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How Does Voxel Size of Cone-beam Computed Tomography Effect Accurate Detection of Root Strip Perforations

Farzaneh Afkhami [a], **Zahra Ghoncheh** [b*], **Fatemeh Khadiv** [c], **Hanieh Kaviani** [d], **Ahmad Reza Shamshiri** [e]

a Department of Endodontics, School of Dentistry, Tehran University of Medical Sciences, International Campus, Tehran, Iran; b Department of Oral and Maxillofacial Radiology, School of Dentistry, Tehran University of Medical Sciences, International Campus, Tehran, Iran; c Dentist, Tehran, Iran; d Department of Oral and Maxillofacial Radiology, School of Dentistry, Tehran University of Medical Sciences, International Campus, Tehran, Iran; e Research Center for Caries Prevention, Dentistry Research Institute, Department of Community Oral Health, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran

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**Corresponding author*: Zahra Ghoncheh, Department of Oral and Maxillofacial Radiology, School of Dentistry, Tehran University of Medical Sciences, International Campus, Tehran, Iran.

Email: z-ghoncheh@tums.ac.ir

ABSTRACT

Introduction: Our study aimed to assess the diagnostic accuracy of different voxel sizes for cone-beam computed tomography (CBCT) when detecting strip perforations of variable sizes. We used 0.2 and 0.3 mm^3 voxel for detecting root strip perforations. **Methods and Materials:** This was an *in vitro* study conducted on 155 extracted humans' mandibular first molars. The teeth were randomly divided into five groups (*n*=31). Perforation were not induced in the control group. In the remaining four groups, strip perforations of 0.5, 1, 1.5, and 2 mm diameters were created in the mesiolingual canal using #3 Gates Glidden drills. The CBCT scans were taken first with a 12×9 cm field of view (FOV), 90 kVp, 4 mA, and 0.2 mm^3 voxel size for 24 sec and then with a 12×9 cm FOV, 90 kVp, 2 mA, and 0.3 mm^3 voxel size for another 24 sec. Two observers evaluated the images and reported the largest diameter of perforations. The results were compared with the gold standard values (determined by an electronic digital caliper) using statistical methods, including the kappa coefficient and generalized estimating equation ($P<0.05$). **Results:** Based on the findings of our study, the inter-observer agreement ranged from 58-100%, while the intra-observer agreement was reported to be around 100%. The difference in accuracy between 0.2 and 0.3 mm^3 voxel sizes was not statistically significant ($P>0.05$). In addition, the accuracy of detecting different perforation sizes in the CBCT did not follow a specific pattern. **Conclusion:** This *in vitro* study showed that CBCT is a reliable diagnostic tool, and even in lower dosages of 0.3 mm^3 voxel size, image resolution and diagnostic accuracy was not affected. Moreover, smaller root perforations could be detected as accurately as larger ones with CBCT.

Keywords: Cone-Beam Computed Tomography; Diagnosis; Strip Perforation; Voxel Size

Introduction

An ideal endodontic treatment depends on many factors, such as the anatomical variations of teeth [1] and the expertise of the clinician. Mandibular first molars are the first posterior teeth to erupt and often have the highest frequency of endodontic treatments [1]. The morphology of mandibular first molars is more complex than that of other teeth. Their mesial root often has a curvature which complicates the endodontic treatment and increases the risk of procedural errors [2, 3]. Perforations that create a path between the root canal and the external root surface, may also occur as the result of anatomical variations [4, 5]. Strip perforation is a type of perforation occurring in the thinner wall of the danger zone. Several factors affect the prognosis for the treatment of perforations, including size and location of the perforation, time of diagnosis and treatment, and degree of periodontal injury [6]. Size of perforation is of particular importance and smaller perforations often show a better prognosis due to their greater sealing ability and less destruction of periodontal tissue [7].

Several methods are available for the detection of perforations, namely radiography, is among the most efficient modalities for this purpose [5]. Two-dimensional (2D) radiographies (*e.g.*, panoramic and periapical) provide 2D images of structures and may compromise the detection of perforation due to the

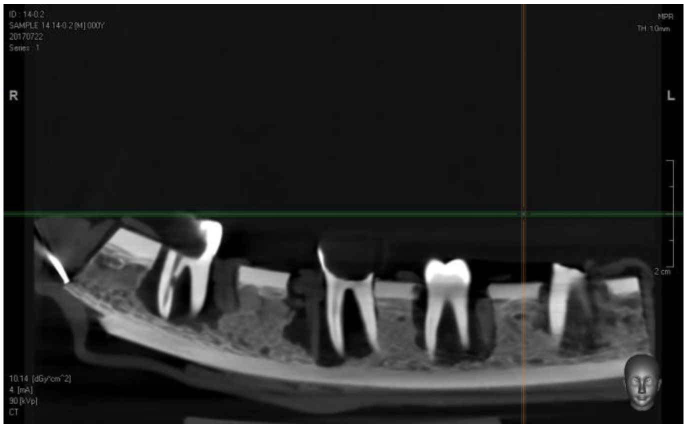

Figure 1. The cone-beam computed tomography imaging and the coronal cut showing the presence of strip perforations

superimposition of intraoral anatomical structures [8]. Therefore, three-dimensional (3D) imaging, such as cone-beam computed tomography (CBCT) are the best method for the detection of perforations [9]. Several factors affect the quality of CBCT images [*e.g.,* tube current (mA), tube voltage (kVp), field of view (FOV), and voxel size]. Voxels are the smallest volumetric elements in 3D images that significantly affect the quality of scanning and time of image acquisition [10, 11]. According to the as low as reasonably achievable (ALARA) rule, adequate image quality must be obtained with minimal patient radiation dose [9].

Using a smaller voxel size increases the radiation dose and image quality [9]. Accordingly, taken into account the ALARA rule, a balance should be achieved in order to obtain the highest image quality with the lowest patient radiation dose [12].

Some previous qualitative studies compared the diagnostic value of different voxel sizes for the detection of furcal perforations [10], external root resorptions [13], root perforations, and vertical root fractures [12]. Some other quantitative studies have evaluated the diagnostic accuracy of CBCT with different voxel sizes for the determination of working length in endodontic treatment [14]. However, the diagnostic accuracy of CBCT with different voxel sizes has not been quantitatively reported for the detection of strip perforations. The present study aimed to quantitatively compare the diagnostic accuracy of CBCT with 0.2 and 0.3 mm^3 voxel sizes for the detection of strip perforations of different sizes.

Materials and Methods

This was an *in vitro* study conducted on extracted humans' mandibular first molars. The proposal of the study was approved by Ethics Committee of Tehran University of Medical Sciences (IR.TUMS.DENTISTRY.REC.1396.2056).

A total of 155 human mandibular first molars extracted for periodontal or endodontic reasons were selected and immersed in a 2% sodium hypochlorite solution for 20 min for the purpose of disinfection [15]. Teeth with calcified root canals or an internal root resorption were excluded from the study. The teeth were then stored in a 0.5% chloramine-T solution until the time of the experiment [16]. Carious lesions were removed and the access cavity was prepared. Moreover, a #15 K-file (Mani, Inc.; Tochigi, Japan) was used for patency. The abovementioned file was introduced into the canal until its tip was visible at the apex. The working length was determined 1 mm shorter than this length. Mesiolingual canals were instrumented using ProTaper rotary system (Dentsply Maillefer, Ballaigues, Switzerland). The S1 to F2 files were employed according to the manufacturer's instructions. After using each file as a lubricant, the RC Prep (Meta Biomed, Cheongju-si, Korea) was used. In addition, a 2% hypochlorite was used for canal irrigation. Following that, each canal was rinsed with 2 mL of distilled water.

The teeth were randomly divided into five groups (n=31). No perforation was induced in the control group. In the remaining four experimental groups, #3 Gates Glidden drills (Mani, Tochigi, Japan) were used in the mesiolingual canal in the axial direction and strip perforation was induced with 0.5, 1, 1.5, and 2 mm diameter with 0.2 mm accuracy at 1 to 3 mm below the furcation area. The desired size of perforation was checked twice by the same observer using an electronic digital caliper (InSize, Sao Paulo, Brazil) with an accuracy of 0.01 mm.

Thereafter, the teeth were mounted in pieces of bovine ribs to simulate alveolar bone. In each piece, four holes measuring 15, 10, and 8 mm in height, length, and width, respectively, were created using a surgical hand-piece (NSK, Tokyo, Japan). To simulate the surrounding soft tissue, the distance between teeth after their random placement was filled with melted wax [17]. In addition, the bovine ribs were coated with three layers of dental wax on the buccal and lingual plates for the simulation of soft tissues.

After mounting the teeth, they were radiographed using Pax-i3D CBCT system (Vatech, Gyeonggi-do, Korea) first with 12×9 cm field of view (FOV), 90 kVp, 4 mA, and 0.2 mm^3 voxel size for 24 sec and then with 12×9 cm FOV, 90 kVp, 2 mA and 0.3 mm^3 voxel size for another 24 sec.

Two calibrated observers blinded to the imaging protocols observed the images using EZ3D Plus software (Vatech, Gyeonggi-do, Korea) and each one separately reported the largest diameter of perforation in the coronal plane (Figure 1). Next, according to the determined accuracy of ±0.2, the results of CBCT were compared to the results of the electronic digital caliper which were divided into two groups of accurate and inaccurate results.

Statistical analysis

In the present study, SPSS software (SPSS version 11, SPSS, Chicago, IL, USA) was used to analyze the data. Quantitative variables were described through mean and standard deviation, and qualitative variables were explained by frequency and percentage. To assess the inter-observer agreement, the percentage of agreement and the kappa coefficient were calculated and reported. Generalized estimating equation (Simple logistic regression analysis) was used to compare the diagnostic accuracy of 0.2 and 0.3 mm^3 voxel sizes separately for each perforation size and also for the comparison of diagnostic accuracy of different perforation sizes with each voxel size. To calculate the intra-observer agreement, 50 teeth (100 measurements) were randomly selected and measured again one month after the first measurement. The collected data were analyzed using the kappa coefficient. *P*-value lower than 0.05 was considered as significant.

Results

The inter-observer agreement was reported for different sizes of perforations using 0.2 and 0.3 mm^3 voxel sizes. It was revealed that except for the absence of perforation which had a 100% inter-observer agreement, the inter-observer agreement was generally within the range of 58%-74.2%. Table 1 presents the frequency of inter-observer agreement for the detection of different perforation sizes with 0.2 and 0.3 mm^3 voxel sizes on CBCT scans. For the detection of strip perforation using a 0.2 mm^3 voxel size, the mean of readings for the first and second readings was the same. Therefore, intra-class correlation coefficient of intra-observer agreement was 97.5% [mean difference (MD)=-0.03; 95% confidence interval (CI)=-0.02-0.07; *P*=0.21]. The Cohen's kappa of intra-observer agreement for 0.3 mm^3 voxel size was estimated 97.6% (MD= 0.04; 95% CI=-0.08-0.00; *P*=0.06).

Table 1. Number and percentage of inter-observer agreement for the detection of different perforation sizes with 0.2 and 0.3 mm^3 voxel sizes on cone-beam computed tomography scans N (%)

Voxel size (mm^3)	Perforation size (mm)	Accurate diagnoses by 1st observer	Accurate diagnoses by 2nd observer	Agreement	Kappa coefficient	*P*-value
0.2	0	31 (100%)	31 (100%)	31 (100%)	1	<0.001
	0.5	16 (51.6%)	18 (58.1%)	23 (74.2%)	0.48	0.007
	1	21 (67.7%)	20 (64.5%)	18 (58.1%)	0.06	0.72
	1.5	15 (48.4%)	15 (48.4%)	23 (74.2%)	0.48	0.007
	2	18 (58.1%)	21 (67.7%)	18 (58%)	0.11	0.53
0.3	0	31 (100%)	31 (100%)	31 (100%)	1	<0.001
	0.5	19 (61.3%)	13 (41.9%)	23 (74.2%)	0.50	0.003
	1	19 (61.3%)	25 (80.6%)	21 (67.7%)	0.25	0.12
	1.5	10 (32.3%)	11 (35.5%)	22 (71%)	0.35	0.05
	2	18 (58.1%)	21 (67.7%)	22 (71%)	0.38	0.03

Table 2. Accuracy of cone-beam computed tomography with 0.2 and 0.3 mm^3 voxel sizes for the detection of strip perforations of different sizes

Observer	Perforation size (mm)	Accuracy with 0.2 mm^3 voxel size N (%)	Accuracy with 0.3 mm^3 voxel size N (%)	Odds ratio	95% CI	*P*-value
1st observer	0	31 (100%)	31 (100%)	1		<0.001
	0.5	16 (51.6%)	19 (61.3%)	0.67	0.29-1.58	0.36
	1	21 (67.7%)	19 (61.3%)	1.33	0.51-3.45	0.56
	1.5	15 (48.4%)	10 (32.3%)	1.97	0.77-5.07	0.16
	2	18 (58.1%)	18 (58.1%)	1.00	0.53-1.89	1.00
2nd observer	0	31 (100%)	31 (100%)	1.00		<0.001
	0.5	18 (58.1%)	13 (41.9%)	1.92	0.77-4.75	0.16
	1	20 (64.5%)	25 (80.6%)	0.44	0.15-1.27	0.13
	1.5	15 (48.4%)	11 (35.5%)	1.70	0.70-4.18	0.24
	2	21 (67.7%)	21 (67.7%)	1.00	0.29-3.41	1.00
Mean of observers	0	31 (100%)	31 (100%)	1		<0.001
	0.5	17 (54.8%)	19 (61.3%)	0.77	0.31-1.88	0.56
	1	22 (71.0%)	23 (74.2%)	0.85	0.30-2.44	0.76
	1.5	15 (48.4%)	8 (25.8%)	2.70	0.93-7.77	0.07
	2	17 (54.8%)	17 (54.8%)	1.00	0.49-2.06	1.00

CI: Confidence interval

The diagnostic accuracy of each voxel size was reported by the observers for different sizes of perforations. Except for the absence of perforation, which showed 100% accuracy for both 0.2 and 0.3 mm voxel sizes, in some cases, as in the detection of 0.5 mm perforation by the first observer, the diagnostic accuracy of 0.3 mm^3 voxel size was found to be higher. In some other cases, such as detection of 1.5 mm perforation by the second observer, the diagnostic accuracy of 0.2 mm^3 voxel size was found to be higher; however, this difference was not statistically significant (Table 2).

For the detection of strip perforations with 0.2 mm^3 voxel size, the first observer did not detect six perforations of 0.5 mm and the second observer did not detect nine perforations of 0.5 mm. In addition, for the detection of strip perforations with 0.3 mm^3 voxel size, the first observer did not detect seven of 0.5 mm perforations while the second observer did not detect nine of 0.5 mm perforations.

Since the accuracy was 100% in the absence of perforation, this variable was not included in the analysis of perforation size. The diagnostic accuracy for each perforation size using 0.2 and 0.3 mm^3 voxel sizes was evaluated by the first and second and mean of observers. It was found that the difference in the detection of different perforation sizes with 0.2 mm^3 voxel size was not significant for any of the observers ($P>0.05$). However, the difference in the detection of different perforation sizes with 0.3 mm^3 voxel size was statistically significant ($P<0.05$), as it was demonstrated by the second observer, as well as the mean of observers. This difference followed no specific pattern for the detection of different perforation sizes.

Discussion

The present study examined the diagnostic accuracy of CBCT with 0.2 and 0.3 mm^3 voxel sizes for the detection of strip perforations of different sizes. The findings showed that the difference in accuracy between 0.2 and 0.3 mm^3 voxel sizes was not statistically significant; furthermore, the difference in the detection of different perforation sizes followed no specific pattern. Mandibular first molars have wider anatomical variations and more complex anatomies [4]. Due to such diverse morphology, the risk of perforation in this type of teeth is higher [6]. Of all root canals of molar teeth, the risk of perforation is higher in the mesial canal due to greater curvature [3] and complexity of the internal anatomy of this canal [7], which can complicate endodontic treatment [3]. According to Berutti and Fedon [18], the thinnest dentin is located in the coronal third of the mesial root, distal root surface, and about 1.5 mm below the furcation area with a mean thickness of 1.2-1.3 mm [18]. However, Harris *et al.* [19] indicated that dentin in this area can even be thinner. This area of the tooth has the lowest amount of dentin and is called the danger zone. The risk of strip perforation in this area during root canal treatment is extremely high [19]. The occurrence of perforation significantly affects the prognosis of the tooth [20] and endangers the health of the periradicular tissues [11]. Therefore, due to high anatomical variations in mandibular first molars, the risk of perforation in these teeth is high. Consequently, mandibular first molars were used in the current research. In the present study, in order to obtain the CBCT images, we had to mount the teeth to simulate their position in the oral cavity. As a result, we mounted the teeth in bovine ribs. Ferreira *et al.* [21] also used bovine rib for the same purpose due to its similarity to the human mandible (in terms of the presence of cancellous and cortical bone). We coated bovine ribs with dental wax to simulate the soft tissue. Similarly, Khojastepour *et al.* [20] used dental wax to simulate the oral environment and demonstrated that dental wax can well-simulate the soft tissue in *in vitro* settings [20].

Early diagnosis is a key factor in the success of the treatment. Evidence shows that 2D radiographs often fail to detect and locate small lesions [22]. The 3D imaging modalities, such as CBCT can help in accurate evaluation of tooth morphology [23].

Liedke *et al.* [13] performed a similar study on CBCT scans and reported that CBCT images had great sensitivity and specificity in detecting external root resorption. Based on one study by Kamburoğlu *et al.* [24], CBCT images have a higher interobserver agreement values than 2D intraoral digital images.

Durack *et al.* [25] compared the diagnostic accuracy of intraoral digital radiography and CBCT for the detection of external root resorption and indicated that CBCT was a reliable and more accurate modality for the detection of external root resorption, compared to intraoral radiography. Madani *et al.* [26] compared the accuracy of CBCT and periapical radiography for the detection of endodontic problems. They reported that overall, CBCT more accurately detected the endodontic procedural errors and external root resorption [26]. In the study by Koç *et al.* [27], CBCT images taken in 3 different voxel sizes using small fixed FOV (55×50 mm) was assessed by observers assessed in comparison to periapical imaging. Based on the obtained results, the performance of CBCT images with different voxel sizes was better than digital intraoral radiographs in detection of strip perforation. However, they don't compare the different voxel sizes with each other [27].

Commonly, the CBCT is used for diagnosis, treatment, and planning for periapical lesions, resorptions, and root canal treatment of canals with anatomical complexities [28]. Other studies have shown that CBCT was more efficient in working length determination, detection of teeth with internal root resorption that led to perforation and detection of procedural errors during root canal preparation than 2D radiography [29-31].

Voxel size is among the factors affecting the diagnostic value of CBCT [32]. Voxels are usually isotropic and their sizes range from 0.075 to 0.4 mm^3 [33]. The smaller voxel size is accompanied by a higher accuracy of CBCT and greater patient radiation dose [9]. According to the ALARA rule, an ideal voxel size should yield the lowest patient radiation dose and acceptable image quality [12]. In the present study, the diagnostic accuracy of CBCT for the detection of strip perforations with 0.2 and 0.3 mm^3 voxel sizes was assessed, that no significant difference was noted between 0.2 and 0.3 mm^3 voxel sizes. Similarly, Kamburoğlu *et al.* [24] reported no difference in the diagnostic accuracy between various CBCT voxel sizes. CBCT images in different voxel sizes have better performance to detection of artificially created furcation perforations in compare to 2D intraoral digital images [24].

Yilmaz *et al.* [33] evaluated the accuracy of working length determination for root canal treatment using an apex locator, periapical radiography, and CBCT with different voxel sizes and FOVs. Their findings showed that all CBCT images with different FOVs and voxel sizes of smaller than 0.3 mm^3 had higher diagnostic accuracy than periapical radiography. Safi *et al.* [10] qualitatively evaluated the diagnostic accuracy of different voxel sizes for the detection of furcal perforation. They found no significant difference between different voxel sizes, which was in line with the findings of the present study. However, Liedke *et al.* [13] reported that 0.3 mm^3 voxel size more efficiently detected the external root resorption among 0.2, 0.3, and 0.4 mm^3 voxel sizes, as well as it had an acceptable quality and low patient radiation dose. Safi *et al.* [12] aimed to find the best voxel size for the detection of external root resorption, vertical root fracture, and root perforation on CBCT scans. They suggested that with 0.25 mm^3 voxel size, all external root resorption defects were detected. In addition, the CBCT with 0.2 mm^3 voxel size had a 100% diagnostic accuracy in detecting vertical root resorption; however, this rate was 90% for the detection of root perforation and no difference was found between 0.125, 0.2, and 0.25 mm^3 voxel sizes. In the current study, although no significant difference was noted between 0.2 and 0.3 mm^3 voxel sizes for the detection of strip perforations, the accuracy ranged from 32.3-100% for different perforation sizes.

There is few published study to compare the various CBCT images at different voxel sizes with a digital intraoral sensor in the diagnosis of furcal perforations. Kamburoğlu *et al.* [24] found no difference between any of the voxel sizes (0.1 mm^3, 0.15 mm^3, 0.2 mm^3, and 0.4 mm^3). However, they reported differences among CBCT voxel sizes when detecting simulated resorption cavities.

In general, it is possible that the observer performance increased due to the use of CBCT units with a smaller FOV and a smaller voxel size. It seems that the use of appropriate image setting and smaller voxel sizes increased the spatial resolution [34]. Moreover, the negative effects of partial volume averaging decreased by using smaller voxel sizes [35]. Probability, the contradictory data on the diagnostic accuracy between various CBCT voxel sizes is due to differences in the sample, different measuring instruments or some unknown variables. Further studies in this regard are recommended.

Although CBCT imaging is considered as a complementary method, it is not a substitution for 2D diagnostic methods in a variety of other endodontically complicated cases like root resorptions, root perforations, and root fractures [17-19]. The present study had the following limitations: 1) using one CBCT system with adjustable 0.2 or 0.3 mm^3 voxel sizes, 2) using *in vitro* design. *In vivo* studies are required to assess other factors affecting image quality, such as patients' head movements.

Conclusion

Based on this *in vitro* study, the CBCT is a reliable diagnostic modality for perforation detection. Considering our results and taking into account the ALARA rule, 0.3 mm^3 voxel size has the same image quality and resolution as 0.2 mm^3 voxel size. The lower radiation dose can therefore be used to minimize patient exposure. CBCT was equally effective in diagnosing large diameter perforations as the smaller ones; no specific difference was noted.

Conflict of Interest: 'None declared'.

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