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RESEARCH ARTICLE

Versatility of high resolution ultrasonography in the assessment of granulomas and radicular cysts: a comparative in vivo study

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Objectives: To evaluate and compare the diagnostic potential of high resolution ultrasound with periapical radiographs (PR) and CBCT in assessing granulomas and radicular cysts.
Methods: This study included a total of 33 teeth from 33 patients with periapical lesions. Subjects were distributed among three groups. A consisted of teeth that were extracted. B consisted of teeth treated with root-canal treatment followed by apical surgery. C consisted of teeth treated with root-canal treatment only. Pre-treatment PR, ultrasound and CBCT images were obtained for Groups A, B and C and 6 month post-treatment PR and ultrasound images were obtained for Groups B and C. In addition, histopathological analysis was performed on lesions in Groups A and B. Lesions were classified as either cystic lesions or granulomas. Width, height, depth, surface area and volume of lesions were measured using the built-in softwares of the appropriate imaging modalities. Measurements were compared by Wilcoxon and paired sample t tests. Ultrasound and histopathological findings were compared with κ and Mc Nemar. Statistical significance was set at $p < 0.05$.
Results: κ coefficient (0.667; $p = 0.002$) suggested good agreement between ultrasound and histopathology. No statistically significant differences were found among periapical radiography, CBCT and ultrasound in the pre-treatment measurements of lesion width ($p = 0.308$) or between CBCT and periapical radiography in the pre-treatment measurements of lesion height ($p = 0.863$). In all cases, mean measurement values for all variables were lower for ultrasound than for CBCT.
Conclusion: Ultrasound provided useful information for the diagnosis and assessment of granulomas and radicular cysts.
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Keywords: Ultrasonography; CBCT; Radiology; Periapical pathosis

Introduction

Accurate assessment of periapical pathosis is of paramount importance in enabling the clinician to provide immediate and appropriate dental intervention. A granuloma presents as a well-developed fibrous capsule infiltrated by lymphocytes, plasma cells, and macrophages,[1] whereas a radicular cyst consists of an epithelium-lined cavity contiguous with the infected tooth's apex.[2,3] The radiolucent appearance of a periapical lesion is due to bone resorption that occurs as a result of the host response to intraradicular infection. In routine clinical practice, X-ray imaging is used in conjunction with clinical examination to assess periapical pathosis; however, intraoral digital periapical radiography (PR) can provide only limited information regarding the origin, size and location of periapical pathosis. The introduction of

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cone beam CT (CBCT), which is uniquely designed for dentomaxillofacial imaging, has enabled three-dimensional (3D) visualizations that can provide useful quantitative information for the diagnosis, differentiation, treatment and monitoring of periapical disease.[4,5] CBCT uses a cone-shaped X-ray beam centered on a two-dimensional (2D) sensor to scan 180°−360° around the patient's head to acquire a full 3D volume of data. In comparison to medical tomography, CBCT offers easier image acquisition, higher bony-image accuracy, lower effective-radiation doses and greater cost-effectiveness; however, it has a number of disadvantages.[4,5] Not only does it deliver higher doses than 2D imaging,[4,5] it is also unable to provide accurate representations of the internal structure of soft tissue and soft-tissue lesions, and it has limited correlation with the Hounsfield Units used to provide standardized quantification of bone density. Moreover, various types of CBCT image artifacts, mainly those produced by metal restorations, can interfere with the diagnostic process by masking underlying structures.[4,5] In view of these shortcomings, there is clearly a need for a non-ionizing, on-site, real-time, objective and quantitative method for the diagnosis, differentiation, treatment planning and follow-up of periapical pathosis.

Ultrasound imaging has been proposed as an alternative technique that can provide real-time images at a low cost and without ionizing radiation. Ultrasound imaging is based on the phenomenon of propagation and reflection of sound waves at the interface of different tissue types. Sound waves may be transmitted, attenuated, or deflected (reflected and/or scattered) when they interact with a medium.[6–9] In diagnostic ultrasound, high-frequency (30–20 KHz) sound waves are generated and transmitted into the body by a transducer that contains piezoelectric crystals, which transform electrical signals into mechanical vibrations and vice versa. Echoes from the interface between tissues are detected, processed, and translated into greyscale images that appear on a computer screen. Tissue may be categorized as either echogenic or anechogenic, with echogenic, or hypergenic, tissue reflected with high intensity to produce light screen images and anechogenic, or hypoechogenic, tissue reflected with low intensity to produce dark screen images.[6–9]

The aim of this study was to evaluate and compare the diagnostic potential of high-resolution ultrasound with intraoral digital radiographs and CBCT in assessing granulomas and radicular cysts. Periapical lesions were assessed in terms of size, surface area, volume and origin, and the diagnostic findings were compared to those of histopathology.

Materials and methods

This study was approved by the Ankara University Faculty of Dentistry's Local Ethical Committee (36290600/110) and included a total of 33 teeth (19 incisors, 1 canine, 10 premolars and 3 molars) from 33 patients (23 female, 10 male; age range: 18–62 years) with periapical lesions that were diagnosed by clinical and radiological examination. Subjects were distributed among three groups according to treatment protocols as determined based on clinical examination, and diagnostic imaging. Group A (n = 7; five female, two male) consisted of teeth with asymptomatic and symptomatic periapical lesions that were extracted because treatment prognosis was considered hopeless. Group B (n = 13, 10 female, three male) consisted of clinically asymptomatic and symptomatic teeth with periapical lesions treated with root-canal treatment followed by apical surgery, indication of which was based on guidelines published by the European Society of Endodontology. Inclusion criteria were as follows: (1) patient age ≥18 years; (2) diameter of the lesion ≥5 mm, assessed based on periapical X-ray; and (3) an acceptable root canal treatment for the involved tooth.[10] Group C (n = 13, eight female, five male) consisted of clinically symptomatic teeth with periapical lesions treated with root-canal treatment only.

Table 1 shows the distribution of patients according to age, gender, tooth symptoms and clinical findings. Clinical examination was conducted by one researcher, and swelling, pain at palpation and percussion, and sensitivity to electrical pulp testing (EPT) (Digitest, 9V battery, Parkell Inc., NY) and cold test (Endo-Frost Spray, Coltene/Whaledent Inc., OH, US) were recorded. In order to evaluate the diagnostic potential of ultrasound and compare diagnostic assessments among imaging modalities, pre-treatment PR, ultrasound and CBCT images were obtained for Groups A, B and C and 6 month post-treatment PR and ultrasound images were obtained for Groups B and C. In addition, histopathological analysis was performed on lesions in Groups A and B in order to compare the results of all three imaging techniques with the histological gold standard.

Digital intraoral periapical radiographs were exposed using a Gendex X-ray machine (Gendex Digital Systems, Hatfield, PA) operated at 65 kVp and 7 mA and a GXPS-500 photostimulable phosphor plate (PSP) detector (Gendex Digital Systems, Hatfield, PA), with Size 2 PSPs, a paralleling technique, and 32-bit colour/64 µm (high) pixel size for image recording. Maximum mesiodistal width and height of lesions were measured using the built-in software.

Ultrasound examinations were performed using an ACUSON S 2000 (Siemens, Munich, Germany) and 9 MHz linear and 15 MHz hockey probes on the transversal plane, with the probe position changed constantly to obtain sufficient transverse scan images on the monitor, and using the colour Doppler flowmeter feature to assess lesion blood supplies. Lesions were classified as either cystic lesions (a well-contoured, hypoechoic cavity surrounded by reinforced, fluid-filled bone walls, with no evidence of internal vascularization on color Doppler examination) or granulomas (a poorly defined, hypoechoic area, showing a rich vascular supply on

Table 1 Distribution of patients according to age, gender, related tooth symptoms and clinical examination

		Age	*Gender*	*Tooth number*	*Percusion*	*Swelling*	*Palpation*	*Sensitivity tests*	
								EPT	*Cold test*
GROUP A	1	45	Male	34	no	no	no	no	no
	2	35	Female	35	yes	no	yes	no	no
	3	62	Female	34	no	no	no	no	no
	4	39	Female	16	yes	intraoral	yes	no	no
	5	31	Female	46	yes	intraoral	yes	no	no
	6	30	Male	35	no	no	yes	no	no
	7	18	Female	22	no	no	no	no	no
GROUP B	8	19	Female	21	yes	no	yes	yes	yes
	9	19	Female	21	no	no	no	no	no
	10	32	Female	11	yes	no	no	no	no
	11	20	Female	12	no	yes	no	no	no
	12	18	Male	11	yes	no	yes	no	no
	13	55	Female	11	yes	no	yes	no	no
	14	25	Female	12	no	no	no	no	no
	15	18	Male	11	yes	no	no	no	no
	16	32	Female	44	yes	intraoral	no	no	no
	17	18	Female	12	no	intraoral	yes	no	no
	18	20	Male	11	yes	no	yes	no	no
	19	61	Female	13	yes	intraoral	yes	no	no
	20	49	Female	22	yes	no	yes	no	no
GROUP C	21	38	Male	31	yes	extraoral	yes	no	no
	22	41	Female	41	yes	no	yes	no	no
	23	49	Female	32	yes	no	no	yes	yes
	24	27	Female	14	no	no	yes	no	no
	25	21	Female	11	yes	no	yes	yes	no
	26	33	Male	34	yes	no	no	no	no
	27	33	Male	47	yes	intraoral	yes	no	no
	28	35	Female	11	no	no	yes	no	no
	29	35	Female	12	no	no	no	no	no
	30	25	Female	14	no	no	no	no	no
	31	38	Male	14	yes	no	no	no	no
	32	21	Male	11	yes	no	yes	yes	yes
	33	44	Female	44	no	no	no	no	no

EPT: Elecrtric pulp testing

color Doppler examination). The term "poorly defined margin" was used for granulomas showing indistinct and obscure outline which showed no posterior acoustic enhancement. On the other hand, the term "well-defined margin" was used for cysts showing distinct and clear-cut outline which showed detectable posterior acoustic enhancement due to fluid content. Maximum mesiodistal width, maximum (buccolingual) depth, surface area and volume of lesions were measured using the built-in software. All measurements were performed by the same researcher. Pre-treatment PR, pre-treament ultrasound, post-treatment PR and post-treatment ultrasound images are shown in Figures 1–4.

CBCT images were obtained using a Planmeca Promax 3D max CBCT unit (Planmeca, Helsinki, Finland) at 90 kVp, 7mA, and a 0.1 mm voxel size using 55 × 50 mm limited FOV. CBCT images were taken from patients who presented with complicated signs and symptoms with untreated teeth and from cases where adequate information regarding true lesion size, relationship of adjacent anatomical structures and pre-surgical assessment could not be obtained from PR.[11]

Maximum width, depth and height measurements were obtained from multiplanar reformatted reconstructions using the built-in software. Lesion surface area and volume were calculated by exporting CBCT images to 3D-DOCTOR (Able Software Corp., Lexington, MA, US). 3D-DOCTOR, a volumetric rendering software that uses vector-based segmentation technology to perform segmentation of periapical lesions on consecutive axial slices, enabling visualization at each level apicocoronally. Lesion borders were segmented manually on

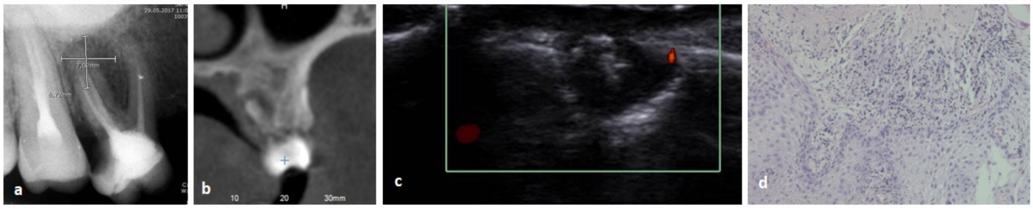

Figure 1 (a) Periapical radiography of a patient from Group A. Representative width and height measurements of a periapical cyst related to a right maxillary first-molar root. (b) Cross-sectional CBCT image of the same lesion showing perforation of the palatinal cortical bone. (c) An ultrasound image obtained from the palatinal surface of the cyst using a 15 Mhz hockey probe shows a clearly defined hypoechonegenic area with posterior enhancement. (d) Histopathological examination of the same lesion showed it to be a periapical cyst; the lesion was lined with non-keratinized squamous epithelium, and it was accompanied by dense, chronic inflammation of oedematous connective tissue.

each slice using a mouse and the "trace boundary" tool to create a turquoise border (Figure 5).

Root canal treatment was performed in 26 teeth (Groups B and C). Coronal access was achieved, and working length was determined using the Root ZX apex locator (J. Morita Corp, Kyoto, Japan). Tooth preparation was performed according to the manufacturer's recommendations using SX files in the cervical third and S1, S2, F1 and F2 files up to working length. A 2.5% sodium hypochlorite solution was used during instrumentation, with 2 ml of the same solution used for irrigation between instruments, and final irrigation performed for 1 min with 1 ml 17% EDTA followed by a final rinse with 2 ml 2.5% sodium hypochlorite applied using a 30-gauge NaviTip needle (Ultradent Products Inc, South Jordan, UT). Root canals were dried with absorbent paper points and dressed with $CaOH_2$. Final obturation was performed with single-cone gutta-percha (ProTaper) and AH Plus sealer (Dentsply, Maillefer, York, PA, US), and composite was used for the coronal restorations.

Histopathological evaluation was performed by an experienced oral pathologist on 20 surgically enucleated lesions (Groups A and B). Following routine tissue processing, formalin-fixed surgical specimens were embedded in paraffin, and 5 µm sections were obtained and stained with hematoxylin & eosin (HE). Histopathological diagnoses were performed using HE slides.

Statistical analysis

A Shapiro–Wilk test was used to determine normality for paired data. Width, depth, surface area and volume measurements were compared by a Wilcoxon test for non-normally distributed data and a paired sample *t* test for normally distributed data. Ultrasound and histopathological findings were compared with a κ test, with a Mc Nemar test used to determine marginal homogeneity. Statistical significance was set at $p < 0.05$ with 95% CI. Statistical analysis was performed using the Stata 12mp4 software package (Stata Corp. LP 2011. Statistical Software: Release 12. College Station, TX, US).

Results

The study population comprised a total of 33 patients (Female: $n = 23$, 69.7%; Male: $n = 10$, 30.3%) ranging in age between 18 and 62 years (mean age: 32.9 ± 12.68). Clinical examination revealed the following: swelling: 25 patients (75.8%); no swelling: eight patients (24.2%); tenderness to palpation: 18 patients (54.5%); no tenderness to palpation: 15 patients (45.5%); pain during percussion: 20 patients (60.6%); no pain during percussion: 13 patients (39.4%); sensitivity to electric pulp testing: 4 patients (12.1%); no sensitivity to electric pulp testing: 29 patients (87.9%); sensitivity to cold test: 3 patients (9.1%); no sensitivity to cold test: 30 patients (90.9%). A statistically significant correlation was found between tenderness to percussion and pre-treatment periapical radiographic width ($p = 0.002$) and height ($p = 0.003$) as well as pre-treatment ultrasound width ($p = 0.021$) and depth ($p = 0.03$). No other significant correlations were found between any other measurements and descriptive data ($p > 0.05$).

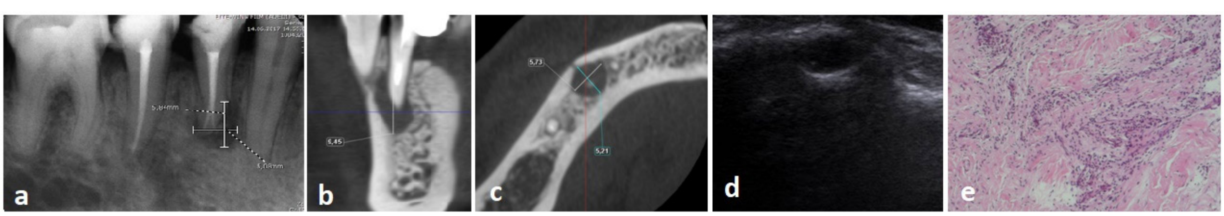

Figure 2 (a) Periapical radiography of a patient from Group A. Representative width and height measurements of a periapical granuloma related to right mandibular first premolar tooth. (b) Height measurement of the same lesion on cross-sectional CBCT image. (c) Depth and width measurements of periapical lesion on axial CBCT images. (d) Poorly defined hypoechoic cavity ultrasound examination. (e) Histopathological examination shows chronic inflammatory infiltration in fibrous connective tissue without epithelial lining which is compatible with periapical granuloma.

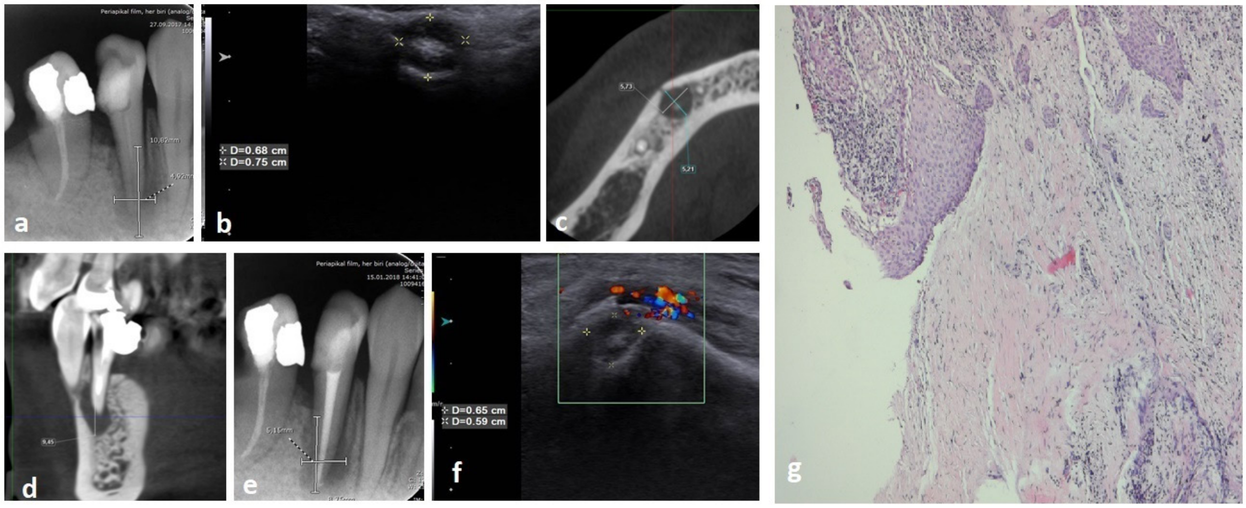

Figure 3 (a) Pre-operative periapical radiography of a patient from group B. Representative maximum width and height measurement of a periapical lesion related to right mandibular first premolar tooth. (b) Representative maximum width and depth measurements conducted on pre-treatment ultrasound images of the same periapical lesion. (c) Maximum width and depth measurements of the periapical lesion on axial plane. (d) Height measurement conducted on cross-sectional CBCT image. (e) Post-treatment periapical radiography of the same patient showing width and height measurement of the periapical lesion 6 months post-operatively. (f)Post-treatment ultrasound image showing width and depth measurements of the same periapical lesion after 6 months. (g) Histopathological examination shows cystic lesion lined by hyperplastic non-keratinized squamous epithelium. Abundant lymphoplasmocytic inflammatory infiltration and foamy histiocytes were also present in fibrous cyst wall.

Histological examinations were performed in Groups A and B. Out of a total of 20 lesions, histopathological diagnosis confirmed 12 to be periapical cysts (6 each in Groups A and B) and 8 to be granulomas (1 in Group A and 7 in Group B). Although three of the granulomas had been identified as periapical cysts from ultrasound (well-defined border with detectable posterior acoustic enhancement), a κ coefficient (0.667; $p = 0.002$) suggested good agreement between ultrasound and histopathological examination, and a Mc Nemar test showed no statistically significant difference between ultrasound and histopathological diagnoses of periapical lesions ($p = 0.25$).

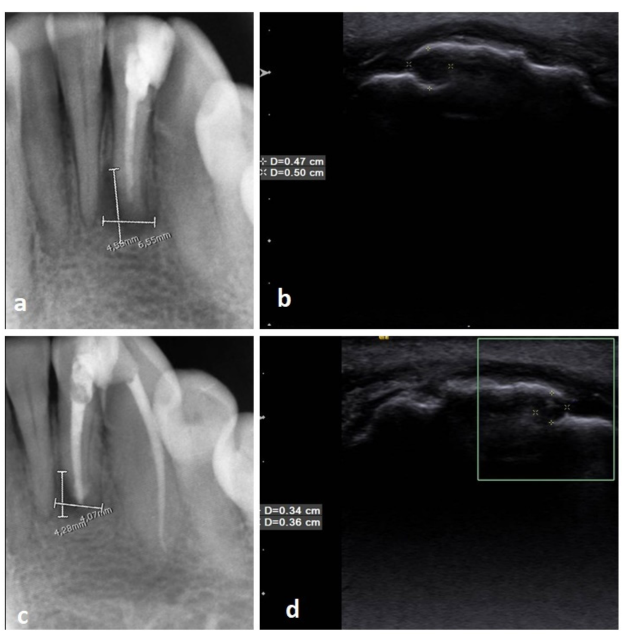

Figure 4 (a) Pre-treatment periapical radiography of a patient from group C. Representative maximum width and height measurement of a periapical lesion related to left mandibular lateral incisor. (b) Pre-treatment ultrasound image of the same periapical lesion shows width and depth measurements. (c) Post-treatment periapical radiography of the same patient, shows width and height measurements of the periapical lesion. (d) Post-treatment ultrasound image shows width and depth measurements of the periapical lesion suggesting reduction in lesion size

Table 2 shows mean/median, standard error, standard deviation, minimum and maximum values obtained with the different imaging modalities. No statistically significant differences were found among periapical radiography, CBCT and ultrasound in the pre-treatment measurements of lesion width ($p = 0.308$) or between CBCT and periapical radiography in the pre-treatment measurements of lesion height ($p = 0.863$). (No ultrasound measurements were obtained for lesion height.) However, statistically significant differences were found between ultrasound and CBCT in pre-treatment measurements of lesion depth ($p = 0.004$), surface area ($p < 0.001$) and volume ($p < 0.001$). In all cases, mean measurement values for all variables were lower for ultrasound than for CBCT.

In addition, statistically significant differences were found between pre-treatment and post-treatment ultrasound measurements of lesion width ($p < 0.001$), depth ($p < 0.001$), surface area ($p < 0.001$) and volume ($p < 0.001$), suggesting a reduction in lesion dimensions 6 months after treatment. Furthermore, ultrasound images of patients in Group B taken 6 months after apical surgery demonstrated hard-tissue healing in eight

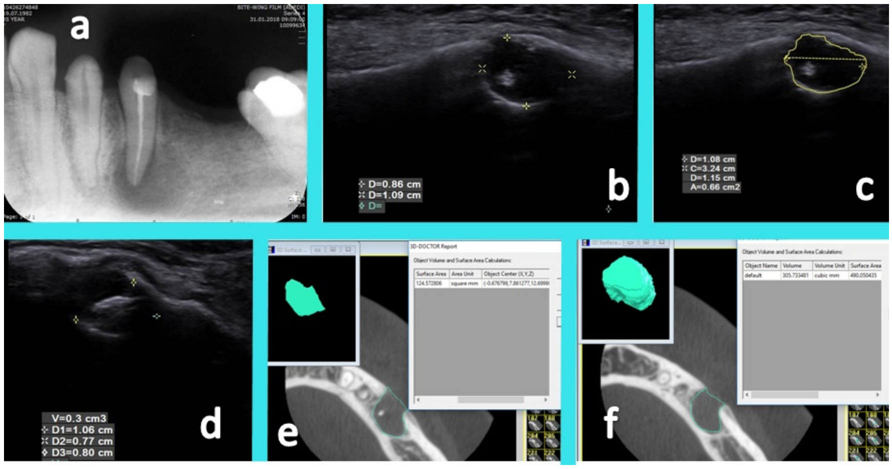

Figure 5 (a) Periapical radiography of a patient with periapical cyst (from Group A) related to left mandibular second premolar tooth. (b) Representative width and depth measurements of the same lesion on ultrasound image. (c) Representative surface area measurement of the same lesion on ultrasound image. (d) Volumetric measurement of the same lesion on ultrasound by using dedicated software. (e) Surface area measurement of the lesion conducted on axial CBCT images by using 3d Doctor software. (f) Volumetric measurement of the same lesion conducted on axial CBCT images by using 3d Doctor software.

patients treated with bone graft and resorbable collagen membrane and soft-tissue healing in five patients treated without bone graft and resorbable collagen membrane. Both clinical and imaging examinations showed all treatment to be successful.

Discussion

An accurate and reliable imaging modality is a necessity in the clinical assessment of periapical pathosis in terms of diagnosis and selection of treatment approach. During imaging, it is important to maintain patient comfort and minimize any pain and psychologic stress on the patient. Various types of X-ray imaging, in combination with clinical examination and anamnesis, are the main tools used in the diagnostic assessment of periapical cysts and granulomas. While histopathology is the gold-standard for the evaluation of periapical pathosis, in the majority of clinical cases, obtaining a biopsy specimen is impossible. Until now, the use of ultrasound imaging in dentistry has been limited mainly to the examination of dentomaxillofacial soft-tissue structures, and there are few studies that have assessed the use of ultrasound in the evaluation of periapical and bone lesions.[12–20] Therefore, the present study compared pre-treatment ultrasound, PR and CBCT images as well as pre- and post-treatment ultrasound in order to assess the use of ultrasound in evaluating granulomas and radicular cysts in patients with periapical pathosis.

In line with previous studies, we found ultrasound imaging to be an effective tool for determining the pathological nature of periapical lesions,[12–16,21] with no statistically significant differences between ultrasound and histopathological examination in the differentiation of periapical lesions ($p = 0.25$). However, in three cases, lesions diagnosed with ultrasound as periapical cysts proved to be granulomas upon histopathological examination. The misinterpretation that occurred with ultrasound may be ascribed to observer performance and/or the inability of colour Doppler flowmeter images to clearly show vascularization in some

Table 2 Mean, median, minimum, maximum and standard deviation values of conducted measurements (Width, height and depth measurements were in mm, surface area measurements were in mm^2 and volume measurements were in mm^3)

	Pre-treatment periapical radiography measurements		*Pre-treatment ultrasound measurements*				*Post-treatment ultrasound measurements*				*Pre-treatment Cone Beam Computerized Tomography Measurements*				
	Width	*Height*	*Width*	*Depth*	*Surface area*	*Volume*	*Width*	*Depth*	*Surface area*	*Volume*	*Width*	*Depth*	*Height*	*Surface Area*	*Volume*
Mean	7,76	8,34	8,02	6,65	308,58	394,85	5,40	5,12	26,40	112,22	9,12	8,57	9,62	1092,02	736,32
Median	5,87	6,71	6,10	5,90	32,00	100,00	4,30	4,30	13,00	100,00	8,51	7,72	7,72	114,50	276,37
Std. dev.	5,17	5,02	5,90	3,71	1321,47	1236,35	4,32	2,50	30,97	35,74	5,09	6,20	6,76	3993,97	1647,67
Minimum	1,2	0,53	2,7	0,57	3	100	1,2	1,2	2	100	2,09	2,09	4,2	4,62	1,3
Maximum	21,94	21,26	23,5	18,9	7626	7200	21,5	10,7	120	200	20,32	31,74	31,76	18017,98	7522,57

areas of granulomas. In evaluating ultrasound findings, it is important to keep in mind that ultrasound is an operator- and patient-dependent imaging modality. In ultrasound imaging the borders of the lesions may differ according to bone thickness and continuity and acoustic impedance. The term "the poorly defined margin" used for granulomas should be considered as a comparison to cysts which show good margins and posterior acoustic enhancement. In particular, image quality may be negatively affected by acoustic impedance, which may vary with patient weight (*i.e.* excessive fat tissue), gender (*i.e.* facial hair in male patients) and age (*i.e.* decreased water concentration in tissue of elderly individuals). Further studies with larger sample sizes are needed to better understand the factors influencing the measurement accuracy and capacity of ultrasound to differentially diagnose radicular cysts and granulomas.

Within the limitations of the present study, in general, we found no significant correlations between the measurements performed and descriptive data, with the exception of tenderness to percussion. Number of teeth with tenderness to percussion increased as measured size of the lesions increased with ultrasound and PA. We also found no statistically significant differences among the three different imaging modalities for pre-treatment lesion width measurements ($p = 0.308$). Measurements of lesion height could not be obtained with ultrasound due to the inability to longitudinally position the ultrasound system probes under clinical conditions. Previous studies comparing the measurement of periapical lesions using ultrasound images, conventional radiographs and periapical radiographs reported ultrasound imaging to underestimate mesiodistal, anteroposterior and superoinferior lesion dimensions.[8,9,12–15] At the same time, it should be noted that the two-dimensional nature of periapical radiography may result in an overestimation of lesion size. Radiographically the main subjective difference between granulomas and cysts is size. We did not use the lesion size as a criterion for differentiating cysts from granulomas as our main objective was to assess the diagnostic potential as well as 2d and 3d measurement accuracy of ultrasound in comparison to histopathology and CBCT, respectively.

Statistically significant differences have also been reported in superoinferior measurements of jaw lesions using ultrasound images and CBCT ($p < 00.1$); however, no statistically significant differences were reported in mesiodistal ($p = 0.700$) or buccolingual ($p = 0.572$) measurements.[13–16] To the best of our knowledge, our study is the first to compare surface area and volume measurements of periapical lesions obtained using a high-resolution hockey stick transducer in a transversal position with CBCT measurements calculated using third-party software. The findings showed significantly lower measurements for depth ($p = 0.004$), surface area ($p < 0.001$) and volume ($p < 0.001$) with ultrasound as compared to CBCT. The difference may be ascribed to effect of buccal cortical bone on ultrasound measurements as well as limitations of the ultrasound imaging system's software.

Endodontic surgery has been shown to be a reliable method for treating persistent periapical lesions, with recent studies reporting successful outcomes in more than 80% of cases.[20–22] The present study also found statistically significant reductions in ultrasound measurements of lesion width ($p < 0.001$), depth ($p < 0.001$), surface area ($p < 0.001$) and volume ($p < 0.001$) 6 months' post-treatment as compared to pre-treatment measurements. These findings are similar to those of earlier studies, which reported ultrasound to show reductions in both lesion size and volume.[18,19] Moreover, Craig et al stated that callus can be easily visualized using ultrasound as either hyperechoic or of mixed appearance.[23] Furthermore, other previous studies reported ultrasound to outperform conventional radiography in monitoring post-surgery healing.[24,25]Although the evaluation of bone healing following endodontic surgery was beyond the scope of the present study, ultrasound images at 6 months post-apical surgery demonstrated healing with either soft or hard tissue. Considering these findings and the non-ionizing, real-time nature of ultrasound imaging, this technology can be considered a good tool for assessing outcomes of periapical lesion treatment.

In the present study, most lesions showed perforation at the cortical bone that facilitated the detection of periapical pathosis using ultrasound. An earlier *in vitro* study,[26] that looked at ultrasound assessment of bony defects by creating artificial lesions of varying sizes in bovine scapula reported that failure to detect central lesions occurred in cortical bone more than 1.1 mm in thickness.[26] In addition to the amount of remaining cortical bone, other factors that can affect the visibility of periapical lesions by ultrasound include the probe and settings used, operator performance, and patient-related factors. In view of recent advancements in ultrasound technology, including the development of high-resolution ultrasound devices, further research is required to determine the cut-off value of overlaying bone thickness in terms of interference with ultrasound imaging.

Conclusion

Accurate assessment of periapical pathosis is of paramount importance in enabling the clinician to provide immediate and appropriate dental intervention. We evaluated the diagnostic potential of high-definition ultrasound that provides real time rapid images, at a low cost and without ionizing radiation in assessing granulomas and radicular cysts. The present study shows high-resolution ultrasound with colour Doppler to provide useful information for the diagnosis and assessment of granulomas and radicular cysts. Although lesion depth, surface area and volume are underestimated, lesion width and pathology as well as treatment outcomes are accurately assessed using ultrasound.

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References

1. Nair PNR. Apical periodontitis: a dynamic encounter between root canal infection and host response. *Periodontol 2000* 1997; **13**: 121–48. doi: https://doi.org/10.1111/j.1600-0757.1997.tb00098.x
2. Nair PN, Sjögren U, Sundqvist G. Cholesterol crystals as an etiological factor in non-resolving chronic inflammation: an experimental study in guinea pigs. *Eur J Oral Sci* 1998; **106**(2p1): 644–50. doi: https://doi.org/10.1046/j.0909-8836.1998.eos106206.x
3. Simon JH. Incidence of periapical cysts in relation to the root canal. *J Endod* 1980; **6**: 845–8. doi: https://doi.org/10.1016/S0099-2399(80)80039-2
4. Kamburoğlu K, Kiliç C, Özen T, Horasan S. Accuracy of chemically created periapical lesion measurements using limited cone beam computed tomography. *Dentomaxillofac Radiol* 2010; **39**: 95–9. doi: https://doi.org/10.1259/dmfr/85088069
5. Kamburoğlu K, Yılmaz F, Gulsahi K, Gulen O, Gulsahi A. Change in periapical lesion and adjacent mucosal thickening dimensions one year after endodontic treatment: volumetric cone-beam computed tomography assessment. *J Endod* 2017; **43**: 218–24. doi: https://doi.org/10.1016/j.joen.2016.10.023
6. Evirgen Ş, Kamburoğlu K. Review on the applications of ultrasonography in dentomaxillofacial region. *World J Radiol* 2016; **28**: 50–8.
7. Hangiandreou NJ. AAPM/RSNA physics tutorial for residents. topics in US: B-mode us: basic concepts and new technology. *Radiographics* 2003; **23**: 1019–33. doi: https://doi.org/10.1148/rg.234035034
8. Musu D, Rossi-Fedele G, Campisi G, Cotti E. Ultrasonography in the diagnosis of bone lesions of the jaws: a systematic review. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2016; **122**: e19–29. doi: https://doi.org/10.1016/j.oooo.2016.03.022
9. Abu-Zidan FM, Hefny AF, Corr P. Clinical ultrasound physics. *J Emerg Trauma Shock* 2011; **4**: 501–3. doi: https://doi.org/10.4103/0974-2700.86646
10. European Society of Endodontology. Quality guidelines for endodontic treatment: consensus report of the European Society of Endodontology. *Int Endod J* 2006; **3**: 921–30.
11. Patel S, Durack C, Abella F, Roig M, Shemesh H, Lambrechts P, et al. European Society of Endodontology position statement: the use of CBCT in endodontics. *Int Endod J* 2014; **47**: 502–4. doi: https://doi.org/10.1111/iej.12267
12. Raghav N, Reddy SS, Giridhar AG, Murthy S, Yashodha Devi BK, Santana N, et al. Comparison of the efficacy of conventional radiography, digital radiography, and ultrasound in diagnosing periapical lesions. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology* 2010; **110**: 379–85. doi: https://doi.org/10.1016/j.tripleo.2010.04.039
13. Shahidi S, Shakibafard A, Zamiri B, Mokhtare MR, Houshyar M, Mahdian S. The feasibility of ultrasonography in defining the size of jaw osseous lesions. *J Dent* 2015; **16**: 335–40.
14. Sandhu SS, Singh S, Arora S, Sandhu AK, Dhingra R. Comparative evaluation of advanced and conventional diagnostic aids for endodontic management of periapical lesions, an in vivo study. *J Clin Diagn Res* 2015; **9**: ZC01–4. doi: https://doi.org/10.7860/JCDR/2015/9301.5360
15. Gad K, Ellabban M, Sciubba J. Utility of transfacial dental ultrasonography in evaluation of cystic jaw lesions. *J Ultrasound Med* 2017;[Epub ahead of print]..
16. Bayrakdar IS, Yilmaz AB, Çağlayan F, Ertas U, Gundogdu C, Gumussoy I. Cone beam computed tomography and ultrasonography imaging of benign Intraosseous jaw lesion: a prospective radiopathological study. *Clin Oral Invest* 2018; **22**: 1531–9. doi: https://doi.org/10.1007/s00784-017-2257-1
17. Prince C, Annapurna C, Sivaraj S, Ali IM. Ultrasound imaging in the diagnosis of periapical lesions. *J Pharm Bioall Sci* 2012; **4**(Suppl 2): 369–72. doi: https://doi.org/10.4103/0975-7406.100275
18. Maity I, Kumari A, Shukla AK, Usha H, Naveen D. Monitoring of healing by ultrasound with color power Doppler after root canal treatment of maxillary anterior teeth with periapical lesions. *J Conserv Dent* 2011; **14**: 252–7. doi: https://doi.org/10.4103/0972-0707.85804
19. Rajendran N, Sundaresan B. Efficacy of ultrasound and color power Doppler as a monitoring tool in the healing of endodontic periapical lesions. *J Endod* 2007; **33**: 181–6. doi: https://doi.org/10.1016/j.joen.2006.07.020
20. Setzer FC, Shah SB, Kohli MR, Karabucak B, Kim S. Outcome of endodontic surgery: a meta-analysis of the literature--part 1: Comparison of traditional root-end surgery and endodontic microsurgery. *J Endod* 2010; **36**: 1757–65. doi: https://doi.org/10.1016/j.joen.2010.08.007
21. Gundappa M, Ng SY, Whaites EJ. Comparison of ultrasound, digital and conventional radiography in differentiating periapical lesions. *Dentomaxillofacial Radiology* 2006; **35**: 326–33. doi: https://doi.org/10.1259/dmfr/60326577
22. Torabinejad M, Landaez M, Milan M, Sun CX, Henkin J, Al-Ardah A, et al. Tooth retention through endodontic microsurgery or tooth replacement using single implants: a systematic review of treatment outcomes. *J Endod* 2015; **41**: 1–10. doi: https://doi.org/10.1016/j.joen.2014.09.002
23. Craig JG, Jacobson JA, Moed BR. Ultrasound of fracture and bone healing. *Radiol Clin North Am* 1999; **37**: 737–51. doi: https://doi.org/10.1016/S0033-8389(05)70126-3
24. Tikku AP, Kumar S, Loomba K, Chandra A, Verma P, Aggarwal R. Use of ultrasound, color Doppler imaging and radiography to monitor periapical healing after endodontic surgery. *J Oral Sci* 2010; **52**: 411–6. doi: https://doi.org/10.2334/josnusd.52.411
25. Curvers F, Meschi N, Vanhoenacker A, Strijbos O, Van Mierlo M, Lambrechts P. Ultrasound assessment of bone healing after Root-end surgery: echoes back to patient's safety. *J Endod* 2018; **44**: 32–7. doi: https://doi.org/10.1016/j.joen.2017.08.028
26. Adibi S, Shakibafard A, Karimi Sarvestani Z, Saadat N, Khojastepour L. Effect of cortical bone thickness on detection of Intraosseous lesions by ultrasonography. *Radiology Research and Practice* 2015; **2015**: 1–6. doi: https://doi.org/10.1155/2015/797593