Comparison of limited- and large-volume cone-beam computed tomography using a small voxel size for detecting isthmuses in mandibular molars

Elen de Souza Tolentino[ID][1], Pablo Andrés Amoroso-Silva[ID][2], Murilo Priori Alcalde[ID][3],
Fernanda Chiguti Yamashita[ID][1,*], Lilian Cristina Vessoni Iwaki[ID][1], Izabel Regina Fischer Rubira-Bullen[ID][4],
Marco Antônio Húngaro Duarte[ID][3]

[1]*Department of Dentistry, State University of Maringá, Maringá, PR, Brazil*
[2]*Department of Restorative Dentistry, State University of Londrina, Londrina, PR, Brazil*
[3]*Department of Operative Dentistry, Endodontics and Dental Materials, Bauru School of Dentistry, University of Sao Paulo, Bauru, Brazil*
[4]*Department of Surgery, Stomatology, Pathology and Radiology, Bauru School of Dentistry, University of Sao Paulo, Bauru, SP, Brazil*

ABSTRACT

Purpose: This study was performed to compare the ability of limited- and large-volume cone-beam computed tomography (CBCT) to display isthmuses in the apical root canals of mandibular molars.
Materials and Methods: Forty human mandibular first molars with isthmuses in the apical 3 mm of mesial roots were scanned by micro-computed tomography (micro-CT), and their thickness, area, and length were recorded. The samples were examined using 2 CBCT systems, using the smallest voxels and field of view available for each device. The Mann-Whitney, Friedman, and Dunn multiple comparison tests were performed ($\alpha = 0.05$).
Results: The 3D Accuitomo 170 and i-Cat devices detected 77.5% and 75.0% of isthmuses, respectively ($P > 0.05$). For length measurements, there were significant differences between micro-CT and both 3D Accuitomo 170 and i-Cat ($P < 0.05$).
Conclusion: Both CBCT systems performed similarly and did not detect isthmuses in the apical third in some cases. CBCT still does not equal the performance of micro-CT in isthmus detection, but it is nonetheless a valuable tool in endodontic practice. *(Imaging Sci Dent 2021; 51: 27-34)*

KEY WORDS: Cone-Beam Computed Tomography; Endodontics; Molar; X-Ray Microtomography

Introduction

An isthmus, defined as narrow extension from either 1 or 2 main root canals,[1] is a routinely encountered anatomic complexity in human permanent teeth, especially in mandibular first molars,[2] with the highest prevalence at the apical level.[3,4] According to Srivastava et al. (2018)[5], the prevalence of isthmuses in the mesial roots is 78.4%. Isthmuses that are not detected in radiographs are difficult to reach by instrumentation, irrigation, and/or medicaments,[6] and therefore function as reservoirs of microorganisms, vital tissue, or necrotic tissue.[7] The apical level is critical for endodontic treatment and its insufficient cleaning may be responsible for treatment failure.

With the recent advent of micro-computed tomography (micro-CT), it has become possible to obtain more detailed qualitative and quantitative descriptions of root anatomy, as micro-CT has important advantages over other techniques, such as the possibility of reproducing the internal dental anatomy in multiple planes without destroying the samples; however, it is unsuitable for clinical use.[7,8] Because micro-CT provides high-resolution, detailed, and accurate information on root canal morphology, it can be used as a reference standard in anatomical *in vitro* studies.[9-11]

Although radiographs used for clinical procedures show important details such as the number of root canals, they do not provide enough details on the internal anatomy.[12] Cone-beam computed tomography (CBCT) has gained broad acceptance in dentistry in recent years as it generates 3-dimensional data at a lower radiation dose and cost and a higher spatial resolution than helical CT.[13,14] However, CBCT involves a considerably higher radiation dose than conventional radiographs.[15]

Several CBCT systems are currently on the market. Those systems vary in terms of image quality and performance. The voxel size, slice thickness, spatial resolution, and the size of the scan volume (field of view; FOV) are important parameters that influence the quality of the images. Since voxels are isotropic in CBCT, images can be constructed in any plane with high fidelity.[16] A smaller voxel size provides a higher resolution, and, in CBCT, voxel sizes range from $0.075\,mm^3$ to $0.4\,mm^3$.[16]

FOV selection is equally important, as the FOV is directly related to voxel size and influences spatial and contrast resolution. Besides providing higher radiation doses, a larger FOV offers lower resolution than a smaller FOV, which directly influences the visibility of anatomical structures on CBCT. FOV selection is indeed a limiting factor for visualizing the canal space, and the smallest FOV available is usually indicated for an endodontic exam.[17] In this setting, some studies have compared different CBCT systems with different FOV and voxel sizes in the assessment of root canals, mainly for detecting root fractures.[16,17] However, few studies have used CBCT images to detect and describe isthmuses in root canal systems.[1,2,4,9] Furthermore, the extant studies assessed only a single CBCT system, FOV, and voxel size, and did not incorporate an analysis of micro-CT images.

The use of CBCT could contribute to the detection and location of isthmuses in the root canal. Thus, the aim of this study was to assess the detection of isthmuses in the apical third of mesial root canals of human mandibular molars, by comparing limited- and large-volume CBCT systems while using their highest-resolution settings.

Materials and Methods

Sample and reference group

After receiving approval from the ethics committee (CEP #1.929.037), a micro-CT system (SkyScan 1174v2; Bruker-micro CT, Kontich, Belgium) was used to scan mandibular first molars extracted from a Brazilian population. The teeth that presented an isthmus in the apical third of the mesial
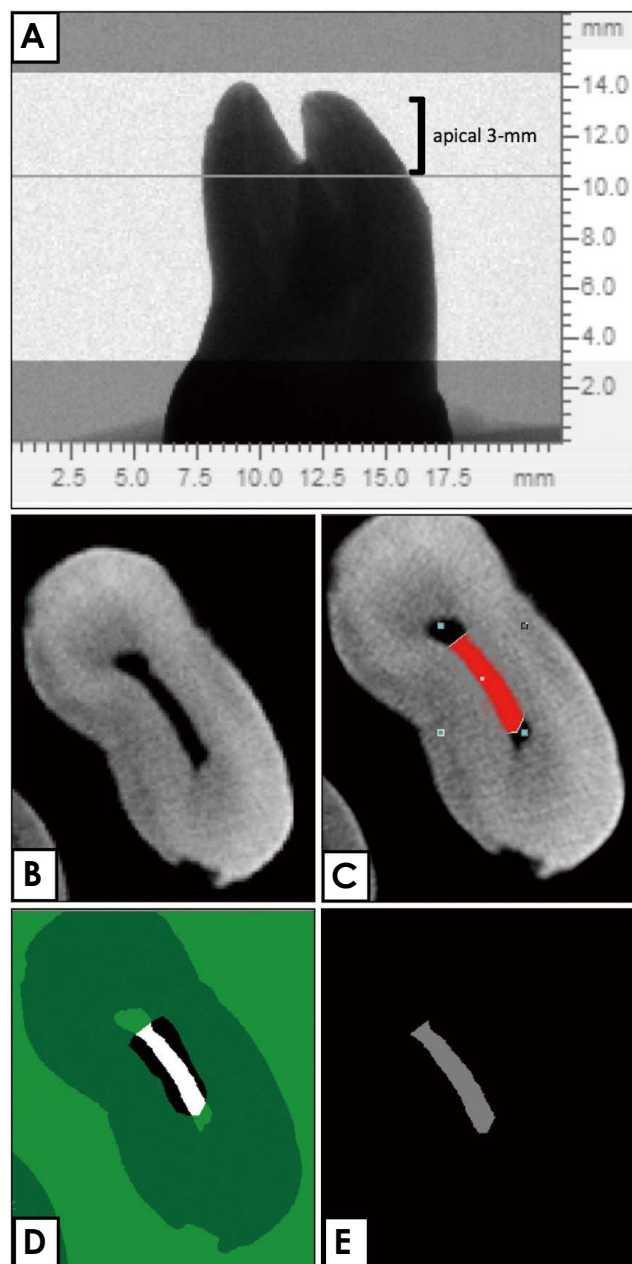

Fig. 1. Visualization and qualitative evaluation of 3-dimensional models (micro-CT). A. Location of the isthmus while viewing the apical 3 mm of the mesial root. B. Raw image preview showing the type II isthmus at the point of its major thickness. C. Region of interest preview. D. Binary selection preview. E. Morphometry preview allowing measurements of the thickness, area, and length of the isthmus (CTVol v.2.2.1 and data viewing software).

root on micro-CT were selected.

The teeth were extracted for periodontal disease, extensive caries, or coronal fractures, and after extraction, they were immediately stored in 10% neutral-buffered formalin solution (Kolplast CI ltda, Itupeva, São Paulo, Brazil). Based on the reconstructed micro-CT images, teeth with in-

complete root development, a C-shaped root canal, calcified root canals, internal or external resorption, root fractures, and/or endodontic treatment were excluded. The sex and age of the patients were unknown. The micro-CT parameters used were 50 kV, 80 μA, 360° of rotation, and an isotropic resolution of 19.6 μm. The system included a charge-coupled device camera (1304 × 1024 pixels). The images of each specimen were reconstructed with dedicated software (NRecon v.1.6.3, Bruker-microCT, Kontich, Belgium) that provided axial cross-sections of the inner structures of the roots in the BMP format.

A total of 40 teeth with isthmuses in the apical third of mesial roots were selected after micro-CT scanning. Sample size was performed using repeated-measures analysis of variance with a significance level of 5% and a power of 95%. Three-dimensional models were reconstructed using automatic segmentation and the surface-modeling software CTAn v.1.12 (Bruker-microCT, Kontich, Belgium). CTVol v.2.2.1 and data viewing software (Bruker-microCT, Kontich, Belgium) were used for visualization and qualitative evaluation of the specimens. For each tooth, the isthmus was located by viewing axial images of the apical 3 mm of the mesial root. At the point of the major thickness of the isthmus in the apical 3 mm, the thickness, area, and length of the isthmus were recorded using these specific software tools (Fig. 1). Since the rate of isthmus detection on micro-CT was 100%, these images served as a reference group.

CBCT scanning

The samples were examined using 2 CBCT systems (3D Accuitomo® 170 (J. Morita Corp., Kyoto, Japan, and New Generation i-Cat®, Imaging Sciences International, Hatfield, PA, USA), according to the protocols recommended by the manufacturer. The specifications of each system, energy parameters, and scan settings are shown in Table 1. For the 2 systems, the smallest voxel size and FOV were used (4 cm × 4 cm/0.08 mm³ and 8 cm × 8 cm/0.125 mm³, respectively), and the images were obtained in different planes (sagittal, coronal, and axial) with a 1-mm slice thick-

ness and 0.5-mm slice interval for both devices.

The teeth were covered with a thin layer of utility wax (Tenatex Red; Kemdent, Swindon, UK) to simulate the periodontal space. They were then fixed in prefabricated sockets in dry human mandibles, which were coated with 3 layers of wax buccally and lingually to provide soft-tissue simulation. Each tooth was scanned separately.

Two independent external observers (radiologists, both with 8 years of experience with CBCT) were calibrated based on the criteria and variants established prior to their evaluation, using 25% of the sample (both were calibrated by evaluating 10 randomly selected CBCT scans, which were measured twice within a 15-day interval). The images were examined using the scanners' proprietary software (Xoran 3.1.62 version, Xoran Technologies, Ann Arbor, MI, USA, and One Volume Viewer, J. Morita MFG. Corporation, Kyoto, Japan) in a Intel® Core™ 2 Duo 1.86 Ghz-6300 (Intel Corporation, Santa Clara, CA, USA) PC workstation with a NVIDIA GeForce 6200 turbo cache video card (NVIDIA Corporation, Santa Clara, CA, USA) running Windows XP Professional SP-2 (Microsoft Corporation, Redmond, WA, USA) and with an EIZO-FlexScan S2000 monitor at a resolution of 1600 × 1200 pixels (EIZO NANAO Corporation, Hakusan, Japan). All analyses were performed in a semi-dark and silent room and examiners were instructed to take breaks between analyses to avoid eye fatigue. Software tools such as filter, zoom, and contrast could be used, allowing image optimization at the discretion of each examiner. All analyses were performed independently and the examiners did not communicate.

Each tooth was analyzed by axial reconstructions of 0.1 mm/0.1 mm, moving from the coronal to apical region. The apical thirds were then evaluated. The blinded examiners analyzed the 1- to 3-mm apical level in the axial reconstructions and recorded whether they detected isthmuses in each tooth in both software programs. Isthmuses were recorded as being present when the scans showed a narrow ribbon-shaped communication between the mesiobuccal and mesiolingual canals on an axial image. When differences were found, a consensus was reached after the image

Table 1. Specifications and energy parameters of the cone-beam computed tomography systems and micro-computed tomography

System	kV	mA	Field of view size	Voxel (μm)	Exposure time
New Generation i-Cat®	120	3-8	8 × 8 cm	125	7 s
3D Accuitomo® 170	80	6	4 × 4 cm	80	30.8 s
SkyScan 1174v2 micro-CT	50	80 μA	30 × 50 mm*	19.6	± 1 h

*: maximum object size: 5-30 mm in diameter, 50 mm in length

was discussed with a third observer, an endodontist with 10 years of experience. When isthmuses were detected, their length (extension) was measured using the ruler tool in each CBCT proprietary software (mm). These values were converted to percentages and compared with the micro-CT records.

Statistical analysis

The results of the diagnostic CBCT methods were reported as percentages for the detection of isthmuses, considering micro-CT as the reference method. The CBCT systems were compared using the Mann-Whitney test, and the isthmus length measurements made using the micro-CT and CBCT devices were compared using the Friedman and Dunn multiple comparison tests, at $\alpha = 0.05$. The kappa test was used to assess inter-examiner variability in detecting isthmuses[18] and the intraclass correlation coefficient (ICC)[19]

was used to test the inter-examiner reliability for length measurements and repeated exams. The data were analyzed using Prism 5.0 software (GraphPad Software Inc., La Jolla, CA, USA).

Results

In the micro-CT images, the major thickness of the isthmuses at the apical 1- to 3-mm level varied from 0.09 to 0.37 mm (mean, 0.15 mm). The volume, area, and length varied from 0.80 to 2.23 mm^3 (mean, 1.21 mm^3); 0.07 to 0.60 mm^2 (mean, 0.29 mm^2); and 0.91 to 2.68 mm (mean, 1.89 mm), respectively. The isthmuses that were not detected on the CBCT scans had volume, area, and length varying from 0.68 to 1.87 mm^3 (mean 0.98 mm^3); 0.07 to 0.47 mm^2 (mean 0.21 mm^2); and 1.13 to 2.43 mm (mean 1.71 mm), respectively. The apical major thickness of these isthmuses

Table 2. Overall detection of isthmuses converted into percentages and length values (minimum, maximum, mean ± standard deviation) on micro-computed tomography (CT) and cone-beam computed tomography (CBCT)

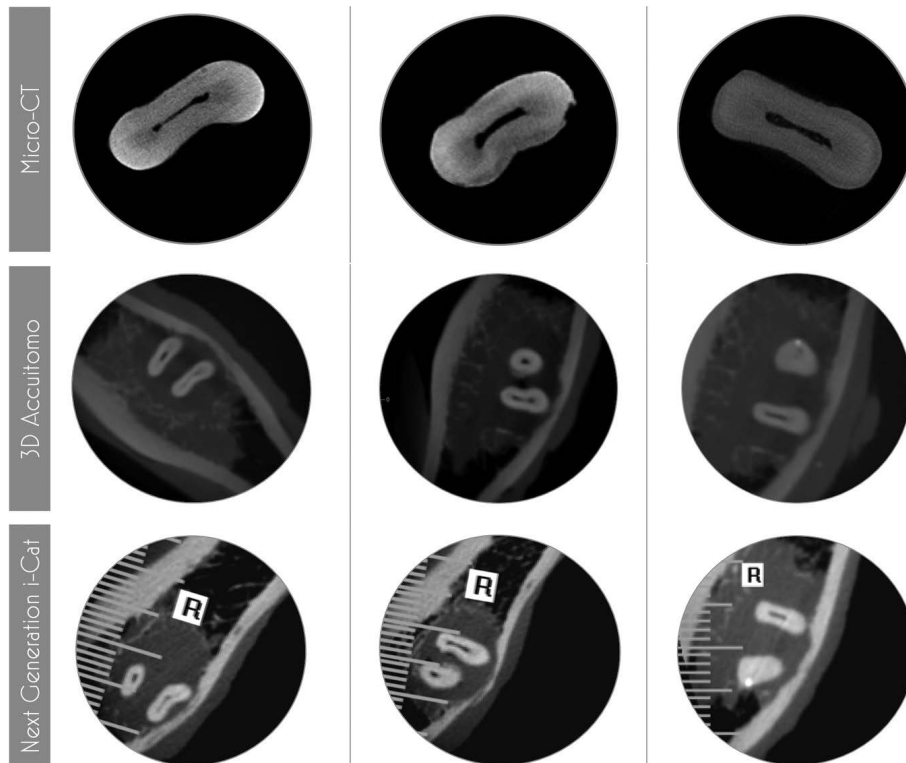|	Overall isthmus detection (%)	Isthmus length (mm)
New Generation i-Cat® CBCT	75%	0.67-2.25 (1.53 ± 0.41)
3D Accuitomo® 170 CBCT	77.5%	0.76-2.33 (1.51 ± 0.40)
SkyScan 1174v2 micro-CT (reference standard)	100%	0.91-2.68 (1.99 ± 0.40)

Fig. 2. Isthmuses identified in the mesial roots of mandibular first molars on micro-computed tomography and on limited- and large-volume cone-beam computed tomographic scans.
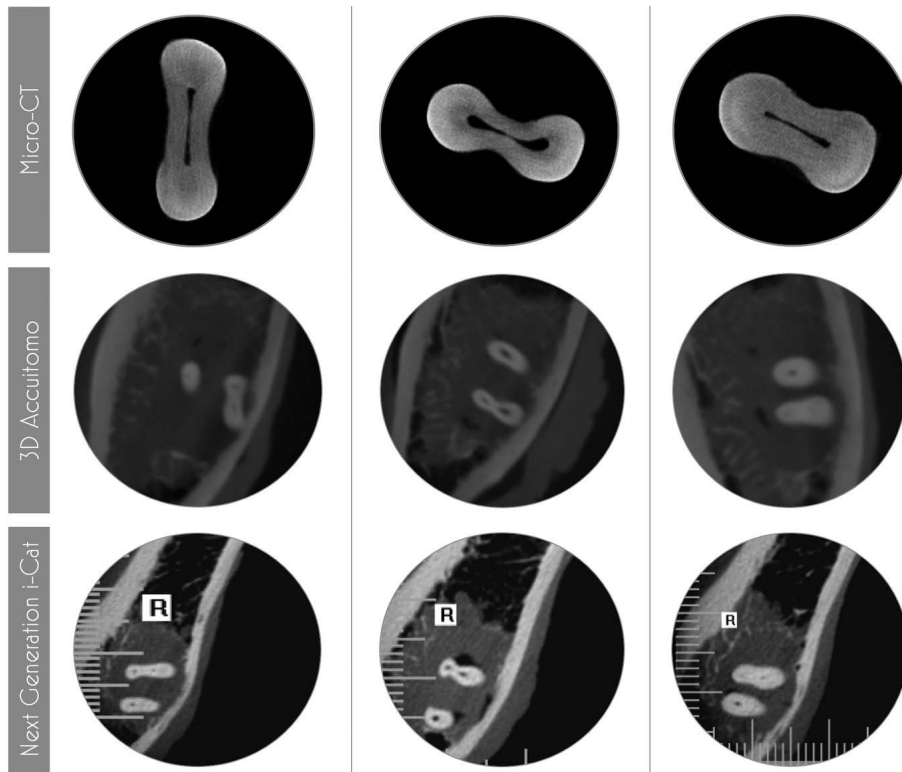
Fig. 3. Isthmuses identified in the mesial roots of the mandibular first molars on micro-computed tomography, but not detected on limited- and large-volume cone-beam computed tomographic scans.
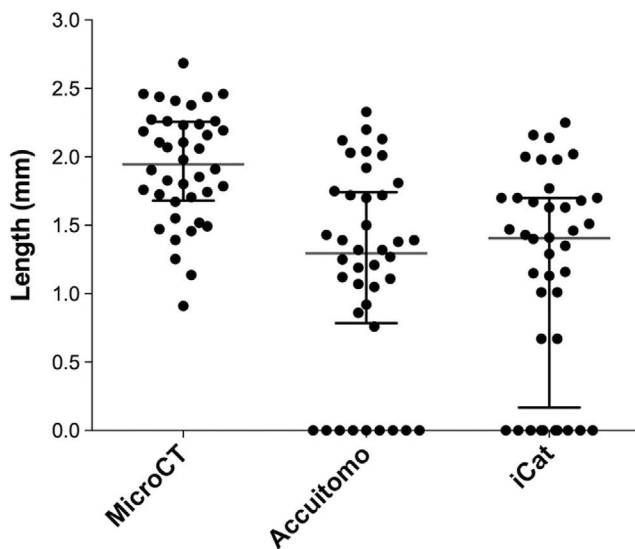

Fig. 4. Median (gray line) and interquartile values of the isthmus length measurements analyzed using micro-CT, 3D Accuitomo 170, and Next Generation i-Cat ($P < 0.05$). CT: computed tomography.

ranged from 0.07 to 0.17 mm (mean, 0.10 mm).

Considering micro-CT as the reference standard, images acquired with the 3D Accuitomo 170 detected 77.5% (31 of 40) of isthmuses in the sample. For the i-Cat system, the detection rate was 75.0% (30 of 40, Table 2). The difference between the systems was not significant ($P > 0.05$).

Figure 2 shows isthmuses identified in both CBCT images. Non-detected isthmuses are illustrated in Figure 3.

Significant differences were found between micro-CT both and 3D Accuitomo 170 and i-Cat ($P < 0.05$), indicating that both CBCT scanners did not detect some isthmuses, impeding their length measurements. When 3D Accuitomo 170 and i-Cat were compared, no statistically significant difference was found ($P > 0.05$). Figure 4 shows the median and interquartile values of the isthmus length measurements made using micro-CT, 3D Accuitomo 170, and i-Cat.

The kappa values for inter-observer agreement in the detection of isthmuses ranged from 0.89 to 1.00 (perfect). Inter-examiner agreement was excellent for length measurements, with replicability at a significance level of 5% ($ICC > 0.90$, Table 3).

Discussion

Anatomical complexities such as isthmuses are not uncommon[2,3,20,21] and may represent a challenge in endodontic therapy. As in other studies,[9,10] this study used micro-CT as a reference standard, since it enables non-destructive 3-dimensional microscopy of the internal dental anatomy.[22] Nevertheless, it is not available for clinical use, which is where CBCT may come into play.[23]

Table 3. Interobserver agreement for isthmus detection and length measurements on cone-beam computed tomographic images

	Isthmus detection	Length measurements	
	Kappa value (interpretation)[19]	ICC (interpretation)[20]	95% CI
New Generation i-Cat	0.89-1.00 (perfect)	0.940 (excellent)	0.87-0.98
3D Accuitomo® 170	0.89-1.00 (perfect)	0.901 (excellent)	0.76-0.99

ICC: intraclass correlation coefficient, CI: confidence interval

Familiarity with the specific features (such as FOV and voxel sizes) of different CBCT systems is important for both clinicians and radiologists, who often decide the acquisition protocol to be used in each specific case. A larger FOV provides less resolution and contrast,[24] whereas limited-volume units tend to offer the highest image resolution,[25] making them preferable for endodontic applications.[17] For this reason, the smallest FOV and voxel size available on each device were used to provide the sharpest image in an attempt to achieve the most comparable results possible. The objective was to compare the highest-resolution settings available on each device, not to compare the equivalent settings on both devices.

Since no previous study has compared different CBCT units for the detection of isthmuses, the purpose of comparing 2 different systems is to simulate a situation similar to that encountered in clinical practice, where an endodontist does not always have the option of choosing a particular system to request an exam. The i-Cat system is among the more commonly used units in the world[26] and the 3D Accuitomo 170 is characterized as one of the best-quality CBCT machines currently on the market,[24] since it presents the smallest FOV available and a superfine voxel size of 80 μm. Nonetheless, both units performed similarly ($P > 0.05$). When comparing the accuracy of Accuitomo, i-Cat, and other 3 CBCT systems in detecting root fractures, Hassan et al.[27] found that i-Cat was the most accurate. In the authors' opinion, the detector design might explain the superiority of this system. The i-Cat is a flat-panel detector (FPD)-based system, while Accuitomo is an image intensifier tube/charged coupled device combination, which has been reported to be inferior to FPD in terms of contrast and spatial resolution.[24]

The present methodology was based on previous *in vivo*[2] and *ex vivo*[1,9,10] investigations. For each tooth, the isthmus was located by viewing the apical 3-mm axial images of the mesial root,[9,10] using a map-reading strategy in axial reconstructions from the coronal to apical region.[1,2,9,10] All isthmuses were classified according to the criteria of Hsu and Kim[28] as type II (definite connection is present between the 2 main canals).

Some studies found that small isthmuses could not be detected on CBCT.[29-31] In the present study, the narrower isthmuses could not be detected. The overall mean apical thickness of the isthmuses was 0.10 mm, while that of the isthmuses detected on CBCT was 0.15 mm. It is known that partial volume averaging can limit the ability of CBCT to detect thinner objects.[25] When comparing micro-CT and CBCT, Ordinola-Zapata et al. (2016)[29] found that CBCT was not accurate for detecting the correct anatomy when variable anatomical configurations were present. Marca et al. (2013)[30] compared CBCT and micro-CT for evaluating variations in 3-rooted maxillary premolars and concluded that CBCT produced poorer image details. In addition, a recent systematic review[31] revealed that CBCT can be considered for root canal evaluations; however, some morphological aspects and voxel size can influence the ability of CBCT to detect certain features.

Previous *in vivo* assays[2,4] using CBCT showed the presence of isthmuses in up to 87.9%[2] of mandibular molars. However, those studies investigated a single type of CBCT system and did not compare different acquisition settings. In the present *ex vivo* study, considering only the apical 1- to 3-mm level, CBCT scans showed isthmuses in more than 75% of the sample. Patient movement and position, root canal fillings, and pins and posts, which are important sources of artifacts *in vivo* were not an issue, and their absence most likely improved observer performance. Nonetheless, soft-tissue simulation was used, and the CBCT scans were generated by applying clinical scanning protocols.

CBCT has been shown to improve decision-making in complex clinical cases in endodontics.[32] However, operational errors due to misinterpretation have negative impacts on endodontic planning. There is a consensus that imaging artifacts play an important role in endodontic diagnoses. Recently, special attention has been given to software programs and their ability to reduce these artifacts.[32] According to Bueno et al.,[32] future technology advancements for CBCT equipment may include artifact reduction, cleaner images with sharper and higher-magnification images, high-quality

diagnostic tools, and mechanical motion stabilizers.[32]

Although the use of a small FOV reduces the radiation dose, the fact that CBCT involves a higher radiation dose than conventional radiographs restricts the application of CBCT to selected cases, and a thorough clinical examination is mandatory before choosing to perform CBCT. Posterior teeth with complex anatomy, symptoms, and/or persistent periapical lesions are strong candidates for a CBCT examination for the presence of isthmuses. Both limited- and large-volume CBCT units have a similar ability to exhibit isthmuses, allowing both clinicians and radiologists to carefully study the root anatomy and its variations even when not all CBCT options are available. This technology still does not outperform micro-CT, since neither CBCT scanner detected isthmuses in the apical third in some cases. Nonetheless, CBCT represents a valuable tool in endodontic practice.

Conflicts of Interest: None

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