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TECHNICAL REPORT

Post-processing open-source software for the CBCT monitoring of periapical lesions healing following endodontic treatment: technical report of two cases

[1]Eduardo M Villoria, [2]Antônio R Lenzi, [1]Rodrigo V Soares, [1]Bernardo Q Souki, [3]Asgeir Sigurdsson, [2]Alexandre P Marques and [2]Sandra R Fidel

[1]School of Dentistry, Postgraduate Program in Dentistry, Pontificial Catholic University of Minas Gerais, Belo Horizonte, Minas Gerais, Brazil; [2]School of Dentistry, Postgraduate Program in Dentistry, State University of Rio de Janeiro, Rio de Janeiro, Brazil; [3]School of Dentistry, Department of Endodontics, New York University, New York, NY, USA

Objectives: To describe the use of open-source software for the post-processing of CBCT imaging for the assessment of periapical lesions development after endodontic treatment.
Methods: CBCT scans were retrieved from endodontic records of two patients. Three-dimensional virtual models, voxel counting, volumetric measurement (mm^3) and mean intensity of the periapical lesion were performed with ITK-SNAP v. 3.0 software. Three-dimensional models of the lesions were aligned and overlapped through the MeshLab software, which performed an automatic recording of the anatomical structures, based on the best fit. Qualitative and quantitative analyses of the changes in lesions size after treatment were performed with the 3DMeshMetric software.
Results: The ITK-SNAP v. 3.0 showed the smaller value corresponding to the voxel count and the volume of the lesion segmented in yellow, indicating reduction in volume of the lesion after the treatment. A higher value of the mean intensity of the segmented image in yellow was also observed, which suggested new bone formation. Colour mapping and "point value" tool allowed the visualization of the reduction of periapical lesions in several regions.
Conclusions: Researchers and clinicians in the monitoring of endodontic periapical lesions have the opportunity to use open-source software.
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Keywords: Cone beam computed tomography; computed generated 3d imaging; periapical disease

Introduction

Periapical lesions are common inflammatory diseases of microbial origin caused by infection in the root canal system. Treatment success relies on the elimination of microorganisms from the root canal system.[1] Treatment result is traditionally assessed in follow-up evaluations by clinical and radiographic analysis.[2] However, radiographic images have limitations such as to obtain a two-dimensional image of three-dimensionsal (3D) anatomical structures that invariably lead to overlapping images.[3]

The advent of CBCT in the late 1990s enabled 3D visualization of teeth and skeletal maxillofacial structures with less ionizing radiation and a lower cost, relative to multislice CT.[4,5] Along the past 15 years, a great evolution of this technology was possible, and currently, CBCT scans have been used in many different fields of dentistry, including endodontics.[6]

Correspondence to: Eduardo Murad Villoria. E-mail: d.villoria82@yahoo.com.br
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Reduction of CBCT ionizing radiation dose has been a constant concern of researchers and of the scientific community.[6] In this regard, the radiation dose of CBCT is lower when the examination is performed with a limited field of view (LFOV) device because the collimation of the radiation beam is limited to the region of interest.[7,8] For endodontic pathologies, including periapical lesions, a scan in a CBCT device with LFOV and small isotropic voxel is recommended since small isotropic voxel provides more than adequate image resolution to visualize changes of approximately 200 μm.[7] According to Hedesiu et al,[8] in cases where the conventional radiographic method combined with clinical evaluation is not precise, CBCT should be the method of choice for the evaluation of periapical pathologies.

Concomitant with the evolution of tomography devices, image post-processing software have been developed. They allow the construction of 3D virtual models after manual and semi-automatic segmentation and construction of virtual 3D models of the anatomical structures, alignment and true overlay of the structures, and qualitative/quantitative analysis of the longitudinal changes in colour-coded maps,[9] enabling the identification of the displacement and/or bone remodeling after therapy or development of a pathology.[10,11]

The present technical report describes two clinical cases demonstrating the use of three open-source software for the post-processing of tomographic imaging (ITK-SNAP v. 3.0, www.itksnap.org; MeshLab 64-Bit v. 1.3.3, www.meshlab.sourceforge.net; and 3DMeshMetric v. 1.4.3, www.nitrc.org) that allow assessment of the evolution of periapical lesions after endodontic treatment.

Methods and materials

CBCT scans used in this study were retrieved from endodontic records of one of the authors (ARL) dental practice. Scans were performed before (T0) and after

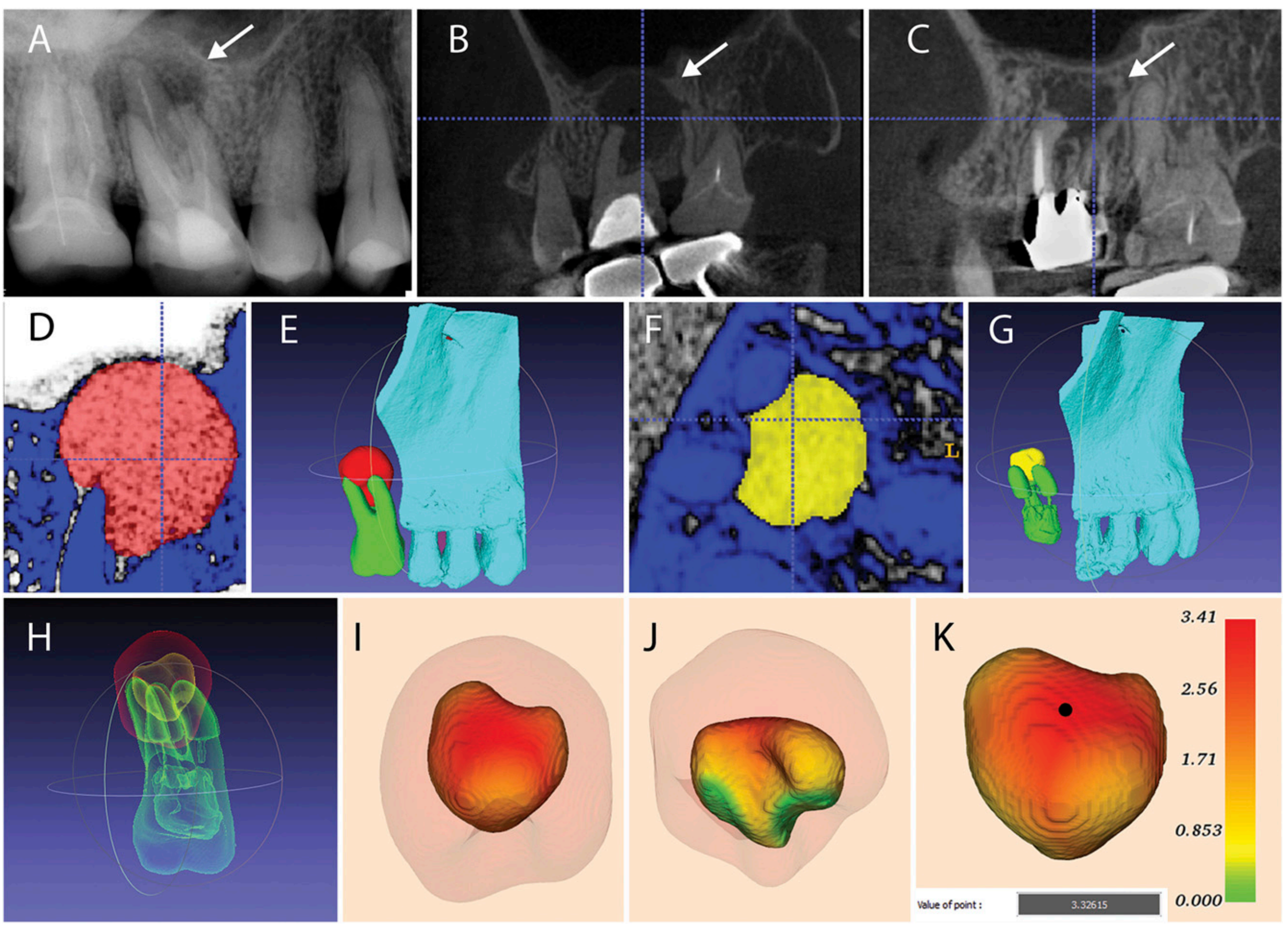


Figure 1 Post-processing of CBCT imaging in Case 1: (a) digital periapical radiography showing the radiolucent image associated with the roots of tooth no. 16 (arrow). (b) A CBCT sagittal slice (T0) demonstrating the periradicular lesion next to the maxillary sinus before the endodontic re-treatment (arrow). (c) A CBCT sagittal slice (T1) demonstrating the periradicular lesion 6 months after the re-treatment (arrow). (d–g) Segmentation, using threshold tool, and construction of virtual three-dimensional (3D) model before the endodontic re-treatment (red label) and 6 months later (yellow label). (h) Virtual 3D models aligned and overlapped. (i, j) Palatal and buccal views of virtual 3D model of periradicular lesion before the re-treatment (translucent) and after re-treatment (colourful). (k) Qualitative and quantitative assessment by colour maps and "point value" tool revealed a greater reduction in the palatal portion of the lesion (3.4 mm).

(T1) endodontic treatment with a PreXion 3D device (TeraRecon, San Mateo, CA) using a LFOV of 8 × 7.5 cm, 0.1-mm isotropic voxel, 90 kV, 4 mA and an exposure time of 19 s. The tomographic images were initially acquired and stored in the "RAW" format and were converted to digital imaging and communications in medicine format. The images of lesions obtained in the CBCT examinations were semi-automatically segmented with the ITK-SNAP v. 3.0 software, which allowed the construction of virtual 3D models more quickly and reliably than strictly manual segmentation methods. The models were saved in the Guys Image Processing Lab format.

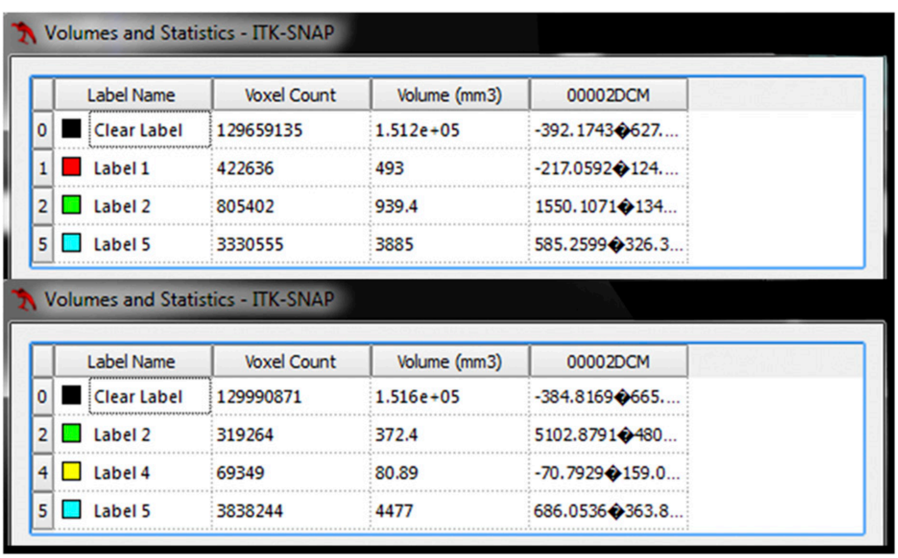
The hypodense images related to periradicular lesions were segmented with red (T0) and yellow (T1) colouring. The ITK-SNAP v. 3.0 software allowed construction of the virtual 3D models, voxel counting, volumetric measurement (mm^3) and mean intensity of the periapical lesion.

To allow alignment and overlay of the virtual 3D models, they were exported to the STerioLitography format (STL) and imported into the MeshLab software, which performed an automatic recording of the anatomical structures, based on the best fit. Then, the superimposed STL virtual models were exported to 3DMeshMetric software in order for qualitative and quantitative assessments of the lesion changes between T0 and T1. Colour-coded maps were created.

Results

Case 1

A 55-year-old female patient was referred for endodontic re-treatment of the maxillary right first permanent molar. During the initial examination, the patient presented an acute dentoalveolar abscess in this tooth. Digital periapical radiography (DPR) was conducted using a Schick33® complementary metal–oxide–semiconductor active-pixel sensor (CMOS-APS; Schick Technologies, Long Island City, NY), which provided a spatial resolution of 33 pl mm^{-2}. The radiographic image revealed periradicular lesions associated with the roots of the upper right first molar, which had inadequate root canal filling (Figure 1a). A CBCT (T0) was indicated to assess the anatomy and integrity of the roots, the extent of the lesions and the proximity and/or invasion of the maxillary sinus (Figure 1b). Based on clinical evaluation and image examinations, the necessary re-treatment was indicated and then successfully accomplished. 6 months later, the patient was clinically asymptomatic and did not exhibit any swelling or abscess. In this moment, a new CBCT (T1) was conducted for evaluation of the treatment result (Figure 1c). Tomographic imaging post-processing software was used and the hypodense images related to periradicular lesions were segmented (Figure 1d,f). Segmentation and construction of the virtual models (Figure 1e,g) revealed a smaller value corresponding to the voxel count and the volume of the lesion segmented in yellow (post-treatment), indicating that a reduction in the lesion volume occurred after endodontic re-treatment (Figure 2). The software ITK-SNAP indicated volumes of 493 mm^3 (T0) and 80.8 mm^3 (T1), therefore the lesion had a reduction of 83.6%. A higher value of the mean intensity of the segmented image in yellow (−70.7929) than in red (−217.0592) was also observed, which may indicate new bone formation (Figure 2). The maxillary right first permanent molar was segmented with green colour, and the surrounding bone and teeth were segmented with blue colour. Alignment and overlay of the virtual 3D models were conducted (Figure 1h) and the virtual models were



Volumes and Statistics - ITK-SNAP

	Label Name	Voxel Count	Volume (mm3)	00002DCM
0	Clear Label	129659135	1.512e+05	-392.1743�627....
1	Label 1	422636	493	-217.0592�124....
2	Label 2	805402	939.4	1550.1071�134...
5	Label 5	3330555	3885	585.2599�326.3...

Volumes and Statistics - ITK-SNAP

	Label Name	Voxel Count	Volume (mm3)	00002DCM
0	Clear Label	129990871	1.516e+05	-384.8169�665....
2	Label 2	319264	372.4	5102.8791�480...
4	Label 4	69349	80.89	-70.7929�159.0...
5	Label 5	3838244	4477	686.0536�363.8...

Figure 2 Voxel count, volumetric measurement (mm^3) and mean intensity of the segmented image by means of ITK-SNAP v. 3.0 software in Case 1. Red label (pre-treatment) and yellow label (post-treatment).

saved in .STL format and imported into the 3DMeshMetric software (Figure 1i). In this software, the colour map and "point value" tool showed the greatest change with dark red colour in the palatine region (3.4 mm) (Figure 1j,k), indicating a higher bone formation in this area.

Case 2

A 20-year-old male patient was referred for endodontic treatment of the darkened maxillary left central incisor. The patient reported traumatic injury, with crown fracture, 9 years before. At the time of the trauma, the fragments were bonded and the tooth was restored. Severe darkening of the crown was noted by the patient, which motivated him to look for treatment. The tooth was asymptomatic and did not respond to thermal or electrical testing. DPR (CMOS-APS, Schick33®) was taken and showed no change in the periapical region of the tooth (Figure 3a). The endodontic treatment was conducted and a new DPR performed showed a radiolucent image associated with periapical region (Figure 3b). The patient was referred to CBCT (T0) for a comprehensive evaluation of the periapical region since DPR suggested some abnormality in the trabecular bone. CBCT images revealed a periradicular lesion near the floor of the nasal cavity (Figure 3c). Given the evident DPR limitation for diagnostic purposes in this case, a new CBCT (T1) was obtained 4 months later for follow-up (Figure 3d). After segmentation and construction of the virtual models (Figure 3e,j), the ITK-SNAP v. 3.0 software revealed that the segmented image in yellow had a lower voxel value number and volume, indicating lesion reduction (Figure 4). The software ITK-SNAP indicated volumes of 168.7 mm^3 (T0) and 106.1 mm^3 (T1), therefore the lesion was reduced by 37.11%. A higher value of the mean intensity of the segmented image in yellow (−153.1578) than in red (−153.5537) was also observed,

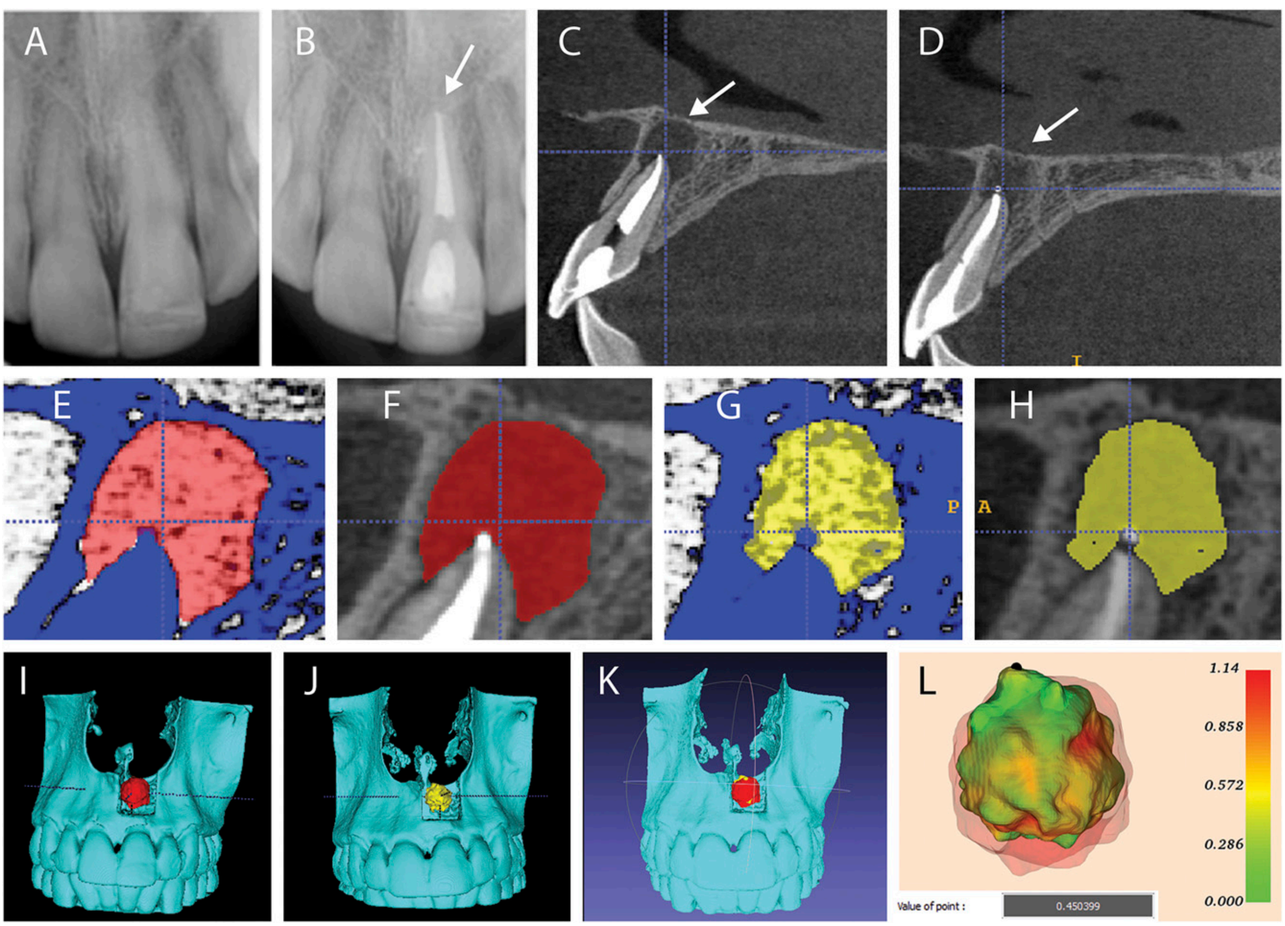


Figure 3 Post-processing of CBCT imaging in Case 2: (a) Digital periapical radiography failed to clearly show the periapical lesion associated with the roots of tooth no. 21 before the endodontic treatment. (b) Soon after the treatment, the digital periapical radiography showed a radiolucent image associated with periapical region (arrow). (c) A CBCT sagittal slice (T0) demonstrating the periapical lesion near the floor of the nasal cavity (arrow) soon after the treatment. (d) A CBCT sagittal slice (T1). Arrow indicates the periapical lesion regression after 4 months of treatment. (e–h) Segmentation using threshold tool soon after the treatment (red label) and 4 months later (yellow label). (i, j) Virtual 3D models constructed soon after the treatment and 4r months later. (k) Virtual 3D models aligned and overlapped. (l) Buccal view of virtual 3D model of periapical lesion before (translucent) and after the treatment (colourful). Qualitative and quantitative assessment by colour maps and "point value" tool revealed a volumetric reduction of the lesion in the buccal view.

which may indicate new bone formation (Figure 4). After alignment and overlay of the models (Figure 3k), the changes of the lesion size were qualitatively and quantitatively analyzed with the 3DMeshMetric software. The colour map showed the greatest changes in dark red (1.14 mm) and reduction of the total lesion volume, and the colour map and point value tool revealed an increase in the upper portion of the lesion (0.4 mm) (Figure 3l).

Discussion

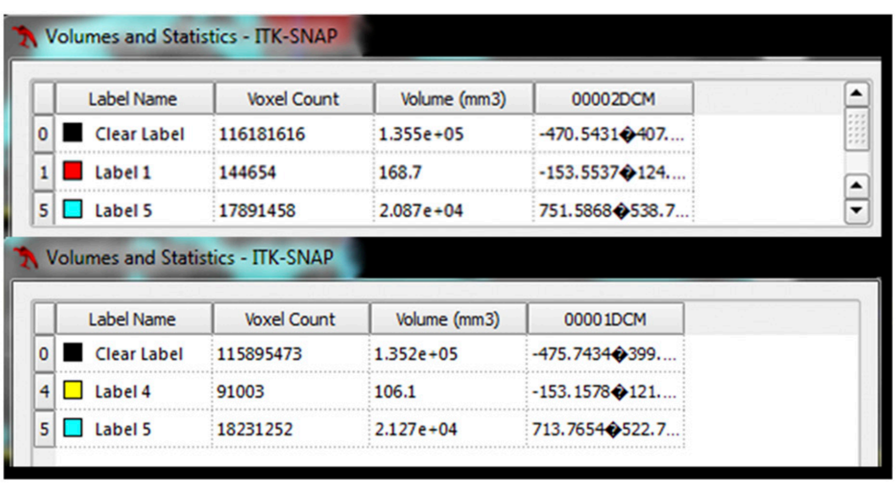
CBCT was developed with the goal of, using a lower dose of ionizing radiation than multislice CT, to allow bone and dentoalveolar structure visualization in three dimensions, and their relationships with anatomical structures.[4,5] In addition, CBCT has been shown to provide high dimensional accuracy without bias occurrence since differences between the measurements made on the CBCT images and the actual physical measurements performed in cadavers did not exist.[12]

Several software for post-processing of CBCT scans were developed simultaneously with the improvement of such technology. These software can assist in diagnosis and in monitoring post-treatment, such as endodontics. In the 1980s, the introduction of subtraction radiography enabled the visualization of bone changes and allowed reliable monitoring of density changes in different clinical situations.[13] Benfica e Silva et al[13] used the "digital subtraction radiography" software to perform the radiographic subtraction technique to evaluate the bone healing process of chronic periapical lesion after root canal treatment. The results showed that, by analyzing the intensity of the pixels and their gray tones, the method could determine the progress of apical healing. However, strict and standardized procedures are necessary with respect to radiation, geometry and contrast which makes the method difficult for the general clinician.

Recently, several authors have used post-processing software in tomography imaging analysis.[9,10,14] Cevidanes et al[9] used tomographic image post-processing software to qualitatively and quantitatively evaluate bone changes in growing Class III patients who underwent orthodontic treatment with mini-implants. Similar to the findings of the present report, these authors concluded that overlaying the virtual models and the qualitative analysis of dimensional changes allows a better comprehension of the different forms of remodeling after treatment.

In this study, it is presented for the first time a clinical report of the 3D image analysis of healing of periapical lesions using a post-processing method using the open-source software, which allowed the construction of 3D virtual models, voxel counting, volumetric measurements (mm^3) and mean intensity of the segmented image. Ahlowalia et al[14] and Esposito et al[15] investigated the volumetric analysis of *in vitro* bone defects using tomographic image post-processing software; compared their results with silicone models (the gold standard) after moulding of these defects; and showed that these software for CBCT images are reliable methods. However, in the present study, we also observed the variation in the mean intensity of the image using ITK-SNAP v. 3.0 software. Since the endodontic lesion exhibits a decrease in mineral density in response to a localized inflammatory reaction in the periapical tissues, the variation towards a higher or lower intensity of the image may characterize new bone formation or worsening of the lesion, respectively.

The 3DMeshMetric software allowed the visualization of periapical lesion regression in different regions (upper and lower, mesial and distal, and buccal and palatal) by overlay and colour maps. However, in the second case, the growth of the lesion was observed in the upper region (0.4 mm), despite the fact that ITK SNAP v. 3.0 had indicated the decrease in the volumetric measurement, and an increase of the mean intensity value of the


Volumes and Statistics - ITK-SNAP

	Label Name	Voxel Count	Volume (mm3)	00002DCM
0	Clear Label	116181616	1.355e+05	-470.5431�407....
1	Label 1	144654	168.7	-153.5537�124....
5	Label 5	17891458	2.087e+04	751.5868�538.7...

Volumes and Statistics - ITK-SNAP

	Label Name	Voxel Count	Volume (mm3)	00001DCM
0	Clear Label	115895473	1.352e+05	-475.7434�399....
4	Label 4	91003	106.1	-153.1578�121....
5	Label 5	18231252	2.127e+04	713.7654�522.7...

Figure 4 Voxel count, volumetric measurement (mm^3) and the mean intensity of the segmented image by means of ITK-SNAP v. 3.0 software in Case 2. Red label (pre-treatment) and yellow label (post-treatment).

segmented lesion after the endodontic treatment. This might be explained by the difficulty of segmentation and superimposition of the lesion during the healing process that presented new bone formation and irregular edges.

In conclusion, open-source software used in this study showed to be a valuable method for comparison and analysis of periapical lesion images. They can assist endodontists in the post-treatment control of lesions of endodontic origin, improving diagnostic resources to confirm lesion regression and preventing unnecessary surgical procedures.

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