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Comparison of the image quality of turbo spin echo- and echo-planar diffusion-weighted images of the oral cavity

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Abstract

The purpose of this study was to compare the image quality of turbo spin echo (TSE) diffusion-weighted imaging (DWI) and echo-planar imaging (EPI) of the oral cavity region.

This retrospective study included 26 patients who had undergone both TSE- and EPI-DWI. Misregistration of DWI with T2-TSE images was assessed in the oral cavity. We also compared geometric distortion, the signal-to-noise ratio (SNR), contrast, and the apparent diffusion coefficient (ADC) for the tongue parotid gland, and spinal cord. On a 5-point scale, 2 radiologists scored the TSE- and EPI-DWI of each patient for ghost artifacts, image contrast, and overall image quality.

Distortion in the phase-encoded direction was significantly lower on TSE- than EPI-DWI. The SNR of the tongue and parotid gland was significantly higher on TSE than EPI-DWI except spinal cord. No significant difference was found in contrast and ADC values (except for the ADC of tongue). TSE-DWI yielded higher qualitative scores for all parameters except image contrast.

For the oral cavity region, TSE-DWI was superior to EPI-DWI with respect to distortion-free images and superior image quality.

Abbreviations: ADC = apparent diffusion coefficient, AP = anterior-posterior, DWI = diffusion-weighted imaging, EPI = echo-planar imaging, LR = left-right, MRI = magnetic resonance imaging, RF = radiofrequency, ROI = regions of interest, SNR = signal-to-noise ratio, TSE = turbo spin echo.

Keywords: DWI, MRI, oral cavity, TSE, turbo spin echo

1. Introduction

Magnetic resonance imaging (MRI) is a useful tool for the clinical staging of oral cavity cancer.[1,2] Diffusion-weighted imaging (DWI) is an MRI technique by which the diffusion properties of water can be quantified as an apparent diffusion coefficient (ADC).[3] Changes in the ADC are inversely correlated with changes in cellularity.[4] In tissues with high cellularity, the diffusion of extracellular water is limited by the cell membrane; this results in low ADC values. In tissues with low cellularity, for example, edematous or necrotic tissues where diffusion is facilitated, the ADC is high. Indications for DWI studies of patients with oral cavity cancer include the tissue characterization of primary tumors and nodal metastases, the prediction and monitoring of the treatment response after chemo- or radiation therapy, and the differentiation of radiation changes from residual or recurrent disease.[5]

However, the image quality of scans of the oral cavity acquired with echo-planar imaging- (EPI)-DWI can be unsatisfactory due to its complex structure with many boundaries between the air and body surface and the presence of restoration materials used in dental treatments.[6] These tend to cause substantial magnetic susceptibility artifact in EPI-based sequences. Because EPI-based sequence has no refocusing, radiofrequency (RF) pulse and the spinning protons accumulate phase errors. Such artifacts often result in geometric distortion, signal intensity dropouts, and signal heterogeneity that render the interpretation of DWI scans difficult.

The turbo spin echo (TSE) technique is an alternate approach for DWI. Because it uses a 180° RF refocusing pulse for each measured echo, susceptibility artifacts and image distortion are lower than on EPI-DWI scans. Previous reports suggested that decrease in the SNR and a long acquisition time are disadvantages of TSE-DWI.[7–9] However, recent commercial available TSE DWI sequences at 3T MRI adapted RF pulse shape to reduce the echo space, and it might result in faster scanning, higher SNR, and reduced blurring. Ours is the first report of TSE-DWI studies of the oral cavity at 3T MRI. We compared the image quality of TSE- and EPI-DWI scans of patients who had undergone imaging studies of the oral cavity.

2. Materials and methods

This retrospective study was approved by our Institutional Review Board; the requirement for informed patient consent was waived.

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The authors have no conflicts of interest.

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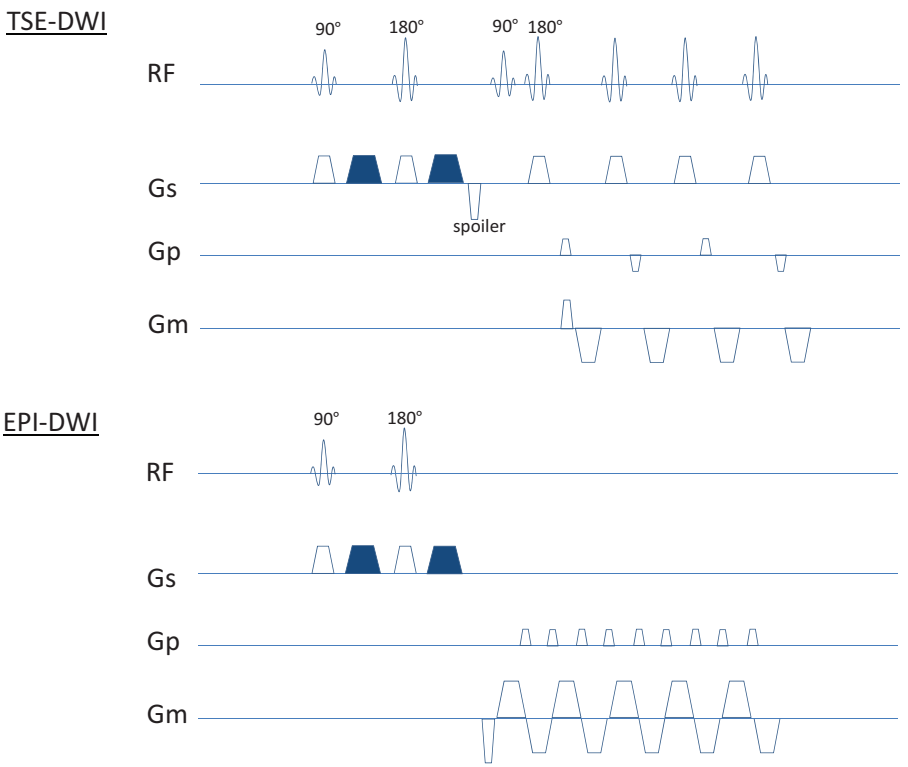

Figure 1. Schematic representation of the basic diffusion-weighted TSE and EPI sequence. The TSE sequence can be made sensitive to diffusion by using a gradient before and after the 180-degree refocusing pulse, as shown in the figure.

2.1. Patients

Between June and July 2015, 35 consecutive patients with suspected or confirmed malignant tumors of the oral cavity underwent TSE- and EPI-DWI studies. As we excluded 9 who had been treated by parotid gland or tongue resection, the study population was comprised of 14 men and 12 women (mean age, 71.5 ± 13.8 years). Of these, 12 patients had histologically confirmed oral cavity cancer [7 gingival, 4 tongue, 1 buccal mucosa cancer(s)]. The other 14 harbored no tumors; 14 had undergone resection earlier and suffered no recurrence in the course of more than 2 years (6 pharyngeal, 4 tongue, 2 larynx, 2 oral floor cancers).

2.2. Scan protocol

MRI was on a 3T scanner (Philips Ingenia 3T; Philips Medical Systems, Best, The Netherlands) using an 8-channel oral cavity coil. We performed axial spin echo (SE) T1-WI-, axial SE T2-WI-, coronal SE T2-WI-, axial and coronal contrast-enhanced (CE) T1 fat suppression (FS)-, TSE-DWI-, and EPI-DWI scans. For EPI-DWI, we used a SE-type single-shot EPI sequence and for TSE-DWI a single-shot SE sequence (Fig. 1). EPI- and TSE-DWI apply a motion probing gradient pulse as a prepulse to obtain a diffusion signal. To the extent possible, we used the same imaging parameters for the 2 DWI sequences (Table 1).

2.3. Quantitative evaluations

A radiologist who was blinded to the protocols with 5 years of experience in MRI of the oral cavity recorded the data from the axial source images. We selected 1 representative slice level that clearly depicted the parotid gland in each patient. Geometric distortion was evaluated by comparing lesion lengths between axial SE T2-WI images and the corresponding DW images. Anterior-posterior (AP) length and left-right (LR) width of the body surface were measured, and the percentage error was calculated (percentage error = DWI distance – T2WI distance / T2WI distance of the body surface × 100).

On each ADC parameter map, ADC values were measured by placing circular regions of interest (ROI) of 100 mm^2 on the healthy tongue, the parotid grand, and the spinal cord. Signal intensity was set to allow the selection of an ROI of 100 mm^2 for TSE- and EPI-DWI. Average ADC values of the oral cavity were calculated in the base of the tongue, in the parotid gland, and in

Table 1

Imaging parameters for DWI sequences.

	TSE-DWI	EPI-DWI
TR/TE, ms	7411/121	4322/59
FOV, mm x mm	250	250
Matrix	112 x 112	128 x 128
Slice thickness, mm	7	7
Spatial resolution, mm^3	$2.23 \times 2.23 \times 7$	$1.95 \times 1.98 \times 7$
Number slices	25	25
b-values, s/mm^2	700	700
Acquisition time, min	1:44	1:05
Flip angle	90	90
Fat suppression	SPIR	STIR
Halfscan	0.65	0.65
Averages	4	4
Acceleration factor	3	2.5
Bandwidth, Hz	871.9	20.4

DWI = diffusion-weighted imaging, EPI = echo-planar imaging, TSE = turbo spin echo.

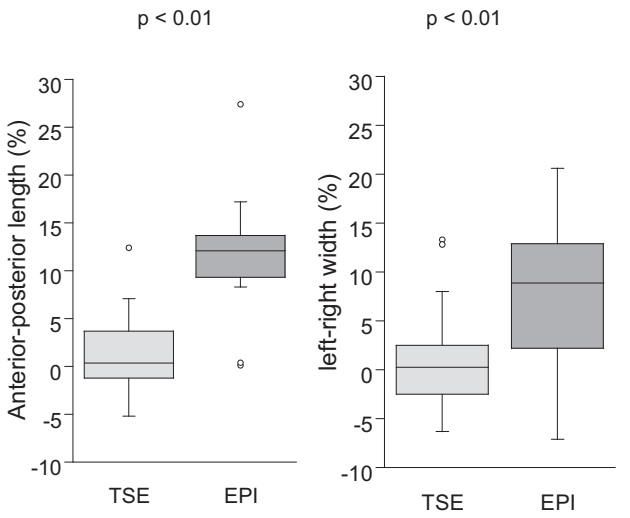

Figure 2. The anterior-posterior (AP) length geometric distortion of TSE-DWI (1.0% ± 3.9) was significantly lower than that of EPI-DWI images (12.0% ± 5.2; $P < .01$). There were significant differences in the left-right (LR) width between the TSE-DWI and the EPI-MRI images (1.1% ± 5.0 vs 7.3% ± 7.1, $P < .01$).

the central gray matter of the spinal cord. Care was taken to measure only the intended region without including structural borders or prominent vascular structures within an anatomic segment.

Signal-to-noise ratio (SNR) was determined by the ratio between the mean signal intensity inside the ROI (SROI) and the standard deviation of the signal intensity (σROI) (SNR = SROI / σROI). Contrast was determined by the ratio between the SROI of parotid gland and the SROI of tongue, between the SROI of spinal cord and the SROI of tongue (contrast = parotid gland SROI / tongue SROI, = spinal cord SROI / tongue SROI).

2.4. Qualitative evaluation

Two trained oral cavity radiologists performed the qualitative analysis for the DWI images on the PACS viewer (View R, version 1.09.15; Yokogawa Electronic, Tokyo, Japan). The image datasets were randomized and the readers were blinded to the acquisition parameters. Adjusting the window level and width was allowed during the qualitative assessment. Ghost artifact was rated as 1 = definitely confounding interpretation, 2 = possibly confounding interpretation, 3 = present, but little impact on interpretation, 4 = faint, and 5 = no artifact. Image contrast was rated as 1 = marked blurring without definable margins, 2 = blurring, but with definable margins, 3 = minimal blurring, 4 = sharp definition, and 5 = marked sharp definition. Overall image quality was rated as 1 = nondiagnostic, 2 = poor, 3 = acceptable, 4 = good, and 5 = excellent. Each reader independently assessed the TSE- and EPI-DWI images from the patients. Decisions were made on the basis of consensus when there were divergences of opinion between the 2 radiologists.

2.5. Statistical analysis

All data are reported as means ± SD. The quantitative evaluation results were compared with a paired Student *t* test. The visual evaluation results were compared with the Wilcoxon test. Furthermore, the degree of agreement between 2 observers regarding the visual evaluation results was measured using kappa statistics. All statistical analyses were performed using the statistical software package JMP 9.0.2 (SAS Institute, Cary, NC). A *P* value of <.05 was considered to be statistically significant.

3. Results

3.1. Quantitative analysis

The mean percentage error in the phase-encoded direction was lower on TSE- than EPI-DWI scans (AP length: 1.0% ± 3.9 vs 12.0% ± 5.2, LR width: 1.1% ± 5.0 vs 7.3% ± 7.1) ($P < .01$) (Fig. 2).

The difference in the ADC value on TSE- and EPI-DWI scans was not statistically significant in the parotid gland and the spinal cord (parotid gland: LR 1.57 ± 0.33 vs 1.48 ± 0.34, spinal cord: 1.29 ± 0.29 vs 1.19 ± 0.26, all $P > .05$) (Fig. 3). On the contrary, there were significant differences in the ADC values of the tongue (1.45 ± 0.46 vs 1.8 ± 0.53 × 10^{-3} mm^2/s, $P < .01$).

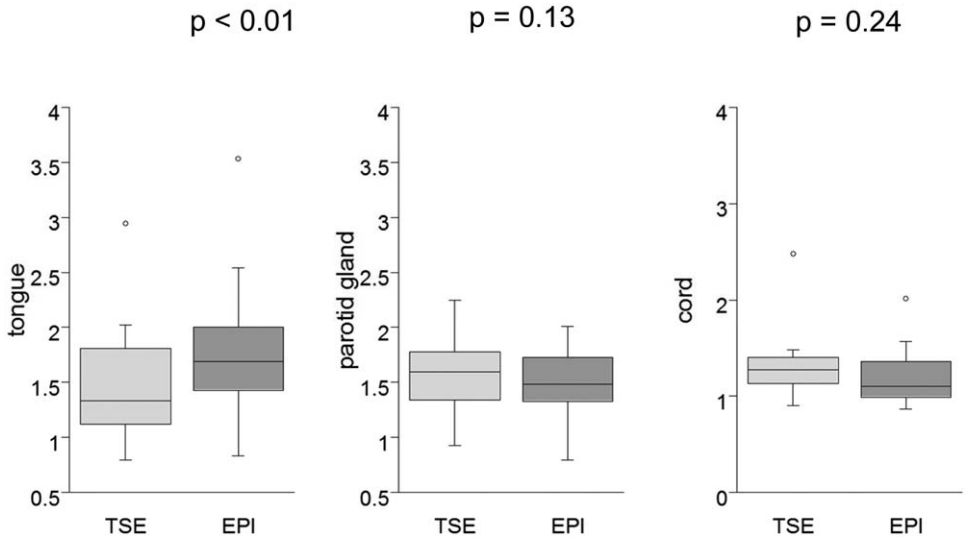

Figure 3. The ADC values of tongue TSE-DWI (1.45 ± 0.46) were significantly lower than that of EPI-DWI (1.8 ± 0.53; $P < .01$). There were no significant differences in the parotid gland and spinal cord between the TSE-DWI and the EPI-MRI images (parotid grand; 1.57 ± 0.33 vs 1.48 ± 0.34, spinal cord; 1.29 ± 0.29 vs 1.19 ± 0.26, all $P > .05$).

Table 2

The image quality of TSE-DWI and EPI-DWI.

Parameter	TSE-DWI	EPI-DWI	*P*
Ghost artifact	3.3 ± 0.9	2.5 ± 1.1	<.05
Image contrast	3.3 ± 0.9	2.8 ± 1.2	.13
Overall image quality	3.4 ± 0.8	2.7 ± 1.1	<.05

DWI = diffusion-weighted imaging, EPI = echo-planar imaging, TSE = turbo spin echo.

The SNR of the tongue and parotid gland was significantly higher on TSE- than EPI-DWI scans (tongue: 7.3 ± 2.8 vs 5.7 ± 1.9, parotid gland: 9.1 ± 3.0 vs 5.3 ± 2.3, $P < .01$). There was no significant difference in the SNR of the spinal cord (14.3 ± 9.1 vs 11.8 ± 6.3, $P = .22$),

There were no significant differences in the contrast between the parotid grand and the tongue, and between the spinal cord and the tongue between TSE- and EPI-DWI ($P = .24$, $P = .38$).

3.2. Qualitative image analysis

Table 2 summarizes that the mean qualitative score for ghost artifacts, and overall image quality were significantly higher on TSE- than EPI-DWI scans (3.3 ± 0.9 and 2.5 ± 1.1; 3.3 ± 0.9 and 2.8 ± 1.2; 3.4 ± 0.8 and 2.7 ± 1.1, respectively) ($P < .05$).

There was mild to moderate interobserver agreement for ghost artifacts, image contrast, and overall image quality (kappa = 0.76, 0.82, and 0.82, respectively). Representative cases are shown in Figs. 4 and 5.

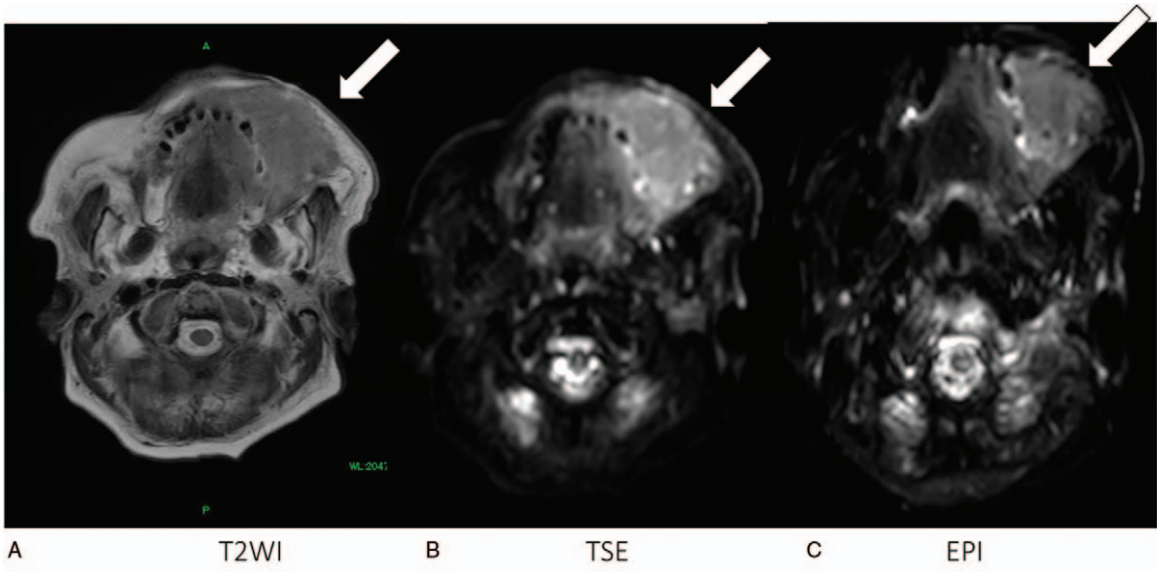

Figure 4. MRI images (A: T2WI image, B: TSE-DWI image, C: EPI-DWI) of a 91-year-old woman with gingival cancer. A tumor of TSE-DWI image (arrows) is more similar to T2WI image than EPI-DWI image.

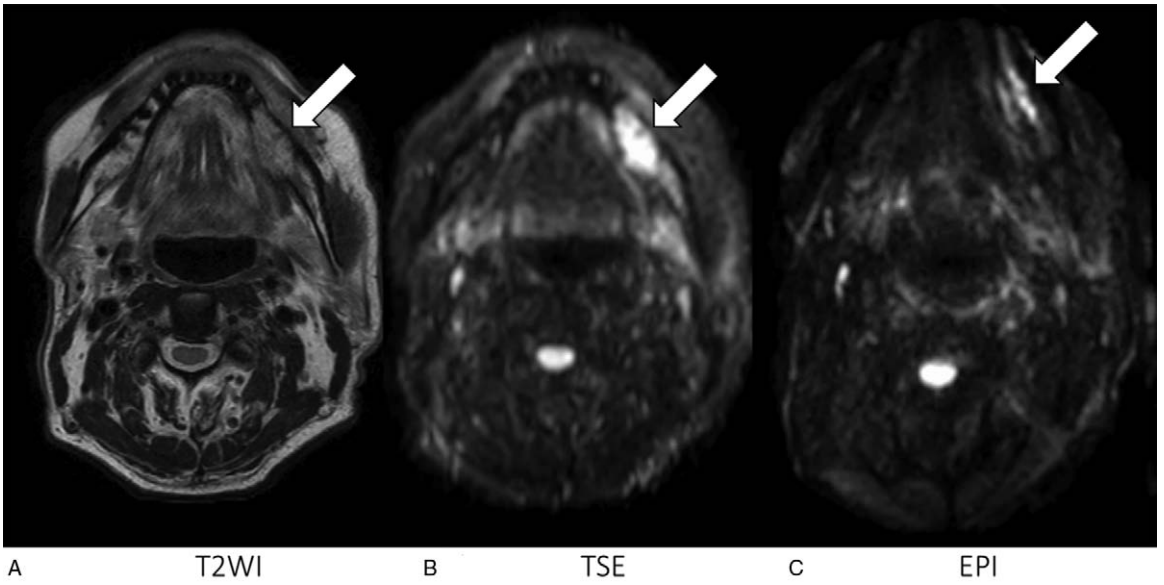

Figure 5. MRI images (A: T2WI image, B: TSE-DWI image, C: EPI-DWI) of a 79-year-old man with gingival cancer. An opacified tumor (arrows) is detectable on the TSE-DWI image (B), whereas it is difficult to identify on the EPI-DWI image (C).

4. Discussion

We found that the image quality was significantly higher on TSE- than EPI-DWI scans of the oral cavity. It indicates that TSE-DWI is an effective method for reducing artifacts and improving the image quality of oral cavity scans. There was significant difference in the ADC values of the tongue except for the parotid gland and the spinal cord.

As DWI involves the random, microscopic movement of water and other small molecules elicited by thermal collisions, rapid image acquisition minimizes the effects of bulk motion such as vascular pulsation on DWI scans.[10] The EPI sequence, a kind of gradient echo sequence, represents the fastest MRI acquisition method (less than 100 ms/slice). It uses a rapidly oscillating phase and frequency gradients that generate multiple gradient echoes. Although this technique drastically reduces the imaging time, it has significant disadvantages.[11] As each echo is acquired at a different echo time, there are blurring artifacts in the phase-encoding direction attributable to signal loss in later echoes due to $T2^*$ decay; this tends to result in low spatial resolution of scans acquired with a short acquisition time. Also, due to the absence of RF refocusing pulses in the EPI sequence, spinning protons result in the accumulation of phase errors that produce positioning errors in the phase-encoding direction and significant distortion. These problems are particularly prominent in anatomic regions with air-tissue interfaces such as the base of the neck and the lungs.

The TSE sequence is another fast imaging method in which multiple echoes are acquired at each excitation (8), and it can be used for DWI. Like the EPI sequence, it is compromised by image blurring. However, TSE sequences is less severe blurring than on EPI sequences because the T2 relaxation time is much longer than the $T2^*$ relaxation time and magnetic field inhomogeneity is abated by RF refocusing pulses. In addition, these pulses prevent the accumulation of phase errors and image distortion.

Our findings suggest that TSE-DWI may be better suited than EPI-DWI in patients undergoing oral examinations. The image quality of EPI-DWI scans of oral cavity lesions is lower than of other lesions because of geometric distortions and signal loss due to the propagation of susceptibility artifacts in the phase-encoding direction.[12] These distortions increase with longer gradient echo times and mimic the encoding of spatial information during image reconstruction. Because TSE-DWI uses an RF refocusing pulse for each measured echo, susceptibility artifacts on scans of the oral cavity are reduced. Among readers of scans of the primary tumors and lymph nodes of 12 patients with oral cavity cancer, TSE-DWI were more reproducible than EPI-DWI findings.[13] Others[14] reported that the sensitivity for detecting cholesteatoma was higher and the probability of a misdiagnosis was lower on TSE- than EPI-DWI scans. We found that the incidence of ghost artifacts was lower and the overall image quality was significantly better on TSE- than EPI-DWI studies.

Reproducibility of the ADC value is important to compare different imaging techniques; therefore, we compared the ADC values generated by TSE- and EPI-DWI studies of different neck regions. On TSE- and EPI-DWI scans, there was a statistically significant difference in their ADC values of the tongue. Whereas the difference in the ADC of the parotid gland and cord was not statistically significant on TSE- and EPI-DWI scans. Others[8,15] reported that the ADC values on oral cavity scans acquired on different MRI systems and with different sequences differed significantly. As the oral cavity often harbors artificial dentition, ADC measurements of the tongue may not be reproducible. Image noise can significantly influence the calculation of diffusion parameters.[16] As image noise increases, the diffusion parameters tend to show lower values.[16] TSE-DWI indicated higher SNR than EPI-DWI in the tongue; thus, the ADC measurements of the tongue from TSE-DWI might be more accurate than EPI-DWI. We suggest that the TSE-DWI sequence may be particularly useful on 3T and greater high-field MR systems and yield scans of improved image quality. Our suggestion applies to oral cavity imaging as well as the imaging of other anatomic areas prone to artifacts such as the prostate and pancreas.

The disadvantage of TSE-DWI might be the longer acquisition time than EPI-DWI. TSE sequence include RF refocus pulse in read/out, and it needs more time than EPI in principle.[8] Our study was a proximate condition, and TSE sequence had a 1.6 times longer than EPI.

Our study has some limitations. It was a single-center study and the study population was small. We did not evaluate diagnostic accuracy because we focused on the image quality under the different imaging protocols. We cannot extrapolate our data acquired on a 3T scanner to 1.5T systems. As susceptibility artifacts are less problematic at 1.5 T because it scales directly with the field strength, the advantages of TSE- over EPI-DWI may be less pronounced at 1.5 T. Distortion was much lower on TSE- than EPI-DWI scans of patients subjected to oral cavity studies, although there was no significant difference between the imaging modalities with respect to the ADC of their lesions.

On the basis of our findings, we suggest that TSE-DWI yields more homogeneous images than EPI-DWI and that it features advantages for the study of the human oral cavity area at 3 T.

Author contributions

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Writing – original draft: Kenichiro Hirata, Takeshi Nakaura.
Writing – review & editing: Takeshi Nakaura, yasuyuki yamashita.

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