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CT image segmentation as a tool for volumetric measurement of external inflammatory root resorption

Segmentação de imagens de TCFC como ferramenta para medição volumétrica de reabsorção radicular inflamatória externa

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ABSTRACT

Objective: The present study aimed to evaluate cone beam computed tomography image segmentation as a tool for measuring the volume of external inflammatory

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root resorption in human permanent teeth. **Methods**: A total of 40 cone beam computed tomography images of permanent maxillary and mandibular anterior teeth diagnosed with external inflammatory root resorption. The images were exported in the DICOM format to the Materialise MIMICS software program (version 10.01; Materialise NV, Belgium) for segmentation and characterisation of resorption cavities in terms of location, number of reabsorption sites, relationship to resorption sites, and nominal and percentage volumetric beside assessment of root resorption cavities and remaining root volume. All measurements were performed in duplicate and blindly by a trained radiologist at an interval of 30 days to analyse the intraclass correlation coefficients. **Results**: The nominal volumetric measures of root resorption cavities ranged from 0.6 mm^3 to 114.4 mm^3 (median, 13.2 mm^3). The percentage volume of root resorption cavities ranged from 0.37% to 39.44% (median, 4.73%). The nominal of remaining root volume ranged from 88 mm^3 to 401.3 mm^3 (median, 212.4 mm^3). The percentage of remaining root volume ranged from 60.34% to 99.63% (median, 95.37%). **Conclusions**: The results of this preliminary study suggest that segmentation is an effective and reproducible tool for measuring the volumetric size of external inflammatory root resorption cavities. Further longitudinal studies are needed to explore the usefulness of cone beam computed tomography image segmentation in improving external inflammatory root resorption diagnosis and supporting decision making for the treatment of such conditions.

Indexing terms: Cone beam computed tomography. Dentistry. Root resorption. Segmentation, Volume

RESUMO

Objetivo: O presente estudo teve como objetivo avaliar a segmentação de imagens de tomografia computadorizada de feixe cônico como ferramenta para medir o volume de reabsorção radicular inflamatória externa em dentes permanentes humanos. **Métodos**: Um total de 40 imagens de tomografia computadorizada de dentes anteriores permanentes superiores e inferiores com diagnóstico de reabsorção radicular inflamatória externa. As imagens foram exportadas no formato DICOM para o software Materialize MIMICS (versão 10.01; Materialize NV, Bélgica) para segmentação e caracterização das cavidades de reabsorção em termos de localização, quantidade de sitios de reabsorção, relação com locais de reabsorção e avaliação volumétrica nominal e percentual da raiz. Além da avaliação das cavidades de reabsorção radicular e do volume radicular remanescente. Todas as medidas foram realizadas em duplicata e às cegas por um radiologista treinado com intervalo de 30 dias para análise dos coeficientes de correlação intraclasse. **Resultados**: As medidas volumétricas nominais das cavidades de reabsorção radicular variaram de 0,6 mm^3 a 114,4 mm^3 (mediana de 13,2 mm^3). O volume percentual de cavidades de reabsorção radicular variou de 0,37% a 39,44% (mediana, 4,73%). O volume nominal de volume radicular remanescente variou de 88 mm^3 a 401,3 mm^3 (mediana 212,4 mm^3). O volume percentual de volume radicular remanescente variou de 60,34% a 99,63% (mediana, 95,37%). **Conclusões**: Os resultados deste estudo preliminar sugerem que a segmentação é uma ferramenta eficaz e reprodutível para medir o tamanho volumétrico das cavidades com reabsorção radicular inflamatória externa. Mais estudos longitudinais são necessários para explorar a utilidade da segmentação de imagens de tomografia computadorizada de feixe cônico na melhoria do diagnóstico de reabsorção radicular inflamatória externa e no apoio à tomada de decisões para o tratamento de tais condições.

Termos de indexação: Tomografia computadorizada de feixe cônico. Odontologia. Reabsorção a raiz.

INTRODUCTION

External inflammatory root resorption (EIRR) is a pathological condition characterised by progressive destruction of the root structure as a sequela of trauma, pressure, or bleaching. The most common type of

EIRR is infection-related resorption after traumatic luxation injuries that cause mechanical damage to the periodontal ligament (PDL) and root surface, as well as pulp necrosis. Healing events aimed at repairing damaged areas of the root surface expose dentinal tubules, allowing the passage of bacteria and their toxic products from the root canal to the lateral PDL, intensifying inflammation in the adjacent periodontal tissue, and leading to aggressive and progressive destruction of the root structure towards the root canal. EIRR can affect any part of the root and histologically consists of areas of cementum and dentin erosion in the root surface, with many Howship's lacunae and odontoclasts, as well as regions of inflammatory infiltration in the neighbouring periodontal tissue [1].

The clinical symptoms of EIRR are not obvious, particularly in the early stages. Therefore, EIRR has traditionally been diagnosed radiographically, with irregular bowl-shaped radiolucent cavities on the mesial or distal external surface of the root. However, the limitations of traditional plain film projection radiographs may lead to missed, late, or underestimation of EIRR severity diagnosis [2]. The advent of three-dimensional (3D) imaging examinations, particularly cone beam computed tomography (CBCT), enabled the acquisition and reconstruction of images in multiple planes, making CBCT an ideal diagnostic tool to overcome the limitations of radiographic examinations. Since then, CBCT has been indicated for various dental applications, including the detection of the presence, location, and extension of root resorption, with clinical studies demonstrating improved performance for the diagnosis of EIRR in human teeth [2-4].

Volumetric measurements using CBCT can serve as additional tools for determining the extent of lesions and enhancing visualisation of other clinical conditions [5,6]. In this context, tooth segmentation is an essential step in acquiring patient-specific dental geometries from CBCT images. Segmentation refers to the identification of one or more existing structures in images and their separation from other structures [6]. Segmentation can be considered a pixel-classification process. Sorting is often based on a property histogram, usually on the gray level. Each of these parts is uniform and homogeneous with respect to certain image properties, such as colour and texture. It allows virtual modelling of the entire dentition, revealing the root anatomy and supporting bone and facilitating the study of alterations and structures. The virtual modelling and development of a 3D setup that displays individual crowns, roots, and craniofacial structures would greatly help clinicians in diagnosis and treatment planning [7]. Few studies have calculated the volume of external root resorption in ex vivo samples [5,8]. But only one study used segmentation during 3D image analysis of internal root resorption [9]. However, no standardised methods are currently available for assessing volumetric EIRR with image segmentation. Therefore, the present propose a new model for volumetric assessment of EIRR using manually segmented images and the Materialise MIMICS software program (version 10.01; Materialise NV, Belgium).

METHODS

This study was approved by the Ethics Committee of the Federal University of Minas Gerais (approval number: 22146919.1.0000.5149). Imaging examinations from the database of the Oral and Maxillofacial Radiology Services. Faculty acquired between 2019 and 2020 were screened by the principal investigator (TMPA) for the presence of EIRR. The images were adjusted to align the root axis with the vertical plane in sagittal and coronal views. The brightness and contrast of all acquired images were enhanced to improve visualization of the resorption sites.

The final sample comprised 40 CBCT images with irregular bowl-shaped radiolucent areas in the root surface and adjacent bone, which is a characteristic feature of EIRR. Patients Imaging examinations from the database of the Oral and Maxillofacial Radiology Service of the School of Dentistry of the Federal University of Minas Gerais (Belo Horizonte, Brazil) acquired between 2019 and 2020 were screened by the principal investigator (TMPA) for the presence of EIRR. Cases of cervical invasive resorption (CIR), external replacement root resorption, and post-orthodontic apical resorption were excluded from the study. In addition, patients whose CBCT images had a large number of artefacts or structures that could not be completely visualized in the CBCT field of view (FOV) were also excluded.

Radiographic techniques

The CBCT scans of all patients were performed using a small-volume Kodak 9000C 3D® scanner (Kodak Dental Systems, Carestream Health, Atlanta, USA) with a voxel size of 0.076 mm, and FOV of 50-mm diameter × 37-mm height, a tube voltage of 65 kVp, a tube current of 8 mA, and a scan time of 10.80 s. The tube current–exposure time product (mAs) was adjusted to partial protocols that limited the FOV to the area of interest, with partial rotation and small voxel sizes when necessary. [10,11]. Before segmentation, the volumetric images were manually reoriented such that most of the slices in the transverse plane contained all tooth contours.

EIRR assessment

The images were exported in the DICOM format to the Materialise MIMICS software program (version 10.01; Materialise NV, Belgium) for segmentation and characterisation of resorption cavities in terms of location, number, relationship to resorption sites, and volumetric assessment. All measurements were performed in duplicate and blindly by a trained radiologist (TMPA) at an interval of 30 days to analyse the intraclass correlation coefficients (ICCs). The images were manipulated for magnification and adjustment of brightness and contrast for optional scan assessments. Each tooth was segmented in a 3D manner. First, the image of each tooth was cropped in axial, coronal, and sagittal dimensions (figure 1).

Subsequently, the minimum and maximum thresholds of the gray level of each tooth were used to produce a mask. The threshold settings were chosen by the examiner based on the best visualization

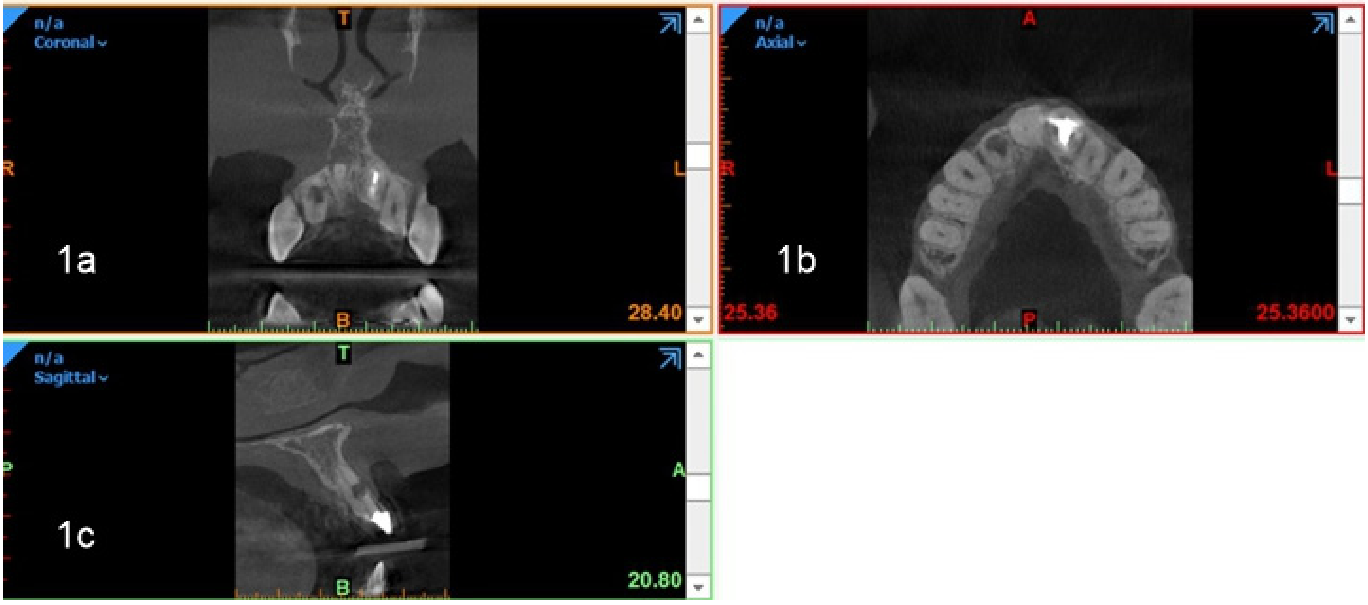

Figure 1. The image of each tooth was cropped in coronal (a), axial (b), and sagittal (c) dimensions.

of resorption cavities. The masks were prepared by marking the structures to be identified using different colours (labels). All image pixels representing the tooth and dental resorption were filled in all planes of sections, axial, coronal and digital. (figure 2). The mask of the whole tooth is represented by yellow colour (figure 3a). "New masks" were created for the root resorption cavities by setting different grayscale threshold values. The mask representing the root resorption cavity (MRRC) is denoted in blue (Figure 3b). The limits of the resorption area were defined by creating a new mask using the "Clear Mask" option. An "empty mask" was filled with all pixels inside the border.

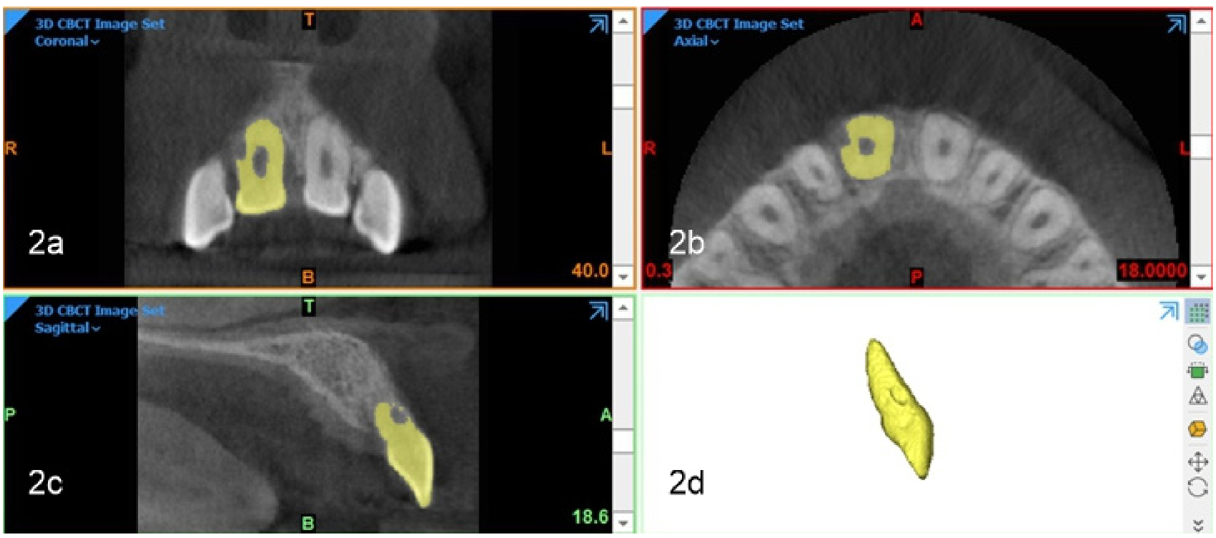

Figure 2. All pixels representing the tooth and dental resorption were filled in all planes of sections, in coronal (a), axial (b), and sagittal (c), mask of the whole tooth (d).

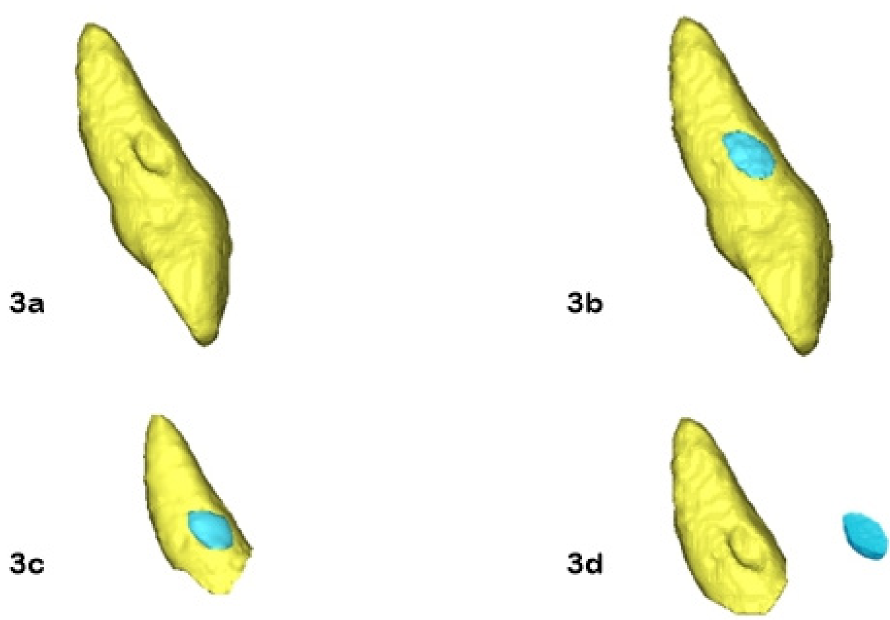

Figure 3. THE MWT with the resorption site (a), the two masks: MWT (yellow) and MRRC (blue) (b), MWT separating from the crown (c), the two separated masks (d).

The "Edit Mask" phase was used manually to check each slice for segmentation and separation from the surrounding structures. Considering the cemento-enamel junction limit, the roots were digitally separated from the crown until the root apex (figure 3c). Finally, the "Boolean Operation" phase was used to separate the two masks (figure 3d). The software then automatically calculated the volumes (mm^3) of both masks: the nominal root resorption cavity volume (NRRCV) and the nominal remaining root volume (NRRV), including the root canal space, which has a much lower radiation density than hard tissues (figure 4). The percentage volumes of root resorption cavities and the remaining root volume were calculated using the following formulas:

$$\%RRCV = \frac{NRRCV}{NRRCV+NRRV} \times 100$$

$$\%RRV = \frac{NRRV}{NRRCV+NRRV} \times 100$$

RRCV: root resorption cavity volume

RRV: remaining root volume

NRRCV: nominal root resorption cavity volume

NRRV: nominal remaining root volume

Statistical analysis

Descriptive analyses of the nominal (NRRCV and NRRV) and percentage (%RRCV and %RRV) volume measures were performed. The ICC was calculated to determine the intraexaminer reliability. Microsoft Excel (Microsoft, Redmond, WA, USA) and SPSS software (Release 13.0, standard version; SPSS, Chicago, IL, USA) were used for these analyses. Assessment of the association between sex and number of sites per tooth was performed using Fisher's exact test.

RESULTS

Sample features regarding sex distribution showed that the 40 CBCT scans evaluated in the present study were equally distributed among men and women [20 subjects were male (50%) and 20 were female (50%)]. Patient´s mean age was 25.5 (±15.7) years (range: 9–72 years). The tooth type distribution was as follows: 30 central incisors, 13 lateral incisors, and 5 canines. Most of the teeth (75%) did not undergo endodontic treatment. The majority of the teeth had just one compromised site, and among those with multiple compromised sites, a minority had fused resorption cavities. Sex did not influence the number of sites affected. The middle third of the root was the most affected site (62.5%) (table 1).

The volumetric measures of root resorption cavities (VRRC) ranged from 0.6 mm^3 to 114.4 mm^3, and the median volume was 13.2 mm^3. The VRRC percentage ranged from 0.37% to 39.44%, with a median value of 4.73%. In contrast, the volumetric measures of root resorption (VRR) ranged from 88 mm^3 to 401.3 mm^3, with and a median value of 212.4 mm^3. The percentage of VRR ranged from 60.34% to 99.63%, with a median

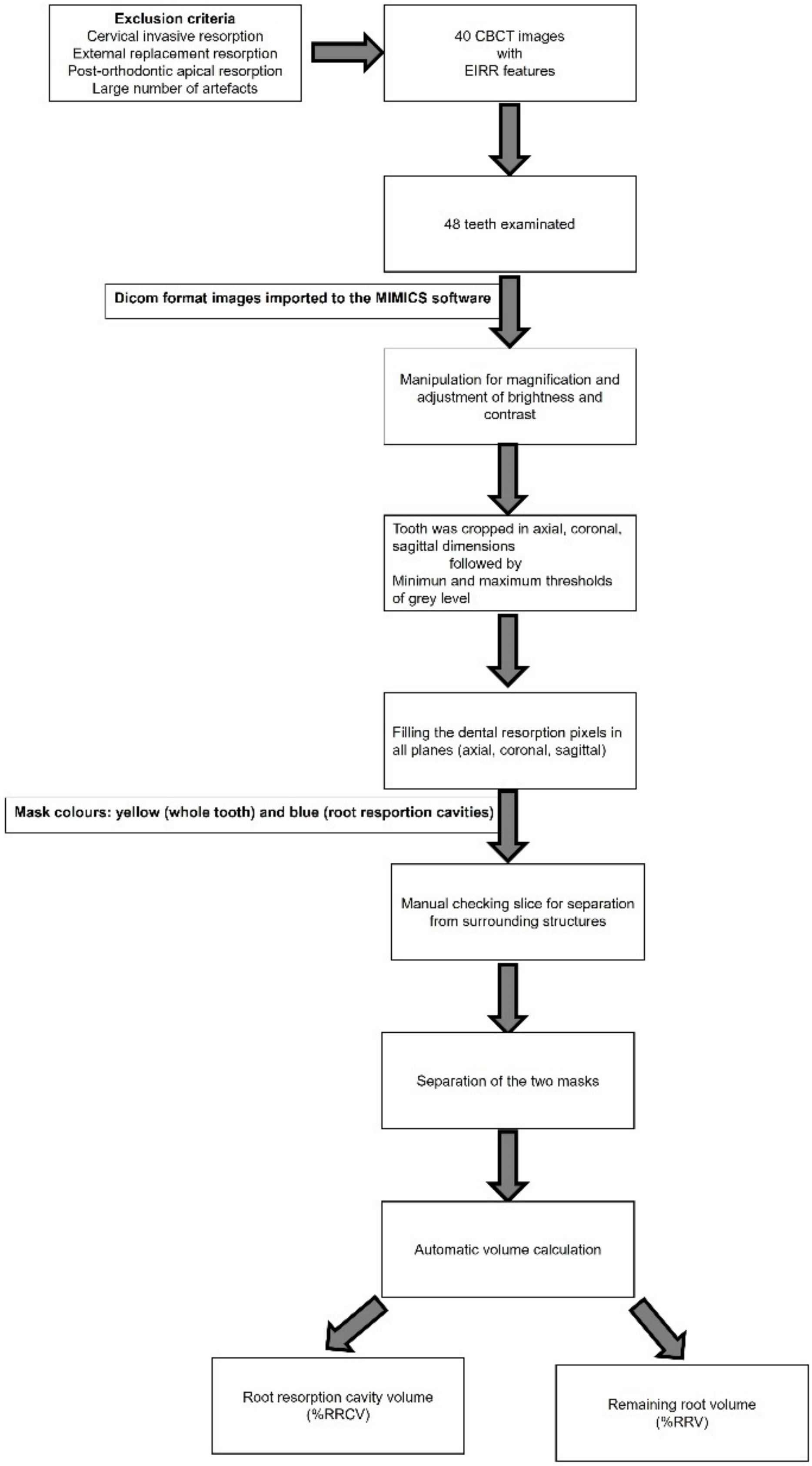

Figure 4. Diagram of the methodology that was used in the present study.

Table 1. Characterization of resorption cavities.

Feature	Frequency	
	n	%
Number of sites per tooth		
1	29	60.4
2	13	27.1
3	6	12.5
Total	48	100.0
Location of resorption		
Apical third	24	50.0
Middle third	30	62.5
Cervical third	19	39.6
Fused/separated cavities		
Fused	6	33.3
Separated	12	66.7
Total	18	100.0

Base: 48 teeth

value of 95.37%. It is possible to see these measurements in a descriptive format, in ascending order of the volume measured in table 2. On the other hand, the variability of the distribution of the measured volume can be seen in figure 5. In this sample, 44 cases had up to 25% resorption cavities and 4 cases had up to 50%. Most of the cases in the sample were relatively small and had medium cavities. The ICC was 0.944 ($P < 0.001$), indicating an excellent or satisfactory reliability index for all measurements performed.

Table 2. Percentage in volume(mm³) of resorption cavities assessed of the specific tooth.

1 of 2

Case	Teeth	Volume (%)		
		Order	Resorption cavities	Remaining root
28	11	1	0.37	99.63
24	11	2	0.56	99.44
5	21	3	0.82	99.18
11	12	4	0.86	99.14
2	11	5	0.95	99.05
3	11	6	1.23	98.77
7	41	7	1.24	98.76
4	12	8	1.36	98.64
23	13	9	1.38	98.62
12	22	10	1.4	98.6
9	11	11	1.43	98.57

Table 2. Percentage in volume(mm³) of resorption cavities assessed of the specific tooth.

Case	Teeth	Volume (%)		
		Order	Resorption cavities	Remaining root
22	11	12	1.48	98.52
1	12	13	1.59	98.41
16	11	14	1.76	98.24
15	11	15	1.87	98.13
37	21	16	2.14	97.86
13	22	17	2.68	97.32
14	11	18	2.83	97.17
17	21	19	2.9	97.1
18	11	20	3.73	96.27
6	31	21	3.93	96.07
30	21	22	4.2	95.8
33	13	23	4.2	95.8
26	23	24	4.67	95.33
10	11	25	4.8	95.2
25	21	26	5.46	94.54
29	11	27	5.55	94.45
8	12	28	5.57	94.43
19	13	29	5.6	94.4
27	21	30	6.19	93.81
31	11	31	6.33	93.67
32	21	32	6.6	93.4
46	11	33	7.59	92.41
34	12	34	7.99	92.01
39	11	35	8.91	91.09
42	22	36	10.42	89.58
38	12	37	11.07	88.93
35	13	38	11.35	88.65
20	21	39	11.63	88.37
43	12	40	11.79	88.21
44	21	41	12.34	87.66
21	12	42	13.68	86.32
45	12	43	14.26	85.74
41	11	44	24.2	75.8
48	21	45	29.16	70.84
47	12	46	33.32	66.68
40	11	47	38.79	61.21
36	21	48	39.66	60.34

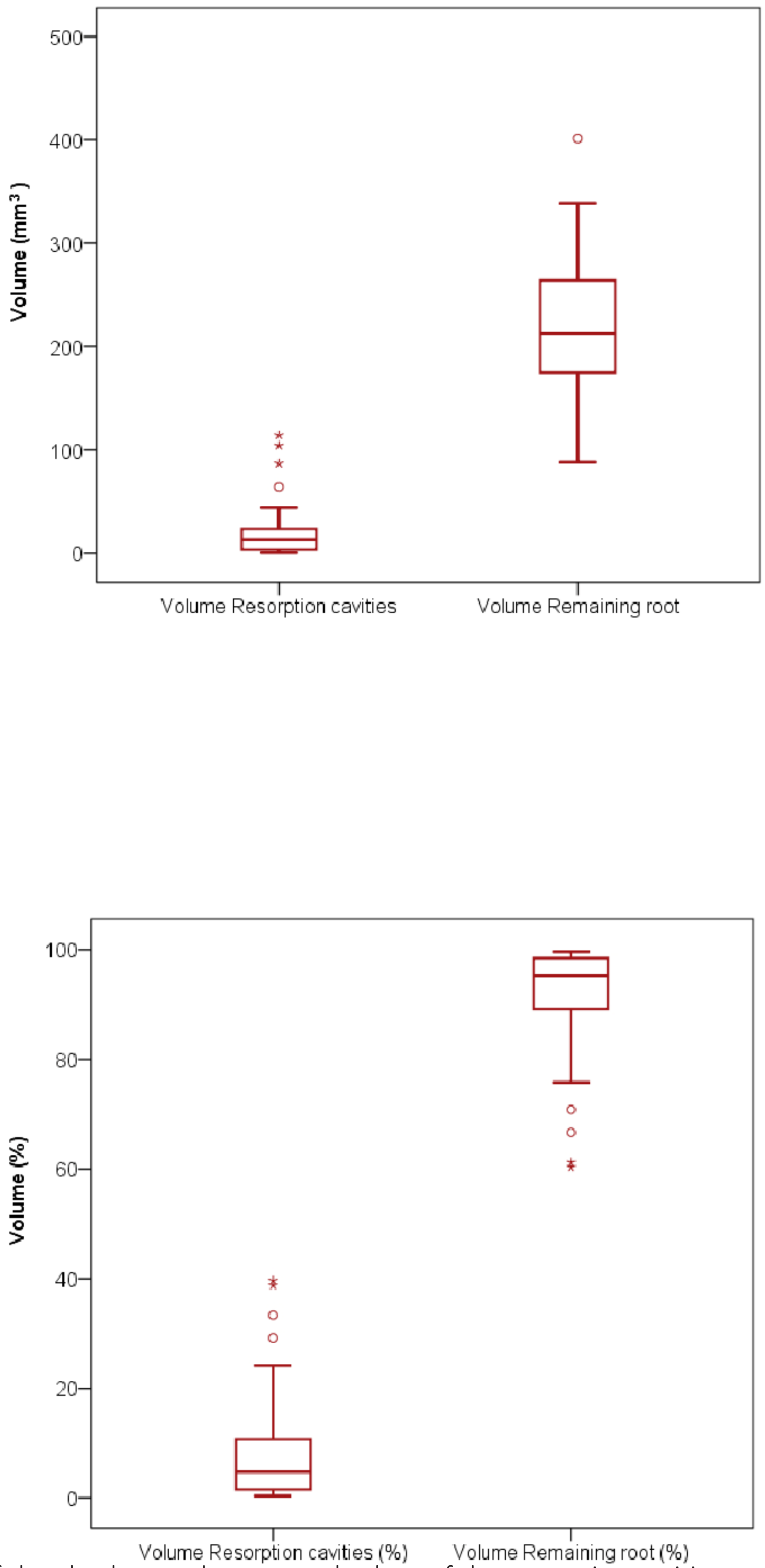

Figure 5. Boxplot of the absolute and percentual values of the resorption cavities and remaining root. The symbols "o" and "*" represent outliers and extreme values, respectively.

DISCUSSION

Many fields of dentistry, such as implantology, orthodontics, prosthodontics, oral surgery, and endodontics, have benefited from new imaging examinations using CBCT [12,13]. In endodontics, CBCT has become an important tool for studying periapical lesions, evaluating dental trauma, planning endodontic surgery, evaluating endodontic therapy, and detecting root resorption [4, 14-16]. The detection and quantification of root resorption is vital for patients and clinicians dealing with the sequelae of root loss [17] and this quantification can be obtained through segmentation.

In recent decades, some methods have been proposed to segment teeth from scanned computed tomographic (CT) images [5,18,19]. Segmentation of anatomical structures from imaging data is common in medical modelling. Liu et al. [20] were the first to validate in vivo segmentation in CBCT to evaluate dental volumetric determinations of the entire tooth in the field of orthodontics for biomechanical considerations. Matny et al. [21] used segmentation for the volumetric quantification of CIR cavities in vivo and correlated it with Heithersay classification and prognosis. They concluded that information about volumetric root loss could be helpful in clinical decision making and treatment planning.

Similarity segmentation techniques are based on object inheritance with characteristics close to a predefined property or value. One of the simplest and most widely used methods for threshold segmentation is classifying pixels according to the thresholds. The thresholding technique aims to highlight sets of pixels in an image that have the same range of gray levels in order to extract attributes from the image or split the image. Currently, few studies have evaluated segmentation to calculate the root resorption volume as a diagnostic tool for CBCT examinations [9,18-22]. The CBCT segmentation method showed the same accuracy in volumetric measurement of teeth in vivo as micro-CT did in vitro [22].

In this study, only anterior teeth were included because EIRR is the most frequent sequela of traumatic dental injuries affecting the anterior teeth [23,24]. We were unable to determine the specific aetiology of EIRR in each of the evaluated teeth because the sample was selected retrospectively from the Oral and Maxillofacial Radiology Service of the School of Dentistry database. In addition to patients from the faculty's clinics, those from private clinics assisted in this Radiology Service for which we have no clinical data.

Root resorption cavities can be detected with greater sensitivity and specificity with high (0.2 mm) and medium (0.3 mm) resolution CBCT images [25,26]. Our images were scanned with a voxel size of 0.076 mm. CBCT and images obtained was improved due to using the small voxel, so the discriminate objects of different attenuation separated by very small distances was chosen viewing plan [26,27].

Segmentation of the teeth using CBCT allows for virtual modelling of the entire dentition, revealing the root anatomy [18]. Currently, there is no standard method for segmentation. In the present study, because manual segmentation was used, it was possible to include all the pixels that made up part of the resorption defects. Therefore, the smallest volume is 0.37 mm^3, contrary to the results of Wang et al. [22] who concluded that while the accuracy of the method was "fairly good" in detecting simulated resorption cavities larger than 3.47 mm^3, it was insufficient for resorption cavities smaller than 1.07 mm^3. Our sample had small resorption cavities, most of which showed up to a 25% loss. The linear measurements system is related to the possibility of assessing lesions on three planes of space, providing values for the longest diameter on each plane, which is sometimes impossible to measure due to the size and extent of the lesions. In contrast, segmentation provides volume values of real sizes even in small cavities [6].

In the Materialise MIMICS software, the investigator can use the "Edit Masks" option to erase artefacts and segment the teeth completely, provided that normal tooth structures are not erased. In the present study, we focused on segmenting the root separated from the crown because the density of a tooth varies greatly from crown to apex, requiring a lower threshold. This study has some limitations that should be considered. The sample size was small, and only one examiner segmented the images. Further, most of the cases in the sample had small cavities.

Ideally, the three dimensions of root resorption cavities should be represented by measuring the volume of the root structures. However, the volumetric quantification of resorptive defects has been a challenge for many researchers [19, 22-26]. Some have already proposed indices to classify the magnitude of resorption cavities [3,4]. There are some limitations associated with the use of a two-dimensional image, such as the area and size of a lesion in the buccolingual plane, characteristics of the lesion that could be smooth or rough, and changes that appear over time when comparing films to detect progression or healing.

In the present study, the segmentation technique allowed the identification of the number of affected sites, the location of resorption, and fused or separate resorption, in addition to the calculation of the volume of the root resorption cavity and the volume of the remaining root; the location of the root resorption cavities and their magnitude were precisely determined. Precise indication of the area of resorption cavities is an important issue because loss of structure in the cervical or medial region of the root is more severe due to its proximity to the gingival sulcus. A longitudinal study evaluating the location and extent would be ideal to propose a new classification and treatment prognosis. For root resorption, the recommendation is to analyse the resorption cavity and the remaining structure because of the complex anatomical characteristics of individual defects of root resorption; further, volume should be used more frequently. Monitoring volume loss could also be an ideal approach to follow-up adequate dental support and the entire volume of the remaining root to support subsequent clinical decisions.

CONCLUSION

Segmentation of CBCT images is effective for volumetric assessment of EIRR cavities in vivo, even if they are small. Further longitudinal studies are required to explore its application in the diagnostic and prognostic evaluation of such lesions.

Collaborators

TMP Amaral, design of the work; the acquisition, analysis, interpretation of data for the work; and drafting the work, study concepts, study design. JV Bastos, design of the work; the acquisition, analysis, interpretation of data for the work; and drafting the work, study concepts, study design, VHF Queiroz AND RMC Milagres, data acquisition. EN Abdo, final approval of the version to be published. MV Abreu: manuscription editing. CB Brasileiro, Manuscription editing. DD Chetan, quality control of data and algorithms. LA Pimenta, final approval of the version to be published.

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