IEJ Iranian Endodontic Journal

Cone Beam Computed Tomography Assessment of the Volume of Dental Tissue Removed During Endodontic Access

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ARTICLE INFO

Article Type: **Original Article**

Received: 08 Dec 2020
Revised: 15 Feb 2021
Accepted: 03 Mar 2021
Doi: *10.22037/iej.v16i2.26583*

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ABSTRACT

Introduction: The purpose of this study was to determine the volume of dental tissue removed during endodontic access preparation with cone-beam computed tomography (CBCT) comparing two different software. **Methods and Materials:** CBCT images of 20 teeth were obtained before and after endodontic access performed with spherical and conical diamond burs. The images were taken with i-CAT Precise system with 0.25 mm voxel size. Digital Imaging and Communications in Medicine (DICOM) images were loaded on two different software programs (Materialise® and InVersalius®), and a 3D reconstruction of the CBCT images was performed on both programs. The baseline volume (BV), and the final volume (FV) were obtained, and the lost tissue volume (LV) was calculated using the formula: LV=BV-FV. The t-test was used to compare initial and final volumes and also to compare the two programs, using a significance level of 5%. **Results:** The volumetric data calculated for the Materialise® and the InVesalius® programs were, respectively: BV-mean of 441.79±85.08 mm^3 and 442.01±84.83 mm^3; FV-mean of 426.75±83.88 mm^3 and 426.94±83.75 mm^3; LV-mean of 15.04±4.32 mm^3 and 15.07±4.16 mm^3. No statistically significant difference was found in the volumes calculated by either program for initial, final, or removed tissue ($P>0.05$). However, there was a significant difference between the BV and LV calculated on the same program ($P<0.05$). **Conclusion:** Our *in vitro* study showed that CBCT was able to determine the volume of dental tissue removed in the endodontic access preparation of extracted human teeth, regardless of the software program used.

Keywords: Cone-beam Computed Tomography; Endodontics; Premolar; Root Canal Preparation

Introduction

Cone-beam computed tomography (CBCT) has been commonly used as an ancillary tool for diagnosis and treatment planning in endodontics, because of its examination accuracy, and because traditional radiographic exams present limitations, such as image overlapping [1, 2]. Research in endodontics frequently uses both CBCT and micro-computed tomography (micro-CT) [1, 3]; moreover, high-resolution micro-CT has been widely applied for 3-dimensional morphology and volume evaluations [4, 5]. Pre-and post-operative images allow different assessments to be made of the same specimen, including an evaluation of the root canal walls that have not been touched during root canal preparation [6-8].

Successful root canal treatment can be influenced by a series of factors, such as knowing the root canal system morphology, and performing proper endodontic access [9]. A coronal opening for root canal treatment must aid in locating the root canals, and provide full access to the canals, while also preserving as much dental structure as possible [10]. Nevertheless, endodontic procedures especially to obtain endodontic access have been associated with weakening of dental structures [11, 12].

This loss of structure induced by endodontic procedures has been studied by many authors [11, 13]. Micro-CT has been used as a tool in volumetric assessments to calculate the volume of tissue removed during endodontic preparation and intracanal

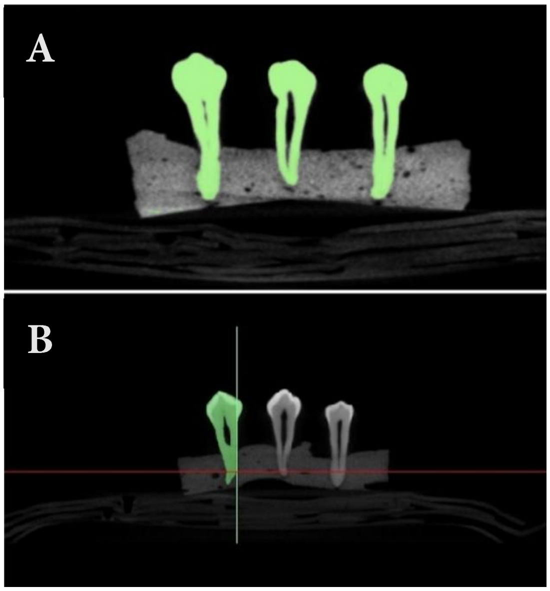

Figure 1. *A*) Application of a filter tool to InVesalius; *B*) Mimics programs to allow an analysis that excludes the voxels that have less density than that of dentin or of enamel

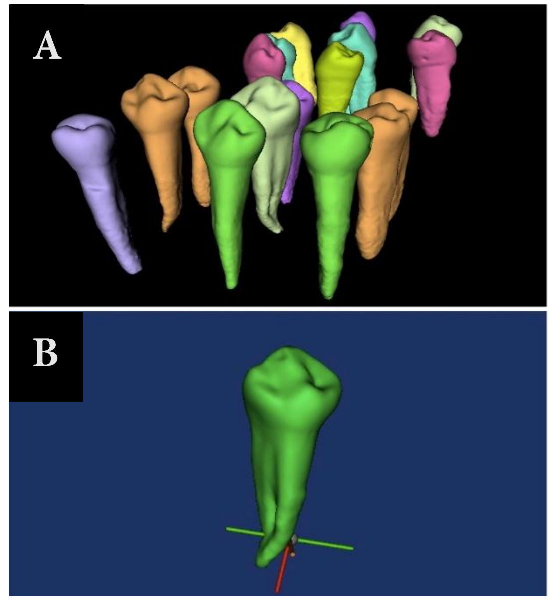

Figure 2. *A*) Tridimensional models built from the CBCT images, on InVesalius; *B*) Mimics

post space preparation [14] as well as the volume of filling material after root canal treatment [4]. However, micro-CT is not widely available to either the researcher or the practitioner; it has an elevated cost, and its use is restricted to *in vitro* samples, thus precluding use on patients. On the other hand, CBCT, provides 3-dimensional images, and is an accessible and accurate method [15-18].

This discussion warrants evaluating the CBCT application to determine the volume (mm^3) of dental tissue removed in endodontic access preparation of extracted human teeth. Moreover, the study compared two different software programs used for this purpose.

Materials and Methods

Sample selection

This study was approved by the Federal University of Goiás Research Ethics Committee (CAAE 73430617.9.0000.5083). The sample size was calculated using the formula $N = \frac{z^2 . s^2}{e^2}$, where "z" stands for "confidence interval (CI)", "*s*" stands for "standard deviation (SD)" and "*e*" stands for "absolute error". The samplesize was defined based on a pilot study that indicated that approximately 15 (*n*=14.4) CBCT images would be needed to estimate the volume values of the software programs, with 95% confidence Interval (CI), maximum error of 2.5 mm^3, and SD of 10 mm^3. A sample of 20 extracted premolars was selected for this study, aimed at reducing the margin of error and increasing the reliability of the results.

Periapical radiographs were taken of all the teeth, and those having an intact crown (absence of caries, restoration and fracture) were selected. Those that showed pulp nodules, root canal obliteration, or root resorption were excluded. The extracted teeth were immersed in 5% sodium hypochlorite (Fitofarma, Lt. 20442, Goiânia, GO, Brazil) for 30 min for organic tissue removal, and were later stored in flasks containing a 2% thymol solution (Fitofarma, Goiânia, GO, Brazil).

Imaging exams

Prior to undertaking the operative steps of the experiment, CBCT images were taken of all the teeth before and after endodontic access. The exams were performed twice, before and after endodontic access. The i-CAT Precise tomography system (Imaging Sciences International, Hatfield, PA, USA) was used to obtain a setup of 0.25 mm voxel, 13 cm FOV, 30 sec, whereas the voltage setup was 120 kVp and 3.8 mA current.

The CBCT exam was performed by first numbering the teeth from 1 to 20, and then positioning them in alginate (ColorChange; Cavex, Haarlem, Holland) support for image standardization, taking care to maintain the same positions on each exam.

Endodontic access

After the initial CBCT exams were performed, endodontic access was obtained with spherical diamond burs #1011HL, and conical burs #3195 and #2200 (KG Sorensen, Barueri, SP, Brazil), in a water-cooled turbine. Each diamond burr was used in up to 5 teeth. A specialist with more than 5 years of experience

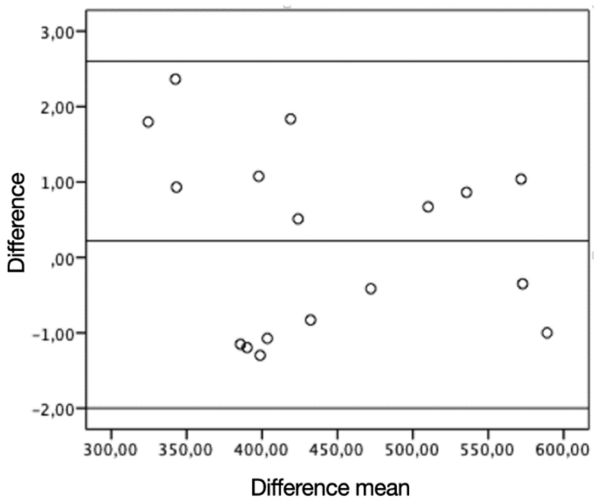

Figure 3. Bland-Altman plot showing results of mean and 95% confidence interval for initial volume obtained by the two software

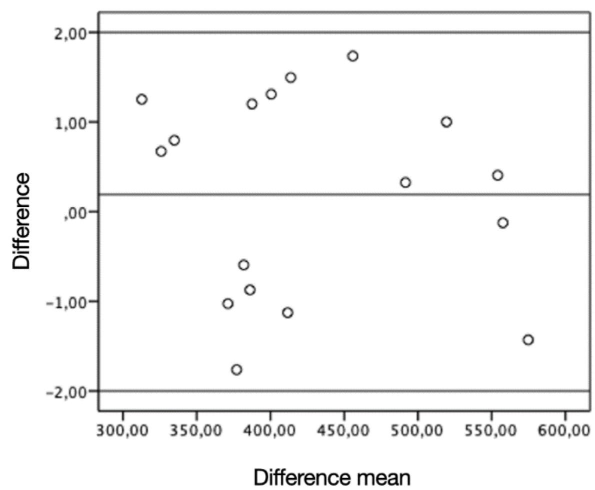

Figure 4. Bland-Altman plot showing results of mean and 95% confidence interval for final volume obtained by the two software

performed the coronal opening, according to the following technique [19]. Access cavities were prepared with spherical burs at the center of the occlusal surface, parallel to the tooth axis. An oval-shaped access was obtained after complete removal of the pulp chamber roof, and the conical burs provided regular and expulsive walls for the endodontic access.

Evaluation of tissue loss volume

The dental tissue lost after endodontic access was assessed with two software programs: InVesalius® (Renato Archer Information Technology Center, Campinas, SP, Brazil), performed on a MacBook Air computer with a MacOS Sierra v.10.12.6 operational system (Apple Inc, Sunnyvale, CA, USA), and Materialise® Mimics (v. 12.0, Materialise, Leuven, Belgium), on a Windows XP professional SP-2 desktop computer (Microsoft Corp., Redmond, WA, USA), 8GB RAM memory, dedicated ATI Radeon X1300 Pro 256 MB Graphics Card.

First, the pulp chamber volume and the alginate support were excluded from the volume evaluation. A filter tool was applied to both software programs to exclude the voxels which present less density than that of dentin or enamel from the analysis (Figure 1). On the InVesalius® software program, the "threshold" configuration was set by selecting the minimum and maximum density values of 1047 and 7190, respectively. This threshold setup was selected by increasing the minimum density value gradually until the alginate support was completely excluded from the image. On the Materialise® Mimics software program, the same procedure was performed, and the minimum and maximum values selected were 1350 and 6300, respectively. This difference in the density values from one program to another may occur because of the different filter mechanisms used by each one. Afterwards, 3-dimensional reconstruction tools were used on each software program to build individual models of the teeth (Figure 2). The volume of dentin and enamel was calculated in cubic millimeters for each tooth at baseline (BV). The same procedures were performed with the CBCT images taken after endodontic access, and a second volume value was calculated as the final volume (FV) for each tooth. The following formula was then applied to determine the volume of dental tissue lost (LV) due to endodontic access:

$$LV=BV-FV$$

Statistical analysis

The data for the dental structure volume were tabulated and analyzed on the Stat Plus: Mac v. 6.2.21 (Analysoft, Atlanta, GA, USA) software program. The data were tested initially for their homogeneity (Levene's test) and normality (Kolmogorov-Smirnov test). Since the distribution was parametric and homogeneous, the t-test was used to compare BV and FV, and also to compare the two programs, using a significance level of 5% (α=0.05). The reliability analysis between Mimics and InVesalius software was evaluated by the Intraclass Correlation Coefficient (ICC) and the data were shown on the Bland-Altman plot.

Results

Twenty teeth were used in this study, 3 of which were lost due to fracture or chipping during the procedures, leaving a final sample of 17 teeth. The results of mean, SD, and 95% CI for the volume values are shown in Table 1. There was no statistical difference between the two software programs in regard to the values calculated for all the volumes: initial, final, and lost (P>0.05). However, there was a significant statistical difference between the initial and final volumes obtained for both software programs (P<0.05).

The results of mean and SD of volumes obtained by the two different software are shown in Table 2, along with the ICC. The reliability analysis between Mimics and InVesalius software was evaluated by the ICC and the data are shown on the Bland-Altman plot, on Figures 3 and 4.

Discussion

InVesalius and Materialise Mimics software programs were used in the present study together with CBCT to interpret the images and determine the volume loss of dental structure resulting from endodontic access. This imaging exam has been used by many dental specialties, and has proven accurate in volumetric analyses [17-19]. Similar tools featured in both programs were used to build a 3-dimensional model from the CBCT images obtained. These images were taken using an i-CAT Precise tomography system, with a 0.25 mm voxel. Sang *et al.* [20] evaluated this 3-dimensional model built based on Materialise Mimics, to show that it is an accurate tool when CBCT is taken with voxel values up to 0.30 mm, but not accurate when the value is altered to 0.15 mm.

There was no statistical difference in the LV calculated by the InVesalius and Materialise Mimics software programs. However, when analyzing the extracted human teeth used in this study, it can be posited that the presence of tissues with different densities in the *in vivo* exams could have interfered in and/or complicated the 3-dimensional tooth reconstruction, and the volume calculation. Esposito *et al.* [21] evaluated CBCT accuracy in determining the volume of bone defects *in vitro* using dedicated software, and observed no statistical difference between the reference values and those obtained by CBCT images. The development of enhanced software and specific tools could expand CBCT application, both in research and in the office.

The mean values for volume of tissue removed in the endodontic access preparation of lower human premolars, calculated using InVesalius and Materialise Mimics, were 15.04 mm^3 and 15.07 mm^3, respectively. The results of the present study conducted to evaluate the volume of tissue removed in obtaining endodontic access to different tooth groups using micro-CT corroborate those reported previously [22]. This exam is often used in 3-dimensional analysis [23] to determine the volume of dentin removed in root canal preparation [14]. However, the cost of the micro-CT is relatively high. Moreover, its application is restricted to *in vitro* samples, thus restricting its use by clinicians on patients.

CBCT is an accurate and affordable imaging method [17-19]. The dimensions obtained herein on the CBCT images showed a strong correlation with those observed in the histological sections [24, 25]. Ezeldeen *et al.* [26] compared CBCT and micro-CT in determining the volume of dental tissue, and noticed that there was no difference in the values obtained by these two methods.

Tayman *et al.* [27] also compared these two methods of assessing periodontal defects *in vitro*, and observed that CBCT is a useful tool for evaluating volumes, and that its results bear substantial agreement with those of micro-CT.

Therefore, it seems that new studies in this field are very timely, including both the use of CBCT *in vivo* for diagnostics and follow-ups, and the development of more complete software tools, to enable broadening the scope of CBCT application as a research device.

Table 1. Results of mean (SD) and 95 % confidence interval (CI) for the volume values presented in mm^3

Software	Volumes	Mean (SD)	95% CI
Materialise Mimics/3-Matic	BV	442.01 (84.83)[A, a]	398.40-485.63
	FV	426.94 (83.75)[B, a]	383.87-470.00
	LV	15.07 (4.16)[a]	12.93-17.21
InVesalius	BV	441.79 (85.08)[A, a]	398.04-485.54
	FV	426.75 (83.88)[B, a]	383.62-469.88
	LV	15.04 (4.32)[a]	12.82-17.26

** Values followed by the same upper case letter do not present any statistically significant difference between initial and final volume for the same software. Values followed by the same lower case letter do not present a statistically significant difference between the software programs for the same value; BV: baseline volume, FV: final volume, LV lost tissue volume*

Table 2. Results of mean (SD) and intraclass correlation coefficient (ICC) of the volumes obtained by Mimics and InVesalius software

	Mimics Mean (SD)	InVesalius Mean (SD)	ρ*	*P-value*
Initial volume	442.02 (84.83)	441.80 (85.09)	1,000	0,000
Final volume	426.94 (83.76)	426.75 (83.89)	1,000	0,000

**ICC: Intraclass correlation coefficient*

Conclusion

Both CBCT software programs, based on this in vitro study, showed that they care accurately determine the volume of dental tissue removed in the endodontic access preparation of extracted human teeth.

Conflict of Interest: 'None declared'.

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Please cite this paper as: Chaves GS, Estrela C, Yamamoto Silva FP, Silva JA, Alencar AHG, Decurcio DA. Cone-beam Computed Tomography Assessment of the Volume of Dental Tissue Removed during Endodontic Access. Iran Endod J. 2021;16(2): 85-9. *Doi: 10.22037/iej.v16i2.26583.*