure 1. Premolars (PM) CBCT images. Axial images of cervical third (CT), middle third (MT) and apical third (AT) for control group and each test groups.

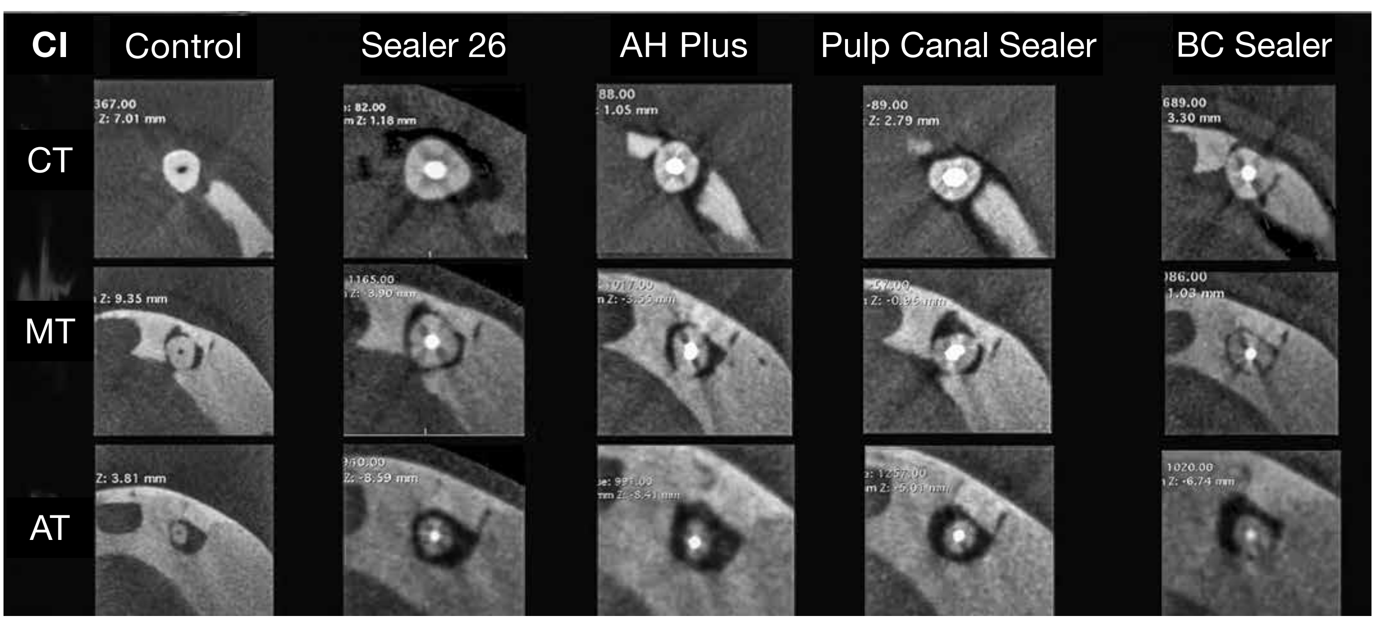

Figure 2. Central incisor (CI) CBCT images. Axial images of cervical third (CT), middle third (MT) and apical third (AT) for control group and each test groups.

Results

In Tables 1 and 2, minimum and maximum values were compared, respectively in each teeth group. Regarding minimum values, Pulp Canal Sealer showed significant statistical difference in the apical third of anterior teeth when compared with BC Sealer and AH Plus.

Table 2 compares the values for central incisors (anterior teeth). For middle and apical thirds, BC Sealer minimum values were statistically different from both AH Plus and Sealer 26. For maximum values, only control group statistically differed from test groups.

Premolars (PM) and Central Incisors (CI) test and control groups minimum and maximum means were compared by ANOVA analysis, to assess artifact interference between anterior and posterior teeth in table 3.

Table 4 depicts the subjective analysis by comparing all the endodontic sealers for anterior and posterior teeth, and for each observer independently. Overall, the observers detected different artifact interference between the test groups, for both anterior and posterior teeth. In a lower frequency the observers detected similar artifact interference between the test groups.

ICC values were used for agreement analysis for interobservers. Premolars values ranged from 0.8627 to 0.9326, and Central Incisors values ranged from 0.8579 to 0.9665. Kappa coefficient for interobserver agreement was fair (ranged from 29% to 33%) and for intraobserver agreement was substantial to almost perfect (ranged from 70% to 87%). These concordance values illustrated the difficult of our analysis and the high experience of the observers.

Table 1. Medium of minimum and maximum values (posterior teeth).

Third Radicular	PulpCanal Sealer	AHPlus	Sealer 26	BC Sealer	Control	Value
Cervical	3027.5	3095	3095	3095	1168.1⌘	maximum
	-424.2	-453.6	306.2	138	-606	minimum
Medium	3090.5	3095	3094.9	3095	1091.8⌘	maximum
	-99.7	-293.5	18.3	-228.7	-119.1⌘	minimum
Apical	2290.8	2872.7§	2493.8	2748.6∞	913.6⌘	maximum
	41.8	-11.1	88.2	25.8	-187.6	minimum

⌘ - Control group statistically different of the other groups.
§ - AHPlus group statistically different of the PulpCanal Sealer group.
∞ - BC Sealer group statistically different of the PulpCanal Sealer group.

Table 2. Medium of minimum and maximum values (anterior teeth).

Third Radicular	PulpCanal Sealer	AHPlus	Sealer 26	BC Sealer	Control	Value
Cervical	3095	3095	3095	3095	1670.4⌘	maximum
	-80.125	-114.575	-102.575	16.2	-496.9Φ	minimum
Medium	3095	3095	3095	3095	1312.3⌘	maximum
	1.7	-78.8	-38.5	65.2β	-188.7Φ	minimum
Apical	3050.7	3048.4	2992.5	2836.2	1174.2⌘	maximum
	53.7	-23.1	26.9	158.5β	-248.9Φ	minimum

⌘- Control group statistically different of the other groups.
Φ – Control group statistically different of the BC Sealer group.
β – BC Sealer group statistically different of the AHPlus e Sealer 26 groups.

Table 3. Kruskal-Wallis p values for comparison of minimum e maximum medium between central incisives (CI) e pre-molares (PM)

		PM					Value
		PulpCanal Sealer	AHPlus	Sealer 26	BC Sealer	Control	
IC	PulpCanal Sealer	NS	NS	NS	NS	< 0.05	**maximum**
		NS	< 0.05	< 0.05	NS	NS	**minimum**
	AHPlus	NS	NS	NS	NS	< 0.05	**maximum**
		NS	< 0.05	< 0.05	NS	NS	**minimum**
	Sealer 26	NS	NS	NS	NS	< 0.05	**maximum**
		NS	NS	< 0.05	NS	NS	**minimum**
	BC Sealer	NS	NS	NS	NS	<0.05	**maximum**
		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	**minimum**
	Control	< 0.05	< 0.05	< 0.05	< 0.05	NS	**maximum**
		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	**minimum**

Table 4. Subjetive analyses. Distribution of frequency to both observers (Obs. 1 - Radiologist e Obs. 2 - Endodontist), in pre-molares (PM) and central incisives (CI), for each radicular third (C=cervical, M=médium, and A=apical) independently.

		Diference of interference of artifact betwwen the test groups	Similarity of interference of artifact betwwen the test groups	
C	Obs. 1	80%	20%	PM
	Obs. 2	75%	25%	
	Obs. 1	83%	17%	CI
	Obs. 2	79%	21%	
M	Obs. 1	78%	22%	PM
	Obs. 2	70%	30%	
	Obs. 1	80%	20%	CI
	Obs. 2	86%	14%	
A	Obs. 1	74%	26%	PM
	Obs. 2	69%	31%	
	Obs. 1	75%	25%	CI
	Obs. 2	89%	11%	

Discussion

The root shape of anterior and posterior teeth is very different in axial view. These differences may be responsible for inherent difficulties in diagnostic tasks based on tomographic images. Dilacerations, curvature and use of endodontic materials turn radiographic diagnosis a challenge to overcome. In this context, several studies have been conducted to analyze the influence of artifacts generated by metallic objects.[3,5,6,9,10] Recent studies[11,12] performed with endodontically treated teeth demonstrated the presence of artifacts represented by streaks and dark bands. According to Salineiro et al.,[11] these images could simulate root fractures, thus reducing the accuracy for dental fracture diagnosis. In the current study, monoradicular teeth of similar length and diameter were selected in order to simulate the clinical enviroment and to allow the insertion of similar amounts of endodontic filling in each root. However, since premolar roots (Fig 1) have a flatter aspect in the mesiodistal direction[13] when compared with central incisors roots (Fig 2), the artifact distribution and appearance may vary in these two groups of teeth. This fact might lead the clinician to have more difficulty while intrepreting the CBCT images.

Benic et al.[14] evaluated artifact formation in dental implants at different positions of the mandibular arch and no numerical differences between the positions were observed, only a visual difference in the artifact shape. In opposition to these authors, we found a values with statistically significant difference in the numerical analysis between the anterior and posterior region, mainly between Sealer 26 cement and control groups. Sealer 26 was also tested by Brito-Junior et al.,[12] and was one of the endodontic fillings that produced more artifact images. The pattern of artifact distribution in tomographic images is multifactorial. The observer should take into account that the interaction between different effects (such as beam hardening and scatter) could lead to different aspects of displaying artifacts in CBCT acquisitions. Thus, besides the position of the tooth in the mandibular arch, the root shape may have also influenced our results.

Comparing the performance of the endodontic sealers between the central incisors and the premolars for ROI analysis, AH Plus, Sealer 26 and BC Sealer cements presented statistical difference in relation to the other test groups (Table 3). This difference was observed at the minimum values obtained (Table 1 and 2). Sealer 26 followed a pattern similar to the other cements for maximum values; however, minimum values were positive for the premolars and negative for the incisors, that is, this cement does not present bands and streaks as dark as the other cements when used on posterior teeth. AH Plus also followed the other cements pattern for maximum values. For minimum values, though, this cements had high negative numbers for all thirds in all regions, id est, this is a cement that generates darker bands and streaks than the other cements tested in this research. When comparing the performance of the endodontic sealers between the central incisors and the premolars for ROI analysis, minimum values for Sealer 26 in premolar group was statistically different from all four endodontic fillings for the incisor group, including Sealer 26 itself. BC Sealer and AH Plus were statistically different between themselves when comparing incisor and premolar groups. AH Plus in premolar group was statistically different from BC Sealer and Pulp Canal Sealer incisor groups.

Brito-Junior et al.,[12] analyzed the formation of artifact in CBCT images in different types of endodontic cements. The authors did not analyze the artifact spreading in the images; they aligned the teeth sealed with the 5 cements, and counted the bands and streaks that were generated by each tooth in the axial images. However, we believe that the manner in which the teeth were positioned makes it hard to differentiate the origin of the streaks or bands, since contigous structures may be influenced by its surrounding materials. Another study has noticed that artifact in CBCT spreads by acquisition, mainly being observed in axial images,[2] thus becoming even more difficult to count these streaks and bands. We considered the importance of the artifact spreading in the nearby areas and proposed a methodology in which each tooth was placed distant from each other, in a way that one tooth did not influence the other. For the quantitative analysis of artifacts, we decided to use the ROI tool to evaluate each root and material individually by determining the variations in grayscale generated by each used endodontic sealer . This method is used in the literature for analysis of CBCT protocols, with and without artifact reduction tools and for artifact formation in implants.[14]

The protocol used in each CBCT device is determinant for image quality. According to Oliveira et al.,[15] acquisitions with high kVp generate a smaller amount of artifact in the images, while the changes in mA values do not alter the quantity of artifacts. The protocol used in this study was High Resolution, which is the protocol with the highest kVp produced by the CBCT device, precisely with the intention of minimizing the formation of artifacts. The selection of this protocol resulted in more energy applied to the flat panel, producing better image quality despite the exposure of the patient to a higher radiation dose. Our data established that all cements had similar performances; BC Sealer cement, however, showed statistically significant differences in apical third for both incisor and premolar groups, and in middle third for incisor group only.

Salineiro et al.[11] concluded that CBCT protocols with proportional FOV and voxel generated images with higher quality and less noise. Since dental arches are not uniform, a single FOV size was selected for the current methodology based on this study, in order to provide a FOV that included the anterior and posterior regions and had the same voxel size, as one can find in clinical situation, bearing in mind issues like radiation dose and single acquisition purposes.

For objective and clinical purposes, the root portion that presents the highest fracture rate and worse prognosis is the middle third.[16] Our objective analysis demonstrated that the root middle third had the highest discrepancies in the maximum and minimum values for both premolars (Table 1) and incisors (Table 2), resulting in a difficult and important diagnostic challenge. Benic et al.[14] also observed a different behavior of the metallic artifact throughout the implant, corroborating our results. These researchers observed that the middle third was the region with the highest minimum values, consequently, the region with more bands and dark streaks than the other root thirds of the tooth. For image quality purposes, the decision of employing a plaster mandible was made based on two main reasons: to standardize the positioning of the teeth in all the acquisitions, and also because plaster has properties fairly similar to the mandibular bone in terms of density and x-ray beams absorption properties (calcium is the main composition of both plaster and bone).[14,17] Another concern with the plaster mandible were the teeth alveoli. We tried to mimick the human sockets by providing a similar thickness of plaster around the teeth, so that the x-ray beam would cross the same distance of plaster that it would pass through the alveolar bone, avoiding in this way any bias of structure thickness.

The high ICC concordance levels obtained for objective analysis support the reproducibility of the methodology and the importance of the ROI tool for this type of analysis. Intraobserver values of Kappa coefficient confirmed the reliability of the observers, while interobserver levels demonstrated the difficulty that the observers faced during observations, which simulated the difficult of diagnostic tasks encountered in a clinical enviroment.

The different formulations of each endodontic sealer are based on specific employments and charachteristics. For this study, we selected these materials with the purpose to cover different compositions and characteristics, such as biocompatibility, better adhesion to dentin or resistance to fracture. Our results demonstrated that all sealers had similar performances when tomographic images is evaluated, what theoretically could lead to similar diagnostic challenges.

The effective dose of CBCT scans is an critical issue to be considered. Low-dose radiation protocols may generate images with more noise, thus interfering with reaching an appropriate diagnosis.[18] If a protocol with a higher kVp (consequently, a higher effective dose) will result in less noise and hence will reduce the difficulty of the diagnosis of root fractures, this protocol might be taken into consideration. CBCT imaging may be an excellent aid in the diagnosis of root fractures as long as the choice of a suitable protocol for each clinical situation is respected. Indiscriminate use of CBCT should not occur. Each case should be individually analyzed and the clinician has to adhere to the ALADA principle ("as low as diagnostically acceptable" - the lowest radiation possible for an acceptable diagnosis).[19]

Conclusions

The endodontic fillings at posterior teeth performed similar behavior. Only Pulp Canal Sealer on apical third presented higher maximum values in relation to others groups, which could represent more white brands. For anterior teeth, BC Sealer performed higher minimum values in relation to other endodontic fillings, which could represent more dark bands.

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