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Original research

Comparison of the accuracy of different cone beam computed tomography systems in measuring the volume of external root resorption

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Purpose
The aim of this study is to compare the accuracy of root resorption volume measurements among three cone-beam computed tomography (CBCT) devices using various imaging parameters.

Materials and Methods
A total of 42 external root resorption (ERR) defects were mechanically created on the buccal and palatinal surfaces of the roots of seven extracted human teeth. Volume measurements of the defects were performed using three CBCT devices and six different imaging protocols. CBCT measurements were then compared with those calculated from micro-computed tomography (micro-CT) images.

Results
The mean absolute error values indicated that the rate of measurement accuracies from best to worst was obtained with KaVo 3D eXam (0.125 mm voxel, 0.2 mm voxel, respectively), Orthophos XG 3D (0.1 mm voxel, 0.16 mm voxel, respectively), and Rainbow CT (0.2 mm voxel, 0.3 mm voxel, respectively). No statistically significant difference was found between any of the CBCT measurements in comparison to the micro-CT evaluations.

Conclusion
Although external root resorption is a small object to evaluate using CBCT, larger voxel sizes (e.g., 0.3 mm) of CBCT systems can be employed during scanning without compromising image quality.

Keywords: *Cone-beam computed tomography, external root resorption, micro computed tomography, imaging parameters*

Introduction

External root resorption (ERR) has a complicated etiological background, including chronic inflammation in adjacent tissues, excessive orthodontic force, periapical pathologies, benign tumors or malignant neoplasms, cysts, chemical agents applied in bleaching treatment, trauma, reimplantation, and impacted teeth. Additionally, various systemic disorders such as hypoparathyroidism, hyperparathyroidism, calcinosis, Turner syndrome, Gaucher's disease, and Paget's disease may be attributed as the causes of this pathology (1-3).

According to the mostly used classification (4), ERR is divided into three categories: external surface resorption, external inflammatory resorption, and external replacement resorption. External cervical resorption was later added as another category to the ERR classification since this resorption type pathophysiologically differs from the others (5,6).

Due to the asymptomatic nature of ERR, significant dental hard tissue damage or tooth loss may occur by the time it is detected. Therefore, early

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and accurate diagnosis of ERR is of great importance for the preservation of dental structures and the tooth (1,7). When ERR is detected early, the vitality of the tooth can be maintained by removing the granulomatous tissue in the resorption area and applying an appropriate material after the root surface is reached by flap operation. Thus, early detection enables the treatment of ERR without affecting the vitality of the pulp (8).

In the majority of cases, radiography may be the only method to detect the pathology since ERR is mostly asymptomatic. An accurate radiographic diagnosis of the location and size of the ERR is crucial to designing an optimal treatment plan and predicting the prognosis of the treatment (9). However, various parameters such as the size, location, and local anatomy of the lesion, and bone density may intervene with the diagnosis (10,11). Both intraoral (12) and extraoral (13) imaging methods have been utilized to detect root resorption. Small resorptions on the buccal and lingual surfaces are easily missed with these techniques (11,14-16). Considering that the diagnostic capability of intraoral radiography is affected by anatomical superposition, beam angulation, and image enhancement procedures (17-19), three-dimensional tomography, including cone-beam computed tomography (CBCT), has been recommended for the evaluation of root resorptions (20,21).

Volumetric data generated by the CBCT peripheral rotating beam source creates opposing images in the axial, sagittal, and coronal planes (22-25). Cone-beam scanner devices with two-dimensional digital sensors combine three-dimensional cone-shaped x-rays in a circular plane and rotate once around the patient to create a three-dimensional image (22,26). The effective dose for CBCT devices is between 52 and 1025 microsieverts and varies according to the device model and the imaging technique applied. Although these values correspond to approximately 4 to 77 times the dose of a panoramic film, it has a low dose value of 51%-96% compared to head imaging obtained with medical CTs. It is known that the radiation dose given to the patient can be reduced by 40% by the correct alignment of the beam, the use of protective barriers, and the positioning of the chin in the appropriate position [23,26]. The ALARA (As Low As Reasonably Achievable) principle, which aims to give the lowest reasonable dose to the patient, requires that the irradiation characteristics of CBCT devices be adjusted according to patient dimensions. This is possible by selecting the appropriate current and voltage values (27).

Our aim in this study is to evaluate the images obtained from different CBCT devices using various field-of-view (FOV), voltage, voxel sizes, tube current values, and to determine the effect of these parameters in accurately measuring the volume of ERR. The alternative hypothesis of this study is that the accuracy of different CBCT devices with different scanning protocols differs significantly from gold standard values.

Materials and Methods

Sample size estimation

A power analysis using G*power, version 3.1.9.2 (Franz Faul, Universität Kiel, Germany) was applied; a total sample size of 41 bone defects would be sufficient to determine a significant difference with 95% confidence, 85% test power, and d = 0.6 effect size. Therefore, 42 ERRs were prepared on teeth surfaces in this study.

Ethical approval

All procedures used in this study were approved by the Van Yüzüncü Yıl University Non-Interventional Ethics Committee (Approval number: 2020/08-06).

Study characteristics

A total of seven extracted teeth, including one maxillary canine, one mandibular canine, two single-rooted maxillary premolars, and three single-rooted mandibular teeth, previously extracted from patients treated at Van Yüzüncü Yıl University Faculty of Dentistry, were used.

Cavity preparation

Three external resorption defects were created on the buccal surface of each tooth, located in the apical third, middle third, and coronal third sections. Likewise, three external resorption cavities were created in each tooth, in the apical third, the middle third, and the coronal third of the lingual/palatal surfaces. Overall, forty-two resorption cavities were created on the seven teeth using a 12 no round diamond bur mechanically (Figure 1). After the cavities were formed, the teeth were numbered and placed in the empty tooth sockets of a model skull. Pink wax was placed just above the alveolar bone to imitate gingival tissue and the attenuation caused by soft tissue on bone in natural clinical conditions.

CBCT image acquisition

The skull model was placed and fixed inside the CBCT devices while taking the images. Three different CBCT devices (KaVo 3D eXam (Biberach, Germany), Rainbow CT (Dentium, South Korea), Orthophos XG 3D (Dentsply Sirona, Germany) (Figure 2) were used with the scanning protocols shown in Table 1.

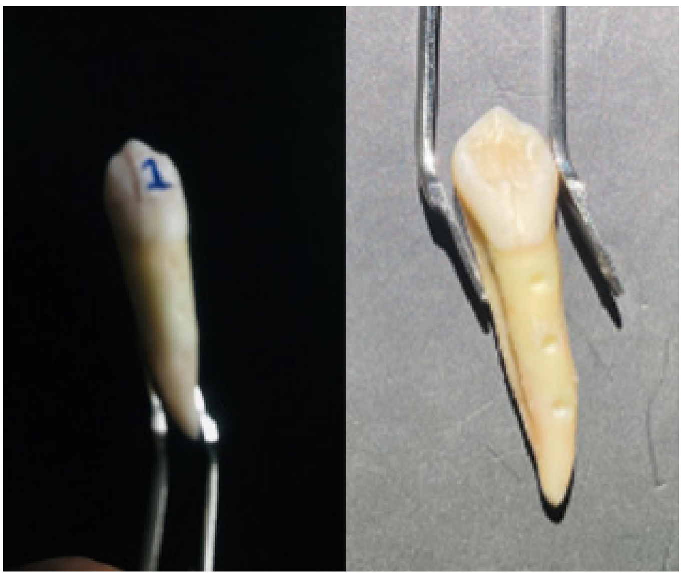

Figure 1. *Resorption defects in teeth created by a round diamond bur.*

Micro-CT image acquisition

SkyScan 1172 scanner (Bruker micro-CT, Kontich, Belgium) device was used for micro-computed tomography (micro-CT) at 15 µm isotropic voxel resolution, 104 µA, 95 kVp, 0.5 mm aluminum + 0.038 Cu filter, 0.4° rotation step, and 180° rotation. Volume measurements were performed on CBCT and micro-CT images using 3D-DOCTOR (Able Software Corp., Lexington, MA, USA) software. The micro-CT evaluations were accepted as the actual volume (gold standard) and were used for comparisons with the CBCT measurements. The volume of bone defects was measured by two oral and maxillofacial radiologists with eight and three years of experiences, respectively. Cross-sectional images of resorption defects were converted to DICOM format and imported into ImageJ software (US National Institutes of Health, Bethesda, Maryland, USA). Then, a 3D model was formed using the software, and the volume was estimated, including the numerical values of the total surface area and the slice thickness (Figure 3 and Figure 4).

Statistical analysis

Statistical analyses were performed using the SPSS (IBM SPSS Statistics 20.0; IBM Co., Armonk, NY, USA) software package. Analyses were performed at the 95% confidence interval, and $p<0.05$ was considered statistically significant. Friedman's two-way analysis of variance test was performed to statistically compare the results of the CBCT measurements and micro-CT results. Volume measurements were performed twice for each sample, and the intra-class correlation coefficient (ICC) was calculated to assess intra- and inter-observer reliability. The mean absolute error (MAE) was calculated to determine the measurement precision accuracy independent of deviation. The confidence level was set to 95%, and p-values less than 0.05 were considered significant.

Results

The descriptive statistics and comparison results of the volumes measured by different CBCT devices and scanning parameters are shown in Table 2. The average values obtained by Rainbow CT (0.2 mm voxel), Rainbow CT (0.3 mm

Table 1. *Scanning protocols applied in the CBCT devices.*

Device	Field-of-view (cm)	Voltage (kVp)	Tube Current (mA)	Voxel Size (mm)	Scan Time (s)
KaVo 3D eXam	16x4	120	5	0.125	7
KaVo 3D eXam	16x4	120	5	0.2	4
Rainbow CT	16x18	94	8	0.2	19
Rainbow CT	16x10	94	8	0.3	19
Orthophos XG 3D	5x5	85	6	0.1	14.4
Orthophos XG 3D	8x8	85	7	0.16	14.2

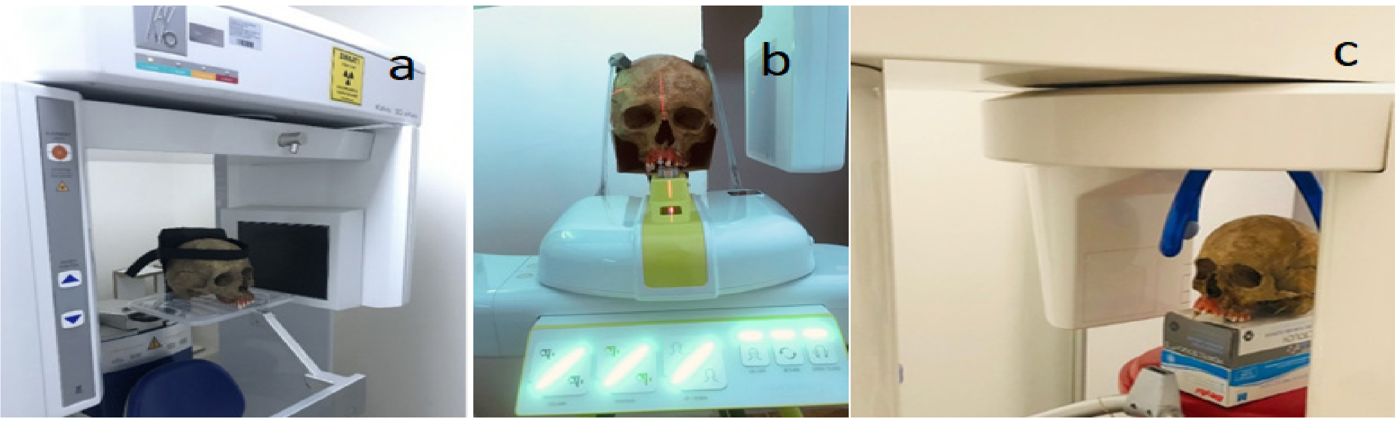

Figure 2. *Images taken while scanning on different brands of CBCT devices; (a) KaVo 3D eXam, (b) Rainbow CT, (c) Orthophos XG 3D.*

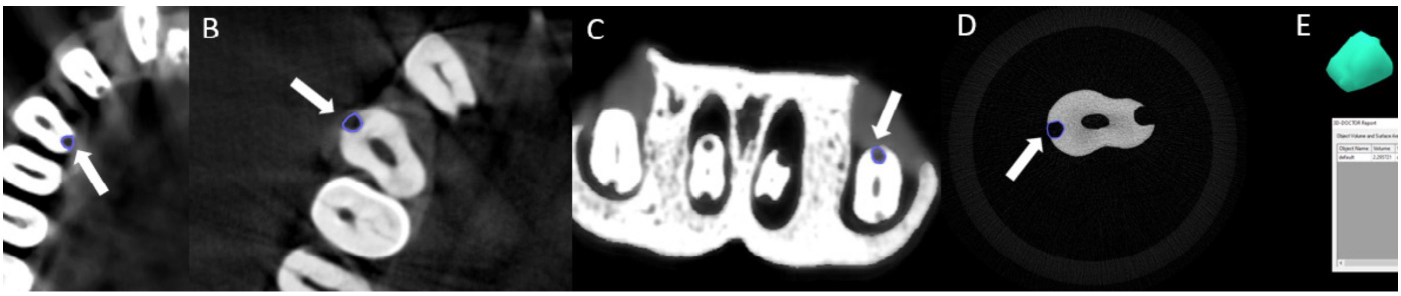

Figure 3. *Manual delineation of resorption cavity; (A) Rainbow CT, (B) KaVo CT, (C) Orthophos XG, (D) microCT.*

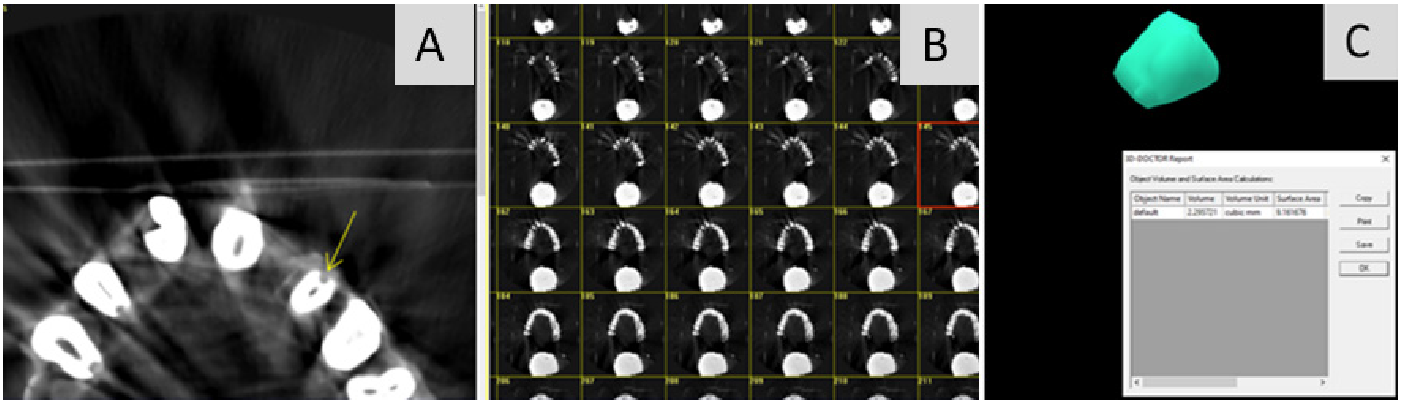

Figure 4. *External root resorption cavity (A), multiple sectional images containing related cavity (B) and demonstration as a 3D model (C).*

Table 2. *Descriptive statistics and comparison results of volume measurements made with different CBCT devices and scanning parameters.*

	Rainbow CT (0.2 mm)	Rainbow CT (0.3 mm)	Orthophos XG 3D (0.1 mm)	Orthophos XG 3D (0.16 mm)	KaVo 3D eXam (0.2 mm)	KaVo 3D eXam (0.125 mm)	Actual Size
Mean±SD	2.10± 0.84	2.03± 0.88	2.13± 0.71	2.31± 0.77	2.29± 0.71	2.15± 0.61	2.11± 0.47
Min: Max	0.60: 3.97	0.51: 4.27	0.56: 3.67	0.70: 4.28	0.56: 3.58	0.64: 3.58	0.76: 3.04
P	1.00	1.00	1.00	0.81	1.00	1.00	-

SD: Standard deviation

Table 3. *Average MAE values in measuring the resorption volumes by different CBCT systems.*

	Rainbow CT		Orthophos XG 3D		KaVo 3D eXam	
Voxel thickness (mm)	0.2	0.3	0.1	0.16	0.2	0.125
MAE (Mean±SD)	0.500±0.333	0.525±0.391	0.402±0.315	0.420±0.308	0.372±0.287	0.327±0.238

SD: Standard deviation, MAE: Mean Absolute Error

voxel), Orthophos XG 3D (0.1 mm voxel), Orthophos XG 3D (0.16 mm voxel), KaVo 3D eXam (0.2 mm voxel), and KaVo 3D eXam (0.125 mm voxel) were 2.10 mm^3, 2.03 mm^3, 2.13 mm^3, 2.31 mm^3, 2.29 mm^3, and 2.15 mm^3, respectively. There was no statistically significant difference between CBCT measurements and micro-CT evaluations.

The MAE values in measuring the resorption volumes of different CBCT systems are presented in Table 3. The accuracy sensitivities for Rainbow CT (0.2 mm voxel), Rainbow CT (0.3 mm voxel), Orthophos XG 3D (0.1 mm voxel), Orthophos XG 3D (0.16 mm voxel), KaVo 3D eXam (0.2 mm voxel), and KaVo 3D eXam (0.125 mm voxel) were found to be 0.500 ± 0.333 mm^3, 0.525 ± 0.391 mm^3, 0.402 ± 0.315 mm^3, 0.420 ± 0.308 mm^3, 0.372 ± 0.287 mm^3, and 0.327 ± 0.238 mm^3, respectively. The MAE values of the CBCT devices and different imaging protocols are plotted in a graph in Figure 5. For each CBCT device, the measurement accuracy increased as the voxel size decreased.

In subsequent measurements, intra-observer and inter-observer agreement were found to be excellent in all measurements (ICC ≥ 0.948).

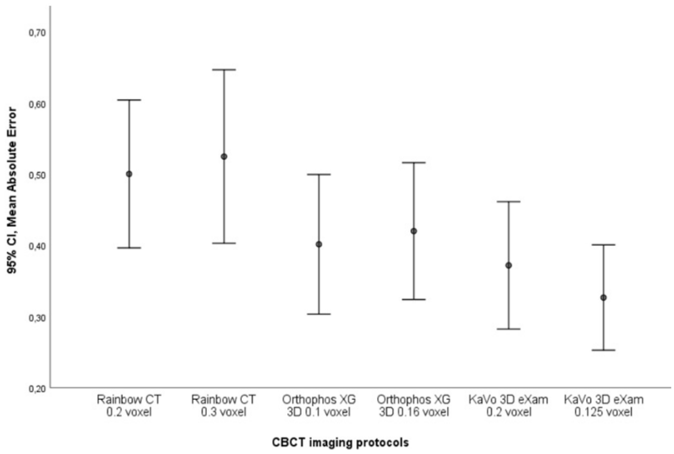

Figure 5. *The average MAE values of the different CBCT devices and imaging protocols in each section.*

Discussion

The null hypothesis of the study was accepted since there was no significant difference between the actual volume and other CBCT systems. In this study, for the first time, ERR volume was calculated using three CBCT devices, and the accuracy of these measurements was compared to the gold standard values obtained from micro-CT. The most recent European guideline for endodontic treatment (28) approved CBCT for use in evaluating ERR in follow-up and prognosis. Therefore, studies such as ours that investigate optimum scanning protocols are needed to ensure radiation safety. A study investigated whether external root resorption can be detected differently in endodontically treated and non-endodontically treated teeth using digital periapical radiography (DPR) and CBCT. According to the results of this study, it was emphasized that both CBCT and DPR are good diagnostic methods for ERR (29).

In recent decades, CBCT has been an important tool for diagnosis, therapy planning, and prognosis. For example, CBCT can reveal from which region (palatal or buccal) the resorption perforates the related tooth. If the perforation is located in the palatinal region, treatment options for ERR may be eliminated due to access difficulties in endodontics (30,31). Additionally, the ratio of the circumferential spread of ERR around the pulp tissue or the remaining healthy tooth structure can be evaluated. A healthy structure is important for prognosis since this tissue is resistant to fractures. Saoud *et al.* (32) observed the arrest of the growth of apical lesions and ERR in traumatized teeth after regenerative endodontic therapy using a 2D imaging modality. This volumetric change would be better evaluated if CBCT were applied in an optimum scanning protocol. Nosrat *et al.* (33) observed the effect of the "no treatment" option for ERR cases. They followed up with patients over an average period of 21 months and found a significant increase in ERR volume between initial and follow-up images. Also, perforation was observed in follow-up appointments in 85% of teeth with ERR. It is not possible to evaluate such detailed changes in ERR using a 2D imaging modality. The most recent guideline of the European Society of Endodontology promoted the use of CBCT in the assessment of ERR cases (28). However, while using this device, clinicians need to carefully plan the optimum radiation dose to balance dose–benefit axis in selecting scanning parameters.

Various standards are used to evaluate CBCT image quality, with the contrast-to-noise ratio (CNR) being the most widely accepted method. Grayscale, quality, and CNR of CBCT images are influenced by settings such as FOV, kVp, mA, and voxel size (34,35). In endodontics, it is recommended to use the smallest FOV, smallest voxel, lowest mA settings, and minimal exposure time for CBCT imaging procedures (36). Choosing a small voxel size for better resolution can lead to increased noise, which manufacturers may attempt to compensate for by using higher doses (37).

Specifically, CBCT units with limited FOV are preferred for ERR evaluation to achieve higher resolution images with lower radiation doses (38). Hirsch *et al.* (39) reported that images taken with smaller FOVs resulted in much less radiation exposure to patients. While larger FOVs are recommended for broader imaging needs, smaller FOVs are advised for dental imaging (39). In the present study, different FOVs were used for CBCT imaging; however, the effect of FOV alone could not be evaluated with these measurements, as other scanning parameters were not kept constant when the FOV was changed.

Freitas *et al.* (40) scanned 22 teeth with three different kVp values to assess the correlation between image quality and metal artifacts caused by implants placed adjacent to teeth with ERR, comparing the accuracy of using different kVps in detecting these ERRs. They reported that increasing the kVp from 70 to 90 improved the diagnostic accuracy for ERR diagnosis (40). In the present study, three different kVps—85 kVp, 94 kVp, and 120 kVp—were used, and no significant difference was found when the results were compared to micro-CT measurements. However, measurements with 120 kVp had the lowest MAE values. Although increasing the kVp resulted in more accurate imaging, the lack of a statistically significant difference suggests that lower values, such as 85 kVp, can be used for ERR volume measurement to reduce radiation exposure to the patient while still obtaining relatively sufficient image quality. Liedke *et al.* (41) also stated that high-resolution (0.2 mm and 0.3 mm voxel size) CBCT images were superior to low-resolution (0.4 mm voxel) images; however, there was no statistically significant difference in ERR diagnosis accuracy.

While the semi-automatic segmentation technique's borders lack the sensitivity to accurately depict ERR defect lines based on pixel density, we opted for the manual segmentation technique. Despite being more time-consuming, manual segmentation proves more sensitive in determining borders (42).

Treatment decisions for ERR may hinge on the severity and location of the defect. In vital therapy, actions such as surgical access, soft tissue debridement in the cavity, application of a trichloroacetic solution, closure of the defect with a bioactive material like glass ionomer cement or mineral trioxide aggregate (MTA), and follow-up periods can be undertaken if root canal therapy is not necessary (43). In the past, planning treatment for ERR cases relied on the Heithersay classification system, utilizing 2D images (44). Recent developments have led to new classification systems based on CBCT images. Patel *et al.* (45) proposed a classification considering three parameters: the height of the resorption, the ratio of circumferential spread around pulp tissue, and pulpal involvement. The authors highlight the importance of CBCT in designing such classifications and suggest further studies to determine whether accurate diagnosis of ERR cases is possible while decreasing CBCT dose levels in adherence to the ALARA principle, a question addressed in the present study.

Although our study found 300 µm (0.3 mm voxel) sufficient for estimating ERR dimensions, some in vivo studies focused on different voxel dimensions. For example, Nosrat *et al.* (33) included a maximum voxel level of 150 µm (0.15 mm voxel), Matny *et al.* (31) used 250 µm (0.25 mm voxel), and Kurt *et al.* (46) employed 80 µm (0.08 mm voxel). In these studies, sub-millimeter voxel dimensions could cause unnecessary radiation overdose in patients. Kolsuz *et al.* (47) obtained CBCT images with Planmeca Promax 3D Max CBCT at four different voxel sizes, concluding that there was no statistically significant difference in inter- and intraobserver reliability, with higher agreement for 0.1 mm and 0.15 mm voxel sizes. For the detection of external root resorption defects, interobserver agreement was highest for the 0.1 mm voxel size (47). Sönmez *et al.* (48) conducted a study similar to ours, finding that 200 µm (0.2 mm voxel) was sufficient to evaluate ERR, without assessing the validity of using a voxel size of 300 µm (0.3 mm voxel) to evaluate ERR. Deliga *et al.* (49) compared three different CBCT systems for the detection of natural external root resorption defects in 126 extracted teeth, using microCT as the gold standard. They found no statistically significant difference in resorption detection between the three CBCT protocols used, with accuracy listed in descending order: 60.3% for 0.2 mm voxel size, 56.7% for 0.166 mm voxel size, and 46.7% for 0.25 mm voxel size. The results indicate that CBCT presents lower sensitivity and specificity values for natural ERR than those detected in previous studies of artificial cavities, demonstrating that natural ERR is neither easily observed nor accurately located by CBCT, as indicated in previous studies using artificial ERR.

The study has inherent limitations, primarily associated with the utilization of different CBCT systems with varying parameters and the lack of standardization in image qualities. Due to the non-identical scanning parameters across different CBCT systems, slight variations may exist in sectional images representing bone tissues. Consequently, when generating 3D models from these diverse sectional images, inherent estimations of volume variations may occur.

Changes in voxel dimensions may trigger automatic adjustments in parameters such as mAs and kVp in each CBCT system. However, the cumulative imaging quality of different CBCT devices, influenced by specific detector types, focal spot dimensions, frame rates, rotation angles, and more, introduces variations that need assessment in comparative studies among these devices. The novelty of this study lies in its pioneering estimation of ERR volume using three CBCT systems, with subsequent comparisons against actual volumes obtained by micro-CT.

Moreover, potential image distortions arising from patient movement pose a limitation in CBCT imaging. Fortunately, in our study, there were no motion artifacts. Further research may delve into the accuracy of CBCT imaging for ERR in teeth subjected to restorative, endodontic, or prosthetic treatments, or in proximity to dental implants, replicating real-world clinical conditions.

Conclusion

The measurement accuracy improved with decreasing voxel size for each CBCT device. Despite variations in accuracy among different CBCT systems, our results revealed no statistically significant difference between the measurements obtained by these systems and the actual volume. In summary, our findings indicate that evaluating the volume of ERR cavities may be reliably done with a voxel size of up to 0.3 mm.

Türkçe öz: *Eksternal Kök Rezorpsiyonu Hacminin Ölçülmesinde Farklı Konik Işınlı Bilgisayarlı Tomografi Sistemlerinin Doğruluğunun Karşılaştırılması. Amaç: Bu çalışmanın amacı farklı tarama parametrelerine sahip üç farklı konik ışınlı bilgisayarlı tomografi (KIBT) cihazının kök rezorpsiyon hacmini ölçüm doğruluğunu karşılaştırmaktır. Gereç ve Yöntem: Yedi adet çekilmiş insan dişinin köklerinin bukkal ve palatinal yüzeylerinde mekanik olarak toplam 42 adet eksternal kök rezorpsiyonu (EKK) defekti oluşturuldu. Defektlerin hacim ölçümleri, üç KIBT cihazı ve altı farklı görüntüleme protokolü kullanılarak tamamlandı. KIBT ölçümleri, mikro bilgisayarlı tomografi (mikro-BT) değerleri ile karşılaştırıldı. Bulgular: Ortalama mutlak hata değerleri, en iyiden en kötüye doğru ölçüm doğruluğu oranının KaVo 3D eXam (sırasıyla 0,125 mm voksel, 0,2 mm voksel), Orthophos XG 3D (sırasıyla 0,1 mm voksel, 0,16 mm voksel) ve Rainbow CT (sırasıyla 0,2 mm voksel, 0,3 mm voksel) ile elde edildiğini gösterdi. KIBT değerleri ve mikro BT değerleri arasında anlamlı fark olmadığı görüldü. Sonuç: Eksternal kök rezorpsiyonu KIBT kullanılarak değerlendirilecek küçük bir obje olsa bile, KIBT taramaları esnasında daha büyük voksel boyutları (örn. 0.3 mm) görüntü kalitesini düşürmeden kullanılabilir. Anahtar Kelimeler: konik ışınlı bilgisayarlı tomografi, dış kök rezorpsiyonu, mikro bilgisayarlı tomografi, görüntüleme parametreleri*

Ethics Committee Approval: All procedures used in this study were approved by the Van Yüzüncü Yıl University Non-Interventional Ethics Committee (Approval number: 2020/08-06).

Informed Consent: Participants provided informed constent.

Peer-review: Externally peer-reviewed.

Author contributions: AGOT, AK participated in designing the study. AGOT participated in generating the data for the study. AGOT, AK participated in gathering the data for the study. AGOT, AK participated in the analysis of the data. AGOT wrote the majority of the original draft of the paper. AK participated in writing the paper. AGOT, AK has had access to all of the raw data of the study. AGOT, AK has reviewed the pertinent raw data on which the results and conclusions of this study are based. AGOT, AK have approved the final version of this paper. AGOT, AK guarantees that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

Conflict of Interest: The authors declared that they have no conflict of interest.

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