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Abstract

Aim: To classify ten CBCT devices, by using a ranking model, according to the detection of fine endodontic structures. **Methods:** A dedicated dentate anthropomorphic phantom was scanned two times using ten CBCT devices: without any metal (metal-free condition) and with an endodontically treated tooth containing a metallic post (metal condition). A reference image acquired on an industrial micro-CT scanner was used to register all CBCT images, yielding corresponding anatomic slices. Afterwards, three experienced observers assessed all acquired CBCT images for their ability to assess narrow canal, isthmus and apical delta ramification following a categorical rank from 1 (best) to 10 (worst). Fleiss Kappa statistics were used to calculate intra- and interobserver agreements for each CBCT device separately. Based on the observers' scores, general linear mixed models were applied to compare image quality among different CBCTs for performing endodontic diagnostic tasks ($\alpha = .05$). **Results:** The ten CBCT devices performed differently for the evaluated endodontic tasks ($P < .05$), with three devices performing better for endodontic feature detection. Yet, in the presence of metal, only two devices were able to keep a high level of endodontic feature detection. **Conclusions:** The evaluated endodontic tasks were CBCT device-dependent, and its detection was influenced by the presence of metal.

Keywords: Anatomy, artifacts, cone-beam computed tomography, endodontics.

1 Introduction

2 The assessment of fine structures, such as narrow canal, isthmus and
3 ramifications may directly impact endodontic treatment planning and outcomes (1-3).
4 Cone-beam computed tomography (CBCT) may be an auxiliary tool for detecting and
5 locating such structures (1, 2, 4, 5). However, CBCT-based diagnosis is hampered by
6 artifacts arising from high-density materials such as gutta percha, sealers, and metallic
7 posts (6-9). Therefore, an accurate CBCT performance remains challenging.

8 Another challenge is the difficulty of comparing performances from different
9 devices, as results found for one CBCT cannot simply be applied to another (10, 11).
10 Thus, caution is needed when interpreting CBCT-based reports on endodontic purposes
11 (2,12-18). Although previous studies have shown high sensitivity and specificity for
12 CBCT images (2, 13), other studies showed no significant difference between this
13 image modality and 2D images for performing different tasks (15, 17, 18). This
14 variability may be explained due to the wide diversity of CBCT devices available on the
15 market, with distinct technical characteristics and consequently different clinical
16 performance (19, 20). Additionally, the diagnostic tasks must also be taken into
17 account, since the size of the structures may directly affect their visualization (14).

18 In clinical scenarios, image quality provided by several CBCT devices may
19 differ significantly, especially in the presence of artifacts generated by high-density
20 objects (21). Therefore, our study aimed to classify ten CBCT devices, by using a
21 ranking model, according to the detection of fine endodontic structures in the presence
22 and absence of a metallic post. For such purpose, CBCT images of narrow canals,
23 isthmus, and apical delta were evaluated. The null hypothesis was that all CBCTs
24 performed similarly for all tasks.

Material and Methods

This experimental study was designed according to the local institutional research ethics committee (protocol number S55619/ML9535). An anthropomorphic phantom composed of a dry human skull and a mandible with all teeth was covered with Mix-D. A mixture of paraffin wax and other chemicals prepared according to Oenning et al 2019 to simulate soft tissue attenuation (22). A mix-D tongue model was positioned in the corresponding space of the phantom (Figure 1A). Two set-ups were created: 1) Metal-free condition: without any metal (Figure 1B); 2) Metal condition: the same model with the right second lower premolar endodontically treated and containing a gold alloy metallic post made in-house (Figure 1C). The root canals were prepared with Reciproc R25 file (VDW, Munich, Germany) and filled by lateral compaction using AH Plus sealer (Dentsply DeTrey GmbH, Konstanz, Germany). Additionally, silicone guides made with Zetaplus silicone (Zhermack SpA, Badia Polesine, Italy) were used to reproduce the positioning of the teeth for image acquisition.

Reference image acquisition

In order to acquire a reference image, the mandible was scanned in an industrial micro-CT scanner Nikon XT H 225 (Nikon Metrology Inc, Brighton, MI, USA) using 200 kVp, 350 μ A, 2.5 mm Cu filtration, and 40 μ m voxel size. This industrial micro-CT reference image was used by one independent examiner to initially evaluate the presence of the fine anatomical structures and mainly to register all CBCT images. Accordingly, this ensured CBCT evaluation of each endodontic task at the same anatomical level by other three experienced observers (Figure 2).

CBCT imaging acquisitions

The two aforementioned set-ups were scanned using ten each CBCT devices. Clinical high-resolution exposure parameters were selected in each CBCT device and coded using letters (A to J). Table 1 shows all CBCT devices, manufacturers, codes, and exposure parameters.

Image registration

Subsequently, mutual information-based registration was performed using Amira 2019 software (Thermo Fisher Scientific, Waltham, USA / Zuse Institute Berlin, Germany) considering the industrial micro-CT scan as reference image. Mutual information-based image registration has been proved to be very effective in multimodal medical image applications. For computing the mutual information between two images, this method measures the statistical dependence or information redundancy between image intensities of corresponding voxels in both images, which is assumed to be maximal if images are geometrically aligned (23). Therefore, reference image (micro-CT) was used to initially detect the presence of the fine anatomical structures and mainly to register CBCT images, ensuring CBCT evaluation of each endodontic structure at the same anatomical level by the three observers.

Subjective image quality assessment

After image registration a set of CBCT images containing each anatomical structure separately was shown to three experienced observers (Figure 2). Images were randomly displayed on the same screen without showing the reference image and the observers were blinded to the CBCT device. Brightness, contrast, and magnification of the image could not be modified and adjusted by the observers. All images were ranked from 1 (best) to 10 (worst) for their ability to detect the fine anatomical structures. Calibration and evaluation sessions were performed in a low-light environment using a 24.1-inch flat-screen monitor (Barco, Kortrijk, Belgium). After 30 days, 25% of the images were re-evaluated to assess intra-observer reproducibility.

Statistical analysis

Statistical modeling and analysis were performed using S-Plus for Linux 8.0 (Tibco Software, Palo Alto, CA, USA). Fleiss Kappa statistics were used to calculate intra- and interobserver agreements for each CBCT device separately. This analysis was based on the observers' scores transformed into a binary variable. The cumulative percentage that each device was ranked among the best five devices were compared between the first and second observations (for intra-observer agreement) and between observers (for inter-observer agreement). Cases in which a specific device was always classified among the best five were considered as perfect agreement.

General linear mixed (GLM) models were applied to compare different CBCT devices in the accomplishment of diagnostic tasks. The models were fit with observers and questions related to the tasks as the random variables and CBCT devices as fixed variables to perform the ranking. This analysis intended to choose the best devices. In the evaluation of challenging endodontic structures using two different clinical conditions (metal-free and with metal). Differences between CBCT images for each purpose were calculated using the fixed effects from the GLM models and their variance-covariance matrix. A correction for simultaneous hypothesis testing according to Tukey was applied. Differences among devices were assessed by first considering the empirical cumulative function of the scores by dividing each score rank by (1+number of scores). These empirical cumulative function values were then subject to probit transformation, in which the corresponding quantiles of a standard normal distribution were taken. Subsequently, a multiple comparison with the hypothetical best and worst device for each task and condition (higher and lower score) was performed at 95% confidence interval. Residual analysis of the GLM models via a normal quantile plot showed that the assumptions of normality of residuals was achieved when using the probit transformed values.

Results

A perfect intra-observer agreement was found in four CBCT devices (A to D). For CBCT devices E to J, kappa values ranged between 0.33 and 0.99. Regarding inter-observer agreement, a perfect agreement was found only for device A.

Table 2 shows the mean ranks and range of scores achieved by each CBCT device for evaluating delta, narrow canal apical, narrow canal middle, and isthmus, respectively, in two different conditions (metal-free and with metal). The table also indicates the multiple comparison of each CBCT position with the best and worst ranked device for each diagnostic task and condition. For such purpose, a three-grade level classification was created by using shades of greys. Lighter shades of grey were used to display the best ranked CBCT devices. Conversely, darker grey represents devices with similar worst ranking.

In metal-free condition, device B scored best for all diagnostic tasks. Devices F and J had a similar worst compared to the others. In the presence of metal, a higher

score was achieved by device A, but the difference was not statistically significant with device D. Contrarily, the ranking of device J was significantly worse than the others, as also shown in Table 2.

Figure 3 illustrates the result of the multiple comparisons of all CBCT images highlighting the best and worst devices.

Discussion

In the present study, the null hypothesis was rejected since endodontic assessment of fine anatomical structures differed significantly among CBCT devices for different endodontic tasks in metal-free condition and in the presence of metal. When a CBCT examination is required, optimized exposure settings should be used to account for the diagnostic task (22). The differences found can be explained by the different technical characteristics of each CBCT device (19, 20). Although all CBCT protocols were selected in 'high resolution' mode, the actual spatial resolution is influenced by several device-specific factors such as focal spot size, detector pixel size, magnification factor, number of projections, and reconstruction filter (19). Nowadays, there is a wide variability concerning physical and technical features; therefore, different machines have varying performance for specific diagnostic tasks (19, 24-26). This variability may be even more evident when metallic materials are present in the scanned volume.

The endodontic tasks were CBCT device-dependent, with three devices allowing for better endodontic feature detection in absence of metal artifacts. In the presence of metal, two devices performed better than the others. Only one CBCT device (A) presented a consistently high rank for all tasks and set-ups. An opposite behavior was observed for another device (J). High-dense materials commonly used in endodontic treatments may cause device-specific artifacts, deteriorating image quality to different extents for each CBCT device (6-8, 27).

Regarding narrow canal, the presence of metallic post in the middle third might have influenced its detectability. In the apical third only gutta percha was present. Previous investigations found that artifacts from metallic objects have a higher impact on image quality, making diagnosis more difficult (28-30). On the other hand, the influence of artifacts from gutta-percha and sealer varies in the current literature (7, 27,

28). For isthmus evaluation, more CBCT devices obtained statistically similar scores compared to the best ranked, irrespective of the presence of metal. This result is in line with the high specificity and sensitivity for isthmus detection founded in the literature (13). On the other hand, for delta ramification, in the presence of metal, only three CBCT devices received the best scores, in agreement with a previous study that found low accuracy of CBCT for detecting ramifications (3, 5).

One of the main advantages of the present study was its reproducibility and clinically realistic comparative set-up. The use of an anthropomorphic phantom with modular teeth having specific endodontic challenges allowed to evaluate the same structure in ten different CBCT devices. Subsequently, image registration standardized the regions of interest (21, 23). Additionally, a dry human skull covered with mix-D material provided similar attenuation as clinical scans (22). Moreover, the present study did not work with simulated tasks. Therefore, all evaluated diagnostic tasks were naturally pre-existing. On the other hand, our study was not able to consider patient movement, which is a factor inherent to a clinical scan that influence image quality (31, 32).

It should be said that our study did not aim to compare diagnostic accuracy or efficacy of CBCT devices. Therefore, although significant variations could be noticed concerning image quality among different machines, further investigation is still necessary to analyze the impact of these dissimilarities for performing a challenging detection of fine endodontic structures. One must bear in mind that a CBCT device should provide an image of sufficient image quality for a specific diagnostic task. Following the ALADAIP (as low as diagnostically acceptable being indication-oriented and patient-specific) principle, the exposure parameters of a CBCT device should be adjusted for each patient and clinical situation in order to provide an image with enough quality for diagnosis with the lowest possible radiation dose (33).

Our results highlighted the diversity regarding the quality and ranking of several CBCT devices for the same endodontic diagnostic task. Thus, differences between CBCT devices should be considered when referring a patient for an endodontic evaluation, especially when the patient has prior metallic restorations or implants. One may opt to use specific devices when a proper detection of narrow canal, isthmus, and apical delta ramification are needed. In case the patient has high-dense materials present, referral to CBCT may be even more restrictive, as only few devices are

showing a good detection of these subtle anatomic structures when metallic objects are present. It is evident that even with the best possible selection of CBCT device and protocol, effective endodontic diagnosis can only be obtained when CBCT reading is combined with a comprehensive dental history and clinical findings (34, 35).

Conclusion

The evaluated endodontic tasks were CBCT device-dependent, and its detection was influenced by the presence of metal.

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Figure legends

Figure 1 - A) Phantom of a dry human skull with mandible covered in mix-D; B) set-up 1 - mandible without metal; C) set-up 2 - mandible with endodontic treated premolars with metallic post and amalgam restoration.

Figure 2 - Reference images (axial and sagittal views) from industrial micro-CT showing all evaluated endodontic diagnostic tasks. A – narrow canal, B – isthmus, C – delta.

Figure 3 - Comparison of CBCT images with the hypothetical best and worst device in two conditions (metal-free and with metal). The CBCT devices marked with + did not differ from the best (95% confidence interval) for all diagnostic tasks, the ones marked with - did not differ from the worst (lower score) and the ones marked with $\neq$ differed from the best and the worst.

Tables

Table 1 - CBCT devices, manufacturers, codes and comparable scanning parameters

CBCT devices	Manufacturer	Code	FOV (cm)	kV	mA	Voxel size (mm)
3D Accuitomo 170	J. Morita, Kyoto, Japan	A	4 X 4	90	5	0.08
Veraview X800	J. Morita, Tokyo, Japan	B	4 X 4	100	7.9	0.08
X1	3Shape, Copenhagen, Denmark	C	4 X 4	90	12	0.1
NewTom VGi evo	Cefla Dental Group, Imola, Italy	D	5 X 5	110	3	0.1
OP 3D Pro	Instrumentarium, Tuusula, Finland	E	5 X 5	90	8.6	0.085
OP 3D	Instrumentarium, Tuusula, Finland	F	5 X 5	95	4	0.08
CS 9300	Carestream, Rochester, NY, USA	G	5 X 5	90	4	0.09
ProMax 3D Max	Planmeca, Helsinki, Finland	H	6 X 6	96	12	0.075
Orthophos SL 3D	Dentsply Sirona, Charlotte, USA	I	5 X 5	85	6	0.079
Spectral Dental UEG	UEG Medical, Shanghai, China	J	6 X 6	110	8	0.075

Table 2 - Comparison of mean scores (range) among all CBCT devices for evaluating narrow canal, delta ramifications and isthmus in two different conditions (metal-free and with metal)

Narrow canal middle				Narrow canal apical				Delta				Isthmus			
Metal-free		With metal		Metal-free		With metal		Metal-free		With metal		Metal-free		With metal	
CBCT Device	Mean Score (Range)	CBCT Device	Mean Score (Range)	CBCT Device	Mean Score (Range)	CBCT Device	Mean Score (Range)	CBCT Device	Mean Score (Range)	CBCT Device	Mean Score (Range)	CBCT Device	Mean Score (Range)	CBCT Device	Mean Score (Range)
C	1.1 (1-1)	I	1.7 (1-2)	B	1.0 (1-1)	A	1.0 (1-1)	A	1.1 (1-1)	A	1.1 (1-1)	A	2.7 (1-6)	G	1.3 (1-2)
A	2.3 (2-3)	A	2.0 (1-4)	A	2.7 (2-4)	B	2.7 (2-4)	B	2.0 (2-2)	D	2.3 (2-3)	C	2.7 (1-5)	E	3.0 (1-5)
B	2.7 (3-7)	D	3.0 (2-4)	C	3.0 (2-4)	D	3.0 (3-3)	G	4.3 (3-6)	E	3.7 (3-4)	G	3.0 (2-4)	A	3.7 (2-6)
D	4.0 (4-4)	C	3.3 (3-4)	D	4.0 (3-5)	G	3.3 (2-4)	C	4.7 (4-5)	C	4.3 (3-5)	B	4.0 (2-6)	B	4.3 (2-7)
I	5.3 (6-6)	G	5.0 (5-5)	G	4.3 (3-5)	F	5.7 (5-7)	E	5.0 (3-6)	B	5.0 (2-8)	E	4.3 (3-7)	D	5.0 (3-6)
G	6.3 (6-7)	H	6.3 (6-7)	I	6.0 (6-6)	E	6.3 (5-8)	I	5.3 (4-7)	I	6.3 (6-7)	I	4.7 (4-5)	F	6.0 (4-7)
H	7.7 (5-10)	E	6.7 (6-7)	H	7.3 (7-8)	H	6.7 (6-7)	D	5.7 (3-7)	G	6.7 (6-7)	D	7.3 (6-9)	I	6.0 (5-8)
E	8.0 (7-9)	B	8.7 (8-9)	E	7.7 (7-8)	C	8.3 (6-10)	J	8.3 (8-9)	F	7.0 (4-9)	J	8.3 (7-10)	C	7.0 (4-9)
F	8.0 (7-9)	J	8.7 (8-10)	F	9.0 (9-9)	J	8.7 (8-9)	H	8.7 (8-9)	H	9.0 (8-10)	F	8.7 (8-10)	H	8.7 (8-9)
J	9.7 (9-10)	F	9.7 (9-10)	J	10.0 (10-10)	I	9.3 (9-10)	F	10.0 (10-10)	J	9.7 (9-10)	H	9.2 (9-10)	J	10.0 (10-10)

Shades of grey indicate statistical similarity among received scores (95% significance). Lighter grey highlights the best ranked and darker grey the worst ranked. The CBCT codes are defined in Table 1.

	Metal Free			With Metal		
A			+			+
B			+			≠
C			+			≠
D			≠			+
E			≠			≠
F			-			≠
G			≠			≠
H			-			-
I			≠			≠
J			-			-