The magnetic resonance imaging characteristics of radicular cysts and granulomas

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Original article

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Abstract

Limited studies have differentiated radicular cysts and granulomas with magnetic resonance imaging. Therefore, we investigated the magnetic resonance imaging characteristics of the two lesions and clarified features for distinguishing between them. We collected data of 27 radicular cysts and 9 granulomas definitively diagnosed by histopathology and reviewed the fat-saturated T2-weighted, T1-weighted, and contrast-enhanced fat-saturated T1-weighted images. We measured the maximum diameter and apparent diffusion coefficient values of the lesions. We employed Fisher’s exact test, Mann–Whitney U test, and independent t-tests to compare the two lesions and created a decision tree for discriminating them. There were significant differences between radicular cysts and granulomas with respect to five imaging characteristics—signal intensity of the lesion centre on fat-saturated T2-weighted images; signal intensity, texture, and contrast enhancement of the lesion centre on contrast-enhanced fat-saturated T1-weighted images; and maximum diameter of the lesion. The cut-off diameter for radicular cysts was 15.9 mm. The area under the receiver operating characteristic curve, sensitivity, and specificity were 0.971, 85.2%, and 100%, respectively. From the decision tree analysis, maximum diameter, lesion centre contrast enhancement on contrast-enhanced fat-saturated T1-weighted images, and lesion centre signal intensity on fat-saturated T2-weighted images were important for discriminating between the two lesions.
Introduction

Bacterial infection of the necrotic dental pulp causes periapical inflammatory lesions, which occasionally progress to form periapical granulomas.[1] Such lesions show apical radiolucency on intraoral periapical radiographs due to “rarefying osteitis” and radiopacity in the surrounding cancellous bone due to “osteosclerosis”. [2] Pathologically, the content of the lesion would be an inflammatory granuloma. However, the inflammatory response may stimulate the epithelial cell rests of Malassez and they may occasionally develop into a cyst in the periapical area. [3,4] Nair et al. reported that 85% of the periapical lesions analysed in their study were granulomas or abscesses, and the remaining were cysts. [5] The incidence of radicular cysts is not very high among periapical lesions. However, true cysts that are pathologically characterised by an enclosed epithelium are less likely to be cured by non-surgical root canal treatment and often require surgical intervention, such as cystectomy. [6] Therefore, it is important to correctly diagnose cysts among periapical lesions to ensure appropriate treatment. [7-10]

Radicular granulomas and cysts are usually examined using intraoral periapical radiographs, but their detection with this modality seems difficult even after the contrast medium is applied. [11-17] Cone-beam computed tomography (CBCT) has recently been introduced in dental practice, and it is essentially employed to scrutinise periapical lesions. However, diagnosing periapical lesions with CBCT has been challenging, and there is little evidence of its reliability. [18-21] Previous studies have shown that radicular cysts are significantly larger than granulomas [22,23] and that periapical lesions of a certain size are not likely to heal after conventional root canal treatments. [22,24] The limitation of these studies that used intraoral periapical radiographs and CBCT is due to the ability of these imaging modalities to detect changes in bone morphology but not differences in soft tissue content within cysts and granulomas. [2] For soft tissue visualisation, medical computed tomography or ultrasonography is considered better, but none of them has offered any effective result. [25,26] For this purpose, magnetic resonance imaging (MRI) is currently considered the best modality.

Most MRI examinations utilise the phenomenon of nuclear magnetic resonance with hydrogen nuclei, which are abundant in body water and fat, for generating images. Water and fat have different T1 and T2 relaxation times. Hence, it is possible to assess their contents in tissue on T1-
weighted images (T1w) and T2-weighted images (T2w) with fat saturation (T2wFS). During many MRI procedures, contrast examination with gadolinium is often performed, which routinely distinguishes the spread of inflammation, cysts and tumours, and benign and malignant tumours. Additionally, there are diffusion-weighted images that can visualise and quantify the diffusion motion of water molecules. We previously reported that cysts and malignant lymphomas and odontogenic tumours and cysts could be efficiently distinguished with this imaging technique. In this context, if the different features of these lesions can be clarified by MRI, it is expected that radicular cysts and granulomas would be distinguishable from each other with high accuracy using MRI. There are already two studies that support this hypothesis. Lizio et al. reported that they established six criteria that could differentiate these lesions with a high accuracy of 74% or 79%, depending on the observers. Juerchott et al. also revealed that they could differentiate them, highlighting the characteristics of radicular cysts as homogeneity in the lesion centre (LC) and no soft tissue involvement on MRI. However, the former study employed the 1.5T MRI equipment, and the latter employed the latest 3T equipment and reported the conclusions from a small number of 11 cases. In this study, we collected data from our database examined by 3T MRI, analysed the radicular cyst and granuloma cases, established the MRI characteristics of these two lesions, and compared our findings to previous reports. The aim of this study was to investigate the MRI characteristics of two lesions and clarify features for distinguishing between them.

Results

We observed 36 cases of periapical lesions, including 27 cases of radicular cysts and 9 cases of periapical granulomas. The intra- and inter-observer agreements were judged as “moderate” or “excellent”, depending on previously established parameters. The characteristics of the lesions are summarised in Table 1. There were statistically significant differences in five imaging characteristics between radicular cysts and granulomas, namely the dominant signal intensity of the LC on T2wFS (Fisher’s exact test, \( p = 0.012 \)), dominant signal intensity of the LC on contrast-enhanced fat-saturated T1w (T1wFS+C) (Fisher’s exact test, \( p = 0.019 \)), signal homogeneity of the LC on T1wFS+C (Fisher’s exact test, \( p = 0.019 \)), contrast enhancement status of the LC on T1wFS+C (Fisher’s exact
test, $p < 0.001$), and maximum diameter of the lesions (Mann–Whitney U test, $p < 0.001$). There were three cases of granuloma and one case of radicular cyst whose radiological diagnoses differed from their pathological diagnoses; hence, the total diagnostic accuracy of MRI in this study was 88.9%.

All radicular cysts showed hyperintense signal in the LC on T2wFS; nevertheless, only three granulomas (33.3%) showed low signal intensity in the LC. On T1wFS+C, most granulomas (8 out of 9 cases: 88.9%) showed contrast enhancement in the LC, while most radicular cysts (23 out of 27 cases: 85.2%) did not show any contrast enhancement in the LC. The average maximum diameter of radicular cysts was 23.9 mm, which was significantly larger than that of granulomas (10.5 mm) (Mann–Whitney U test, $p < 0.001$) as shown in Figure 1. A receiver operating characteristic curve analysis set the cut-off value for the diameter of radicular cysts as 15.9 mm, and the area under the curve was 0.971 (95% confidence interval= 0.90–1.00) with a sensitivity of 85.2% and specificity of 100% (as shown in Figure 2). Figure 3 demonstrates each type of lesion with its typical MRI features. Figures 4 and 5 demonstrate cases with atypical MRI features in the LC and peripheral rim (PR), i.e., features that differed from the criteria established by Juerchott et al.[35] Figure 6 shows a lesion that was misdiagnosed as a granuloma with MRI at the time of examination in our hospital. Figure 7 is the decision tree for discriminating between radicular cysts and granulomas.

There were no statistically significant differences in the average apparent diffusion coefficient (ADC) values (independent $t$-test, $p = 0.513$) or any other imaging characteristics between the two lesions.

**Discussion**

This retrospective study analysed the MRI features of 27 radicular cysts and 9 granulomas with the aim of distinguishing the two types of lesions. The cysts constituted three-quarters of the total number of cases, which is consistent with previous studies.[1,16] To the best of our knowledge, our study has the largest number of periapical lesions examined with 3T MRI. Lizio et al. analysed 34 periapical lesions, but their equipment was a 1.5T scanner.[34] Generally, the magnetic field strength is related to signal-to-noise ratio improvement, which allowed us to obtain images with higher spatial resolution.[37] Juerchott et al. analysed lesions examined with a 3T MRI machine, but the study was
limited to only 11 cases. We encountered cases that did not meet the criteria used in previous studies.

Periapical lesions are frequently encountered in dental practice and are mainly treated by endodontists. However, larger periapical lesions are associated with a higher incidence of cysts and have lower success rates with conservative root canal treatment than smaller lesions. Large lesions of a specific size could indicate true cysts, which ought to be subjected to surgical intervention, as previous studies reported that radicular cysts have higher success rates when treated with periapical surgery. Therefore, it is important to determine whether a periapical lesion is a radicular granuloma or a cyst because these two lesions require different treatment approaches to achieve favourable outcomes.

Several studies have tried to differentiate these two lesions preoperatively, using intraoral periapical radiographs, CBCT, and medical computed tomography. However, the results lacked reliability. Beconsall-Ryan et al. reported that 31.2% of radicular cysts and 40.1% of periapical granulomas were misdiagnosed for each other with the conventional imaging diagnostic criteria. Gbadebo et al. also reported that 52% of radicular cysts were misdiagnosed as granulomas, and 62.5% of periapical granulomas were misdiagnosed as cysts. Generally, an intraoral periapical radiograph is frequently employed for investigating a periapical lesion because it can depict the lesion in detail. However, impressions based on periapical radiographs do not always correlate with histopathological diagnoses. CBCT only has moderate accuracy in differentiating these two lesions. The low discriminative power of intraoral periapical radiograph and CBCT is due to the fact that they only highlight morphological changes in bone; they cannot clarify the content of soft tissue within a lesion. However, measurement of the lesion’s maximum diameter may help distinguish between radicular cysts and granulomas, which was also confirmed in this study. MRI, on the other hand, is effective for highlighting soft tissue components and, therefore, expected to distinguish the two lesions with higher accuracy.

Recently, MRI features of radicular granulomas and cysts were investigated by Lizio et al. and Juerchott et al. Juerchott et al. concluded that the following six MRI characteristics could be used to distinguish radicular cysts from granulomas: (1) lesion margin, (2) PR texture on
Although they described their study as a pilot study, they were able to distinctly categorise their 11 cases into two types of lesions, using lesion margin (criterion 1), PR texture on T1wFS+C (criterion 2), and soft tissue involvement on T2wFS (criterion 4) and T1wFS+C (criterion 5). Additionally, LC texture on T2wFS (criterion 3) was successfully used to distinguish the two lesions except for one case. Hence, these characteristics were thought to be diagnostically important. However, the results of this present study did not show any statistically significant differences in these characteristics between radicular cysts and granulomas.

Juerchott et al. reported that all granulomas in their study showed ill-defined, inhomogeneous, thickened walls with a mean PR thickness of 4.6 mm on T1wFS+C and soft tissue involvement on both T2wFS and T1wFS+C. All cases except for one showed inhomogeneous LC on T2wFS. In contrast, the granulomas in our study mostly showed well-defined margin (7 out of 9: 77.8%) with an average maximum PR thickness of 1.7 mm, and the homogeneity of the PR and LC varied on both T2wFS and T1wFS+C (as shown in Figure 4). Juerchott et al. also reported that all the cysts in their study showed well-defined homogenous thin walls with a mean PR thickness of 1.6 mm on T1wFS+C, homogenous LC on T2wFS, and no soft tissue involvement on both T2wFS and T1wFS+C. However, in the present study, one radicular cyst showed an ill-defined margin with a thick PR, as shown in Figure 3b, and nine radicular cysts (33.3%) showed soft tissue involvement on T1wFS+C (Figure 5b). Additionally, four periapical granulomas (44.4%) showed homogeneity in the LC and PR on T2wFS (Figure 4a) and T1wFS+C (Figure 5a), respectively; however, according to the criteria used by Juerchott et al., these characteristics are supposed to be found in cysts. Moreover, we found that about half of the granulomas in this study showed no soft tissue involvement on T2wFS and T1wFS+C (as shown in Figures 4a and 5a).

In summary, our findings indicate that a granuloma may not show inflammatory signs in soft tissue, and a cyst could possibly cause inflammation in soft tissue; hence, soft tissue involvement is not a key characteristic for distinguishing these two lesions. Furthermore, nearly half of the
granuloma cases (4 out of 9: 44.4%) showed homogeneous high signal intensity on T2wFS; therefore, this feature is not a defining characteristic of radicular cysts.

Lizio et al. clarified six criteria for differentiating radicular cysts and granulomas, as follows: (1) signal intensity on T1w, (2) signal intensity on T2w, (3) lesion margin, (4) signal homogeneity, (5) low-intensity outline on both T1w and T2w, and (6) contrast agent distribution pattern.[34] They reported that the 34 cases in their study could be diagnosed by two observers with an accuracy of 74% and 79%. We applied these criteria to our cases, and the result was satisfactory, i.e., the accuracy of our results was 86.1%. However, none of our cases showed a low-intensity outline on T1w or T2w (criterion 5). Moreover, granulomas with well-defined margins (criterion 3) were frequently observed (7 out of 9 cases: 77.8%), and they could have been mistaken as cysts if the criteria by Lizio et al.[34] had been applied; hence, it should be noted that lesion margin is not a distinctive parameter for identifying a radicular cyst or granuloma.

In this study, five significant MRI characteristics were used to identify granulomas and cysts. They are as follows:

1. **Maximum diameter of lesion:** Measurements of the lesion’s maximum diameter differentiated radicular cysts and granulomas, which is consistent with the findings of previous studies.[22,38,39] All granulomas were smaller than 15.9 mm, whereas cysts had a wider diameter range of 10.5–40.9 mm, which is similar to the results of Juerchott et al.[35] Although this finding could have been influenced by case selection bias, it may also indicate that there is growth limitation in granulomas, but not in cysts.[39,40] We now believe that it is acceptable to employ a maximum diameter of 16 mm and above as a diagnostic parameter for identifying a radicular cyst.

2. **Signal intensity of the LC on T2wFS:** Low signal intensity in the LC was a characteristic found in three granulomas but not in any cyst. This may demonstrate the late healing stage of granulomas, which correlated with their pathological characteristics of fibroblasts and hemosiderin granule-rich status within a fibrous connective tissue stroma.[40] Contrarily, the hyperintense signal found in all the cysts might reflect their fluid nature, which is in agreement with the result of a previous study.[35]
However, this characteristic does not confirm that a lesion is a cyst because two-thirds of granulomas also showed high signal intensity on T2wFS. Accordingly, we considered that the ADC value might be used to differentiate these two lesions by analysing the diffusion state of their water molecules,[30,33] but this approach also failed as the average of ADC values was not significantly different between the two lesions.

(3) Signal intensity, (4) signal homogeneity, and (5) contrast enhancement of the LC on T1wFS+C:
The majority of the cystic lesions showed no enhancement in the LC, as is expected, since they are non-vascularised, liquid-filled cavities.[31] This finding is similar to that reported by Juerchott et al.[35] as all of their five radicular cysts showed no enhancement on T1wFS+C. However, four radicular cysts showed LC enhancement in the present study, which may be explained by the histopathological finding of hemosiderin within these lesions, indicating bleeding. In addition, one granuloma showed no contrast enhancement in the LC. Its pathological findings include fibrous tissue within the lesion, which may explain the non-enhanced LC on T1wFS+C and low signal intensity on T2wFS.[27]

The MRI characteristics clarified in this study are useful for differentiating radicular cysts and granulomas. However, there were a few inconsistent findings; hence, it is not practical for any of these characteristics to be used as a definitive discrimination point between radicular cysts and granulomas. We, therefore, established a decision tree for discrimination between these two lesions (as shown in Figure 7). We distinguished the two lesions following the decision tree model by first measuring the maximum lesion diameter. If the diameter was larger than 17 mm, the lesion was considered a radicular cyst. Conversely, if the diameter was 17 mm or less, we further evaluated the LC contrast enhancement status on T1wFS+C. If the lesion showed an enhanced LC, it was considered a granuloma. If it showed a non-enhanced LC, we thoroughly investigated the LC signal intensity on T2wFS. A lesion that showed a hyperintense LC was considered a radicular cyst. These discriminative factors are easy to use and consistent with the pathological characteristics of the lesions. In this study, we assessed the final radiological diagnosis made at the time the MRI was performed, and its accuracy was 88.9%. This result means that the subjective assessment made by the interpreters based on the aforementioned objective characteristics, without measuring the lesion’s diameter, can
provide an accurate diagnosis. However, 33.3% of the granulomas (3 out of 9) and 3.7% of the cysts (1 out of 27) were misdiagnosed. One of the misdiagnosed granulomas is shown in Figure 6. In this case, the lesion exhibited contrast enhancement in the LC on T1wFS+C (Figure 6d and e), and its maximum diameter was 10.2 mm. Based on the decision tree, it should be diagnosed as a granuloma. However, its average ADC value was as high as 1.46 x 10^-3 mm²/s; therefore, the examiner suspected that it was a radicular cyst. The other two misdiagnosed granulomas also showed similar findings. The misdiagnosed radicular cyst had an inhomogeneous LC with a maximum diameter of 10.2 mm on T2wFS, as shown in Figure 4b; hence, the examiner considered it a granuloma. The lesion size, in this case, was too small to judge whether the LC was enhanced or not, which is a limitation of the current MRI.[27] Recently, there has been an increasing number of attempts to make MRI more useful in dental practice. One of them is increasing the resolution of MRI. Specifically, many coils are placed outside the oral cavity,[41] while some wiring or wireless intraoral coils are also being tested.[42,43] These new methods will allow us to obtain images with higher resolution and signal-to-noise ratio to observe periapical structures in detail and, hopefully, rightly diagnose lesions such as the misdiagnosed radicular cyst in this study.

We successfully discriminated radicular cysts and granulomas in this study with the decision tree, yet the diagnosis of 14 cases (38.8%) depended on contrast medium enhancement. Although it is undeniable that gadolinium contrast examination has a significant impact on qualitative diagnosis with MRI, the administration of the contrast medium during the procedure may cause allergic reactions[44] and/or induce systemic renal fibrosis,[45] making it inapplicable to some patients. Therefore, careful administration is necessary. In cases where the contrast imaging technique is unachievable, the decision tree cannot be applied. According to our results, if the information on T1wFS+C had been ignored, six of the nine granulomas (66.7%) would have been misdiagnosed as cysts.

The limitation of this study is that the periapical granuloma cases were few. Nevertheless, our study still has the largest number of granuloma cases examined with 3T MRI according to our knowledge. Generally, granulomas tend to be small, as is evident here and supported by other studies;[22,23,35,38,39] hence, they are unlikely to be investigated using MRI and/or biopsy.
Additionally, periapical granulomas are responsive to conventional endodontic treatments; therefore, MRI for them would not be necessary. The results of this study should be confirmed with further prospective studies. However, we believe our findings would be useful for differentiating radicular cysts from granulomas.

MRI is relatively expensive compared to other conventional dental imaging modalities, such as intraoral periapical radiograph, panoramic radiograph, and computed tomography, including CBCT. Notwithstanding, MRI has the outstanding advantage of being able to directly delineate soft tissue properties inside lesions, and patients are not exposed to radiation during the procedure. We, therefore, propose that dental MRI should continue to be studied and developed as a tool to aid the diagnosis of oral lesions in the future.

We conclude that this study clarified the MRI characteristics of radicular granulomas and cysts and demonstrated that MRI is a promising diagnostic modality for differentiating these two lesions.

Methods
Patients

We collected 48 images of radicular granulomas and radicular cysts from the MRI database from June 2013 to March 2022. The cases were definitively diagnosed histopathologically. However, 12 cases were excluded due to undetectable lesions on ADC maps and/or severe motion/susceptibility artefacts on the images. The final population consisted of 27 cysts and 9 granulomas from 36 patients (26 men and 10 women; average age of 48 years and range of 24–75 years). This was a retrospective study that was conducted in accordance with the Declaration of Helsinki 1975 (as revised in 1983) and approved by Institutional review board of Tokyo Medical and Dental University (IRB; No. D2020-066). Informed consent was waived by the IRB of Tokyo Medical and Dental University due to the nature of the study.

MRI protocols
In all cases, MRI was performed using one 3T equipment (Magnetom Spectra, Siemens Healthineers, Erlangen, Germany) with a 16-channel head and neck coil. A routine MRI protocol was applied for all the patients as follows: a T1-weighted turbo spin-echo sequence (echo time [TE]: 10 ms, repetition time [TR]: 650 ms, number of signal averages [NSA]: 1) in the axial and coronal planes; a T2-weighted turbo spin-echo sequence (TE: 71 ms, TR: 5 400 ms, and NSA: 12) with fat suppression, using the two-point Dixon technique in the axial plane; and a post-contrast T1-weighted turbo spin-echo sequence (TE: 12 ms, TR: 640 ms, and NSA: 1) with fat suppression, using the two-point Dixon technique in the axial and coronal planes, after intravenous gadobutrol (Gadovist®, Bayer, Leverkusen, Germany) injection at a dose of 0.1 mmol/kg of body weight. All the images were obtained with a section thickness of 3.0 or 4.0 mm and an intersection gap of 0.9 or 1.0 mm, using a 230 × 187 mm² field of view and a matrix of 384 × 312. A single-shot spin-echo echo-planar diffusion-weighted image sequence (TE: 85 ms, TR: 3 150 ms, NSA: 2) was acquired with fat suppression by short tau inversion recovery in the axial plane, 4.0 mm section thickness, 1.0 mm intersection gap, 230 × 173 mm² field of view, and matrix of 128 × 96 (interpolated to 256 × 192). Generalised auto-calibrating partially parallel acquisition was used for parallel imaging with an acceleration factor of 3. Ten b-values (0, 50, 100, 150, 200, 300, 500, 800, 1 000, and 1 500 s/mm²) were used, and a bipolar scheme was applied. The ADC maps were constructed from the diffusion-weighted images with all b-values by using the fit of a linear regression model.

**Image analysis**

The characteristics of the lesions were observed by focusing on the lesion margin and diameter, PR and LC features, soft tissue involvement on T2wFS and T1wFS+C, and average ADC values on ADC maps. All these were analysed by two independent observers on Syngo via workstation (Siemens). Each observer performed the image analysis twice with an interval of more than 8 weeks and without knowing the histopathological results. Based on the lesion margin, we classified the lesions into well-defined or ill-defined. We evaluated the signal intensity of the lesions as hypointense or hyperintense compared to the adjacent masseter muscle and evaluated homogeneity as heterogeneous or homogeneous. We measured the maximum PR thickness of the lesion in
subtracted pre- and post-contrast T1w. Contrast enhancement was evaluated by comparing T1w and T1wFS+C images, and it was sometimes observed in their subtracted image. We decided whether there was soft tissue involvement by observing signal change in the surrounding tissues. These features were established by Juergott et al.[35] and we utilised them in this study. Additionally, we measured the lesion’s maximum diameter with a digital calliper on T1w and the average ADC value using a round-shaped region of interest on the ADC map. We recorded the final radiological diagnosis given at the time that MRI was performed for each lesion.

Decision tree analysis

We made a decision tree for discriminating radicular cysts from granulomas with the five significant factors using the Chi-squared automated interaction detection growing method (SPSS Inc., Chicago, IL).

Statistical analysis

Statistical analysis was performed using SPSS software version 28.0.1.0 (SPSS Inc.). Normality was assessed with the Shapiro–Wilk test. We executed Fisher’s exact test for matrix tables and the Mann–Whitney U test for comparing maximum diameter and maximum PR thickness values between radicular cysts and granulomas. We used an independent sample t-test to compare the patient’s age and average ADC value between the two lesions. Intra- and inter-observer reliability was analysed with an intraclass correlation coefficient. A P-value less than 0.05 was considered statistically significant.

References


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Author Contributions

NW: conceptualisation, data curation, formal analysis, investigation, resources, validation, visualisation, and writing of the original draft

SY: data curation, investigation, and validation

HW: conceptualisation, data curation, formal analysis, investigation, methodology, project administration, resources, validation, visualisation, writing of original draft, and editing of the final draft

JS: investigation, review, and supervision

KK: data curation, investigation, and supervision

TK: review, supervision, and editing of the final draft

Data availability

All data generated or analysed during this study are included in this published article.

Conflict of Interests

The authors declare no conflict of interests related to this study.
Figure legends

Figure 1: A plot graph showing the maximum diameters of radicular cysts and granulomas. The horizontal lines indicate the averages. The differences in diameter between the two lesions are statistically significant based on Mann–Whitney U test ($p < 0.001$).

Figure 2: A receiver operating characteristic analysis based on the maximum diameters of the lesions. The cut-off value is set to 15.9 mm, and the area under the curve (grey area) is 0.971.

Figure 3: Typical magnetic resonance images of a radicular granuloma (a) and a cyst (b). (a) is a radicular granuloma in the right mandible of a 54-year-old male, showing high signal intensity on T2-weighted image with fat saturation (T2wFS) and enhancement of the lesion centre on T1-weighted image (T1w) with fat saturation with contrast media (T1wFS+C). (b) is a radicular cyst in the anterior left mandible of a 32-year-old male, showing high signal intensity on T2wFS, and no lesion centre enhancement but rim enhancement on T1wFS+C.

Figure 4: “Atypical” lesion centre findings in a radicular granuloma (a) and a cyst (b). (a) is a radicular granuloma in the right mandible of a 36-year-old female. The lesion shows a hypointense signal on T1-weighted image (T1w), but homogeneously high intensity on T2-weighted image with fat saturation (T2wFS). Heterogeneous relatively weak enhancement is shown on contrast-enhanced T1-weighted image with fat saturation (T1wFS+C). (b) is a cyst in the left molar of a 43-year-old female. The lesion shows a heterogeneous, high intensity signal in the lesion centre on T2wFS, whereas a homogeneous area is shown on T1wFS+C.

Figure 5: “Atypical” soft tissue involvement in a radicular granuloma (a) and a cyst (b). (a) is a radicular granuloma in the anterior right maxilla of a 29-year-old male, showing no soft tissue involvement on both T2-weighted image with fat saturation (T2wFS) and contrast media enhanced T1-weighted image with fat saturation (T1wFS+C). (b) is a radicular cyst in the right mandible of a 56-year-old female, showing soft tissue involvement on both T2wFS and T1wFS+C.
Figure 6: A radicular granuloma misdiagnosed as a cyst in a 24-year-old female. (a) is a panoramic view of dental computed tomography showing a periapical lesion at the right mandibular canine periapical site. (b) is an axial T1-weighted image showing hypointense signal in both the lesion centre and peripheral rim, with maximum diameter of 10.2 mm. (c) is an axial T2-weighted image showing heterogeneously high signal in the lesion centre and peripheral rim, and soft tissue involvement. (d) is an axial contrast-enhanced T1-weighted image with fat saturation, and (e) is a subtraction image of pre- and post-contrast T1-weighted image showing high signal intensity in the peripheral rim and soft tissue involvement. (f) is an axial ADC map showing high signal intensity in the lesion centre and ADC value of $1.463 \times 10^{-3} \text{ mm}^2/\text{s}$.

Figure 7: A decision tree for discriminating radicular cyst and granuloma. The tree was created with the five significant parameters, using Chi-squared automated interaction detection growing method.

LC: lesion centre; T1wFS+C: contrast media enhanced T1-weighted image with fat saturation; T2wFS: T2-weighted image with fat saturation
| Table 1 Demographic and radiographic characteristics of radicular granulomas and cysts |
|---------------------------------|-----------------|-----------------|-------------|
| Gender                         | Granuloma | Cyst | p-value |
| Male                           | 5         | 21   | 0.226     |
| Female                         | 4         | 6    |            |
| Age (years)                    |           |      |            |
| Average                        | 42        | 50   | 0.896      |
| Minimum                        | 24        | 27   |            |
| Maximum                        | 60        | 75   |            |
| Lesion margin                  |           |      |            |
| Ill-defined                    | 2         | 1    | 0.148      |
| Well-defined                   | 7         | 26   |            |
| PR features                    |           |      |            |
| T2wFS Dominant signal          |           |      |            |
| Hypointense                    | 2         | 0    | 0.057      |
| Hyperintense                   | 7         | 27   |            |
| Texture                        |           |      |            |
| Heterogenous                   | 4         | 10   | 0.712      |
| Homogenous                     | 5         | 17   |            |
| T1wFS+C Dominant signal        |           |      |            |
| Hypointense                    | 0         | 0    | NS         |
| Hyperintense                   | 9         | 27   |            |
| Texture                        |           |      |            |
| Heterogenous                   | 5         | 5    | 0.079      |
| Homogenous                     | 4         | 22   |            |
| Maximum thickness (mm)         |           |      |            |
| Average                        | 1.72      | 1.93 | 0.089      |
| Minimum                        | 0.90      | 0.80 |            |
| Maximum                        | 4.20      | 3.20 |            |
| contrast-enhancement            |           |      |            |
| Yes                            | 9         | 26   | 1.000      |
| No                             | 0         | 1    |            |
| LC features                    |           |      |            |
| T2wFS Dominant signal          |           |      |            |
| Hypointense                    | 3         | 0    | 0.012      |
| Hyperintense                   | 6         | 27   |            |
| Texture                        |           |      |            |
| Heterogenous                   | 5         | 12   | 0.706      |
| Homogenous                     | 4         | 15   |            |
| T1wFS+C Dominant signal        |           |      |            |
| Hypointense                    | 2         | 19   | 0.019      |
| Hyperintense                   | 7         | 8    |            |
| Texture                        |           |      |            |
| Heterogenous                   | 7         | 8    | 0.019      |
| Homogenous                     | 2         | 19   |            |
| contrast-enhancement            |           |      |            |
| Yes                            | 8         | 4    | <0.001     |
| No                             | 1         | 23   |            |
| ST involvement                 |           |      |            |
| T2wFS                          |           |      |            |
| Yes                            | 5         | 8    | 0.235      |
| No                             | 4         | 19   |            |
| T1wFS+C                        |           |      |            |
| Yes                            | 4         | 9    | 0.693      |
| No                             | 5         | 18   |            |
| Maximum diameter (mm)          |           |      |            |
| Average                        | 10.47     | 23.90 | <0.001     |
| Minimum                        | 5.85      | 10.50 |           |
| Maximum                        | 14.70     | 40.90 |           |
| ADC value \((\times 10^{-3}\ \text{mm}^2/\text{s})\) |           |      |            |
| Average                        | 1.108     | 1.018 | 0.513      |
| Minimum                        | 0.047     | 0.392 |           |
| Maximum                        | 1.463     | 2.139 |           |
| Initial diagnosis by MRI       |           |      |            |
| Granuloma                      | 6         | 1    | <0.001     |
| Cyst                           | 3         | 26   |            |
| Total number of cases          | 9         | 27   |            |

PR, peripheral rim; T2wFS, T2-weighted with fat saturation; T1wFS+C, contrast-enhanced T1-weighted with fat saturation; NS, not significant; LC, lesion center; ST, soft tissue; ADC, apparent diffusion coefficient.
Figure 1

A plot graph showing the maximum diameters of radicular cysts and granulomas. The horizontal lines indicate the averages. The differences in diameter between the two lesions are
statistically significant based on Mann–Whitney U test ($p < 0.001$).

Figure 2

A receiver operating characteristic analysis based on the maximum diameters of the lesions.

The cut-off value is set to 15.9 mm, and the area under the curve (grey area) is 0.971.
Figure 3 LC enhancement status on T1wFS+C of granuloma (a) and cyst (b);
Typical cases

<table>
<thead>
<tr>
<th>(a) Granuloma</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
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<tr>
<td><img src="image2.png" alt="Image" /></td>
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<tr>
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<table>
<thead>
<tr>
<th>(b) Cyst</th>
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</thead>
<tbody>
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<td><img src="image4.png" alt="Image" /></td>
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<td><img src="image5.png" alt="Image" /></td>
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<tr>
<td><img src="image6.png" alt="Image" /></td>
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</tbody>
</table>

Granuloma: 16047886  
Cyst: 20038111  

Figure 3

Typical magnetic resonance images of a radicular granuloma (a) and a cyst (b). (a) is a radicular granuloma in the right mandible of a 54-year-old male, showing high signal intensity on T2-weighted image with fat saturation (T2wFS) and enhancement of the lesion centre on T1-weighted image (T1w) with fat saturation with contrast media (T1wFS+C). (b) is a radicular cyst in the anterior left mandible of a 32-year-old male, showing high signal intensity on T2wFS, and no lesion centre.
enhancement but rim enhancement on T1wFS+C.

Figure 4

(a) Granuloma

[Images of T2wFS, T1w, T1wFS+C for a granuloma]

(b) Cyst

[Images of T2wFS, T1w, T1wFS+C for a cyst]

“Atypical” lesion centre findings in a radicular granuloma (a) and a cyst (b). (a) is a radicular granuloma in the right mandible of a 36-year-old female. The lesion shows a hypointense signal on T1-weighted image (T1w), but homogeneously high intensity on T2-weighted image with fat saturation (T2wFS). Heterogeneous relatively weak enhancement is shown on contrast-enhanced T1-weighted image with fat saturation (T1wFS+C). (b) is a cyst in the left molar of a 43-year-old female. The lesion shows a heterogeneous, high intensity signal in the lesion centre on T2wFS,
whereas a homogeneous area is shown on T1wFS+C.

**Figure 5**

(a) *Granuloma*  

(b) *Cyst*

"Atypical" soft tissue involvement in a radicular granuloma (a) and a cyst (b). (a) is a radicular granuloma in the anterior right maxilla of a 29-year-old male, showing no soft tissue involvement on both T2-weighted image with fat saturation (T2wFS) and contrast media enhanced T1-weighted image with fat saturation (T1wFS+C). (b) is a radicular cyst in the right mandible of a 56-year-old female, showing soft tissue involvement on both T2wFS and T1wFS+C.
Figure 6

A radicular granuloma misdiagnosed as a cyst in a 24-year-old female. (a) is a panoramic view of dental computed tomography showing a periapical lesion at the right mandibular canine periapical site. (b) is an axial T1-weighted image showing hypointense signal in both the lesion centre...
and peripheral rim, with maximum diameter of 10.2 mm. (c) is an axial T2-weighted image showing heterogeneously high signal in the lesion centre and peripheral rim, and soft tissue involvement. (d) is an axial contrast-enhanced T1-weighted image with fat saturation, and (e) is a subtraction image of pre- and post-contrast T1-weighted image showing high signal intensity in the peripheral rim and soft tissue involvement. (f) is an axial ADC map showing high signal intensity in the lesion centre and ADC value of $1.463 \times 10^{-3}$ mm$^2$/s.
Figure 7

A decision tree for discriminating radicular cyst and granuloma. The tree was created with the five significant parameters, using Chi-squared automated interaction detection growing method.

LC: lesion centre; T1wFS+C: contrast media enhanced T1-weighted image with fat saturation;
T2wFS: T2-weighted image with fat saturation