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High-resolution magnetic resonance imaging of teeth and periodontal tissues using a microscopy coil

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ABSTRACT

Purpose: This study aimed to assess the performance of 2-dimensional (2D) imaging with microscopy coils in delineating teeth and periodontal tissues compared with conventional 3-dimensional (3D) imaging on a 3 T magnetic resonance imaging (MRI) unit.
Materials and Methods: Twelve healthy participants (4 men and 8 women; mean age: 25.6 years; range: 20-52 years) with no dental symptoms were included. The left mandibular first molars and surrounding periodontal tissues were examined using the following 2 sequences: 2D proton density-weighted (PDw) images and 3D enhanced T1 high-resolution isotropic volume excitation (eTHRIVE) images. Two-dimensional MRI images were taken using a 3 T MRI unit and a 47 mm microscopy coil, while 3D MRI imaging used a 3 T MRI unit and head-neck coil. Oral radiologists assessed dental and periodontal structures using a 4-point Likert scale. Inter- and intra-observer agreement was determined using the weighted kappa coefficient. The Wilcoxon signed-rank test was used to compare 2D-PDw and 3D-eTHRIVE images.
Results: Qualitative analysis showed significantly better visualization scores for 2D-PDw imaging than for 3D-eTHRIVE imaging (Wilcoxon signed-rank test). 2D-PDw images provided improved visibility of the tooth, root dental pulp, periodontal ligament, lamina dura, coronal dental pulp, gingiva, and nutrient tract. Inter-observer reliability ranged from moderate agreement to almost perfect agreement, and intra-observer agreement was in a similar range.
Conclusion: Two-dimensional-PDw images acquired using a 3 T MRI unit and microscopy coil effectively visualized nearly all aspects of teeth and periodontal tissues. ***(Imaging Sci Dent 2024; 54: 276-82)***

KEY WORDS: Magnetic Resonance Imaging; Tooth; Periodontium; Dental Pulp

Introduction

Magnetic resonance imaging (MRI) has been used to diagnose temporomandibular joint dysfunction, tumors, cysts, and osteomyelitis in dentistry.[1-7] Despite its potential benefits, the use of MRI in dentistry is less extensive than other radiological techniques, including computed tomography (CT) and dental cone-beam CT.[8] MRI examinations may be precluded for patients with metal in their bodies, individuals with claustrophobia, and those unable to meet the high cost. Moreover, a major problem with conventional MRI is its limited spatial resolution, which makes it difficult to distinguish microstructures surrounding the teeth, such as the periodontal ligament, pulp, and other periodontal tissues.[8,9]

To date, 3-dimensional T1-weighted (3D T1w) imaging has been used to delineate inferior alveolar neurovascular bundles and nutrient tracts; however, the usefulness of 3D T1w imaging in the delineation of teeth and periodontal tissue has not yet been adequately investigated.[10,11] 3D enhanced T1 high-resolution isotropic volume excitation

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(eTHRIVE) is similar to 3D volumetric interpolated breath-hold examination (3D-VIBE). In contrast, 2D proton density-weighted (PDw) imaging with microscopy coils introduced here is characterized by its small field of view (FoV) and high resolution. High-resolution microscopy coils have been used to delineate detailed anatomical structures in MRI, focusing on the skin, the joints, the orbit, and other regions.[12-14] The use of microscopy coils often reveals anatomical structures that are difficult to delineate with conventional head coils or head-neck coils and is considered helpful in improving the accuracy of the diagnosis and determining the extent of lesions. The imitations of the microscopy coil are the same as that of the head-neck coil for head and neck imaging—in particular, the presence of numerous metal objects makes imaging difficult due to metal artifacts. Several studies have delineated dental structures and periodontal tissues, including the periodontal ligament and the dental pulp, using MRI with head-neck coils and intraoral coils; however, few studies have applied microscopy coils to visualize dental and periodontal tissues.[15-24]

The purpose of this study was to evaluate the performance of 2D imaging with microscopy coils in delineating teeth and periodontal tissues in comparison with conventional 3D T1w imaging using 3 T MRI.

Materials and Methods

The study protocol was approved by the Ethics Committee of Osaka Dental University (no. 111238). This study was designed as a non-invasive prospective study. Each participant provided informed consent, and all were free to refuse to participate.

Selection of participants

Twelve healthy participants (4 men and 8 women; mean age: 25.6 years; range: 20-52 years) with no dental symptoms were included. The left mandibular first molars and the surrounding periodontal tissues were investigated.

MR imaging

The 2D-PDw images were taken with a 3 T MRI unit (Ingenia Elition, Philips Healthcare, Best, Netherlands) and a 47 mm diameter microscopy coil (Fig. 1). The microscopy coil was fixed to the skin surface near the left first molars with surgical tape.

The following parameters were used for the 2D-PDw imaging: FoV, 40 × 40 mm; matrix, 160 × 160; voxel size, 0.25 × 0.25 mm; slice thickness, 1.2 mm; repetition time/echo time (TR/TE), 2000 ms/35 ms; number of signal average (NSA), 1; and acquisition time, 3:00.

The 3D-eTHRIVE images were taken with a head-neck-coil using the same MRI unit with the following parameters: FoV, 150 × 150 mm; matrix, 192 × 192; voxel size, 0.78 × 0.78 mm; slice thickness, 0.78 mm; TR/TE, 14 ms/3.9 ms; flip angle, 90°; fat suppression, spectral atten-

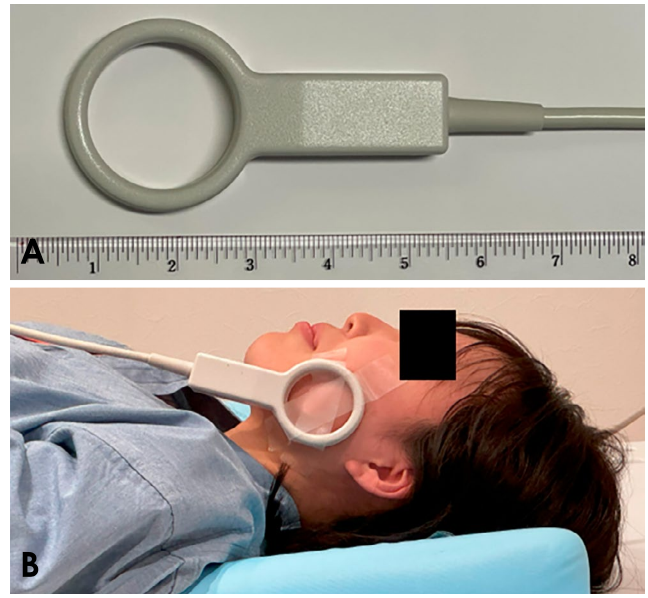

Fig. 1. A. Microscopy coil. B. The microscopy coil is fixed to the skin surface near the left first molars with surgical tape.

Table 1. Scan parameters

	2D-PDw	3D-eTHRIVE
Parameter	Microscopy-coil	Head-neck-coil
Field of view (mm)	40 × 40	150 × 150
Matrix	160 × 160	192 × 192
Pixel size (mm)	0.25 × 0.25	0.78 × 0.78
Reconstructed pixel size (mm)	0.09 × 0.09	0.586 × 0.586
Slice thickness (mm)	1.2	0.78
Slice gap (mm)	0	−0.39
Number of slices	14	140
TR (ms)	2000	14
TE (ms)	35	3.9
Fat suppression	no	SPAIR
Compressed SENSE	no	1.9
NSA	1	3
Scan time (min)	3 : 00	4 : 25

2D-PDw: 2-dimensional proton density-weighted, 3D-eTHRIVE: 3-dimensional T1-high resolution isotropic volume excitation. TR: repetition time, TE: echo time, SPAIR, spectral attenuated inversion recovery, SENSE: sensitivity encoding, NSA: number of signal average uated inversion recovery (SPAIR); sensitivity encoding (SENSE) factor, 1.9; NSA, 3; and acquisition time, 4:25. The details of the parameters are listed in Table 1.

Image analysis

The oblique sagittal images obtained with 2D-PDw and 3D-eTHRIVE imaging were displayed on a high-resolution monitor (500 cd/m^2, 1600 × 1200, RadiForce MX216, EIZO Corporation, Hakusan, Japan) connected to the instrument, and observed by 2 oral and maxillofacial radiologists (S.K., 12 years of experience and H.W., 28 years of experience). They observed the 2D-PDw images and 3D-eTHRIVE images while independently adjusting window settings on the workstation, and they could observe 3D images by freely adjusting sectional planes. They evaluated the visualization of the outline of the tooth, the root dental pulp, the periodontal ligament, the lamina dura, the coronal dental pulp, the gingiva, and the nutrient tract according to a Likert 4-point scale ranging from 1 to 4, in which 1 denoted "not at all visible"; 2, "less than half visible"; 3, "more than half visible"; and 4, "completely visible" (Fig. 2). These observations were repeated twice at 3-week intervals. The average of the visualization scores between the 2 sessions was used for analysis. Major disagreements between observers at the time of the initial observation were resolved through discussion until a consensus was reached.

Statistical analysis

Inter- and intra-observer agreement was calculated using the weighted kappa coefficient, interpreted in qualitative terms: <0.40, poor; 0.40-0.60, moderate; 0.60-0.80, good; and >0.80, almost perfect agreement. To compare 2D-PDw images and 3D-eTHRIVE images, the Wilcoxon signed-rank test was used. *P* values below 0.05 were considered significant. Statistical analysis was performed with IBM SPSS Statistics software (version 28.0; IBM Corp, Armonk, NY).

Results

Inter- and intra-observer agreement

Inter-observer agreement ranged from moderate to almost perfect (Cohen's kappa: first session, 0.514-0.892; second session, 0.724-0.860) for all structures. The tooth and the nutrient tract showed only moderate agreement, but the other structures showed either substantial or almost perfect agreement.

Intra-observer agreement ranged from moderate to almost perfect (Cohen's kappa: first session, 0.538-0.932; second session, 0.606-1.000) for all structures. The tooth showed only moderate agreement, and the other structures showed either substantial or almost perfect agreement.

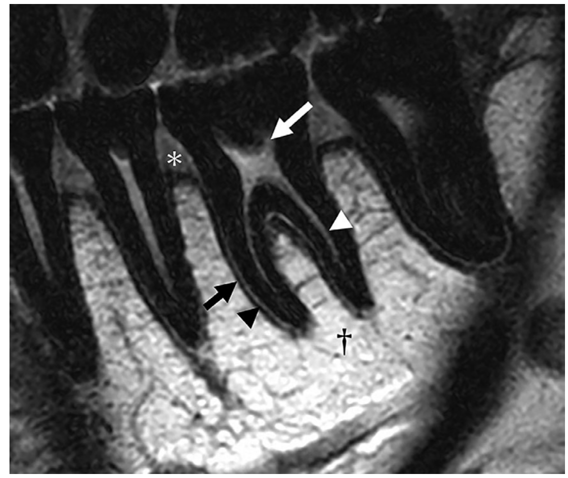

Fig. 2. Examples of images of each structure on 2-dimensional proton density-weighted images: the root dental pulp (white arrowhead), the periodontal ligament (black arrow), the lamina dura (black arrowhead), the coronal dental pulp (white arrow), the gingiva (*), and the nutrient tract (†).

Table 2. Visualization scores (mean ± standard deviation)

	2D-PDw	3D-eTHRIVE	*P* value
Tooth	3.9 ± 0.3	1.3 ± 0.5	<0.05
Root dental pulp	3.5 ± 0.6	1.2 ± 0.4	<0.05
Periodontal ligament	3.5 ± 0.6	1.0 ± 0.0	<0.05
Lamina dura	3.5 ± 0.6	1.0 ± 0.0	<0.05
Coronal dental pulp	3.8 ± 0.4	1.1 ± 0.3	<0.05
Gingiva	3.3 ± 0.5	1.0 ± 0.0	<0.05
Nutrient tract	4.0 ± 0.0	1.8 ± 0.4	<0.05

2D-PDw: 2-dimensional proton density-weighted, 3D-eTHRIVE: 3-dimensional T1-high resolution isotropic volume excitation

Visualization scores

Table 2 shows the visualization scores of each structure. A qualitative analysis demonstrated significantly better visualization scores for 2D-PDw imaging than 3D-eTHRIVE imaging (Wilcoxon signed-rank test, $P = 0.002$ for any evaluation item). The 2D-PDw images yielded better visibility of the tooth, the root dental pulp, the periodontal ligament, the lamina dura, the coronal dental pulp, the gingiva, and the nutrient tract (Table 2, Figs. 3 and 4). A comparison of the highest- and lowest-scoring images in 2D-PDw imaging is presented (Fig. 5).

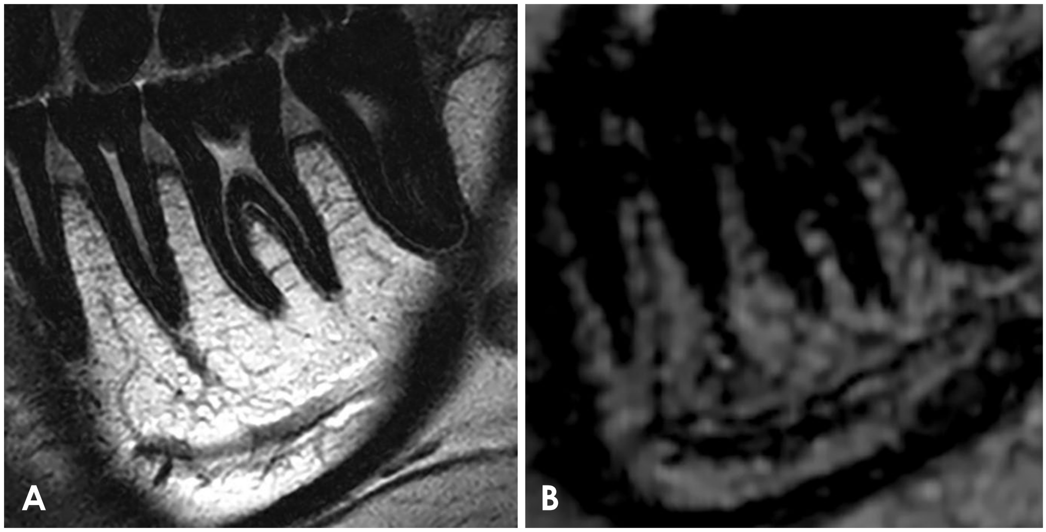

Fig. 3. Images of a 20-year-old woman. A. 2-dimensional proton density-weighted image with visualization scores of over 4.0 for the tooth, root dental pulp, periodontal ligament, lamina dura, coronal dental pulp, gingiva, and nutrient tract (completely visible). The high-signal intensity area around the periapical root is consistent with the periodontal ligament. B. A 3D-eTHRIVE image with a visualization score of 2.0 in the nutrient tract (less than half visible), but 1.0 in the other structures (not at all visible). 3D-eTHRIVE: 3-dimensional T1-high resolution isotropic volume excitation.

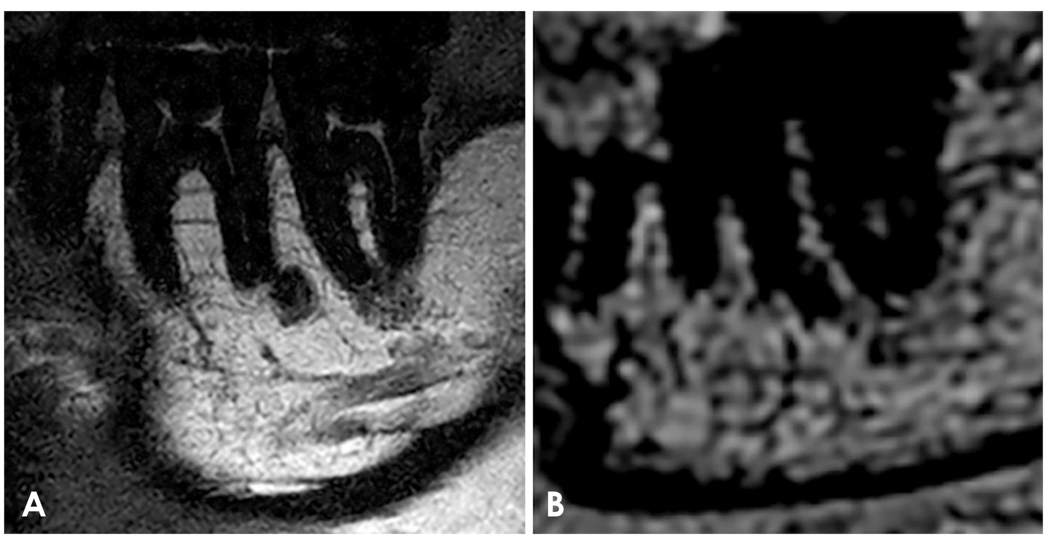

Fig. 4. Images of a 52-year-old man. A. A 2-dimensional proton density-weighted image with visualization scores of 3.0 in the tooth, coronal dental pulp, and nutrient tract (more than half visible), but only 1.0 or 2.0 in the root dental pulp, periodontal ligament, lamina dura, and gingiva (less than half visible or invisible all around). Endosmosis was suspected at the root apex of the left mandibular first molar. B. A 3D-eTHRIVE image with visualization scores of 1.0 in all structures (not at all visible). 3D-eTHRIVE: 3-dimensional T1-high resolution isotropic volume excitation.

Discussion

This study aimed to investigate the visibility of teeth and periodontal tissues using 3 T MRI with a microscopy coil. 2D-PDw imaging with a microscopy coil was significantly superior to 3D-eTHRIVE imaging in terms of visualization of the tooth, the root dental pulp, the periodontal ligament, the lamina dura, the coronal dental pulp, the gingiva, and the nutrient tract. Although there have been many studies of dental MRI, these have primarily used head-neck coils or complex extra-oral or intra-oral coils.[15-25] This study demonstrated that a standard microscopy coil could allow excellent delineation of teeth and periodontal tissues.

Microscopy coils are often used for other body areas,

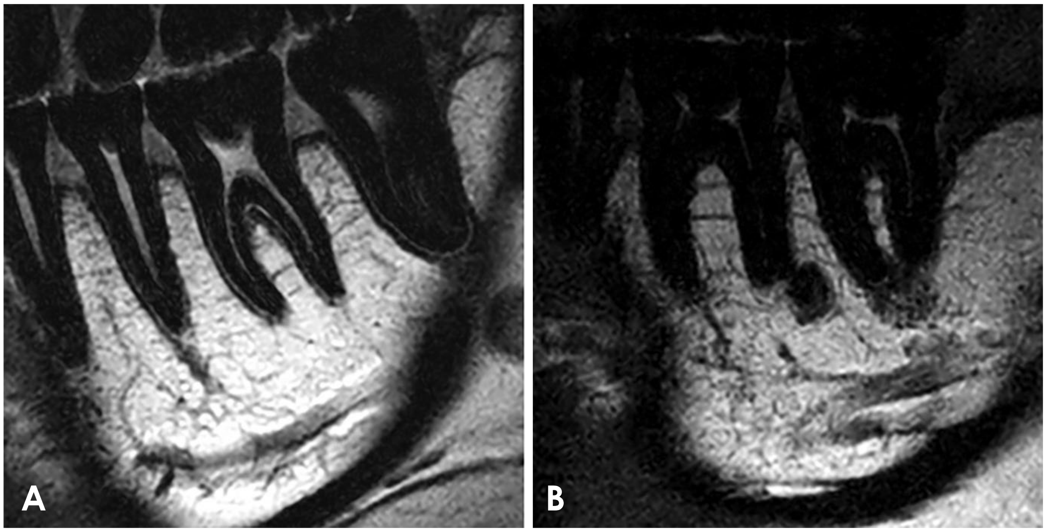

Fig. 5. The highest scoring 2-dimensional proton density-weighted image (A) and the lowest scoring 2-dimensional proton density-weighted image (B).

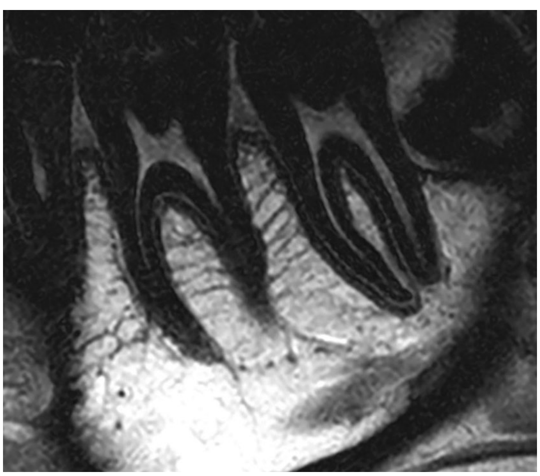

Fig. 6. Image of a 20-year-old woman. The dental pulp is clearly delineated down to the root apex in the mandibular second molar.

such as the orbit and the skin, but they have rarely been applied in dentistry.[12-14] The characteristics of the microscopy coil allow it to visualize only a small FoV, but it can produce images with high resolution and signal-to-noise ratio. These characteristics can be used to delineate intraocular structures and diagnose invasive skin lesions, among other applications.

Using 3 T MRI with a head-and-neck coil and a 3D-VIBE sequence, a 3D T1w MRI image can clearly delineate the neurovascular bundle (NVB) in the mandibular canal.[26] 3D T1w imaging can visualize not only the NVB, but also the nutrient tracts in 58.4% to 97.6% of cases. Additionally, 3D T1w imaging can delineate dental and periodontal structures to some degree. Both 3D-VIBE and 3D-eTHRIVE are techniques for 3D T1w imaging and involve similar MRI sequences, although the MRI unit manufacturer is different.[27,28]

The 3D-eTHRIVE technique minimizes blurring artifacts during reconstruction by not filling the center of the k-space with unstable signals at the beginning of a steady state. This technique allows rapid imaging of 3D volume data and is particularly beneficial in 3 T MRI, where spatial resolution can be increased simultaneously.[29] In the present study, this sequence was applied instead of the 3D-VIBE sequence that was used in previous studies.[11,26] This study showed 91.6% (11/12) visibility of the NVBs in 3D-eTHRIVE imaging, which is consistent with the results of previous studies. Although 3D-eTHRIVE imaging can delineate NVBs, pulp and periodontal tissue are difficult to trace because of the difficulty of increasing the signal-to-noise ratio with the head-neck coil.

The dental pulp is a connective tissue structure that is highly innervated and vascularized. It comprises an extracellular matrix composed of collagenous fibers and ground substance. Because of its high vascular component, the dental pulp can be observed with high signal intensity in PDw and T2w images. However, the periodontal ligament consists of 20%-35% cellular components, 50%-55% extracellular components, including collagen fibers, and 10% vascular components.[30] The remaining epithelial tissue comprises neural tissue and the epithelial cell rests of Malassez. T2w images show low-to-intermediate signal intensity with fibrous tissues, making it challenging to distinguish the periodontal ligament from other surrounding structures. In light of the factors discussed above, PDw images are well suited for depicting the dental pulp, which has a high-water content, and the periodontal ligament, which contains collagen fibers, and may provide a clear and accurate representation of these tissues. PDw images were chosen instead of the conventional T1w and T2w images for MRI because PDw images are widely used in the temporomandibular joint and this sequence is excellent for depicting teeth and periodontal tissues, including the pulp and periodontal ligament.[31]

The tooth, lamina dura, and gingiva can also be visualized on 2D-PDw imaging with a microscopy coil, compared to 3D-eTHRIVE images. This is due to the high resolution and signal-to-noise ratio achieved using microscopy coils. However, further investigation is required to determine why nearly inorganic structures such as the tooth and lamina dura are well delineated with a microscopy coil.

A typical 2D-PDw image clearly displays the coronal dental pulp extending to the root dental pulp, which may allow us to determine whether the inflammatory spillover in the pulp reaches either the crown pulp or the root pulp as a change in signal intensity on the MR image (Fig. 6). Microscopy coils offer several advantages over intraoral coils in oral imaging. From a patient experience perspective, microscopy coils are less invasive and more comfortable than intraoral coils. By avoiding direct placement inside the oral cavity, microscopy coils significantly reduce patient discomfort. Holding an intraoral coil can be challenging for women or individuals with small intraoral spaces. Furthermore, microscopy coils are less prone to motion artifacts caused by patient movement or swallowing since they do not require direct contact with the oral cavity. This reduction in motion artifacts leads to more precise and accurate images.

A limitation of this study was that it investigated only the mandibular first molars in relatively young and healthy individuals. Therefore, the improvement in image quality may have been due to the small amount of intraoral metal. Additionally, 3D imaging using microscopy coils was not considered due to the possibility of motion artifacts and image capture taking longer than 20 minutes. The sequences used in 3D-VIBE and 3D-eTHRIVE were not exactly the same as those reported in previous studies. Additionally, the effectiveness of the visual evaluation might have varied with the application of alternative fat suppression techniques.[28]

In conclusion, 2D-PDw images acquired using 3 T MRI and a microscopy coil can effectively visualize almost all aspects of teeth and periodontal tissues. These findings suggest that 2D-PDw imaging with a microscopy coil could be a promising tool for imaging the teeth and periodontal tissues.

Conflicts of Interest: None

Acknowledgments

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