BJOS Brazilian Journal of Oral Sciences

Original Article

Volume 18
2019
e191627

Root canal segmentation in cone-beam computed tomography: comparison with a micro-CT gold standard

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Received: April 16, 2019
Accepted: October 06, 2019

Aim: The purpose of this study was to compare root canal volumes (RCVs) obtained by means of cone beam computed tomography (CBCT) to those obtained by micro-computed tomography (micro-CT) after applying different segmentation algorithms. **Methods:** Eighteen extracted human teeth with sound root canals were individually scanned in CBCT and micro-CT using specific acquisition parameters. Two different images segmentation strategies were applied to both acquisition methods (a visual and an automatic threshold). From each segmented tooth, the root canal volume was obtained. A paired t-test was used to identify differences between mean values resulted from the experimental groups and the gold standard. In addition, Pearson correlation coefficients and the agreement among the experimental groups with the gold standard were also calculated. The significance level adopted was 5%. **Results:** No statistical differences between the segmentation methods (visual and automatic) were observed for micro-CT acquired images. However, significant differences for the two segmentation methods tested were seen when CBCT acquired images were compared with the micro-CT automatic segmentation methods used. In general, an overestimation of the values in the visual method were observed while an underestimation was observed with the automatic segmentation algorithm. **Conclusion:** Cone beam computed tomography images acquired with parameters used in the present study resulted in low agreement with root canal volumes obtained with a micro-CT tomography gold standard method of RCV calculation.

Keywords: Root canal therapy. X-ray microtomography. Cone-beam computed tomography. Imaging, three-dimensional.

http://dx.doi.org/10.20396/bjos.v18i0.8657328

Introduction

Cone-beam computed tomography (CBCT) is an important resource for examination of bone and dental structures in the maxillofacial region. The tridimensional nature of the obtained images is used in diagnosis, treatment planning and follow up of patients treated for diverse oral conditions[1,2]. In Endodontics, CBCT images enable determination of root canal morphology and length, as well as the presence of accessory canals, particularly in complex cases, in which periapical radiographs fail to reveal with precision, important anatomic features[3,4].

Some cone-beam scanners are equipped with a small field of view (FOV), allowing examination of specific areas of interest and, especially in endodontics, high resolution images are obtained with small FOV equipments. This is important because it restricts the area of exposure, possibly reducing the radiation dose to the patient[5,6]. Certain factors however, such as voxel size, acquisition parameters, and number of acquired images, can directly influence the quality of the produced tomographic images[7]. On the other hand, micro-CT has been recently suggested as a possible gold standard for a precise and non-destructive *in vitro* study of the 3D anatomy of the root canal system[8,9] due to its high resolution, low noise and precise three-dimensional reproduction of the internal and external morphology of the tooth[10,11].

Image segmentation is an important tool in digital image analysis, providing information on the volume and dimensions of a specific area of interest. Selection of threshold values in micro-CT acquired images of root canals can be done visually, based on the operator's ability to detect histogram peaks and valleys or automatically, by means of computer-based algorithms[12]. However, it is unclear whether differences among segmentation methods are indeed significant in the determination of root canal volume by CBCT. Thus, the purpose of the present study was to evaluate the accuracy of CBCT examination in calculating the root canal volume after application of two segmentation methods (visual and automatic) compared to a gold standard micro-CT evaluation.

Materials and Methods

Specimen screening and preparation

This *in vitro* study protocol has been approved by the Ethics in Research Committee of the host institution (registration number 1.884.298). In this work, 18 extracted human permanent teeth were used. Single and multiradicular teeth were randomly included, provided they presented intact apical root thirds.

All teeth were disinfected by immersion in 2% glutaraldehyde for two hours, after which they were kept in distilled water. In order to simulate the condition of the teeth being implanted in the alveoli, the roots were entirely covered in utility wax, and the teeth were individually placed in a custom-made transparent acrylic positioner. This device allowed a standardized placement of the sample to be scanned and simulated soft tissues, without interfering in the quality of the obtained images[13].

Image acquisition and data preparation

Eighteen individual specimen acquisitions were obtained for each scanning method. For the CBCT images, acquisitions were performed in a Picasso Trio 3D apparatus (Vatech, Hwaseong, Republic of Korea), using the following parameters: 85kV, 4.5mA, 8X8 cm FOV, 0.2 mm isotropic voxel size, and exposure time of 15 seconds.

For the micro-CT procedures, the Skyscan 1173 system was used (Bruker micro-CT, Kontich, Belgium) and acquisition parameters were 70kV, 114μA, isotropic voxel size of 14.25μm, 1.0mm Al filter, exposure time of 250ms and step rotation of 0.5° under 360°. Reconstruction was performed using the NRecon software (NRecon, version 1.51, Skyscan, Kontich, Belgium) using a 50% beam hardening correction scheme, ring artefact correction of 5 and input of contrast limits between 0 and 0.1. The reconstruction parameters were specifically optimized for the characteristics of the specimens used in the present study.

Both CBCT and micro-CT image stacks were visualized and prepared using the ImageJ/Fiji open-source software[14] (Fig. 1A and B). A volume of interest (VOI) containing the root part of the tooth was selected from each image stack. The images were saved in optical media and imported in.*tiff* format into the software interface. Image stacks from the CBCT modality were resized to match the dimensions of the micro-CT images.

Root canal segmentation in CBCT and micro-CT images

ImageJ/FIJI software was used to perform segmentation in both image modalities: CBCT (n=18) and micro-CT (n=18). Two segmentation methods were used for each image modality: a visual (n=36) and an automatic based algorithm (n=36), resulting in a total of 72 segmented images.

First, the images were converted into 8-bit grayscale, and for the visual threshold method, a simple binary format was attributed (0 for background and 255 for the foreground) (Fig. 2A, B, C and D). The visual threshold was applied at the lowest gray value representing dentin tissue, as judged by the operator. The automatic segmentation method was based on the application of a minimum algorithm[15], incorporated into the ImageJ threshold menu, for both tomographic and micro-CT images. For both threshold methods, after binary format conversion, an image subtraction method was applied, in order to obtain the final root canal volume[16].

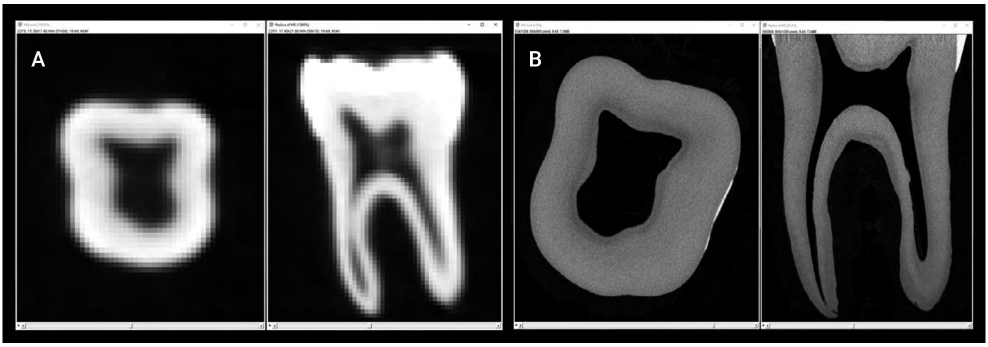

Figure 1. Image stacks visualized using ImageJ/Fiji software. Cone beam computed tomography (A); micro-computed tomography (B).

Figure 2. Image segmentation process before and after a binarization. Non-binarized micro-computed tomography image (A); binarized micro-computed tomography image (B); non-binarized Cone beam computed tomography image (C); binarized Cone beam computed tomography image (D).

The segmented root canals were then individually visualized, and its volume was obtained (Fig. 3A and B). The precision of the root canal volume acquired by the CBCT images and the degree of agreement between the tested segmentation methods were compared to the automatic segmentation method of the micro-CT images, which was considered as the gold standard for root canal volume evaluation.

Statistical Analysis

Statistical analysis was performed using the SPSS® software (SPSS Statistics for Windows, Version 13.0. Chicago, USA). The variables were expressed by means, standard deviation, medians, interquartile range, minimum and maximum values. Paired t-test was used to verify differences between root canal volumes obtained by each tested segmentation method and modality with the gold standard (automatic micro-CT threshold). Pearson's correlation coefficients were also obtained, to verify the degree of correlation between the tested variables and the gold standard. A correlation is considered strong whenever the high values of a given variable were related to the high values of another variable, but as this does not imply that variables are in agreement[17], these were also calculated among the groups.

Results

For micro-CT, automatic and visual segmentation methods resulted in similar mean root canal volumes (7621.8 and 7741.8 voxels, respectively; $t = -1.621$; $df = 17$; $p=0.123$). For CBCT, automatic segmentation resulted in the lowest root canal volume (4144 voxels), while the visual method resulted in the largest volume (11572 voxels). Differences between the gold standard and CBCT automatic segmentation were positive ($t=4.135$; $df=17$; $p \leq 0.001$), showing that CBCT with automatic segmentation resulted in underestimation of root canal volume. Differences between the gold standard and CBCT visual method, were negative ($t=-3.950$; $df=17$; $p \leq 0.001$), showing that this method overestimated root canal volume. Table 1 shows distribution of root canal volumes among the groups.

Figure 3. Root canal volume after segmentation. Cone beam computed tomography (A); micro-computed tomography (B).

Table 1. descriptive data of root canal volume obtained for the tested groups. Mean, median, minimum and maximum root canal volumes (in voxels) for all threshold and acquisition methods are shown.

Threshold	Mean (DP)	Median [q1 ; q3]	Minimum ; Maximum
micro-CT automatic (gold standard)	7621.8 (6585.1)[a]	5788 [2560 ; 10168]	872 ; 25072
Micro-CT visual	7741.8 (6630.3)[a]	6196 [2384 ; 9848]	744 ; 25200
CBCT automatic	4144 (3703.3)[b]	4040 [832 ; 5096]	208 ; 12944
CBCT visual	11572 (7189.4)[c]	11936 [5680 ; 15488]	1504 ; 26520
Difference (micro-CT automatic, micro–CT visual)	-120 (314.1)	-128 [-216 ; 120]	-912 ; 320
Difference (micro-CT automatic, CBCT automatic)	3477.8 (3568.1)	2112 [1208 ; 4.680]	120 ; 14872
Difference (micro-CT automatic, CBCT visual)	-3950.2 (2905.0)	-3380 [-5512 ; -1472]	-9624 ; 152

* Different lowercase superscript letters indicate statistically significant differences. Paired t-test, $p<0.05$
† Micro-CT: micro-computed tomography;
‡ CBCT: cone beam computed tomography.

Pearson correlations and agreement between the volumes obtained for the tested acquisitions and thresholds compared to the gold standard are described in Figure 4. Although correlation coefficients were statistically significant and positive for all comparisons (Figure 4 A-C), no agreement has been found between the gold standard and CBCT segmentation methods (Figure 4E and F).

Discussion

Optimal knowledge of the internal anatomy of the root canal, in addition to an accurate diagnosis and treatment planning, are essential pre-requisites for a successful endodontic treatment, since appropriate root canal cleaning and shaping procedures rely on this information[18]. In fact, imaging technology are currently being applied to clinical diagnosis of teeth in need of endodontic treatment to gain additional information regarding the root canal anatomy, in an attempt to help clinical decisions[19]. Main drawbacks of tridimensional imaging as CBTC, as applied for the precise evaluation of root canal morphology include patient's overexposure to radiation[20].

The need to acquire more detailed images of complex root canal structures has been combined with technological advances and development of imaging techniques, such as digital radiography, CBCT and micro-CT[4,21]. In addition, many resources for image analysis using specific software have been nowadays applied to tomographic images[9].

In the present study, the accuracy of root canal segmentation obtained from tomographic images was compared to those obtained by micro-CT images, using an automatic micro-CT segmentation method as a gold standard. Results showed no statistical differences when the volumes obtained by the "visual micro-CT" and the gold standard were compared. Thus, for micro-CT images, both segmentation methods are reliable to calculate root canal volume, corroborating a previous study[11]. Such findings may be attributed to the high resolution and low noise produced by micro-CT,

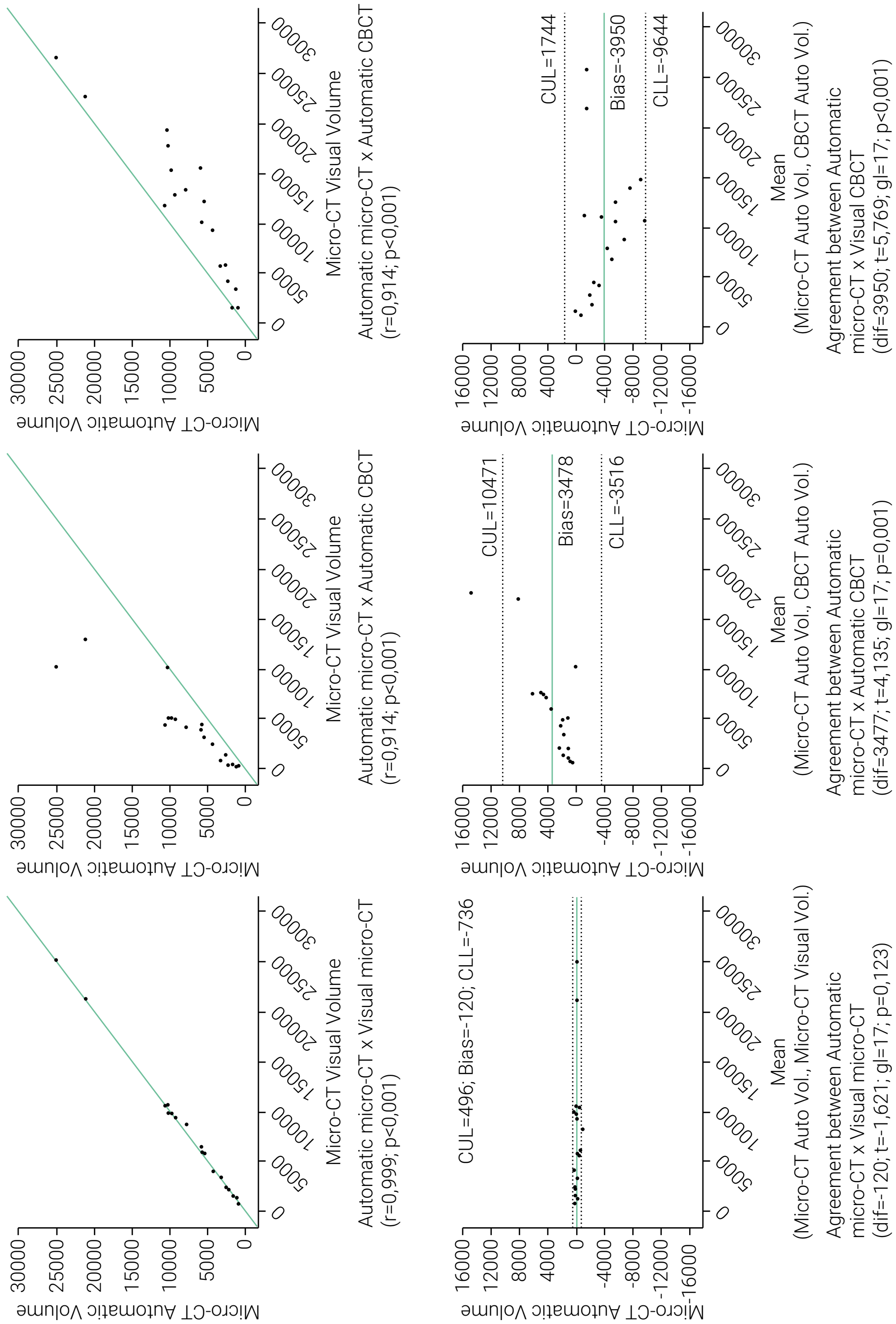

Figure 4. Correlations and agreement between the root canal volumes for the tested acquisitions and thresholds and the gold standard.

what makes identification of dentin borders accurate. In fact, it has been shown that micro-CT has a unique potential of showing detailed root canal morphological features in an accurate manner, without destruction of the tooth, while offering reproducible data in three-dimension[10,12,18].

Regarding the segmentation performed on CBCT images, the results showed that, when compared to the gold standard, both the “automatic CBCT” and “visual CBCT” were statistically different compared to the gold standard, revealing a limitation of the accurate determination of root canal volume using this image modality (with acquisition parameters used in this study). Despite the accuracy of CBCT in allowing a three-dimensional and detailed view of bone[3,22], in this study, it did not allow a precise determination of root canal volume. This may be probably explained by the specific acquisition parameters and resolution of the CBCT used. It is known that results of image segmentation in CBCTs depend on the acquisition configuration, because they have a direct influence on the reconstructed image quality[20]. An increase in milliamperage leads to an increase in the signal-noise ratio but also increase the radiation dose. An increase in kilovoltage increases the mean photon energy and reduces the grayscale resolution. The present study used 85 kV and 4.5 mA as acquisition parameters in CBCT, in other words, a low milliamperage, when compared to the gold standard (114 μA). In addition, the higher kilovoltage used in CBCT compared to the micro-CT acquisition (70kV) may have led to the decrease of the image contrast.

Another study, using high spatial resolution cone beam tomography (76μm) showed very strong correlations between root canal areas obtained from selected slices in CBCT and histologic sections[23] or root canal volume obtained by micro-CT data[24]. In both cases, the automatic segmentation implemented resulted in CBCT data which was slightly smaller than the gold standard (underestimation), corroborating results of the present study. On the other hand, the whole volume tends to be selected in the visual segmentation, rather than being restricted to the root canal area, due to the difficulty in perceiving the different attenuation coefficients of the dentin structure, explaining overestimation of CBCT after visual threshold compared to the gold standard.

In the present study, the correlation among the analyzed variables were high (r=0.99; r=0.914 and r=0.922), demonstrating that the grayscale values increased or decreased in a correlated manner, regardless of the method. However, there was only agreement when the automatic and visual micro-CT methods were compared (Figure 4D), corroborating the other comparisons shown in the present study (Table 1).

Unfortunately, micro-CT analysis is not a viable alternative for clinical practice. Instead, CBCT, the most common technique used for this, presents resolution limitations depending on the available system. The acquisition parameters used to obtain the tomographic images may significantly interfere with the results, especially the spatial resolution. Therefore, the difference between the segmented volumes of the root canals obtained in both CBCT methods, when compared to the gold standard, can be attributed to the high noise level and the used voxel size in the CBCTs. Although the segmentation methods were efficient, they depended directly on the acquisition parameters and the fact that the used voxel was rather large may have had a significant influence on the results.

The visual and automatic segmentation methods performed on CBCT images overestimated and underestimated, respectively, the volume of the root canals. They were therefore considered inconsistent with root canal volumes considered as gold standards. However, CBCT is certainly an additional resource for treatments in dentistry, and is recognized as an accurate method for analysis of root canals[25,26], however, volumetric analysis of the data obtained from CBCT image stacks should be interpreted taking into account the acquisition parameters, including spatial resolution, especially for endodontic applications. New studies are needed to improve root canal segmentation methods by testing different tomographic scanners with varying acquisition parameters.

In conclusion, volumetric analysis of root canals in single or multiradicular teeth obtained with CBCT should not be used as absolute values, since no agreement with gold standard values were obtained. Further studies are needed to elucidate optimized acquisition parameters of CBCT scanners to ensure the best endodontic segmentation image processing protocol that can be applied in clinical situations.

Acknowledgments

We would like to thank Brazilian Research Funding Agencies (FAPERJ and CAPES), the School of Dentistry of the Universidade Federal do Rio de Janeiro, and University Hospital Clementino Fraga Filho (HUCFF) for their support.

References

1. Nasseh I, Al-Rawi W. Cone Beam Computed Tomography. Dent Clin North Am. 2018 Jul;62(3):361-391. doi: 10.1016/j.cden.2018.03.002.
2. Scarfe WC, Li Z, Aboelmaaty W, Scott SA, Farman AG. Maxillofacial cone beam computed tomography: Essence, elements and steps to interpretation. Aust Dent J. 2012 Mar;57 Suppl 1:46-60. doi: 10.1111/j.1834-7819.2011.01657.x.
3. Scarfe WC, Levin MD, Gane D, Farman AG. Use of cone beam computed tomography in endodontics. Int J Dent. 2009;2009:634567. doi: 10.1155/2009/634567.
4. Patel S, Durack C, Abella F, Shemesh H, Roig M, Lemberg K. Cone beam computed tomography in endodontics - a review. Int Endod J. 2015 Jan;48(1):3-15. doi: 10.1111/iej.12270.
5. Iikubo M, Nishioka T, Okura S, Kobayashi K, Sano T, Katsumata A et al. Influence of voxel size and scan field of view on fracture-like artifacts from gutta-percha obturated endodontically treated teeth on cone-beam computed tomography images. Oral Surg Oral Med Oral Pathol Oral Radiol. 2016 Nov;122(5):631-7. doi: 10.1016/j.oooo.2016.07.014.
6. Nascimento HA, Andrade ME, Frazão MA, Nascimento EH, Ramos-Perez FM, Freitas DQ. Dosimetry in CBCT with different protocols: Emphasis on small FOVs including exams for TMJ. Braz Dent J. 2017 Jul-Aug;28(4):511-6. doi: 10.1590/0103-6440201701525.
7. Bechara B, McMahan CA, Moore WS, Noujeim M, Geha H, Teixeira FB. Contrast-to-noise ratio difference in small field of view cone beam computed tomography machines. J Oral Sci. 2012 Sep;54(3):227-32.
8. Swain MV, Xue J. State of the art of Micro-CT applications in dental research. Int J Oral Sci. 2009 Dec;1(4):177-88. doi: 10.4248/IJOS09031.
9. Nair MK, Nair UP. Digital and advanced imaging in endodontics: a review. J Endod. 2007 Jan;33(1):1-6.
10. Wolf TG, Paque F, Woop AC, Willershausen B, Briseno-Marroquin B. Root canal morphology and configuration of 123 maxillary second molars by means of micro-CT. Int J Oral Sci. 2017 Mar;9(1):33-7. doi: 10.1038/ijos.2016.53.
11. Tomaszewska IM, Skinningsrud B, Jarzebska A, Pekala JR, Tarasiuk J, Iwanaga J. Internal and external morphology of mandibular molars: An original micro-CT study and meta-analysis with review of implications for endodontic therapy. Clin Anat. 2018 Sep;31(6):797-811. doi: 10.1002/ca.23080.

12. Queiroz PM, Rovaris K, Santaella GM, Haiter-Neto F, Freitas DQ. Comparison of automatic and visual methods used for image segmentation in Endodontics: a microCT study. J Appl Oral Sci. 2017 Nov-Dec;25(6):674-9. doi: 10.1590/1678-7757-2017-0023.

13. Visconti MA, Verner FS, Assis NM, Devito KL. Influence of maxillomandibular positioning in cone beam computed tomography for implant planning. Int J Oral Maxillofac Surg. 2013 Jul;42(7):880-6. doi: 10.1016/j.ijom.2013.03.001.

14. Schindelin J, Arganda-Carreras I, Frise E, Kaynig V, Longair M, Pietzsch T, et al. Fiji: an open-source platform for biological-image analysis. Nat Methods. 2012 Jun 28;9(7):676-82. doi: 10.1038/nmeth.2019.

15. Prewitt JM, Mendelson ML. The analysis of cell images. Ann N Y Acad Sci. 1966 Jan;128(3):1035-53.

16. Neves AA, Silva EJ, Roter JM, Belladona FG, Alves HD, Lopes RT, et al. Exploiting the potential of free software to evaluate root canal biomechanical preparation outcomes through micro-CT images. Int Endod J. 2015 Nov;48(11):1033-42. doi: 10.1111/iej.12399.

17. Giavarina D. Understanding Bland Altman analysis. Bioch Med. 2015 Jun;25(2):141-51. doi: 10.11613/BM.2015.015.

18. Fan B, Yang J, Gutmann JL, Fan M. Root canal systems in mandibular first premolars with C-shaped root configurations. Part I: Microcomputed tomography mapping of the radicular groove and associated root canal cross-sections. J Endod. 2008 Nov;34(11):1337-41. doi: 10.1016/j.joen.2008.08.006

19. Cohenca N, Shemesh H. Clinical applications of cone beam computed tomography in endodontics: a comprehensive review. Quintessence Int. 2015 Sep;46(8):657-68. doi: 10.3290/j.qi.a34396.

20. Michetti J, Georgelin-Gurgel M, Mallet JP, Diemer F, Boulanouar K. Influence of CBCT parameters on the output of an automatic edge-detection-based endodontic segmentation. Dentomaxillofac Radiol. 2015;44(8):20140413. doi: 10.1259/dmfr.20140413.

21. Zhang R, Wang H, Tian YY, Yu X, Hu T, Dummer PM. Use of cone-beam computed tomography to evaluate root and canal morphology of mandibular molars in Chinese individuals. Int Endod J. 2011 Nov;44(11):990-9. doi: 10.1111/j.1365-2591.2011.01904.x.

22. Elsherief SM, Zayet MK, Hamouda IM. Cone-beam computed tomography analysis of curved root canals after mechanical preparation with three nickel-titanium rotary instruments. J Biomed Res. 2013 Jul;27(4):326-35. doi: 10.7555/JBR.27.20130008.

23. Michetti J, Maret D, Mallet JP, Diemer F. Validation of cone beam computed tomography as a tool to explore root canal anatomy. J Endod. 2010 Jul;36(7):1187-90. doi: 10.1016/j.joen.2010.03.029.

24. Michetti J, Basarab A, Diemer F, Kouame D. Comparison of an adaptive local thresholding method on CBCT and microCT endodontic images. Phys Med Biol. 2017 Dec 19;63(1):015020. doi: 10.1088/1361-6560/aa90ff.

25. Venskutonis T, Plotino G, Juodzbalys G, Mickeviciene L. The importance of cone-beam computed tomography in the management of endodontic problems: a review of the literature. J Endod. 2014 Dec;40(12):1895-901. doi: 10.1016/j.joen.2014.05.009.

26. De Carlo Bello M, Tiburcio-Machado C, Dotto Londero C, Branco Barletta F, Cunha Moreira CH, Pagliarin CML. Diagnostic efficacy of four methods for locating the second mesiobuccal canal in maxillary molars. Iran Endod J. 2018 Spring;13(2):204-8. doi: 10.22037/iej.v13i2.16564.