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Estudo comparativo no diagnóstico por imagem de reabsorções radiculares externas naturais e artificiais

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Tese apresentada ao Programa de Pós-Graduação em Odontologia da Pontifícia Universidade Católica do Paraná, como parte dos requisitos para obtenção do título de Doutor em Odontologia, Área de Concentração em Clínica Odontológica Integrada (Ênfase em Radiologia).

Orientador: Profa. Dra. Vânia Portela Ditzel Westphalen

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TERMO DE APROVAÇÃO

ANGELA GRACIELA DELIGA SCHRODER

ESTUDO COMPARATIVO NO DIAGNÓSTICO DE REABSORÇÕES RADICULARES EXTERNAS NATURAIS E SIMULADAS POR MEIO DE MICROTOMOGRAFIA, TOMOGRAFIA COMPUTADORIZADA DE FEIXE CÔNICO E RADIOGRAFIA PERIAPICAL DIGITAL

Tese apresentada ao Programa de Pós-Graduação em Odontologia da Pontifícia Universidade Católica do Paraná, como parte dos requisitos parciais para a obtenção do Título de **Doutor em Odontologia**, Área de Concentração em **Radiologia**.

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Ao pai criador pelo dom da vida
Aos pais terrenos por oportunizá-la

SUMÁRIO

RESUMO

Objetivo: o objetivo desse estudo foi comparar a acurácia da radiografia periapical digital e da tomografia computadorizada de feixe cônico no diagnóstico de cavidades naturais e artificiais de reabsorção radicular externa tendo como padrão de referência a microtomografia

Material e métodos: 126 dentes foram submetidos à microtomografia e avaliados quanto a presença ou não de cavidades naturais de reabsorção radicular externa. Após, os dentes foram divididos em 3 grupos: (1) controle, (2) com cavidades de reabsorção radicular externa naturais e (3) com cavidades de reabsorção radicular externa artificiais. As tomografias computadorizadas de feixes cônicos e as radiografias periapicais digitais em três angulações diferentes foram avaliadas por três avaliadores treinados. A especificidade e sensibilidade dos dois métodos foi calculado, bem como a acurácia.

Resultados: A TCFC apresentou acurácia superior que a radiografia periapical. A sensibilidade e especificidade das TCFC na detecção das reabsorções radiculares naturais foi menor que a encontrada nas reabsorções artificiais.

Conclusão: A configuração, ou seja, tamanho, forma e profundidade, das cavidades naturais de RRE são diferentes e mais difíceis de serem observadas que as cavidades artificiais . A tomografia computadorizada de feixe cônico permanece como o melhor método para a detecção da RRE, mas a acurácia encontrada com a TCFC na detecção das cavidades naturais de RRE não foi a mesma que a encontrada para as cavidades artificiais de RRE.

INTRODUÇÃO GERAL

A reabsorção radicular externa (RRE) é um processo biológico multifatorial que pode ser definido como a dissolução fisiológica ou patológica dos tecidos mineralizados, incluindo dentina, cemento e osso alveolar adjacente, como um resultado da atividade celular osteoclástica. Ela pode iniciar-se após trauma dentário, movimento ortodôntico, clareamento interno, tratamento periodontal e eventos idiopáticos.[1, 2] Aparece comumente como um efeto colateral do tratamento ortodôntico que resulta em perda permanente da estrutura dentária no ápice radicular[3]; mas entre 7 a 13% da população que nunca se submeteu a nenhum tratamento ortodôntico também tem algum tipo de RRE. [4]

O diagnóstico da RRE é difícil devido a falta de sintomas patognomônicos, levando à necessidade de um método de diagnóstico mais preciso para a sua detecção.[5] No passado, o exame radiográfico era a primeira escolha e o método mais comumente utilizado para obter-se um diagnóstico inicial.[5] Alguns estudos demonstraram que as RRE menores que 0.60 mm de diâmetro e 0.30 mm de profundidade não podem ser detectadas com exames radiográficos; além de que RRE nas faces vestibular ou lingual e de severidade leve são menos diagnosticadas por esses exames.[6, 7] . Com a chegada da radiografia digital, pesquisas nessa área continuaram a ser realizadas, demonstrando que a mesma é mais sensível na detecção de RRE do que as radiografias convencionais.[8]

O uso de tomografia computadorizada foi sugerido para a avalição da RRE, entretanto, ela apresenta algumas limitações na detecção de RREs de grau leve no terço apical.[9] Com o advento da tomografia computadorizada de feixe cônico (TCFC), ela tornou-se uma alternativa promissora, porque fornece imagens tridimensionais das estruturas dentárias com resoluções milimétricas com qualidade diagnóstica.[5] A TCFC tem um menor tempo de aquisição, menor dose de radiação e menor custo quando comparada com a tomografia convencional[10], mas a dose ainda é significantemente maior que a radiografia periapical digital.

Vários estudos compararam a radiografia convencional com a TCFC para a detecção da RRE e observou-se que a detecção de RRE foi maior na TCFC do que com radiografia convencional, sugerindo que as imagens TCFC são uma ferramenta viável para a localização e detecção da RRE.[3, 5, 10] Uma revisão sistemática[11] realizada em 2017 comparou a acurácia da TCFC e da radiografia periapical para a detecção da RRE. Os resultados sugeriram que a TCFC poderia ser viável para detectar a presença de RRE na prática clínica e tem uma eficácia diagnóstica maior que a radiografia periapical, mas todos os estudos incluídos nessa revisão usaram RRE artificiais como referência. Já os estudos realizados in vivo para comparar a eficácia da TCFC no diagnóstico das RRE não são convincentes, devido à falta de um teste de referência apropriado in vivo.[11]

Então o objetivo desse estudo foi comparar a acurácia da radiografia periapical digital e da TCFC no diagnóstico *in vitro* das reabsorções radiculares externas naturalmente produzidas tendo a microtomografia como padrão de referência.

ARTIGO 1 - VERSÃO EM INGLÊS

Morphological study of external root resorption: a microtomography study

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Abstract

Introduction: root resorption (RR) may occur on the internal or external surface of the tooth, but differential diagnosis is difficult using conventional radiography**. Objective**: this work aimed to study the external root resorption (ERR) by analyzing the micro tomography of ex vivo teeth as a preliminary part of a subsequent study, because it is known that even those teeth that have not undergone any orthodontic movement or trauma may present ERR lacunae. **Methods:** 126 teeth were scanned in a Skyscan 1172 with thick 9µm in medium resolution. The images were evaluated in specific software by two experienced radiologists properly calibrated (kappa test). **Results:** Of the 126 evaluated, 41 teeth had ERR and of these 11 teeth presented more than one RR gap per tooth. The premolars showed more RR with (29.8%), followed by molars (27.7%), canines (23.4%) and incisors (19.1%), and has the same relationship with the third root and where it occurs independent of the face. **Conclusions:** It was possible observed that the arquitecture of the RR cavitys are heterogeneous because there was not a definite shape; another interesting finding was that in this study there is a relationship between ERR and root one-third, but not with dental group.

Key words: X-Ray Microtomography. Root Resorption. Diagnosis.

INTRODUCTION

Root resorption (RR) represents the loss of dental hard tissue[1] caused by inflammation initiated after dental trauma, orthodontic movement, internal bleaching, periodontal treatment and idiopathic events[2, 3]. It appears as a common side effect of orthodontic treatment that results in permanent loss of tooth structure at the radicular apex[4]; but it is known that between 7 to 13% of the population never underwent orthodontic movement also has some type of root resorption[12,13]. RR may occur on the internal or external surface of the tooth, but differential diagnosis is difficult using conventional radiography[14].

The diagnostic efficiency of ERR is an essential aspect to the definition of the adequate therapeutic approach and eventually to success in treatment[15]. The periapical radiograph is the most widely used method to diagnose the presence of apical external root resorption (ERR) but there must be a certain degree of resorption to make it detectable. However, there are many limitations to the image acquisition of ERR using conventional radiography, since the three-dimensional (3D) structure is displayed on a two-dimensional (2D) image[15]. There may be cases where the identification of the type

ERR, its degree of progress and its limits are definitely not possible to determine. In these cases you can use cone beam computed tomography (CBCT) as an alternative, for the detection of resorption, determining its extent and location will be much easier due to the various directions of the section planes, increasing the precision of diagnose[16]. CBCT is characterized by extraordinary accuracy, rapid scan time, reduced radiation dose and unmatched 3D image reconstruction capabilities[15].

Recently, micro tomography proved to be a fast and accurate method with high resolution, providing higher quality imaging[17]. It can also be used to detect and quantify the reabsorption of craters in the root surfaces of extracted teeth which have or not been submitted to orthodontic treatment[17]. When compared to the digital periapical X-rays in the evaluation of ERR, radiographic method showed a specificity of 78% and a sensitivity of 44%, that means that the radiographic method can detect less than 50% of the cases detected by micro tomography[18].

So, this work aimed to study the ERR by analyzing the microtomography of ex vivo teeth as a preliminary part of a subsequent study, because it is known that even those teeth that have not undergone any orthodontic movement or trauma may present ERR lacunae. And to find out if there is relationship among size and shape with one-third, one-face and dental group.

MATERIAL AND METHODS

This work was carried out after the approval of the Ethics Committee under the CAAE number: 50214515.0.0000.0020, featuring an observational cross-sectional study with a sample of 126 ex vivo teeth of the lower arch, 36 incisors, 18 canines, 36 premolars and 36 molars belonging to the bank of teeth, a number which enables the assembly of nine lower dental arches, which will be part of a later study. The inclusion criteria of the teeth in the sample were not present any kind of root destruction, dental crowns that enabled its morphologic classification of the dental group, absence of carious / abrasion cavity in the cervical region.

The teeth were randomly selected from the tooth bank, using a magnifying glass (3x magnification) and natural light, until reaching the number determined for the study. After the teeth were examined by two evaluators to confirm the anatomy, which tooth group each tooth belonged and also to verify the inclusion criteria. They received a randomized number (software program) from 1 to 126..

All teeth were scanned by micro-CT scanner (SkyScan 1172, Kontich, Belgium), detectability of isotropic details 9µm in medium resolution camera X-ray 11MP with total correction of distortion, 3D reconstruction by a computer cluster, which allows nondestructive viewing fine-scale objects. For scanning the crowns of the teeth were embedded in polystyrene, a material that does not interfere with image acquisition, in groups of 6 teeth, incisors, canines and premolars and three groups of teeth to the molars due to limitation of the micro-CT´s working area.

After scanning, the images were evaluated in NRecon software (SkyScan NV, Belgium), which allows viewing of the teeth in the axial, sagittal and coronal planes, and the presence or absence of ERR lacunae in the apical, middle and cervical; the face where the gap occurred has also been reported, being classified as buccal, lingual and proximal. Data were recorded in a spreadsheet and the analysis was repeated one week later, and the two moments all 126 teeth were evaluated on the same day, by two evaluators, the kappa value for inter and intra-rater agreement was greater than 0.80.

RESULTS

The results were analyzed and tabulated using SPSS software (version 24.0: SPSS Inc., Chicago, Il, USA), by two blinded examiners and can be seen in Tables 1 to 3.

Of the 126 teeth evaluated, 85 teeth did not have ERR and 41 teeth had ERR, and of these 11 teeth presented more than one RR gap per tooth: 4 incisors, 2 canines, 2 premolars and 3 molars, making a total of 54 resorption gaps..

Table 1. Relationship of presence or absent of external root resorption in the different dental groups

		TOOTH				Total
		INCISOR	CANINE	PREMOLAR	MOLAR	
Micro-CT	Without RR	29_a (20,9%)	11_a (7,9%)	23_a (16,5%)	25_a (18%)	88 (63,3%)
	With RR	11_a (7,9%)	10_a (7,2%)	15_a (10,8%)	15_a (10,8%)	51 (36,7%)
Total		40 (28,8%)	21 (15,1%)	38 (27,3%)	40 (28,8%)	139 (100%)

Source: raw data, Chi-square Test= 0.445, RR= root resorption

Table 2. Relationship of external root resorption and one-root third according of different dental groups

		TOOTH				Total
		INCISOR	CANINE	PREMOLAR	MOLAR	
Root Third	Without RR	29_a (20,9%)	11_a (7,9%)	23_a (16,5%)	25_a (18%)	88 (63,3%)
	Apical	9_a (6,5%)	6_a (4,3%)	2_b (1,4%)	9_a (6,5%)	26 (18,7%)
	Medium	0_a (0%)	$1_{a,\,b}$ (7%)	7_b (5%)	6_b (4,3%)	14 (10,1%)
	Cervical	$2_{a,\,b}$ (1,4%)	3_b (2,2%)	6_b (4,3%)	0_a (0%)	11 (7,9%)
Total		40 (28,8%)	21 (15,1%)	38 (27,3%)	40 (28,8%)	139 (100%)

Source: raw data, Chi-square Test=0,008, RR=root resorption.

Table 3. Relationship of external root resorption and root surface according of different dental groups

		TOOTH				
		Incisor	Canine	Pre-molar	Molar	Total
Root surface	Without RR	29_a (20,9%)	11_a (7,9%)	23_a (16,5%)	25_a (18%)	88 (63,3%)
	Proximal	9_a (6,5%)	6_a (4,3%)	9_a (6,5%)	13_a (9,4%)	37 (26,6%)
	Buccal	2_a (1,4%)	2_a (1,4%)	5_a (3,6%)	2_a (1,4%)	11 (7,9%)
	Lingual	0_a (0%)	2_b (1,4%)	$1_{a,\,b}$ (0,7%)	0_a (0%)	3 (2,2%)
Total		40 (28,8%)	21 (15,1%)	38 (27,3%)	40 (28,8%)	139 (100%)

Source: raw data, Chi-square Test=0.262, RR=root resorption

The morphological aspect, it was observed that resorption lacunas are quite heterogeneous because there was not a definite shape, since it ranges from relatively oval cavities, but with irregular edges, to rectangular and conical cavities, and others completely shapeless. They have a variety of extensions and depths as we can see in Figures 1 and 2, that is, the cavities present a heterogeneous pattern even in the same cavity and in the same tooth.

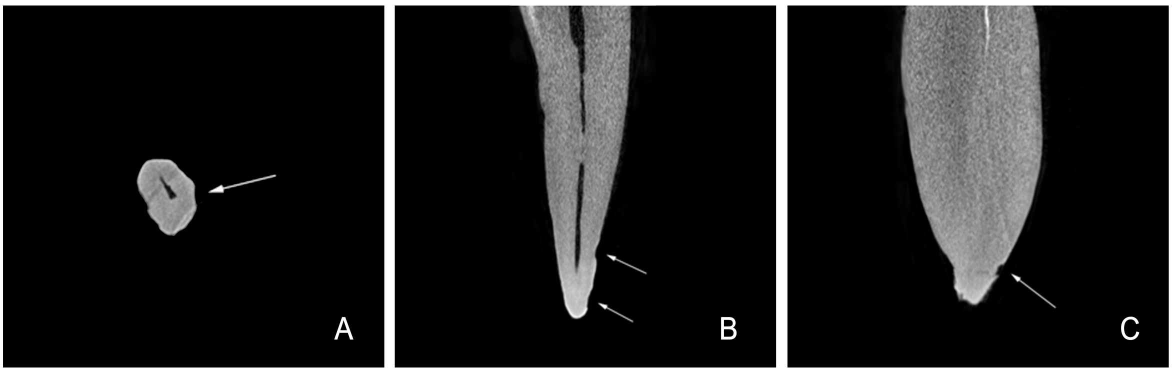

Fig 1 Microtomographic view of a lower canine (tooth number 49) with root resorption area marking the apical third, with (A) axial (B) and coronal (C) sagittal section

The size of the cavities was calculated in relation to their volume in cubic millimeters by NRecon software (SkyScan NV, Kontich, Belgium), varying from 2.46 mm^3 to 3.11 mm^3, corresponding to cavities 1.67 mm and 1.81 mm in diameter, respectively. A cavity 0.3 mm in diameter would be considered small. That is, all the cavities observed in this study can be classified as large cavities, since the literature cites values from 0.3 mm to 0.5 mm for small cavities, 0.7 mm to 1mm for medium cavities and greater than 1 mm for large cavities[16, 19-23].

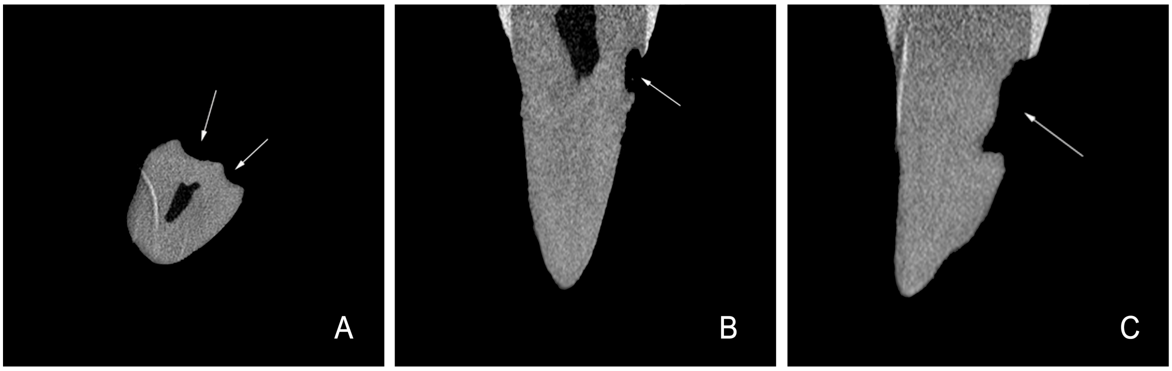

Fig 2 Microtomographic view of a lower premolar (tooth number 71) with root resorption area marking the apical third, with (A) axial (B) and coronal (C) sagittal section

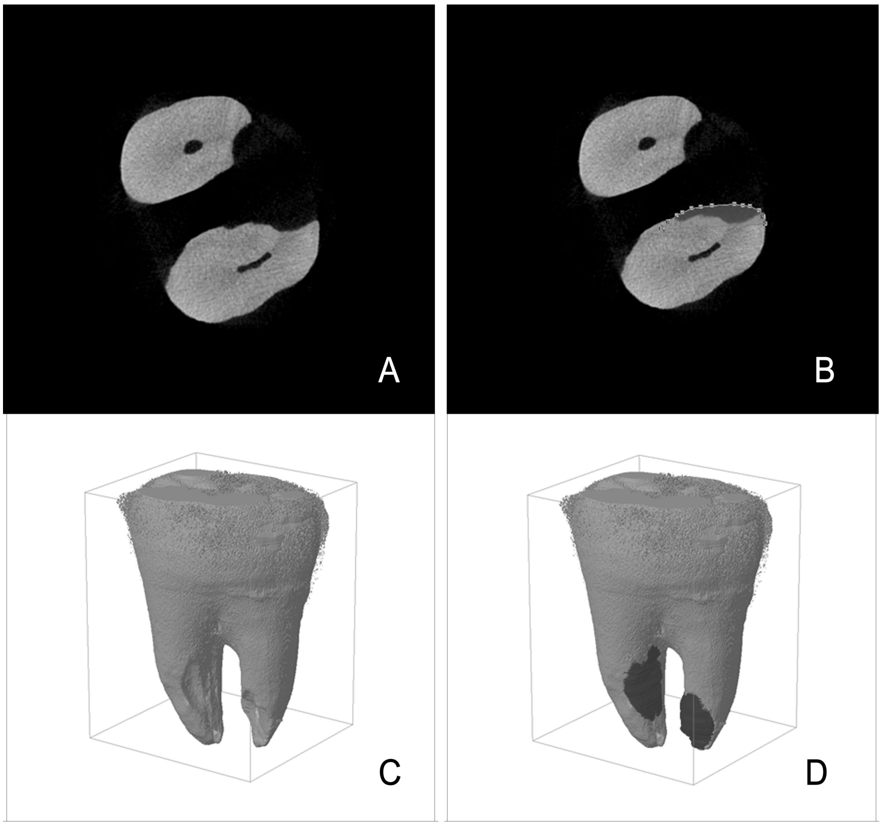

Fig 3 Microtomographic view of a mandibular molar with reconstruction of root resorption area in an (A) axial section and (B) tridimensional viewer.

The relationship of ERR in this study was 36.7%. The premolars and molars (10.8%) was more teeth presented ERR, followed by incisors (7.9%) and canines (7.2%), but this result was not statistically significant (Chi-square= 0.445) (Table 1).

The presence of ERR showed statistically significant relationship with the root one-third (Chi-square=0,008) but not with root surface where it occurs (Chi-square=0,262) as can be seen in Tables 2 and 3.

DISCUSSION

All permanent teeth are subject to present clinically irrelevant ERR that it is not detectable by X-ray and as a rule does not compromise the functional capacity or tooth longevity[24]. Of the 126 teeth analyzed in this study, 36.7% teeth had some ERR. An example of the configuration and architecture of these RR lacunas can be observed in Figures 1 and 2. All RR occurs tridimensional, and its bidimensional radiographic evaluations is not geometrically accurate, yielding questionable extent values of the lesions[25].

The premolar and molar had the higher prevalence of ERR in this study (10.80%), and it does not agree with the literature, which states that the most likely teeth to make ERR are the upper and lower incisors, due to factors such as root configuration, periapical anatomy and bone architecture[5, 26-28]. Another study stated that central and lateral incisors are also the most prevalent teeth with ERR, especially in studies orthodontic[29-33] where it is called orthodontics induced external apical root resorption (OIEARR). Already in this study the premolars and molars had a higher prevalence of ERR, a justification for this finding may be the fact that we worked with micro tomography, which show the teeth at all levels, as most other studies used periapical radiographs(3,4,6,8) where there is the superimposition of images; but even in studies using CT scan[5, 22-28], the values found in micro tomography were higher due to the detail of the image.

Radiographic identification of RR lacunae can be influenced by the location on the tooth[34]. In our study it was noted that RR is correlated with the root one-third (apical, middle and cervical) but not with root surface (proximal, buccal and lingual) and dental group (incisor, canine, premolar, molar).

When we tried to establish a relationship between dental group and the root one-third or root surface, we noted that there was a preference for the proximal surface as in a study where mesial and distal surfaces have considerably more resorption than the others[35]; whereas other showed that the lacunae of RR was located on all surfaces[36].

Regarding the root one-thirds, the apical one-third was the most prevalent with RR, that confirms previous studies showing that specially after applications of an orthodontic force, small areas of surface resorption always occurs, with high incidence of apical RR[18, 31].

One limitation of this study was to have used teeth from a tooth bank, which did not allow the knowledge of the previous clinical history of the patients, what diseases they had, the treatments that the tooth was submitted to or traumas. Ideally, teeth should be used, which dental and medical history should be known to be able to correlate with possible RR.

CONCLUSIONS

It was possible observed that the morphological aspect of the RR cavities are quite heterogeneous because there was not a definite shape, since it ranges from relatively oval cavities, but with irregular edges, to rectangular and conical cavities, and others completely shapeless. They also have a variety of extensions and depths even in the same tooth.

Another interesting finding was that in this study there is a relationship between ERR and root one-third, but not with dental group.

REFERENCES

ARTIGO 2 - VERSÃO EM INGLÊS

Accuracy of digital periapical radiography and cone beam computed tomography for diagnosis of natural and simulated external root resorption

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Ethical approval: The Ethics Committee at the Catholic University of Paraná under the CAAE number: 50214515.0.0000.0020 agreed with the study protocol. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

ABSTRACT

Objective: To compare the sensitivity and specificity of digital periapical radiography and cone beam computed tomography (CBCT) in the detection of natural and simulated external root resorptions (ERR) having microtomography (micro-CT) as a reference standard.

Material and Method: 126 teeth were scanned by the Skyscan micro-CT scanner, model 1172 and the images were evaluated using NRecon software. After micro-CT, the teeth were divided in 3 groups: Control: 42 teeth that did not present any ERR cavities; Natural: 42 teeth that presented one or more ERR cavities; and Artificial: 42 teeth without ERR, but perforations were created to simulate the cavities. Ortho, mesio, and distoradial digital periapical radiographs and CBCT images were obtained and the images were evaluated by two double-blinded qualified radiologists.

Results: The sensitivities and specificities for the radiographic and tomographic methods were 78.18% and 97.27%, and 59.52% and 97.62%, respectively. Within the individual groups, both methods had lower sensitivity and specificity for natural and artificial resorptions, and the differences were statistically significant.

Conclusion: CBCT was the best method for the detection of ERR. Only 74.5% of natural ERR gaps were observed on the digital periapical radiographs and 94.5% in CBCT; on the other hand, in the artificial group this number increased to 81.8% and 100%, respectively. The configuration of the natural ERR gaps is different from those artificially simulated and is much more difficult to observe.

KEY WORDS: Cone-Beam Computed Tomography; Dental Radiography; X-Ray Microtomography; root resorption; diagnostic imaging

INTRODUCTION

The external root resorption (ERR) is the lost of dental tissue, cemento or dentina, as a result of the action of odontoclastic cells [3], caused by inflammation and it can occur in different situations as dental trauma, apical infection, internal bleaching, periodontal treatment, ectopic eruption and the most common in the presence of orthodontic movement [2, 16, 37]. The severity of ERR can lead to a compromised crown-to-root ratio and compromised tooth functioning [4].

As ERR did not present clinical sintomatology [6, 8], it is almost fully detected by x-rays exams [16], being the periapical radiography is the most commonly used method for diagnosing ERR [32]. The principal problem with diagnosing ERR by periapical radiography is due to the fact that the three-dimensional anatomy of the region being radiographed is compressed into a two-dimensional image [3] and its diagnostic accuracy is affected by anatomic superposition and angle of the x-ray spectrum [38].

Cone beam computed tomography (CBCT) can be used as an alternative. The determination of its extension and location will be facilitated by the various senses in the cutting planes, increasing the detection of the same ones (2). Since the early diagnosis of ERR during orthodontic treatment is essential to identify teeth at risk of developing severe reabsorption during the same [39]. High cost and radiation exposure make this modality generally unsuitable as the first choice for dental imaging [40]; for example, in the case of root resorption (RR) and using it as a diagnosis or control exam.

With the evolution of imaging technology, microtomography (micro-CT) has been widely used in dental research as a non-invasive diagnostic technique, being a high resolution method that provides comprehensive and accurate evaluation of dental tissues and periodontal disease in a three-dimensional perspective (3D) [41]. In addition, high resolution allows the method to detect tiny resorption craters before ERR is diagnosed [4].

In the study by Creanga et al [16], the authors cite that the external root resorption cavities created artificially in the teeth *in vitro* do not exactly reproduce the natural injury ERR. Thus, the objective of this study was to compare the diagnostic value of CBCT and digital periapical radiography in the detection of natural ERR in vitro and to determine whether the ability to detect defects with these two modalities was influenced by the type of RR produced, artificially made cavities or natural cavities, with micro-CT as a reference standard.

METHODOLOGY

This cross-sectional observational study included a sample of 126 *ex-vivo* teeth (Ethics Committee CAAE: 50214515.0.0000.0020) from a previous study, number sufficient to complete 9 jaws with 14 teeth each. The teeth were randomly selected from a tooth bank, using a magnifying glass (3x magnification) and natural light, until reaching the number determined for the study. The teeth were examined by two evaluators to confirm the anatomy, which tooth group each tooth belonged, and also to verify the inclusion criteria.

Inclusion criteria were as follows: no root destruction, complete root formation, absence of caries/abrasions in the cervical region, and no endodontic treatment. The presence/absence of ERR in all teeth were determined by a micro-CT examination, since it is known that between 7 and 10% of the people that have never undergone orthodontic movement have some type of ERR [12, 13].

The micro-CT images were acquired by the Skyscan microtomography scanner, model 1172 (Bruker microCT, Kontich, Belgium) at a resolution of 9 μm at 100 kV, milliamperage at 100 μA, and energy of 10 W. The raw images were reconstructed using NRecon software, version 1.4.4 (Skyscan, Kartulzersweg 3B 2990 Kontich, Belgium). The reconstructed images of the scanned teeth were analyzed using CTvox software, version 3.1.1 (Skyscan N.V., Kontich, Belgium), which enables visualization of the teeth in the axial, sagittal, and coronal planes to determine if ERR gaps exist in the apical, middle, and cervical thirds, as well as the surface of the root (buccal, lingual or proximal) where the gap occurred (Figure 1A e 2A).

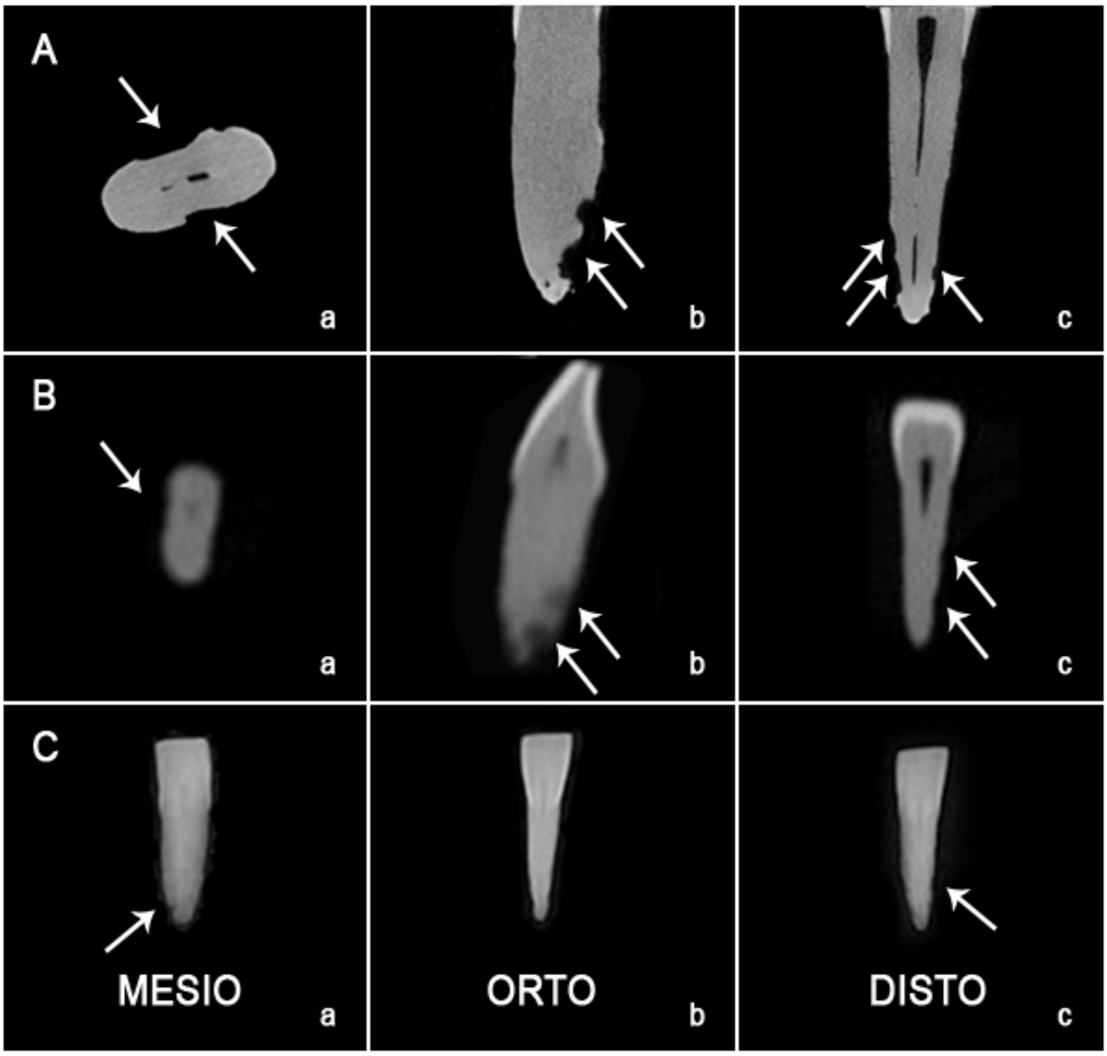


Figure 1: (A) Microtomography of a lower incisor (tooth number 12) with the marking of the root resorption area in the apical third as seen on the (a) axial, (b) sagittal, and (c) coronal cuts. (B) CBCT of the same lower incisor as seen on the (a) axial (b) sagittal, and (c) coronal cuts. (C) Periapical radiograph of the same lower incisor as seen on the (a) mesio, (b) ortho, and (c) distoradial views.

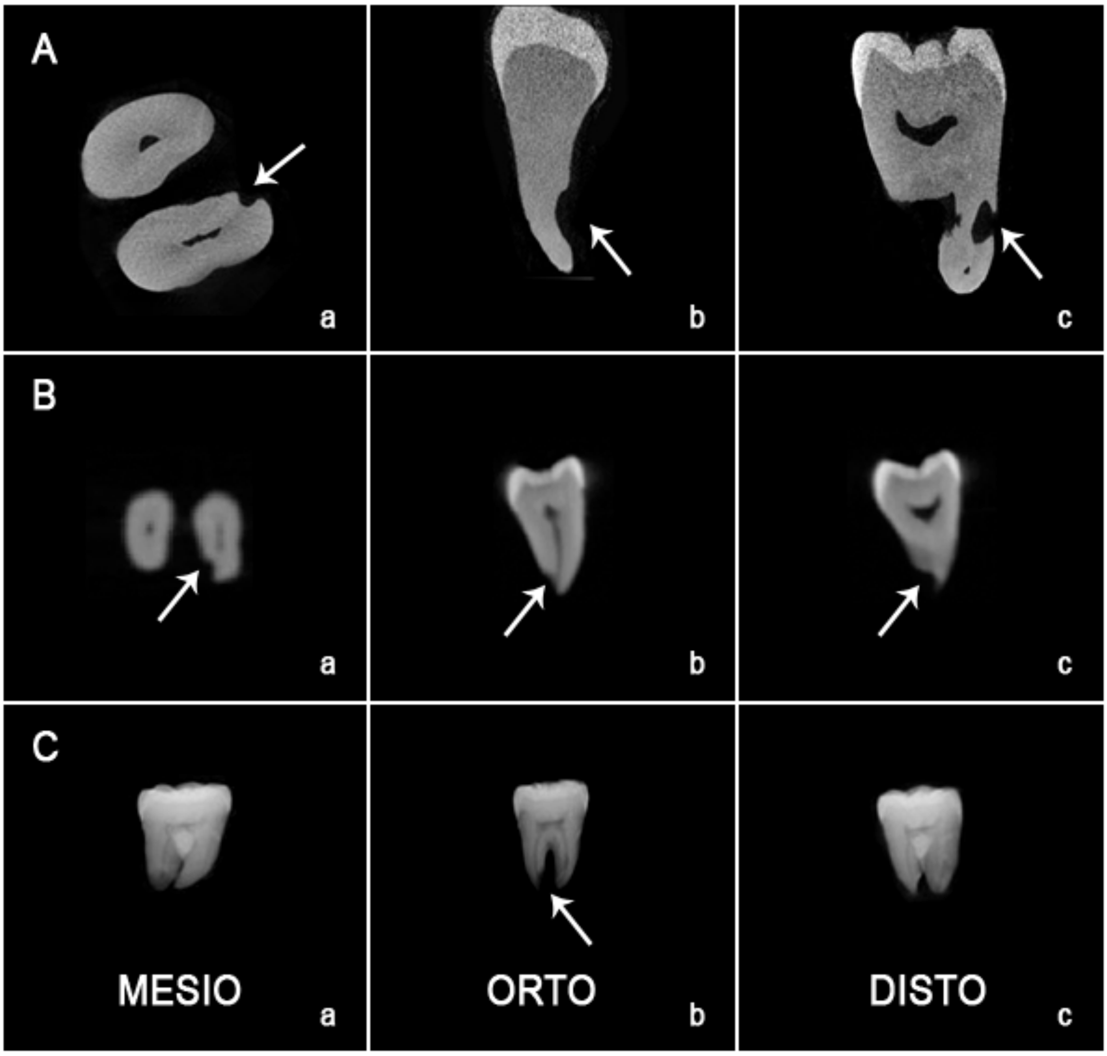


Figure 2: (A) Microtomography of a lower molar (tooth number 98) with the marking of the root resorption area as seen on the (a) axial, (b) coronal, and (c) sagittal cuts. (B) CBCT of the same lower incisor as seen on the (a) axial, (b) coronal, and (c) sagittal cuts. (C) Periapical radiograph of the same lower molar as seen on the (a) mesio, (b) ortho, and (c) distoradial views.

After obtaining the micro-CT images, the teeth were divided into the following groups: (1) Control: 42 teeth without ERR cavities; (2) Natural: 42 teeth with one or more ERR cavities (total of 55 cavities), and (3) Artificial: 42 teeth without ERR gaps in micro-CT, but artificial gaps were created to simulate cavities (55 cavities) (Table 1). The division between control and artificial group was randomized by a computed software, the same number of teeth and cavities found in natural group were used in the artificial group. In each tooth selected for the Artificial group (42 teeth), one or two cavities were created to simulate ERR, totaling 55 gaps depending on the dental group, with variations of root surfaces and root thirds randomly distributed (Table 1). The cavities were made with 0.7 mm diameter drill bits (DORMER® – HSS – High speed steel) with 0.7 mm depth on the buccal, lingual, and proximal faces and cervical, middle, and apical root thirds. The drills were coupled to a milling machine (INTOS®) and the teeth were secured by means of locking pliers (GEDORE VANADIUM®). The pliers were attached to a vise of the milling machine itself, so that it would remain stationary during the drilling [6].

Table 1. Distribution of teeth throughout the 3 groups: artificial, natural and control

	ARTIFICIAL		NATURAL		CONTROL	TOTAL	
	Tooth	Cavity	Tooth	Cavity	Tooth	Tooth	Cavity
Incisors	8	11	8	11	8	24	22
Canines	7	12	7	12	7	21	24
Premolars	13	15	13	15	13	39	30
Molars	14	17	14	17	14	42	34
Total	42	55	42	55	42	126	110

After dividing the teeth into groups (control, natural and artificial), three digital periapical radiographs (orthoradial, mesioradial and distoradial) were acquired for each tooth. The focus/film distance was standardized at 18 cm (positioner), counting from the base of the cylinder to the radiographic sensor. For obtaining the mesial-angled radiography and distal-angled radiography, the horizontal angulation was modified by 20 degrees, by moving the locator cylinder.

The radiographs were obtained using a VistaScan No. 2 phosphor sensor (Dürr Dental Systems, Germany) and a Heliodent Plus x-ray machine (Sirona Dental Systems LLC, USA), with the following exposure parameters: 60 kVp, 7 mA, 120 VAC+/- 10%, 0.175-0.25 s. The time of exposure varied because it followed the parameters recommended for each dental group. The radiographic images were inserted in a template with the number of each tooth and exported as TIFF files in order to avoid any loss of quality from compression. A total of 378 radiographic images were evaluated (Figure 3).

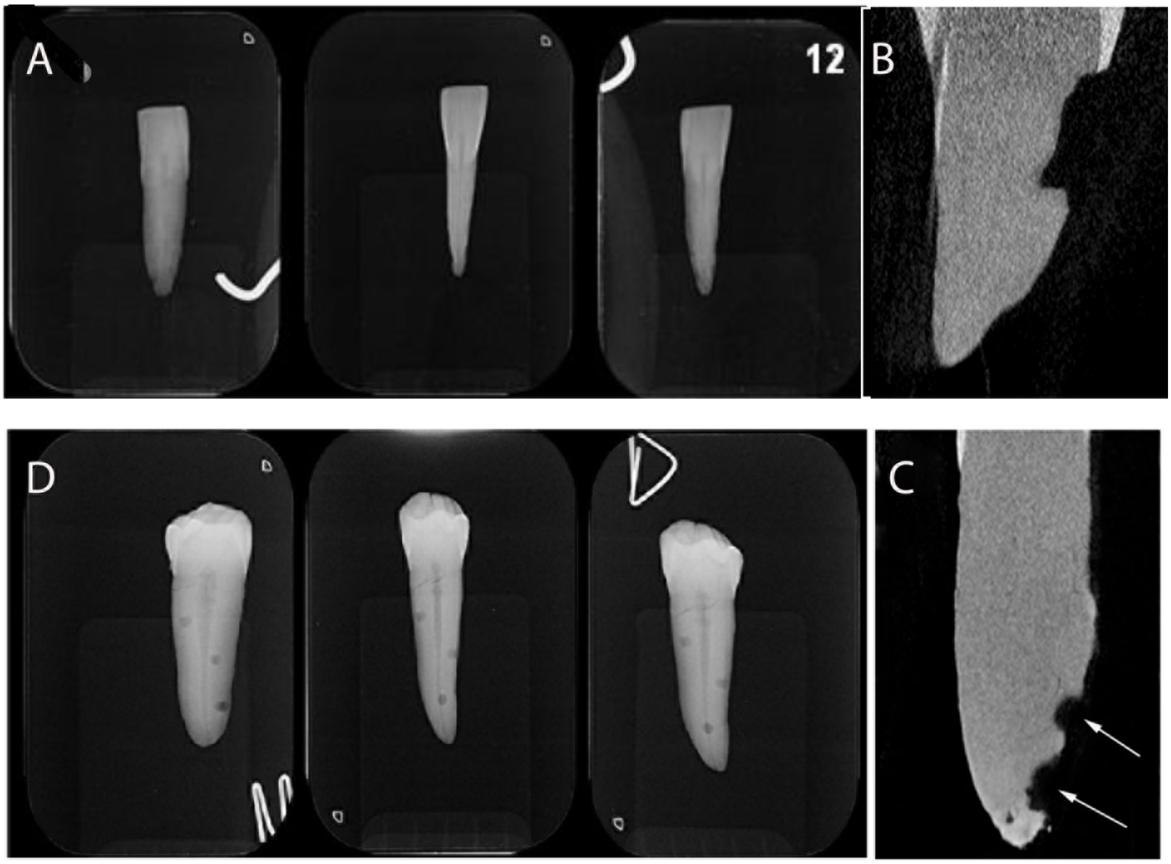


Figure 3: (A) Periapical radiography of lower incisor with natural cavities as seen on the mesio-, orto- and distoradial views. (B) and (C) Micro-CT of a lower incisor with natural cavitiy, note the difference of size and shape of the cavities, specially when comparing with the round one of the artificial cavities. (D) Periapical radiography of lower premolar with artificial cavities as seen on the mesio-, orto- and distoradial views.

For the CBCT, the teeth were also inserted into polystyrene, in groups of 10, randomly distributed into one of the three groups (control, natural and artificial) and then numbered consecutively from 1 to 126 (Figure 1C and 2C). A large volume scanner (I-CAT, Imaging Sciences International, Hatfield, PA, USA) was used with the following settings: 120 kV, 5 mA and 0.25 mm voxel size, 26.9 s exposure time), for a large volume CBCT scan. The tomographic images were exported to the software integrated with the device (Xoran, version 3.1.62; Imaging Sciences International, Hatfield, USA), all CBCT data were reformatted (1 mm slice intervals and 1 mm slice thicknesses).

A radiologist and an orthodontist assessed the radiographic and tomographic images. Examiners individually assessed the images and were not aware of whether the tooth had an ERR gap or which region or third was in question. The evaluation of the digital images was performed on a 23-inch SVGA Dell monitor, screen with a pixel resolution of 1280 x 1024 using the Imaging Preview program. The data were recorded on a spreadsheet and the analyses were repeated one week later. In both analyses, all 126 teeth were evaluated on the same day in the following sequence: session 1- radiographs, session 2- CBCT scans, session 3- radiographs and session 4- CBCT scans repeated to assess intra-observer agreement, obtaining Kappa test scores between 0.80 and 1.00, which were classified as excellent. Examiners also had access to the raw CBCT data allowing them to scroll thought any of the orthogonal scans.

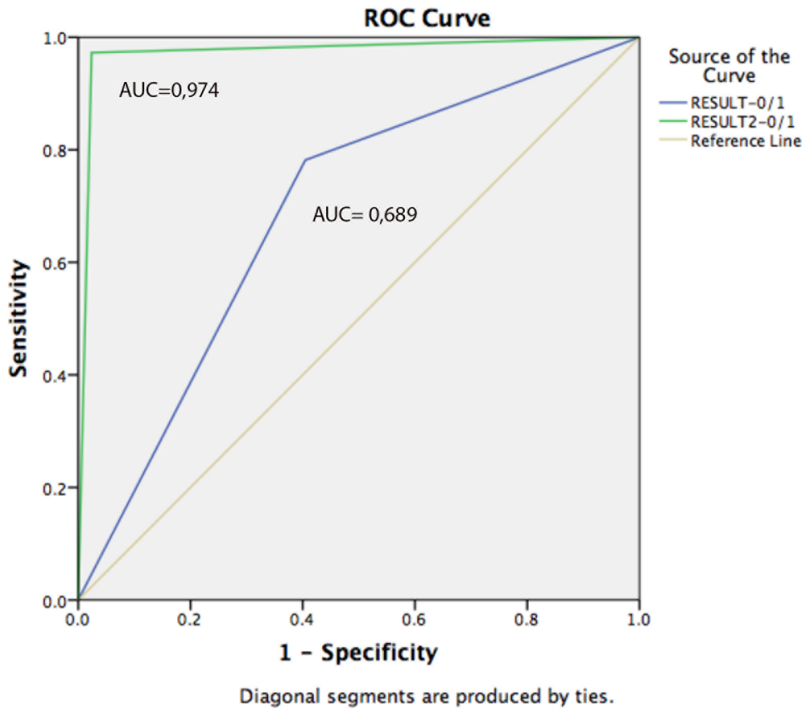
The results were tabulated and statistically analyzed using SPSS software (version 21.0; SPSS Inc., Chicago, IL, USA). Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) were determined. Receiver operating characteristic (ROC) curve analysis were used to assess the diagnostic accuracy of each imaging system in detecting the presence ERR defect against the microtomography. The differences between radiographs and CBCT were analyzed using t-student test.

RESULTS

The kappa value for intra- and inter-examiner agreement was greater than 0.80 for all evaluators, ranking excellent (0.80 --- 1.00) according to Landis and Koch [42].

Sensitivity, specificity, positive predictive value and negative predictive value results of the radiographic and tomographic method using micro-CT as gold standard (sensitivity and specificity 100%) are summarized in Table 2. It was observed that CBCT images had higher scores than radiography method and this result was statistically significant. The overall sensitivity and specificity of digital periapical radiography was lower than CBCT as show in ROC Curve (Chart 1), being the accuracy of radiographic method 0,7302, tomographic method 0,9736 and considering Micro-CT with 100% of accuracy.

Chart 1. Receiver operating characteristic (ROC) curve analysis of radiography and tomography method



Gold standard=Micro-CT (100% of sensitivity and specificity)

Table 2. Sensitivity and specificity of root resorption detection according to imaging methods

		RESULT							
		Sensitivity	Specificity	PPV	NPV	LR+	LR-	Accuracy	Younder 's Index
EXAM	X-RAY	0.781	0.595	0.835	0.510	1.931	0.366	0.730	0.377
	CBCT	0.972	0.976	0.990	0.931	40.854	0.027	0.973	0.948

Chi-square= 0.000 (p<0.05) _- raw data. CBCT, cone beam computed tomography,, PPV, positive predictive value, NPV, negative predictive value, LR+,likelyhood positive, LR-, likelyhood negative.

In Table 3 the teeth were divided in 3 groups (control, natural and artificial), and the differences between the imaging methods and ability to detect ERR in the groups were statistically significant (p<0.05).

Table 3. True positive, false positive, false negative and true negative of the radiographic and tomographic methods based on the evaluated group (control, natural, and artificial)

EXAM			RESULT				Total
			TRUE POSITIVE	FALSE POSITIVE	FALSE NEGATIVE	TRUE NEGATIVE	
X-RAYS	GROUP	ARTIFICIAL	45_a (81.8%)	0_b (0%)	10_a (18.2%)	0_b (0%)	55
		NATURAL	41_a (74.5%)	0_b (0%)	14_a (25.5%)	0_b (0%)	55
		CONTROL	0_a (0%)	17_b (40.5%)	0_a (0%)	25_b (59.5%)	42
	Total		86 (56.6%)	17 (11.2%)	24 (15.8%)	25 (16,4%)	152
CBCT	GROUP	ARTIFICIAL	55_a (100%)	$0_{a,b}$ (0%)	$0_{a,b}$ (0%)	0_b (0%)	55
		NATURAL	$52_{a,b}$ (94.5%)	$0_{b,c}$ (0%)	3_a (5.5%)	0_c (0%)	55
		CONTROL	0_a (0%)	1_b (2.4%)	0_a (0%)	41_b (97.6%)	42
	Total		107 (70.4%)	1 (0.7%)	3 (2%)	41 (27%)	152

Chi-square= 0.000 (p<0.05) _- raw data. CBCT= cone beam computed tomography. RR=root resorption. Each letter inscribed denotes a subset of X-RAY / CBCT categories whose column ratios do not differ significantly from each other at the level p 05.

Table 4 shows the distribution of the results of true positive, false positive, false negative and true negative within each of the dental groups (incisors, canines, premolars and molars) of the radiographic and tomographic methods.

Table 4: True positive, false positive, false negative and true negative of the radiographic and tomographic methods based on dental group (incisors, canines, premolars and molars)

EXAM			RESULT				Total
			TRUE POSITIVE	FALSE POSITIVE	FALSE NEGATIVE	TRUE NEGATIVE	
X-RAYS	TOOTH	INCISOR	22_a	$1_{a,b}$	0_b	7_a	30
		CANINE	20_a	5_a	4_a	2_a	31
		PREMOLAR	18_a	9_b	12_b	4_a	43
		MOLAR	$26_{a,b}$	2_b	$8_{a,b}$	12_a	48
	Total		86	17	24	25	152
CBCT	TOOTH	INCISOR	22_a	0_a	0_a	8_a	30
		CANINE	23_a	0_a	1_a	7_a	31
		PREMOLAR	29_a	1_a	1_a	12_a	43
		MOLAR	33_a	0_a	1_a	14_a	48
	Total		107	1	3	41	152
Total	TOOTH	INCISOR	44_a	$1_{a,b}$	0_b	15_a	60
		CANINE	43_a	5_a	5_a	9_a	62
		PREMOLAR	47_a	10_b	13_b	16_a	86
		MOLAR	$59_{a,b}$	2_b	$9_{a,b}$	26_a	96
	Total		193	18	27	66	304

Chi-square= 0.002 (p<0.05) X-RAYS and 0.918 CBCT- raw data CBCT= cone beam computed tomography. RR=root resorption,. Each letter inscribed denotes a subset of X-RAY / CBCT categories whose column ratios do not differ significantly from each other at the level p 05.

The correlation of the presence of ERR with its location on the root in which it was present (root third and root surface) was statistically significant (p<0.05): there was only 1 false positive in CBCT, found on the medium third, and three false negatives on the apical third. With the radiographic method, 17 false positives (3 apical, 6 medium and 8 cervical third) and 24 false negatives (16 in teeth without RR, 4 proximal, 2 buccal and 7 oral surfaces) were found. With the tomography method, only 1 false negative (proximal surface) and 3 false positives (2 proximal and 1 buccal) were found.

DISCUSSION

In the present study, the diagnostic accuracy of the digital periapical radiography and CBCT scans was investigated, as well as their capabilities in leading to a correct diagnostic having Micro-CT as gold standard. Micro-CT is a new imaging detection and analysis technology that can be applied without damaging the internal structures of a subject, and it has become widely used in dental research as a noninvasive detection technique[41]. With a high resolution at 9 µm per pixel, can be used to detect the RR craters, and it is equipped with a microfocus X-ray tube that emits X-rays that are collimated and filtered to narrow the energy spectrum[17]. Using the micro-CT, it is possible to show that even in clinically normal teeth without macroscopic resorption, microscopic resorption can still be measured and quantified[36].

All *in vitro* studies that have been made until now, have used artificially created cavities that do not reproduce the natural shape of RR's gaps, yielding a result of sensibility and specificity of the image methods that did not reproduce the natural condition. In the study by Creanga et al [16] the authors cite as one of the limitations that the ERR cavities were created artificially in the teeth *in vitro* using dry mandibles, which does not exactly reproduce the natural injury ERR; this fact was eliminated in this study which used natural lesions in human *ex vivo* teeth. Thus, the most frequently cited limitations in the previous studies[16] were not included in this study since natural ERRs, which were observed by micro-CT scanning of all teeth, were used.

There are two methods for simulating ERR cavities: (1) mechanically, with drills of different diameters, inserted manually, or with the aid of precision devices at different depths, which makes their creation more reliable [6], and (2) chemically, where the tooth is treated with acids at similar or varying concentrations several times, to simulate loss the of tooth structure (10). Until better *in vitro* methods are developed to simulate ragged, ill-defined edges of RR [40], these results should be interpreted with the understanding that

ERR cavities drilled with a round bur are not real replicas of ERR, and that future studies should consider methods to create irregular lesions.

The detection of ERR has been evaluated in some studies by the radiographic method, which may underestimate ERR due to its limitations [43, 44]. This method do not correctly reproduce the shape of natural ERR gaps, which has been cited as a limitation for such studies. What can be observed with Micro-CT and CBCT in this study is that the morphology of the ERR cavities is quite heterogeneous, with varying depths and diameters. In those with shallow surfaces, but great extension, their shapes can vary from oval to completely shapeless and also have a variety of extensions and depths (Figures 1 and 2), this is the reason why, in our study, we used natural RR cavities as showed the Micro-CT method. The results has showed that artificial cavities had the lowest percentages of false-positive and false-negative detection and the highest true positive values, 81.8% for radiography method and 100% for CBCT method.

In this study, the sensitivity of the radiographic and tomographic method were 78.18% and 97.27%, the specificity 59.52% and 97.62% respectively. It meant that in the radiography method it was not possible to observe about 25% of ERR, and this value was statistically significant. This corroborates the results from a study by Creanga et al [16], in which CBCT was able to eliminate the effects of overlapping factors of teeth and adjacent tissues, resulting in images with the high level of details needed to detect ERR, even in its early stages.

The shape of ROC curve and the area under the curve (AUC) shows the discriminative power of a test; the closer the curve is located to upper-left hand corner and the larger the area under the curve, the better the test is at discriminating between diseased and non-diseased [45]. In this study CBCT method is located closer to the upper-left hand corner than radiographic method and the area under curve (AUC) had 0.689 to radiographic method and 0.974 to CBCT, a perfect diagnostic test has an AUC 1.0 and CBCT stayed so close of this. On the other hand, a non discriminating test has an area 0.5 [45] and radiographic method stayed far from it too.

When this result was analyzed based on the study groups (control, natural, and artificial), only 74.5% of natural ERR gaps were observed in the digital periapical radiographs versus 94.5% in the CBCT images; however, in the artificial group these values increased to 81.8% and 100%, respectively (Table 3), that is, the cavities created by a round bur have more defined borders than natural shapes which make diagnosis easier [46].

Since previous studies [3] have shown that periapical radiography has poor performance in detecting small lesions [43, 44], studies that evaluate the presence of ERR have chosen to produce artificial lesions ranging in size from 0.5 to 0.7 mm [16, 21, 22, 47-49], here it was used 0.7 mm to create artificial cavities and the size of natural ERR cavities varied from 2,46 mm^3 to 3,11 mm^3, corresponding to cavities with 1.67 mm and 1.81 mm in diameter, respectively, being bigger than artificial cavities.

The diagnosis of the initial RR and/or those located on the buccal and lingual surfaces may be difficult to make by the radiographic method; however, knowledge of and previous experience with the variations in the angulations when obtaining the periapical radiographs generally elucidate these doubts [50]. In the present study, three radiographs at different angulations were used for the evaluation of each tooth. 86 of the 110 ERR gaps were diagnosed by digital periapical radiographic, remembering that in this study the x-rays did not have overlaps, bone and soft tissues. On the other hand, in the CBCT evaluation, 107 ERR gaps out of 110 were detected.

Even when eliminating the overlap of tissues adjacent to the tooth, the thickness of the root may obscure certain details and reduce the radiograph's potential for detecting ERR cavities. According to our results, when compared to the digital periapical radiography, CBCT was more useful for the detection of ERR gaps, regardless of the root surface or the third root in which they were located. However, the question of identifying which surface the ERR occurs should be taken into account by the clinical when requesting an imaging examination of the patient. The following factors and questions, which could alter the treatment and its prognosis, should be taken into consideration: the biological cost of each examination; whether the information regarding the presence of an ERR would be clinically relevant; whether it is necessary to know which surface it is located.

In tomographic method the score was higher in apical third when compared with radiographic method. This is according to other studies [22] that pointed sensitivity of CBCT and conventional radiography film was equal in detection of simulated ERR defects located in the middle and cervical one-third of the root. Our study showed that CBCT images were superior to digital periapical radiographs for accurately establishing RR since and artificial as in natural lesions.

In our study the percentage of false negative and false positive evaluations of RR in all root one-third was so low for radiography and tomography method. According to our results, CBCT was useful for detection of cavities located in all one-thirds of the root, but in special in the apical one-third of the root, compared to radiographic method. The percentage of false positive and false negative evaluation of RR was much lower for digital periapical radiography than CBCT in root one-thirds.

One of the limitations of this study was that in micro-CT, it was not possible to insert the tooth in a macerated jaw to perform the examination, due to the size limitation of the work area of the device. Therefore, the decision was made to acquire radiographs and CBCT images of the tooth only, without inserting it in a jaw. Although this did not reproduce the exact situation of the mouth, where there is overlapping of cortices, teeth, adjacent structures, and the presence of soft tissues in the radiographic and tomography method, we were able to standardize the way the images were acquired by the different methods. Another point is that the scanned images used in this study were in static defects and we know that in clinical practice we commonly have some degree of patient movement and even a small amount of patient movement as in the respiration, can cause blurring of the 3D images. Another limitation of this study, was that it was not possible to know the clinical history and dental information of the teeth of the sample in order to classify them by the possible etiologies of ERR (pulp infections, periodontal infections, orthodontic treatment, impacted teeth or tumors, and ankylosis); therefore, the etiology of ERR was not evaluated in the present study.

CONCLUSIONS

The CBCT appeared to be the best method for detecting ERRs, being the sensitivity and specificity of the periapical radiographs lower and this difference statistically significant. The tomography method was also useful for detection of cavities located in the apical one-third of the root, compared with radiography method. So CBCT has a higher sensitivity and specificity in comparison with periapical radiography and this difference was significant in this study.

Were observed 74.5% of natural ERR gaps on the periapical radiographs and 94.5% in CBCT; on the other hand, in the artificial group this number increased to 81.8% and 100%, respectively. So, the cavities created by a round bur make diagnostic easier because have more defined borders than natural shapes.

The configuration of the natural ERR gaps were different from and much more difficult to observe than the artificially simulated ones. This leads us to question the sensitivity and specificity results from the studies of radiographic and tomographic methods that used them. Therefore, it is suggested that only teeth with natural ERR are used, this would simulate the actual conditions of the buccal environment in which the ERR occurs.

REFERENCES

Accuracy of Digital Periapical Radiography and Cone-beam Computed Tomography for Diagnosis of Natural and Simulated External Root Resorption

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Abstract

Introduction: The aim of this study was to compare the sensitivity and specificity of digital periapical radiography and cone-beam computed tomographic (CBCT) imaging in the detection of natural and simulated external root resorptions (ERRs) with micro–computed tomographic (micro-CT) imaging as the reference standard. **Methods:** One hundred twenty-six teeth were scanned using the SkyScan 1172 micro-CT scanner (Bruker microCT, Kontich, Belgium), and the images were evaluated using NRecon software (Bruker microCT). After micro-CT imaging, the teeth were divided into 3 groups: control, 42 teeth that did not present any ERR cavities; natural, 42 teeth that presented 1 or more ERR cavities; and artificial, 42 teeth without ERRs but perforations were created to simulate the cavities. Ortho-, mesio-, and distoradial digital periapical radiographs and CBCT images were obtained, and the images were evaluated by 2 double-blinded qualified radiologists. **Results:** The sensitivities and specificities for the radiographic and tomographic methods were 78.18% and 97.27% and 59.52% and 97.62%, respectively. Within the individual groups, both methods had lower sensitivity and specificity for natural and artificial resorptions, and the differences were statistically significant. **Conclusions:** CBCT imaging was the best method for the detection of ERRs. Only 74.5% of natural ERR gaps were observed on the digital periapical radiographs and 94.5% on CBCT imaging; in the artificial group, this number increased to 81.8% and 100%, respectively. The configuration of the natural ERR gaps is different from those artificially simulated and is much more difficult to observe. *(J Endod 2018;■:1–8)*

Key Words

Cone-beam computed tomography, digital periapical radiography, external root resorption, image diagnosis, microtomography

Significance

A natural root resorption has a different configuration (shape size) than an artificial root resorption. This is the first study that used a natural root resorption to test the accuracy of digital periapical radiography and cone-beam computed tomographic imaging with micro-CT imaging as the gold standard.

External root resorption (ERR) is the loss of dental tissue, cementum and dentin, as a result of the action of odontoclastic cells (1) caused by inflammation; it can occur in different situations such as dental trauma, apical infection, internal bleaching, periodontal treatment, ectopic eruption, and, most commonly, in the presence of orthodontic movement (2–4). The severity of ERR can lead to a compromised crown-to-root ratio and tooth functioning (5).

Because ERRs do not present clinical symptomatology (6, 7), they are almost always detected by x-ray examinations (2). Periapical radiography is the most commonly used method for diagnosing ERRs (8). The principal problem with diagnosing ERRs by periapical radiography is that the 3-dimensional anatomy of the region being radiographed is compressed into a 2-dimensional image (1), and its diagnostic accuracy is affected by anatomic superposition and the angle of the x-ray spectrum (9).

Cone-beam computed tomographic (CBCT) imaging can be used as an alternative method. The determination of the extension and location of ERRs will be facilitated by the various senses in the cutting planes, increasing their detection (2). Early diagnosis of ERR during orthodontic treatment is essential to identify teeth at risk of developing severe resorption (10). The high cost and radiation exposure make this modality generally unsuitable as the first choice for dental imaging (11) (eg, in case of root resorption [RR] and when using it as a diagnostic or control examination).

With the evolution of imaging technology, micro–computed tomographic (micro-CT) imaging has been widely used in dental research as a noninvasive diagnostic technique because it is a high-resolution method that provides comprehensive and accurate

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ARTIGO 3 - VERSÃO EM INGLÊS

Accuracy of three different imaging CBCT systems for the detection of natural external radicular reabsorption cavities – an ex vivo study

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Ethical approval: The Ethics Committee at the Catholic University of Paraná under the CAAE number: 50214515.0.0000.0020 agreed with the study protocol. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Accuracy of three different imaging CBCT systems for the detection of natural external radicular reabsorption cavities – an ex vivo study

ABSTRACT

OBJECTIVE: to compare the sensitivity and specificity of three different systems of cone beam computed tomography (CBCT) in the detection of natural external root resorption (ERR) cavities using microtomography as the gold standard.

METHOD: a sample of 126 ex vivo teeth were submitted to a microtomography examination to verify the presence/absence of ERR cavities. After they were divided into: (1) Control Group: 85 teeth that did not present with an ERR cavity; (2) Experimental Group: 41 teeth that presented with one or more ERR cavities. The size of natural ERR cavities varied from 2.46 mm^3 to 3.11 mm^3, corresponding to cavities with 1.67 mm and 1.81 mm in diameter, respectively. They were placed on a dry human mandible for scanning in each of the 3 protocols with different voxel sizes: 0,25 mm, 0.20 mm and 0.166 mm.

RESULTS: The accuracy of the three protocols evaluated in this study were in decreasing order: 60.3% for voxel size of 0.20 mm, 56.7% for voxel size of 0.166 mm and 46.7% for voxel size of 0.25 mm, which were smaller values than studies using artificial ERR cavities. Statistically significant results were not found among the three protocols of CBCT used ($p > 0.05$), and the ROC (Receiver Operating Characteristic) curve shows the small differences found in the protocols.

CONCLUSION: The results of the present study show lower sensitivities and specificities than those detected in previous studies for artificial cavity. It demonstrated that natural ERR are not so easily observed and they do not have the same accuracy with regard to their location as it can see in studies using artificial ERR.

KEY WORDS: cone beam computed tomography; accuracy; root resorption

INTRODUCTION

An accurate diagnosis is essential for an appropriate treatment plan. External root resorption (ERR) cavities, especially natural ones, may present a challenge to be correctly diagnosed, which may result in inadequate treatment.[3, 43, 51]

In 1999, Arai et al.[52] developed the first specific tapered cone beam computed tomography (CBCT) device for dentistry, which made it possible to clearly distinguish even the periodontal ligament space but with a very small work area (4 cm in diameter by 3 cm in height). In the sequence, many other CBCT devices were developed, many of which had larger field of view making it possible to scan the maxilla and mandible.[53]

It is known that the quality of the image in CBCT depends on some factors such as detector type of the scanner[5], field of view (FOV)[54, 55], size of voxel[9], tube current[5], milliamperage settings[55] and time of scanning[55]. The size of the voxel determines the level of detail an image provides, that is, its resolution[56], as well the scan mode (number of basis images, since they are directly related to the special resolution of images.[57] The lower the voxel in image acquisition and the longer the scan time, the better the resolution and details will be. However, a smaller voxel size is linked to a longer exposure time, which provides some disadvantages, such as greater possibility of patient movement during the examination, longer reconstruction time and higher doses of radiation[58]. Providing the minimal radiation dose to the patient is to respect the principle of ALARA (as low as reasonably achievable)[56]. The ideal imaging protocol would be a balance of the best resolution achievable with the minimum radiation exposure, considering what needs to be investigated[57].

Several studies have already been carried out to test the accuracy of CBCT in the detection of ERR cavities (using different voxels sizes, FOV and acquisition time), but all studies so far have used artificially produced ERR cavities, either mechanically or chemically.[9, 16, 19-23, 59, 60] These cavities do not reproduce reality, since they are sharper with well-defined and regular edges, which are different from those observed naturally. In the in vivo studies[3, 17, 31, 32] this limitation is solved, but it is not possible to expose the patient to different image acquisition protocols to test their accuracy or to quantify the volume of ERR cavities that can be detected. A systematic review[11] in 2017 compared the diagnostic accuracy of CBCT and periapical radiographs for the detection of ERR and the results suggests that CBCT could be reliable to detect the presence of ERR in clinical practice and has a higher diagnostic efficacy than PR, but all the studies included used simulated ERR as reference test. Another systematic review and meta-analysis[61], evaluated the ERR following orthodontic treatment using CBCT and although it seems to be a reliable tool to examine RR at the end of orthodontic treatment, the results should be interpreted with some caution due to data hererogeneity and low quality of the included studies.

Recently in 2018, a study[62] have compared the accuracy of digital periapical radiography and CBCT for diagnosis of natural and simulated external root resorption and concluded that natural cavities are more difficult to detect than artificial ones. This was the first study to use natural external root resorption in in vitro study. So, the aim of this study was to compare the sensitivity and specificity of three different imaging system of CBCT for image quality and tomography diagnostic accuracy for detection of natural ERR cavities using microtomography as the gold standard.

MATERIALS AND METHODS

This study was carried out after the approval of the Ethics Committee under the number CAAE: 50214515.0.0000.0020, characterising an observational cross-sectional study with a sample of 126 ex vivo teeth, 36 incisors, 18 canines, 36 premolars and 36 molars belonging to a bank of teeth, number sufficient to complete 9 jaws with 14 teeth each. Inclusion criteria were complete root formation, no root destruction, absence of carious cavity/abrasion in the cervical region and no endodontic treatment. The teeth were randomly selected with the aid of a magnifying glass (3X magnification) and natural light until they filled the number of teeth determined for the study. In addition, they were examined by two evaluators (JCS and AKS) to confirm the anatomy (i.e., which tooth group each tooth belonged to and also met the inclusion criteria). Afterwards, all teeth were submitted to a microtomography examination to verify the presence/absence of ERR cavities, with teeth numbered 1 to 126.

The micro-CT was acquired by the Skyscan 1172 (Bruker Micro-CT, Belgium) in a resolution of 9 μm at 100 kVp, 100 μA and 10 W energy in groups of six elements in each acquisition for the incisors, canines and premolars and in groups of three elements for the molars, due to the size of the area of acquisition of the apparatus. The raw images were reconstructed using NRecon software version 1.4.4 (Skyscan, Kartulzersweg 3B 2990 Kentich, Belgium) and the reconstructed images of the scanned teeth were analysed using CTvox software (Version 3.1.1, Skyscan NV, Kentich, Belgium), which allows the observation of the teeth in the axial, sagittal and coronal planes for the presence or absence of ERR gaps in the apical, middle and cervical thirds, as well as the face where the lacuna occurred being classified as buccal, oral and proximal. The data were recorded in a spreadsheet and the analysis was repeated one week later, and in the two moments all 126 teeth were evaluated on the same day by the same duly calibrated evaluator (kappa test with 0.98 reliability).

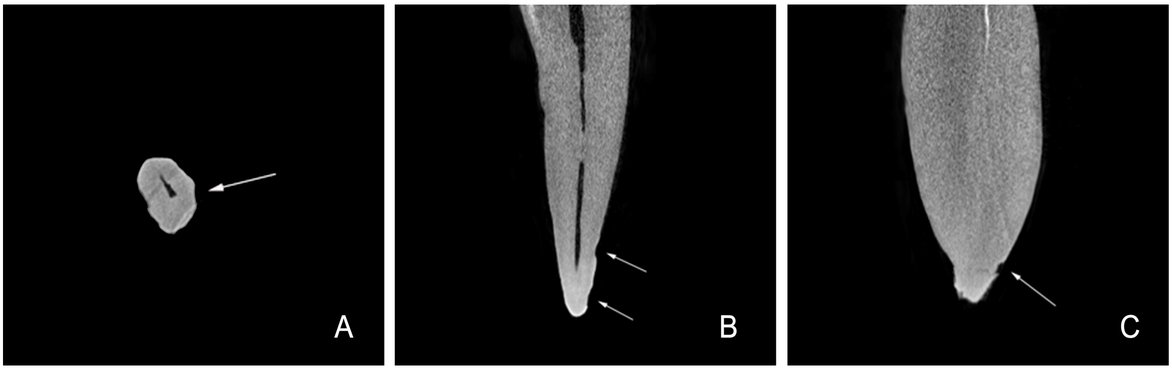

Fig 1. Example of a scanned tooth by micro tomography being (A) axial cut, (B) sagittal cut and (C) coronal cut where arrows point to ERR cavities.

The teeth after the micro-CT were divided into the following groups: (1) Control Group: 85 teeth that did not present with an ERR cavity, which were randomly selected by software that performed the randomisation to compose the 57 teeth of the control group (28 teeth were not used for statistic reason); (2) Experimental Group: 41 teeth that presented with one or more ERR cavities (total of 52 cavities) (Fig 1). The size of natural ERR cavities varied from 2.46 mm^3 to 3.11 mm^3 (Fig 2), corresponding to cavities with 1.67 mm and 1.81 mm in diameter, respectively.

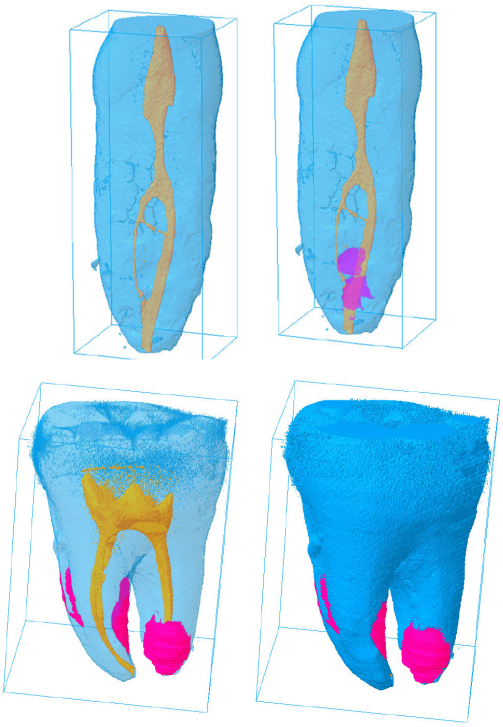

Fig 2. 3D reconstruction illustrating the natural ERR cavities found and their volume in mm^3 (in pink).

After separation of the teeth into groups (control and experimental), they were again randomly distributed by the software to form a set of 14 teeth with control and natural ERR cavities constituting a whole double blind, that is, neither the operator nor the evaluators knew which tooth had an ERR cavity, a result only revealed at the time of the statistical analysis. Each set of teeth numbered from 1 to 7 was placed on the same dry human mandible (Fig 3), fixed with utility wax, for scanning in each of the following protocols:

Protocol 1: Scanora 3D apparatus (Soredex, Tuusula, Finland), 7,5 cm FOV, 90 kVp, 13 mA, voxel size of 0.25 mm and 13 second exposure time

Protocol 2: I-Cat Next Generation apparatus (Imaging Science International, Hatfield, Pennsylvania, United States), 8 cm FOV, 120 kVp, 8 mA, voxel size of 0.20 mm and 26.7 second exposure time.

Protocol 3 : Orthophos XG apparatus (Sirona, Bensheim, Germany), 8 cm FOV, 85 kVp, 6 mA, voxel size of 0.166 mm and 20 second exposure time (Table I).

Table I. Characteristics and thecnical specifications of the CBCT systems

	Voxel size (mm)	Potential (kV)	Current (mA)	Field of view (FOV) cm	Exposure Time (s)	Resolution	Detector type
Scanora 3D	0.25	90	13	7,5	13	High	Flat panel
I-Cat Next Generation	0.20	120	8	8	26.7	High	Flat panel
Orthophos XG 3D	0.166	85	6	8	20	High	Flat panel

To allow maintenance of the position of the mandible during the examination, it was fixed on an acrylic base using utility wax at three points: an anterior at the lower edge of the mental symphysis and two posterior points located at the lower edge of the mandibular angle. The set was submerged in a plastic container with water to simulate the soft tissues at the time of acquisition (Fig 3).

Fig 3. Teeth positioned in the jaw to be submitted to CBCT in the three protocols.

The analysis of the tomographic images obtained was performed by three experienced oral radiologists in working with CBCT, with previous experience using the software packages, blindly evaluated the presence of resorption (Fig. 4). During the training session, the observers were given examples of root resorption with similar presentations to what they were expected to identify in the study sample. They were also oriented on software use and the tools that could change the quality of the images were prohibited (e.g. filters).

The jaw sets were viewed in the following sequence: day 1 - all the protocol 1, day - 2 all the protocol 2, day - 3 all the protocol 3. One week after day 1 – all protocol 1 again, one week after day 2 – all protocol 2 and one week after day 3 – all protocol 3. It was done to avoid learning by the examiner of where they might find a lesion if they had just evaluated the same set earlier the same day, and also to avoid visual fatigue.

Digital image evaluation was performed on a 23-inch SVGA Dell monitor by the viewer of each CBCT apparatus. The observers were allowed to use the system tools as zoom, brightness and contrast. The results were tabulated and analysed statistically in SPSS software (version 22.0: SPSS Inc., Chicago, IL, USA). Sensitivity, specificity, false positive and false negative values were determined as well as the accuracy of each protocol, Qui-Square test was used.

RESULTS

The kappa value for intra- and inter-examiner agreement was greater than 0.8 for all evaluators (Table II), ranking excellent (0.80–1.00) according to Landis and Koch.[42]

Table II. Values of kappa for intra- and inter-examiner agreement, where E1 = evaluator 1, E2 = evaluator 2 and E3 = evaluator 3.

Values			Asymptotic Standard Error		
E1	E2	E3	E1	E2	E3
0.865	0.857	0.871	0.091	0.096	0.088

The results are expressed in tables and graphs. The sensitivity as well as the specificity are shown in Table III. Also in this table are the positive predictive values and negative predictive values for the tests. The accuracy of a test was in decreasing order: 60.3% for Protocol 2 (voxel size of 0.20 mm), 56.7% for Protocol 3 (voxel size of 0.166 mm) and 46.7% for Protocol 1 (voxel size of 0.25 mm).

Table III. Mean sensitivity, specificity, PPV, NPV, accuracy rate, LR +, LR - and odds among the three protocols evaluated in the detection of natural ERR.

Screening items	Protocol 1	Protocol 2	Protocol 3
Sensitivity	0.441	0.608	0.565
Specificity	0.493	0.600	0.569
PPV	0.277	0.518	0.481
NPV	0.655	0.684	0.649
Accuracy rate	0.477	0.603	0.567
LR+	0.869	1.520	1.310
LR-	1.133	0.653	0.764
ODDS	0.768	2.321	1.718
AUC (95% CI)	0.472	0.601	0.565

$p=0.271$ PPV=positive predictive value, NPV=negative predictive value, LR+= positive likelihood rate, LR-= negative likelihood rate, AUC= area under curve

The numerical value of the positive likelihood ratio (LR +) refers to how many times a positive test increases disease probability (i.e., in Protocol 3 (voxel size of 0.166 mm) the LR + of 16 means that those patients who have a positive test are 16 times more likely to have the disease than healthy ones). In turn, the negative likelihood ratio (LR -) shows that the chance of disease is lower in the negative test; if we return to the above case, Protocol 3 has an LR - of 0.53, which tells us that the patient has half of the probability of having the disease when the test is negative. If we observe the same aspects for Protocol 1 (voxel size of 0.25 mm), the values of both LR + and LR - are close to 1, that is, the quality of the test is not useful for the evaluation of ERR cavities (Fig 4).

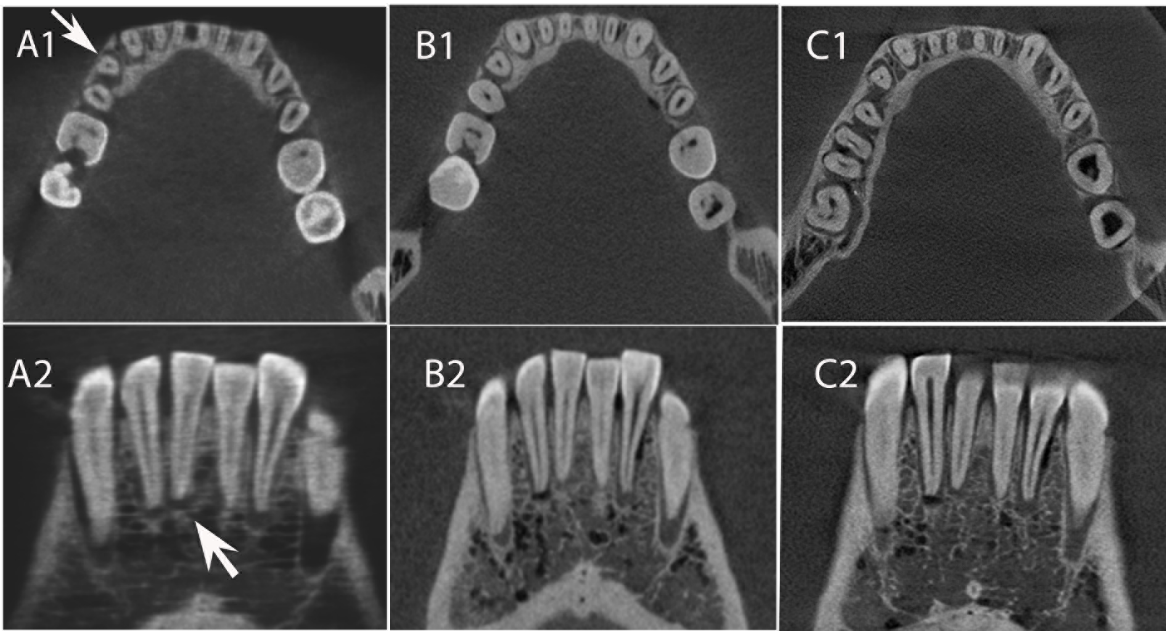

Fig 4. Figure 4 – Axial (1) and coronal (2) slices of the scan made on the same mandible (number 1) in each protocol: A, protocol 1 (0.25 mm voxel size); B, protocol 2 (0.20 mm voxel size); and C, protocol 3 (0.166 mm voxel size). The natural root resorption is evident (arrow) in protocol 1 (tooth number 34- cervical third and buccal surface and 42- apical third and proximal surface)

It was sought to correlate the detection of the ERR cavities with the dental group (Fig 5), the root third and face where they occurred (Table IV and V), but these results were not statistically significant ($p > 0.05$).

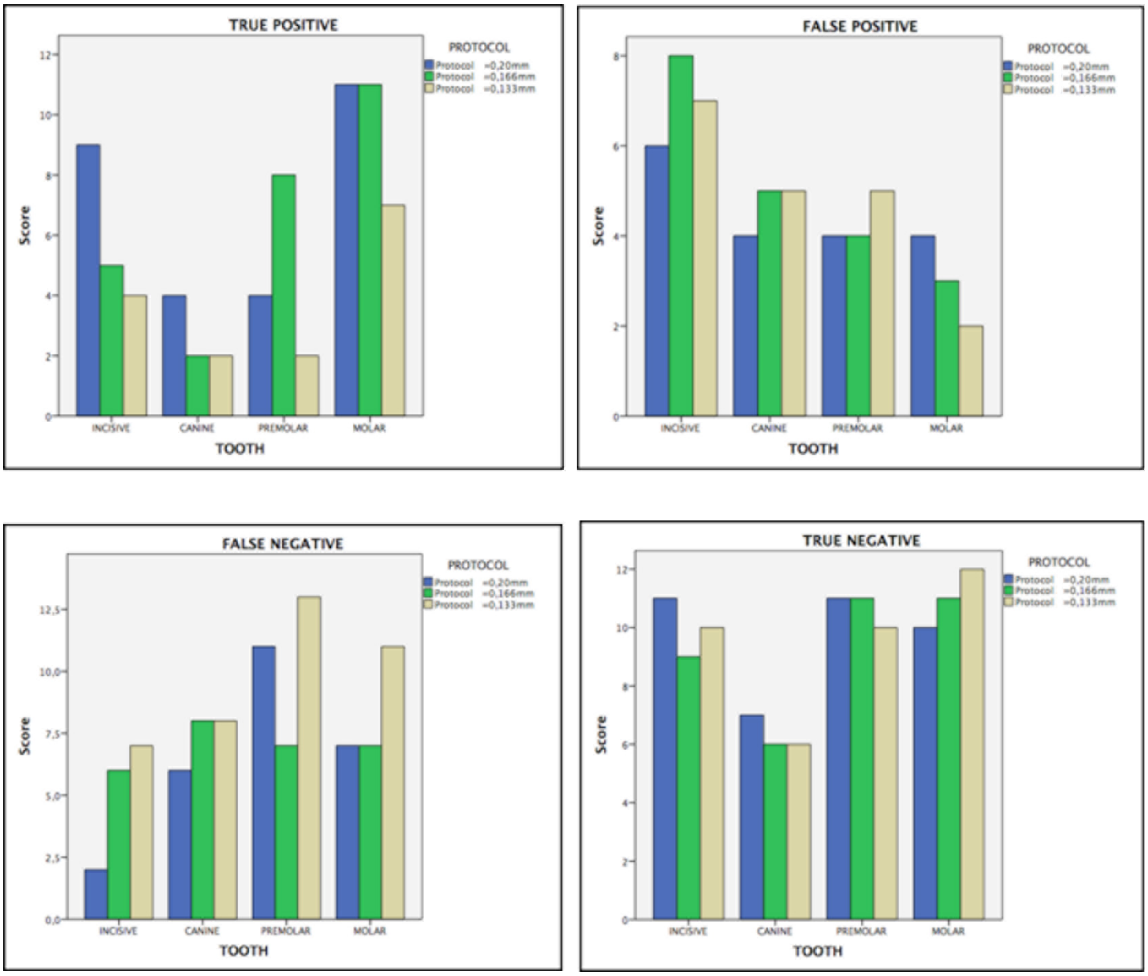

Fig 5. Dental group and its relation with the three protocols evaluated—values of true positives, false positives, false negatives and true negatives being p > 0.05 in all groups.

Table IV. Root third and the relation with the three protocols evaluated in detection of natural ERR.

		PROTOCOL			Total
		Protocol 1	Protocol 2	Protocol 3	
ROOT THIRD	ABSENT	77_a (37.2%)	65_a (31.4%)	65_a (31.4%)	207 (100%)
	APICAL	33_a (27.7%)	42_a (35.3%)	44_a (37.0%)	119 (100%)
	MEDIUM	1_a (16.7%)	4_a (66.7%)	1_a (16.7%)	6 (100%)
	CERVICAL	0_a (0%)	0_a (0%)	1_a (100%)	1 (100%)
Total		111 (33.3%)	111 (33.3%)	111 (33.3%)	333 (100%)

p=0.229

Table V. Root face and the relation with the three protocols evaluated in detection of natural ERR.

		PROTOCOL			Total
		Protocol 1	Protocol 2	Protocol 3	
ROOT FACE	ABSENT	77_a (37.2%)	65_a (31.4%)	65_a (31.4%)	207 (100%)
	PROXIMAL	27_a (28.4%)	32_a (33.7%)	36_a (37.9%)	95 (100%)
	BUCCAL	4_a (19%)	11_a (52.4%)	6_a (28.6%)	21 (100%)
	ORAL	3_a (30%)	3_a (30%)	4_a (40%)	10 (100%)
Total		111 (33.3%)	111 (33.3%)	111 (33.3%)	333 (100%)

$p=0.360$

Statistically significant results were not found among the three protocols of CBCT used ($p > 0.05$), and the ROC (Receiver Operating Characteristic) curve (Fig 6) shows the small differences found among protocols.

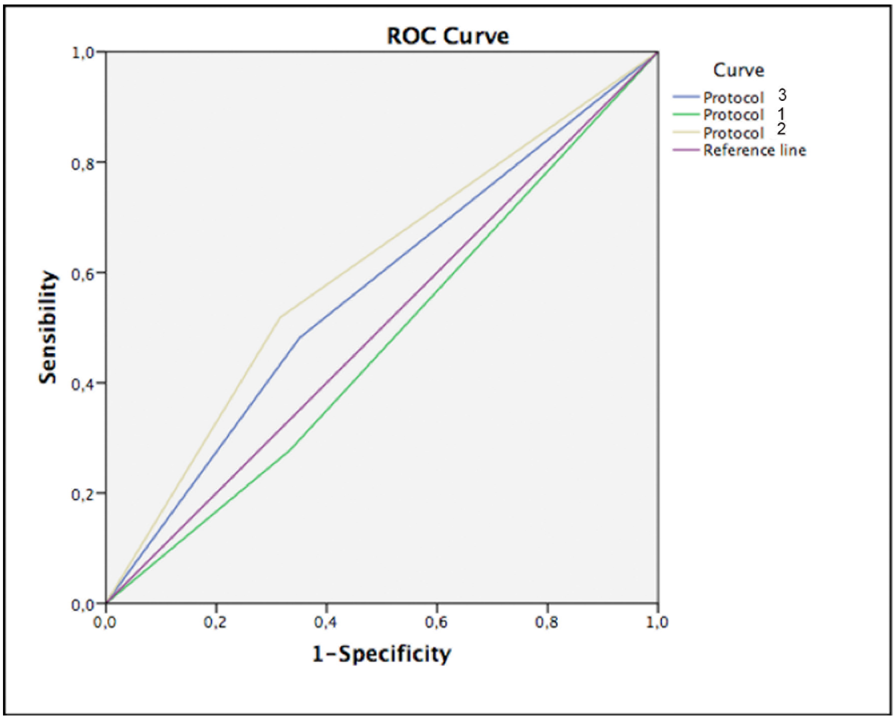

Fig 6. Receiver operating characteristic (ROC) curves for the three CBCT protocols used, where the value below the area for Protocol 2 = 0.601, Protocol 3 = 0.565 and Protocol 1 = 0.472 and the value of p = 0.066, 0.236 and 0.614, respectively.

DISCUSSION

Considering the increasing applicability of CBCT in dentistry, it is very important to determine which imaging protocol is capable of providing a three-dimensional (3D) observation with resolution and sharpness appropriate for measurements of small structures, such as natural ERR cavities. The 3D image was readily available for accurately and easily interpreted observations of radicular resorption[5]; when evaluating the natural ERR cavities, this study demonstrated that they are not so easily observed with little accuracy with regard to their locations (either in the third of the root or face).

In the study performed by Creanga et al.,[16] the authors reported one of the limitations of that study was the fact that ERR cavities were artificially created in vitro in dentists using dry jaws, which do not exactly reproduce the natural lesions of ERR. This fact was elucidated in this study that used natural lesions in ex vivo human teeth, inserted in a human dry jaw and placed inside a container with water to simulate the soft tissues.

Perhaps due to this fact, the sensitivity (the ability of a test to diagnose and identify the true positives in the truly sick individuals) in the three protocols of this study showed low sensitivity (around 50%). In one of them, Protocol 1 the sensitivity was only 27.78%, but these values were not statistically significant, corroborating the results found by other studies that also evaluated the voxel size difference in CBCT.[9, 16, 19, 22, 60] One explanation for this may be that natural ERR cavities are not well delimited and defined when compared to artificially created cavities by drills,[22] thus making their identification more difficult than artificial ones, which were used in studies of accuracy to date.[9, 16, 19-23, 59, 60] Another limitation of the simulated cavities is that mechanically created defects usually have a greater contrast than natural lesions and are easier to identify.[60]

The occurrence of false negatives and false positives in the three protocols evaluated did not present statistically significant results. But if we observed the false negative values, we had 39 cases in Protocol 1 and 26 and 28 in Protocols 2 and 3. The numbers may not be statistically significant but are clinically relevant, because we would have more than 10 false negatives. We must be careful in the interpretation and application of statistics in clinical cases day by day.[63]

The size of the natural ERR cavities ranged from 2.46 mm^3 to 3.11 mm^3, corresponding to cavities 1.67 mm and 1.81 mm in diameter, respectively. A cavity 0.3 mm in diameter would be considered small. That is, all the cavities observed in this study can be classified as large cavities, since the literature cites values from 0.3 mm to 0.5 mm for small cavities, 0.7 mm to 1mm for medium cavities and greater than 1 mm for large cavities.[6, 9, 16, 19-23, 60] Although the ERR cavities in this study were classified as large, the sensitivity and specificity of the three protocols presented lower values than those found in the literature with size of artificial cavities classified as small or medium.[9, 16, 19, 22, 60]

Most of the ERR cavities in this study were located in the apical third and were identified, with no statistically significant differences in the three protocols evaluated (although Protocol 1 values were the lowest). This result is in contrast to the results of three previous studies, which showed that ERR cavities located in the apical third of the root are more difficult to resolve than those in the middle and cervical root thirds.[9, 64, 65]

As for the radicular face, the one that presented the largest number of ERR cavities was the proximal face, followed by the buccal and lingual; and it was the proximal face that presented the highest true positive values in the sample evaluated independent of the voxel used. Although no statistical difference was found in the evaluation of the location of ERR cavities in the different voxels sizes used, this result is in agreement with other studies.[9, 64-66]

The results of the present study show lower ROC curve values as well as lower sensitivities and specificities than those detected in previous studies for cavity sizes approximately similar to those used in the present study.[5, 16, 21, 22, 48, 59] That is, the accuracy of CBCT decreased when using natural ERR cavities, leading us to question the results found so far in the sensitivity and specificity of the tests and devices investigated.

The incisors are the most prevalent teeth with ERR cavities, especially in orthodontic studies,[32,31,30,31] perhaps because they are uniradicular, which facilitates their evaluation. Already in this study, the largest number of ERR cavities identified as true positive in the three tomographic imaging protocols were in the incisors and molars as shown in Graph 2. CBCT eliminates the problem of overlapping anatomical structures as well as ensuring that the tooth is evaluated in all planes with sophisticated software that allows the observer/dentist to select the most favourable view/cut for each problem to be evaluated.

CBCT is an imaging modality that offers the advantages of 3D scans but with a shorter scanning time and lower radiation dose when compared with conventional CT scans[40]. However, the dose of ionising radiation to which the patient is exposed during this procedure is greater than in the use of periapical radiographs,[9] so it is important to use a protocol that guarantees good image quality with the lowest radiation dose possible. The voxel size, independently, does not influence the radiation dose, that is, when the exposure factors (i.e., exposure time, kVp and mA) are maintained, the simple change in voxel size does not significantly influence the radiation dose. However, protocols entail the use of smaller voxels at longer exposure times and greater mAs, which invariably results in better image resolution and increased radiation dose.[58]

When choosing an image acquisition protocol, the ALARA principle should be taken into account, keeping the dose of radiation as low as possible and with the best information necessary for a correct diagnosis. Knowing that smaller voxels lead to higher radiation exposures, the selection of various voxel configurations should be used to reduce the dose of radiation to the patient according to the purpose of each examination.

CBCT remains, in the opinion of the literature[5, 11], the best method for the detection of ERR, but the acuracy found with CBCT in the detection of simulated ERR cavities was not the same as that found with natural ERR cavities in this study, so it is necessary to carry out future research with natural ERR cavities for more real results.

LIMITATIONS

The scanning protocols were different for each machine, having different kvp, mA and scan time (although all of them were in high resolution) and also, each unit have its own proprietary reconstruction and optimization algorithms.

Another limitation of this study was that the scanning was performed on an immobile object—a macerated jaw. Scanning routinely used in clinical practice involves a minimal degree of movement of the patient due to the time to perform the examination and even a small amount of movement, such as breathing, can cause blurring in the image and lead to a decrease in its accuracy.

CONCLUSIONS

Based on the results of this study, the CBCT systems tested showed variable image qualities. The results also showed lower ROC curve values as well as lower sensitivities and specificities than those detected in previous studies for artificial cavity sizes approximately similar to those used in the present study.

The accuracy of the three protocols evaluated in this study were in decreasing order: 60.3% for Protocol 2 (voxel size of 0.20 mm), 56.7% for Protocol 3 (voxel size of 0.166 mm) and 46.7% for Protocol 1 (voxel size of 0.25 mm).

This study demonstrated that natural ERR are not so easily observed, independent of the voxel size, and they do not have the same accuracy with regard to their location as it can see in studies using artificial ERR.

CONFLICT OF INTERESTS

The authors attest that there was no potential conflict of interest or financial support from any organisation or person that might inappropriately lead to bias in the results of the study.

REFERENCES

CONCLUSÕES GERAIS

A configuração, ou seja, tamanho, forma, profundidade e desenho, das cavidades naturais de RRE são diferentes e mais difíceis de serem observadas que as cavidades artificiais. Isso nos leva a questionar a sensibilidade e especificidade dos resultados encontrados nos estudos realizados com os métodos radiográficos e tomográficos que as utilizaram.

A tomografia computadorizada de feixe cônico permanece como o melhor método para a detecção da RRE, mas a acurácia encontrada com a TCFC na detecção das cavidades naturais de RRE não foi a mesma que a encontrada para as cavidades artificiais de RRE. É necessário que pesquisas futuras com cavidades naturais de RRE sejam levadas em consideração para resultados mais reais.

REFERÊNCIAS BIBLIOGRÁFICAS

1. Gunst V, Mavridou A, Huybrechts B, et al. External cervical resorption: an analysis using cone beam and microfocus computed tomography and scanning electron microscopy. Int Endod J 2013;46(9):877-87.
2. Fuss Z, Tsesis I, Lin S. Root resorption--diagnosis, classification and treatment choices based on stimulation factors. Dent Traumatol 2003;19(4):175-82.
3. Patel S, Dawood A, Wilson R, Horner K, Mannocci F. The detection and management of root resorption lesions using intraoral radiography and cone beam computed tomography - an in vivo investigation. Int Endod J 2009;42(9):831-8.
4. Zhuang L, Bai Y, Meng X. Three-dimensional morphology of root and alveolar trabecular bone during tooth movement using micro-computed tomography. Angle Orthod 2011;81(3):420-5.
5. Alqerban A, Jacobs R, Fieuws S, et al. Comparison of 6 cone-beam computed tomography systems for image quality and detection of simulated canine impaction-induced external root resorption in maxillary lateral incisors. Am J Orthod Dentofacial Orthop 2011;140(3):e129-39.
6. Westphalen VP, Gomes de Moraes I, Westphalen FH, Martins WD, Souza PH. Conventional and digital radiographic methods in the detection of simulated external root resorptions: a comparative study. Dentomaxillofac Radiol 2004;33(4):233-5.
7. Ericson S, Kurol PJ. Resorption of incisors after ectopic eruption of maxillary canines: a CT study. Angle Orthod 2000;70(6):415-23.
8. Westphalen VPD, Moraes IGd, Westphalen FH. Efficacy of conventional and digital radiographic imaging methods for diagnosis of simulated external root resorption. Journal of Applied Oral Science 2004;12(2):108-12.
9. da Silveira HL, Silveira HE, Liedke GS, et al. Diagnostic ability of computed tomography to evaluate external root resorption in vitro. Dentomaxillofac Radiol 2007;36(7):393-6.
10. Alqerban A, Jacobs R, Lambrechts P, Loozen G, Willems G. Root resorption of the maxillary lateral incisor caused by impacted canine: a literature review. Clin Oral Investig 2009;13(3):247-55.
11. Yi J, Sun Y, Li Y, et al. Cone-beam computed tomography versus periapical radiograph for diagnosing external root resorption: A systematic review and meta-analysis. Angle Orthod 2017;87(2):328-37.
12. Harris EF, Butler ML. Patterns of incisor root resorption before and after orthodontic correction in cases with anterior open bites. Am J Orthod Dentofacial Orthop 1992;101(2):112-9.
13. Harris EF, Robinson QC, Woods MA. An analysis of causes of apical root resorption in patients not treated orthodontically. Quintessence Int 1993;24(6):417-28.
14. Lima TF, Gamba TO, Zaia AA, Soares AJ. Evaluation of cone beam computed tomography and periapical radiography in the diagnosis of root resorption. Aust Dent J 2016.
15. Ren H, Chen J, Deng F, et al. Comparison of cone-beam computed tomography and periapical radiography for detecting simulated apical root resorption. Angle Orthod 2013;83(2):189-95.
16. Creanga AG, Geha H, Sankar V, et al. Accuracy of digital periapical radiography and cone-beam computed tomography in detecting external root resorption. Imaging Sci Dent 2015;45(3):153-8.
17. Ru N, Liu SS, Zhuang L, Li S, Bai Y. In vivo microcomputed tomography evaluation of rat alveolar bone and root resorption during orthodontic tooth movement. Angle Orthod 2013;83(3):402-9.
18. Dudic A, Giannopoulou C, Martinez M, Montet X, Kiliaridis S. Diagnostic accuracy of digitized periapical radiographs validated against micro-computed tomography scanning

in evaluating orthodontically induced apical root resorption. Eur J Oral Sci 2008;116(5):467-72.
19. Liedke GS, da Silveira HE, da Silveira HL, Dutra V, de Figueiredo JA. Influence of voxel size in the diagnostic ability of cone beam tomography to evaluate simulated external root resorption. J Endod 2009;35(2):233-5.
20. Dalili Z, Taramsari M, Mousavi Mehr SZ, Salamat F. Diagnostic value of two modes of cone-beam computed tomography in evaluation of simulated external root resorption: an in vitro study. Imaging Sci Dent 2012;42(1):19-24.
21. Bernardes RA, de Paulo RS, Pereira LO, et al. Comparative study of cone beam computed tomography and intraoral periapical radiographs in diagnosis of lingual-simulated external root resorptions. Dent Traumatol 2012;28(4):268-72.
22. Durack C, Patel S, Davies J, Wilson R, Mannocci F. Diagnostic accuracy of small volume cone beam computed tomography and intraoral periapical radiography for the detection of simulated external inflammatory root resorption. Int Endod J 2011;44(2):136-47.
23. Wang Y, He S, Guo Y, Wang S, Chen S. Accuracy of volumetric measurement of simulated root resorption lacunas based on cone beam computed tomography. Orthod Craniofac Res 2013;16(3):169-76.
24. Tsesis I, Fuss Z, Rosenberg E, Taicher S. Radiographic evaluation of the prevalence of root resorption in a Middle Eastern population. Quintessence Int 2008;39(2):e40-4.
25. Campos MJ, Silva KS, Gravina MA, Fraga MR, Vitral RW. Apical root resorption: the dark side of the root. Am J Orthod Dentofacial Orthop 2013;143(4):492-8.
26. Levander E, Bajka R, Malmgren O. Early radiographic diagnosis of apical root resorption during orthodontic treatment: a study of maxillary incisors. Eur J Orthod 1998;20(1):57-63.
27. Levander E, Malmgren O. Long-term follow-up of maxillary incisors with severe apical root resorption. Eur J Orthod 2000;22(1):85-92.
28. Mohandesan H, Ravanmehr H, Valaei N. A radiographic analysis of external apical root resorption of maxillary incisors during active orthodontic treatment. Eur J Orthod 2007;29(2):134-9.
29. Maues CP, do Nascimento RR, Vilella Ode V. Severe root resorption resulting from orthodontic treatment: prevalence and risk factors. Dental Press J Orthod 2015;20(1):52-8.
30. Castro IO, Alencar AH, Valladares-Neto J, Estrela C. Apical root resorption due to orthodontic treatment detected by cone beam computed tomography. Angle Orthod 2013;83(2):196-203.
31. Lund H, Grondahl K, Hansen K, Grondahl HG. Apical root resorption during orthodontic treatment. A prospective study using cone beam CT. Angle Orthod 2012;82(3):480-7.
32. Makedonas D, Lund H, Hansen K. Root resorption diagnosed with cone beam computed tomography after 6 months and at the end of orthodontic treatment with fixed appliances. Angle Orthod 2013;83(3):389-93.
33. Yu J-H, Shu K-W, Tsai M-T, et al. A cone-beam computed tomography study of orthodontic apical root resorption. Journal of Dental Sciences 2013;8(1):74-79.
34. Bernier-Rodriguez JA, Sidow SJ, Joyce AP, McNally K, McPherson JC, 3rd. Radiographic interpretation of experimental lesions in radicular tooth structure of human maxillary anterior teeth. J Endod 2008;34(12):1466-9.
35. Harris DA, Jones AS, Darendeliler MA. Physical properties of root cementum: part 8. Volumetric analysis of root resorption craters after application of controlled intrusive light and heavy orthodontic forces: a microcomputed tomography scan study. Am J Orthod Dentofacial Orthop 2006;130(5):639-47.
36. Wierzbicki T, El-Bialy T, Aldaghreer S, Li G, Doschak M. Analysis of orthodontically induced root resorption using micro-computed tomography (Micro-CT). Angle Orthod 2009;79(1):91-6.

37. Li J, Wang X, Li N, et al. Short-term effects of nicotine on orthodontically induced root resorption in rats. Angle Orthod 2016;86(2):199-205.
38. Bjorndal L, Carlsen O, Thuesen G, Darvann T, Kreiborg S. External and internal macromorphology in 3D-reconstructed maxillary molars using computerized X-ray microtomography. Int Endod J 1999;32(1):3-9.
39. Poleti ML, Fernandes TMF, Paiz CC, Rubira-Bullen IRF, Capelozza ALA. Pixel value analysis for detection of simulated early external root resorption. Brazilian Oral Research 2014;28(1):1-6.
40. Kumar V, Gossett L, Blattner A, et al. Comparison between cone-beam computed tomography and intraoral digital radiography for assessment of tooth root lesions. Am J Orthod Dentofacial Orthop 2011;139(6):e533-41.
41. Xu X, Zhou J, Yang F, Wei S, Dai H. Using Micro-Computed Tomography to Evaluate the Dynamics of Orthodontically Induced Root Resorption Repair in a Rat Model. PLoS One 2016;11(3):e0150135.
42. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33(1):159-74.
43. Chapnick L. External root resorption: an experimental radiographic evaluation. Oral Surg Oral Med Oral Pathol 1989;67(5):578-82.
44. Andreasen FM, Sewerin I, Mandel U, Andreasen JO. Radiographic assessment of simulated root resorption cavities. Endod Dent Traumatol 1987;3(1):21-7.
45. Simundic AM. Measures of Diagnostic Accuracy: Basic Definitions. EJIFCC 2009;19(4):203-11.
46. Madani Z, Moudi E, Bijani A, Mahmoudi E. Diagnostic Accuracy of Cone-Beam Computed Tomography and Periapical Radiography in Internal Root Resorption. Iran Endod J 2016;11(1):51-6.
47. Alqerban A, Jacobs R, Fieuws S, Willems G. Comparison of two cone beam computed tomographic systems versus panoramic imaging for localization of impacted maxillary canines and detection of root resorption. European Journal of Orthodontics 2011;33(1):93-102.
48. Shokri A, Mortazavi H, Salemi F, et al. Diagnosis of simulated external root resorption using conventional intraoral film radiography, CCD, PSP, and CBCT: a comparison study. Biomed J 2013;36(1):18-22.
49. Kamburoglu K, Tsesis I, Kfir A, Kaffe I. Diagnosis of artificially induced external root resorption using conventional intraoral film radiography, CCD, and PSP: an ex vivo study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;106(6):885-91.
50. Consolaro A, Furquim LZ. Extreme root resorption associated with induced tooth movement: a protocol for clinical management. Dental Press J Orthod 2014;19(5):19-26.
51. Patel S, Dawood A. The use of cone beam computed tomography in the management of external cervical resorption lesions. Int Endod J 2007;40(9):730-7.
52. Arai Y, Tammisalo E, Iwai K, Hashimoto K, Shinoda K. Development of a compact computed tomographic apparatus for dental use. Dentomaxillofac Radiol 1999;28(4):245-8.
53. Tanimoto HA, Y. The effect of voxel size on image reconstruction in cone-beam computed tomography. Oral Radiology 2009;25(2):149-53.
54. Cohnen M, Fischer H, Hamacher J, et al. CT of the head by use of reduced current and kilovoltage: relationship between image quality and dose reduction. AJNR Am J Neuroradiol 2000;21(9):1654-60.
55. Rustemeyer P, Streubuhr U, Suttmoeller J. Low-dose dental computed tomography: significant dose reduction without loss of image quality. Acta Radiol 2004;45(8):847-53.
56. Ozer SY. Detection of vertical root fractures by using cone beam computed tomography with variable voxel sizes in an in vitro model. J Endod 2011;37(1):75-9.

57. Sousa Melo SL, Vasconcelos KF, Holton N, et al. Impact of cone-beam computed tomography scan mode on the diagnostic yield of chemically simulated external root resorption. Am J Orthod Dentofacial Orthop 2017;151(6):1073-82.
58. Torres MGG CP, Pena N, Ribeiro M, Navarro M, Crusoé-Rebello I. . Avaliação de doses referenciais obtidas com exames de tomografia computadorizada de feixe cônico adquiridos com diferentes tamanhos de voxel. . Dental Press J Orthod 2010;15(5):42-3.
59. Kamburoglu K, Kursun S. A comparison of the diagnostic accuracy of CBCT images of different voxel resolutions used to detect simulated small internal resorption cavities. Int Endod J 2010;43(9):798-807.
60. Hahn W, Fricke-Zech S, Fricke J, et al. Detection and size differentiation of simulated tooth root defects using flat-panel volume computerized tomography (fpVCT). Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;107(2):272-8.
61. Samandara A, Papageorgiou SN, Ioannidou-Marathiotou I, Kavvadia-Tsatala S, Papadopoulos MA. Evaluation of orthodontically induced external root resorption following orthodontic treatment using cone beam computed tomography (CBCT): a systematic review and meta-analysis. Eur J Orthod 2018.
62. Deliga Schroder AG, Westphalen FH, Schroder JC, Fernandes A, Westphalen VPD. Accuracy of Digital Periapical Radiography and Cone-beam Computed Tomography for Diagnosis of Natural and Simulated External Root Resorption. J Endod 2018;44(7):1151-58.
63. Nuzzo R. Scientific method: statistical errors. Nature 2014;506(7487):150-2.
64. Lermen CA, Liedke GS, da Silveira HE, et al. Comparison between two tomographic sections in the diagnosis of external root resorption. J Appl Oral Sci 2010;18(3):303-7.
65. Stephanopoulos G, Mikrogeorgis G, Lyroudia K. Assessment of simulated internal resorption cavities using digital and digital subtraction radiography: a comparative study. Dent Traumatol 2011;27(5):344-9.
66. Ponder SN, Benavides E, Kapila S, Hatch NE. Quantification of external root resorption by low- vs high-resolution cone-beam computed tomography and periapical radiography: A volumetric and linear analysis. Am J Orthod Dentofacial Orthop 2013;143(1):77-91.

ANEXOS

Respostas aos revisores do periódico caso o artigo já tenha sido submetido e/ou aprovado

ARTIGO 2 – Artigo aceito no Journal of Endodontics (A1)

Reviewers' comments:

Reviewer #1: JOE 17-1030

Thank you for submitting this manuscript for possible publication in the Journal of Endodontics. In general, the manuscript needs a thorough review to edit typos and English grammar errors.

Answer: It was reviewed for someone that uses English as a first language.

Abstract

In the abstract conclusions, in the conclusions of the body of the manuscript and the highlights, you state that "CBCT was the best method for the detection of ERR, although the sensitivity and specificity of the periapical radiographs were not much lower." This statement seems to be the opposite of what your results indicate, namely a 20% difference that was statistically significant.

Answer: ok, we changed it in all the parts above cited

Abstract- page 1 line 18

Conclusion -page 9 line 7

Highlights – lines 6 and 7

Introduction

Page 2 line 16 you state, "High cost and radiation exposure make this modality generally unsuitable as the first choice for dental imaging."

In fact, this entirely depends on the diagnosis. In trauma cases, for example, CBCT considerably reduces the number of images necessary and provides significantly more information. In fact, the AAE and The AAE and AAOMR joint position statement on use of cone-beam-computed tomography in endodontics states "Limited FOV CBCT is the imaging modality of choice in the localization and differentiation of external and internal resorptive defects and the determination of appropriate treatment and prognosis."

Answer: ok. Page 2 lines 6 and 7

Materials and Methods

How did you select the different teeth? You state the specimens were randomly picked out of a pool but end up with an even distribution of the tooth types.

Answer: This sample was from a previous study, 126 teeth was the number to complete 9 jaws with 14 teeth each of that study.

Page 3 line 22 you state "42 teeth without ERR gaps, but had perforations that were created

to simulate cavities." Perforations imply a communication with the root canal system, yet the images show shallow defects. Please change accordingly.

Answer: ok, we changed the word to "cavity", page 3 line 11

Page 3 line 33, "perforations' see above.

Answer: ok, we changed the word to "cavity", page 3 line 16

Results

You said that "Receiver operating characteristic (ROC) curve analysis was used to assess the diagnostic accuracy of each imaging system in detecting the presence ERR defect against the microtomography."

Please list the micro CT scans, e.g. as sensitivity and specificity 100% in the tables and the text to make this clearer.

Answer: ok, we've done in the main text page 5 line 2 and in the footnote of ROC curve

Discussion

Please shorten the discussion and avoid duplications of statements. Numerous authors have compared CBCT and PA radiographs for external root resorption detection. The main strength of the article as I see it is that natural cavities were used. Please debate this in the beginning of the discussion.

Answer: ok, done. Page 6 line 3 to 10.

The results discussion should follow the steps described in Materials and Methods

1. Tooth selection:

discuss micro CT as tool, Answer: ok, done. Page 5 lines 27 to 31.

how the tooth distribution was reached, why this particular number per type, e.g. to match the available natural resorption teeth

Answer: ok, done. Page 2 line 23 and 24.

2. Cavities: How was cavity preparation done in comparison to other studies? Bring the section on page 7, line 50ff to the beginning of the discussion

Answer: ok, done, page 5 lines 26 to 32 and page 6 lines 1 to 12.

3. Radiographic methods: Please discuss why you chose a coarse resolution of 250 micron. The more detailed or smaller the analysed structure is, the higher the resolution should generally be, that is why micro CT is useful as reference. Compare to other authors who recommend a high resolution, for example Neves at al 2012, Bragatto 2016, Sousa Melo 2017.

Answer: We did not find the references of the 3 authors mentioned above talking about micro-CT only articles that talk about CBCT. We used the same resolution cited in the studies of Wierzbick, 2009 (*Angle Orthod.* 2009; 79:91–96.); Dudic, 2008 (Eur J Oral Sci 2008; 116: 467–472), Stauber M, Muller R. (Methods Mol Biol. 2008; 455:273–292). Even though there are higher resolutions, they require extensive more time for scanning and consequently an increase in cost.

Page 6 lines 7 to 14.

4. Limitations should be mentioned with the points of discussion, not a separate section.

Answer: ok, done. Page 8 line 26.

Conclusions

The conclusions should highlight the statistically significantly higher detection rate of ERR with CBCT versus PA imaging, using micro CT as reference.

Answer: ok, done page 9 line 7.

Figures: please clearly identify which images are artificial resorptive cavities and which are natural resorptive cavities. You do this correctly in Figure 1.

Answer: ok, done in all figures in details in figure 3.

Tables

Tables 2, 3, and Chart 1 and 2 can be omitted and included in the results and discussion sections.

Answer: because we have tables and charts deleted all of them have the number changed and it was correct in the main text

Table 2 was deleted and the results included in the text of “results” page 4 lines 29 and 30

Table 3 it was not possible to delete because it is important for understanding the differences between radiographic and tomographic method and we completed it with the accuracy, LR+, LR- and Younder’s index.

Chart 1 and 2: I think it means charts 2 and 3 (?) it was deleted and the results included in the text of “results”

Reviewer #2: By comparing digital periapical radiography and CBCT the authors evaluate sensitivity and specificity of detecting natural and artificially created areas of external root resorption. There is a substantial body of literature that has previously undertaken these comparisons (for example: Aust Dent J (Australia), Dec 2016, 61(4) p425-431, Am J Orthod Dentofacial Orthop (United States), Jun 2017, 151(6) p1073-1082, J Endod (United States), Jan 2017, 43(1) p121-125). The authors attempt fo identify a very narrow gap in knowledge in the beginning of the Discussion.

Answer: ok, done. Page 6 line 3 to 10

Strengths of the Manuscript:

1) A good study design

2) Excellent use of available technology

3) Good analysis of data

Weakness of Manuscript:

1) Unfortunately a substantial weakness is in the writing with frequent errors in syntax, grammar and spelling. I respectfully suggest a review and rewriting particularly of the Introduction.

Answer: It was reviewed for someone that uses English as a first language.

2) Your identified a radiologist and orthodontist as the examiners. Endodontists are well trained and highly capable of identifying resorptive processes radiographically -- especially when submitting to an endodontic journal.

Answer: It is a good idea but sorry, now it is not possible to change the examiners. In the next study certain

ARTIGO 3 – American Journal Orthodontics and Dentofacial Ortopedics (A1)

Manuscript: AJODO-D-18-00236

Title: Accuracy of different imaging CBCT systems for the detection of natural external radicular resorption cavities – an ex vivo study

American Journal of Orthodontics & Dentofacial Orthopedics

22-August-2018

Dear Dr. Rolf Behrents

Editor-in-Chief

American Journal of Orthodontics and Dentofacial Orthopedics

We thank the reviewers for carefully reviewing the manuscript. Your comments, suggestions, and recommendations helped us to improve the quality of the revised manuscript, and we appreciate the insightful critiques.

We carefully considered the Reviewers' suggestions and revised the manuscript accordingly. Specific itemized responses to the Reviewers' comments are listed below.

We have done our best to address all the issues raised. In the following letter, we provide detailed responses to each comment and suggestion.

We hope that you now find the manuscript acceptable for publication in American Journal of Orthodontics and Dentofacial Orthopedics

Sincerely and with best regards,

Dr. Angela Schroder, on behalf of all the authors.

REVIEWER(S)' COMMENTS TO AUTHOR:

Reviewer #1:

Thank you for submitting your article to AJODO. Its really interesting topic and here is my comments:

Response: We thank you for your comments.

* The title is not clear. Are you comparing different machines or different settings? If you want to compare different CBCT systems you should have different machines with similar settings.

Response: Thank you for the observation, we wanted to compare different machines with similar settings.

Title

"Accuracy of different imaging CBCT systems for the detection of natural external radicular reabsorption cavities - an ex vivo study"

* "Radicular reabsorption cavities." The word reabsorbtion was used only in the title. Is that intentional?

Response: Thank you for the observation, no it was not. We made this change in the manuscript.

Title

"Accuracy of different imaging CBCT systems for the detection of natural external radicular resorption cavities - an ex vivo study"

* The names of the groups are not very descriptive of the groups. Please use something like experiment or resorption group vs control.

Response: Thank you for the observation, we made this change in the manuscript.

Abstract page 1 line 28

"(2) Experimental Group: 41 teeth that presented with one or more ERR cavities."

Material and Methods page 3 line 28

"(2) Experimental Group: 41 teeth that presented with one or more ERR cavities (total of 52 cavities)"

Material and Methods page 4 line 1

"After separation of the teeth into groups (control and experimental), they were again randomly distributed by the software to form a set of 14 teeth with control and

natural ERR cavities constituting a whole double blind…"

*   Check the highlights character limits.

Response: Thank you once more for the observation, we made the change in the highlights character limits as you can see below:

Highlights

"-compare sensitivity and specificity of 3 differents CBCT in the detection of natural ERR cavities (85 characters)

-arquitecture of ERR is so different of that produced artificially and seen in others image exams (83 characters)

-Results show lower sensitivities and specificities than those in studies for artificial cavity (84 characters)

-CBCTs used at the exposure parameters given are not useful for the detection of natural ERR defects." (84 characters)

*   There is a systematic review and meta-analysis regarding CBCT and ERR that was published in 2017 in Angle orthodontics. I think you should add that with other more recent publications to your literature review of the topic

Response: Thank you for your pertinent comment. Based on your observation, we added the reference of this statement as you can see below:

Introduction page 2 lines 24 to 28

"Several studies have already been carried out to test the accuracy of CBCT in the detection of ERR cavities (using different voxels sizes, FOV and acquisition time), but all studies so far have used artificially produced ERR cavities, either mechanically or chemically.[9, 16, 19-23, 59, 60] *These cavities do not reproduce reality, since they are sharper with well-defined and regular edges, which are different from those observed naturally. In the in vivo studies*[3, 17, 31, 32] *this limitation is solved, but it is not possible to expose the patient to different image acquisition protocols to test their accuracy or to quantify the volume of ERR cavities that can be detected. A systematic review*[11] *in 2017 compared the diagnostic accuracy of CBCT and periapical radiographs for the detection of ERR and the results suggests that CBCT could be reliable to detect the presence of ERR in clinical practice and has a higher diagnostic efficacy than PR, but all the studies included used simulated ERR as reference test. So, the aim of this study was to compare the sensitivity and specificity of three different imaging system of CBCT in the detection of natural ERR*

cavities using microtomography as the gold standard."

* "In the sequence, many other CBCT devices were developed, many of which had larger work areas making it possible to scan the maxilla and jaw". Please use the correct terminology for field of view and mandible

Response: Thank you once more for the observation, we made this change in the manuscript as you can see below:

Introduction page 2 line12 and 13

"In the sequence, many other CBCT devices were developed, many of which had larger field of view making it possible to scan the maxilla and mandible.[53]*"*

* "It is known that the quality of the image in CBCT depends on some factors such as field of view (FOV), size of voxel and time of scanning." How about the effect of changing the KvP and mA? Would these affect the image quality? Please add all factors that have effects of image quality

Response: Thank you for your pertinent comment. Based on your observation, we added

Introduction page 2 lines 9-11

"It is known that the quality of the image in CBCT depends on some factors such as detector type of the scanner[5]*, field of view (FOV)*[54, 55]*, size of voxel*[9]*, tube current*[5]*, milliamperage settings*[55] *and time of scanning*[55]*."*

* "The teeth were randomly selected with the aid of a magnifying glass (3X magnification) and natural light until they filled the number of teeth determined for the study." How was the number of teeth determined for this study? Can you explain?

Response: We thank you for your comment and constructive input. In order to clarify it and avoid possible misinterpretations, we added this sentence:

Material and Methods page 3 lines 8-9

"This study was carried out after the approval of the Ethics Committee under the number CAAE: 50214515.0.0000.0020, characterising an observational cross-sectional study with a sample of 126 ex vivo teeth, 36 incisors, 18 canines, 36 premolars and 36 molars belonging to a bank of teeth, number sufficient to complete 9 jaws with 14 teeth each."

* Add the evaluator's initials to the methodology.

Response: Once more, we thank you for the observation. We have done this as you can see below:

Material and Methods page 3 lines 12-14

“In addition, they were examined by two evaluators (JCS and AKS) to confirm the anatomy (i.e., which tooth group each tooth belonged to and also met the inclusion criteria).”

* Three duly calibrated oral radiologists. How was the calibration done?! Did they have any previous experience using the three software packages?

Response: Once more, we thank you for your considerations. Yes, all the three oral radiologists had previous experience using the software. To avoid misinterpretations we added this sentence:

Material and Methods page 4 lines 26-27

“The analysis of the tomographic images obtained was performed by three duly calibrated oral radiologists with previous experience using the software packages.”

* "Protocol 3: Scanx 3Dx apparatus (Soredex, Tuusula, Finland), 8 cm x 10 cm FOV, 90 kVp, 12.5 mA, voxel size of 0.133 mm and 18-34 second exposure time." Why the wide range of the scan time? Did you measure the actual scan time?

Response: Thank you for the observation, we added the actual scan time in the manuscript.

Material and Methods page 4 lines 19-20

“Protocol 3: Scanx 3Dx apparatus (Soredex, Tuusula, Finland), 8 cm x 10 cm FOV, 90 kVp, 12.5 mA, voxel size of 0.133 mm and 18 second exposure time.”

* Add a table to show the difference between the three scanning protocol and machine's detectors type.

Response: Thank you for the observation, we accepted this suggestion as you can see below:

Table I. Characteristics and tecnical specifications of the CBCT systems

	Voxel size (mm)	Potential (kV)	Current (mA)	Field of volume (FOV) cm	Exposure Time (s)	Detector type
I-Cat Next Generation	0.20	120	8	8	26.7	Flat panel
Orthophos XG 3D	0.166	85	6	8	20	Flat panel
Scanora 3D	0.133	90	12.5	8	18	Flat panel

* The examiners did not report the existence or absence of ERR gap and neither the face and third in question? What does that mean?

Response: Thank you for the observation, the correct sentence is this one:

Material and Methods page 4 lines 27-29

"For the examiners the existence or absence of gap ERR was not reported and neither the face and the third one in question."

* The effective dose of a CBCT in the case of I-Cat, for example, is 69 <mu>Sv. What was the scanning protocol for this specific value?

Response: Once more, we thank you for your considerations. To avoid misinterpretations we excluded this sentence:

Discussion page 8 line 13

* Is figure 1 representing the micro scan or one of the three protocols? Can you add an example of one tooth in the three protocols

Response: Thank you for the observation. Figure 1 representing the micro-CT. To avoid misinterpretation we added these words in the sentence:

"Fig 1. Example of a scanned tooth by microtomography being (A) axial cut, (B) sagittal cut and (C) coronal cut where arrows point to ERR cavities."

* The figure legends are not clear. Figure 2 can be removed.

Response: Thank you for your suggestion, we made this change in the manuscript.

Figure 2 was removed (the flowchart), as a consequence all the others figures were renumbered.

Reviewer #2:

Abstract: Is a little bit confusing and needs to be rewritten. You mentioned that three protocols/systems have been used but did not explain them. And in the result section you stated only one difference (Voxel size).

Response: Thank you for the observation. Because of the limit of words it was not possible to explain in details all the three protocols. So only one difference, the voxel size, was talked about in result section.

Introduction: Needs to include more information. (Like the effect of using different CBCT settings on the image quality).

Response: Thank you for the observation, we made this change in the manuscript.

Introduction page 2 lines 9-12

"It is known that the quality of the image in CBCT depends on some factors such as detector type of the scanner[5], field of view (FOV)[54, 55], size of voxel[9], tube current[5], milliamperage settings[55] and time of scanning[55]."

Material and methods: In your study there are so many variables like (Kvp, mA, FOV, voxel size etc..). Even though you mentioned this as limitation, I think it is really hard comparing different settings within different machines. Maybe as a start it is better to evaluate ERR using one machine and different settings.

Response: Thank you for the observation, despite we are using different machines all of them had the same detector type and FOV, similar potential an current, as we can see in the table above that was insert in manuscript as a suggest of other reviewer.

Table I. Characteristics and tecnical specifications of the CBCT systems

	Voxel ize (mm)	P otential (kV)	C urrent (mA)	Fi eld of volume (FOV) cm	Ex posure Time (s)	D etector type
I-Cat Next Generation	0. 20	12 0	8	8	26 .7	Fl at panel
Orth	0.	85	6	8	20	Fl

ophos XG 3D	166					at panel
Sca nora 3D	0. 133	90	12 .5	8	18	Fl at panel

Conclusion: You mentioned that taking CBCT images is not a useful way to detect ERR. So, what do you suggest as an alternative way to detect ERR in orthodontic treatments?

Response: Thank you again. I said: "*The CBCT units used at the exposure parameters given are not useful tests for the detection of ex vivo natural external root resorption defects.*" Because *"The results of the present study show lower ROC curve values as well as lower sensitivities and specificities than those detected in previous studies for artificial cavity sizes"*. My concern is that the acuracy found with CBCT in the detection of simulated ERR cavities was not the same as that found with natural ERR cavities. CBCT remains, in the opinion of the literature, the best method for the detection of ERR, but it is necessary to carry out future research with natural ERR cavities for more real results. And I put a sentence with this thought at the end of the discussion.

Discussion page 8 line 26-29

"CBCT remains, in the opinion of the literature[5, 11], the best method for the detection of ERR, but the acuracy found with CBCT in the detection of simulated ERR cavities was not the same as that found with natural ERR cavities in this study, so it is necessary to carry out future research with natural ERR cavities for more real results."

Also I excluded the last conclusion to avoid misinterpretation.

Excluded - ~~"The CBCT units used at the exposure parameters given are not useful tests for the detection of ex vivo natural external root resorption defects."~~