RESEARCH

Influence of scan setting selections on root canal visibility with cone beam CT

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Objectives: The aim of this study was to assess the influence of scan setting selection, including field of view (FOV) ranging from small to large, number of projections and scan modes on the visibility of the root canal with cone beam CT (CBCT).

Methods: One human mandible cadaver was scanned with CBCT (Accuitomo 170; J Morita MPG Corp., Kyoto, Japan) using six different FOVs (4 × 4 cm, 6 × 6 cm, 8 × 8 cm, 10 × 10 cm, 14 × 10 cm and 17 × 12 cm) with either 360 or 180 projections in standard and high resolution. The right canine was selected for evaluation. Ten observers independently assessed the visibility of the canal space and overall image quality on a five-point scale.

Results: The results indicate that both selections of FOV and number of projections have significant influence on root canal visibility ($p = 0.0001$), whereas scan mode, whether standard or high resolution, was less relevant ($p = 0.34$).

Conclusions: The smallest FOV available should always be used for endodontic applications, and it is not recommended to reduce the number of projections to 180. Using the standard scan mode instead of high resolution does not negatively influence the visibility of the root canal space and is therefore recommended.

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Introduction

The management of endodontic problems is reliant on radiographs to assess the root canal and its surrounding structures. Teeth with unusual anatomy, including those with an unusual number of roots, dilacerations and dens in dente, complicate endodontic treatment.¹ Owing to the two-dimensional nature of conventional radiographs, they do not consistently reveal the actual number of canals present in teeth.² Cone beam CT (CBCT) has brought a new dimension to endodontic diagnosis because it provides three-dimensional information of the root canal at a reasonably accessible scan cost. CBCT technology overcomes several limitations of conventional radiography as thin, relatively high-resolution, high-contrast slices eliminate the artefacts resulting from superimposition of adjacent anatomical structures. This is especially

the case for the roots of maxillary (pre)molars, where superimposition of the zygomatic buttress and adjacent roots typically mask the root canal.³ Furthermore, pre-operative CBCT scans could play a significant role in revealing the complex anatomy of the root and its relationship with important adjacent anatomical structures, including the inferior dental canal and maxillary sinus.⁴ However, the relatively increased radiation dose delivered to the patient compared with conventional periapical radiographs restricts the application of this technology to selected cases. A thorough clinical endodontic examination should precede any CBCT referral.

Scan settings including size of field of view (FOV), the number of basis projections (acquisitions used to create the raw data) and scan mode (peak tube potential, current and scan time in seconds) are among the most important factors in determining image quality and radiation dose levels with CBCT.^{5,6} Contemporary systems come with a wide range of scan settings that could affect the visibility of anatomical structures in the scan. It has previously been reported that the visibility of small anatomical structures

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with CBCT including trabecular bone, periodontal ligament space and root canal largely depends on FOV and scan settings selections.⁷ These structures are typically visualized on thin-slice multiplanar reformatted images created from volumetric datasets. The voxel size, slice thickness, spatial and contrast resolutions of these multiplanar reformatted images vary with respect to machine type, FOV and scan settings.^{6,7} In an *ex vivo* comparison of the diagnostic performance of five CBCT systems for the detection of vertical root fractures in endodontically treated teeth, significant differences among the systems in depicting fracture lines were found.⁸ Moreover, it has been recently reported that CBCT FOV and scan settings are limiting factors for the quality of three-dimensional surface model reconstructions of the jaws and teeth.⁹ It is therefore speculated that the visibility of the root canal with CBCT could vary with respect to the specific chosen protocol to create the scan. The aim of this study is to assess the influence of FOV and scan setting selections on the visibility of the root canal space in a human cadaver mandible as subjectively evaluated by ten observers.

Materials and methods

Sample selection and radiographic scan

A single formalin-fixed cadaver mandible not identified by age or sex was obtained from the department of functional anatomy. Informed consent was obtained to use human remains for research purposes. The mandible was scanned with the Accuitomo 170 CBCT system (JMorita MFG Corp., Kyoto, Japan). The scan position followed the manufacturer's recommended protocol with the occlusal plane parallel to the floor. The mandible was scanned with six FOVs (4 × 4 cm, 6 × 6 cm, 8 × 8 cm,

10 × 10 cm, 14 × 10 cm and 17 × 12 cm). Additionally, for each FOV there were two extra scan settings to choose from: the number of basis projections (360 or 180) and scan mode (standard or high resolution). In total there were 24 scans made for the mandible (six FOVs × two basis projections × two scan modes). The different scan settings used in this study are reported in Table 1. All data sets were saved in study format for further analysis.

Data analysis

The data sets were reconstructed using the manufacturer's software (I-Dixel v. 2.0.4, JMorita) to create three orthogonal slices (axial, coronal and sagittal). The isotropic voxel size for each individual scan was kept to the original value. It ranged from 0.08 mm³ for the high-resolution 4 × 4 FOV to 0.25 mm³ for the standard resolution 17 × 12 FOV. The root canal of the right mandibular canine was selected for evaluation as the canine root is typically the longest and the most adequately depicted on radiographs. The selection criteria included normal root anatomy and absence of internal root resorption, canal obliteration and fractures. The image boundaries were confined to the tooth and the rest was digitally removed using software tools. Images were then saved in BMP file format.

Observations

Custom-made software was used to assess the images. Ten dentists who were trained in interpreting CBCT volumes were recruited as observers for this study. The observers assessed the overall visibility of the root canal on a 27 inch diagnostic screen in a radiology room under standard dim lighting conditions. The assessment was on a five point scale (1, very good; 2, good; 3, acceptable; 4, poor; 5, very poor). The software presents the images to

Table 1 An overview of the fields of view and scan settings used in this study

FOV (cm)	NuP	Scan mode	Peak tube potential (kVp)	Current (mA)	Ex. time (s)	Dose (mGy)	Isotropic voxel size (3 mm)
40 × 40	180°	Std	90	5	9.0	2.4	0.080
40 × 40	180°	Hi-fi	90	5	15.8	4.2	0.080
40 × 40	360°	Std	90	5	17.5	4.6	0.080
40 × 40	360°	Hi-fi	90	5	30.8	8.1	0.080
60 × 60	180°	Std	90	5	9.0	2.9	0.125
60 × 60	180°	Hi-fi	90	5	15.8	5.2	0.125
60 × 60	360°	Std	90	5	17.5	5.7	0.125
60 × 60	360°	Hi-fi	90	5	30.8	10.1	0.125
80 × 80	180°	Std	90	5	9.0	3.4	0.160
80 × 80	180°	Hi-fi	90	5	15.8	6.0	0.160
80 × 80	360°	Std	90	5	17.5	6.6	0.160
80 × 80	360°	Hi-fi	90	5	30.8	11.7	0.160
100 × 100	180°	Std	90	5	9.0	3.5	0.250
100 × 100	180°	Hi-fi	90	5	15.8	6.3	0.250
100 × 100	360°	Std	90	5	17.5	6.9	0.250
100 × 100	360°	Hi-fi	90	5	30.8	12.1	0.250
140 × 100	180°	Std	90	5	9.0	4.2	0.250
140 × 100	180°	Hi-fi	90	5	15.8	7.4	0.250
140 × 100	360°	Std	90	5	17.5	8.2	0.250
140 × 100	360°	Hi-fi	90	5	30.8	14.4	0.250
170 × 120	180°	Std	90	5	9.0	4.5	0.250
170 × 120	180°	Hi-fi	90	5	15.8	7.9	0.250
170 × 120	360°	Std	90	5	17.5	8.7	0.250
170 × 120	360°	Hi-fi	90	5	30.8	15.4	0.250

Ex. time, exposure time; FOV, field of view; Hi-fi, high fidelity; NuP, number of projections; Std, standard.

Figure 1 Example of the differences in image quality and visibility of the root canal of the right mandibular cuspid among the different fields of view (FOVs) and number of projections. FOVs from A to F were 4×4 cm, 6×6 cm, 8×8 cm, 10×10 cm, 14×10 cm and 17×12 cm using 360 projections; from G to L they were the same but with 180 projections. All images are created with the high resolution scan mode

the observers in a random order. The observers assessed the images independently. There were in total 720 observations (10 observers $\times$ 24 scans $\times$ 3 slice orientations “axial, coronal and sagittal”).

Statistical analysis

All scoring data were analysed using SPSS® (v. 17.0, SPSS Inc., Chicago, IL). A general linear model design and Fisher’s (*F*) test were used to assess the influence of FOV, number of basis projections and scan mode on the visibility of the root canal. The interclass correlation coefficient was used to assess interobserver reliability. The significance level was set to $p \leq 0.05$.

Results

The results were subdivided by slice orientation (axial, coronal and sagittal) averaged over all observers. Overall, FOV selection had a statistically significant influence on visibility of the root canal ($p = 0.0001$). The small FOV of 4×4 cm produced the best visibility and was significantly superior ($p = 0.0001$) to the 8×8 cm and 10×10 cm FOV selections. The large FOV of 17×12 cm yielded the worst results since the scan area covers the entire maxillofacial region and the root canals of individual teeth are poorly depicted (Figure 1). There was a statistically significant influence of the selection of number of projections (360 or 180) on the visibility of the root canal in the coronal ($p = 0.05$) and sagittal ($p = 0.001$) orientations but not the

axial ($p = 0.6$). There was no statistically significant influence of scan mode selection, whether high or standard resolution, on root canal visibility ($p = 0.34$) in all orientations. Overall, there were no statistically significant interactions among FOV, number of basis projections and resolution ($p = 1.2$). Interobserver reliability was excellent ($r = 0.96$).

Discussion

The study was conducted to evaluate the influence of scan setting selection in CBCT on root canal visibility as assessed by subjective observer rating. With CBCT, a cone-shaped X-ray beam revolves around the patient’s head acquiring a cylindrical or a spherical volume known as the FOV. The number and size of available FOVs for each machine is dependent on the manufacturer and the specific model chosen.^{10,11} The results indicate that FOV selection is indeed a limiting factor for visualizing the canal space. The smallest FOV available is usually indicated for an endodontic exam. However, a larger FOV is routinely selected in cases where a small FOV is not available with the machine or where two or several non-adjacent teeth are suspected for periapical pathosis. In the latter scenario, a large FOV is typically chosen to eliminate the need for a second examination, thus reducing the patient’s discomfort. The results indicate, however, that this has negative consequences for image quality and diagnostic performance.

Several commercial systems permit the user to manipulate the number of basis projections (acquisitions) used to create raw data. Reducing the number of basis projections plays a significant role in reducing radiation dose. However, it increases inconsistencies in image reconstruction and noise levels.^{12,13} The results showed that reducing the number of projections had a significant influence on root canal visibility in the sagittal and coronal planes but not the axial. Depending on the specific implementation of the reconstruction algorithm, CBCT image artefacts become accentuated in the sagittal and coronal orientations owing to reduced reliability (redundancy) of the data required for reconstruction.¹³ In general, excessive reduction in the number of projections significantly deteriorates image quality and diagnostic performance.¹⁴

Our results showed that scan mode whether standard or high resolution had no significant influence on root canal visibility. Nomenclature such as “high resolution”, “zoom scan”, “high fidelity” and “boosted dose” are among the currently employed jargon used by different manufacturers to describe scan modes. The idea behind different scan modes is to provide the user with freedom of choice to tailor the scan to the specific needs of the patient. This, however, is not necessarily always the case as standardized and internationally accepted CBCT scan protocols are absent. In effect, using the high-resolution scan mode increases the dose delivered to the patient while simultaneously reducing image noise, thus leading to better image quality.⁶

However, there is little evidence in the literature to corroborate the premise that reducing the level of noise in the image has a clinically significant influence on diagnostic performance.^{15,16} Utilizing high-resolution scan modes increases spatial resolution while increasing image noise at very thin slice thicknesses, and it additionally exacerbates the influence of metal streak artefacts in the image and therefore could result in a poor image.¹⁷ Several reconstruction algorithms and techniques are currently under investigation and have been partially implemented by several manufacturers to improve image quality at low scan modes.

It was recently reported in a systematic review of the literature regarding CBCT applications and technical factors that there is still a lack of uniformity in the design of the models produced from different manufacturers.¹⁸ High-end models have mostly adjustable parameters in contrast to low-budget systems, which have mostly fixed settings. This lack of uniformity in technical specifications of different systems and different models resulted in a wide disparity in the resulting image quality and radiation dose delivered to the patient, which in turn affected the visibility of anatomical structures in the oral region.⁷ This study was limited in that only a single CBCT system with specific scan settings was used. Technical specifications of other systems may vary widely. Therefore, caution should be exercised when extrapolating the current results to other CBCT systems. In addition, the human cadaver mandible used in this study may not mimic the clinical situation because of the absence of the

vertebrae, tongue and surrounding musculature. Scans of real patients also suffer from artefacts and reduction in spatial resolution due to micro-movements of the jaw, which were not simulated here. Finally, our results are limited by the subjective ability of the observers to identify the root canal and judge image quality. The absence of a clinical reference standard confined the results to the subjective assessment of the observers recruited in this study.

In conclusion, selection of scan settings including FOV size and number of acquisitions significantly influences the visibility of the root canal with CBCT while scan mode selection is less relevant. The smallest FOV available should always be used to examine the root canal and it is not recommended to reduce the number of projections to 180 or less. Utilizing standard instead of high-resolution settings reduces radiation dose without significant deterioration in the visibility of the root canal. Therefore, it is recommended to use the standard mode instead of high resolution for endodontic applications. Ultimately, radiation dose should be seen as a function of image quality.¹⁹ Excessive reduction in radiation dose inevitably increases noise level in the image and might lead to unacceptable image quality or even non-diagnostic scans. Future research should concentrate on identifying the proper CBCT scan protocols for the various endodontic applications and on examining the effect of streak metal artefacts from metal posts and root canal fillings on the visibility of the roots, fracture lines and periapical lesions.

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