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Original contribution

Effectiveness of the periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER) technique for reducing motion artifacts caused by mandibular movements on fat-suppressed T2-weighted magnetic resonance (MR) images

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ABSTRACT

Purpose: To compare a fat-suppressed T2-weighted periodically rotated overlapping parallel lines with enhanced reconstruction (T2W-PROPELLER) sequence with a fat-suppressed T2-weighted fast spin-echo (T2W-FSE) sequence in the oral and maxillofacial regions for the evaluation of the presence of motion artifacts caused by mandibular movements.

Methods: Fifty-six healthy adult volunteers were examined in a closed mouth position and then with three different rhythmical mandibular movements throughout MR scanning: open-close movement (movement 1), lateral movement (movement 2) and open-close and lateral movement (movement 3). All subjects were scanned first with fat-suppressed T2W-FSE and then with fat-suppressed T2W-PROPELLER while performing the same movements. Motion artifacts, including ghosting or pulsation artifacts, streak artifacts, susceptibility artifacts and the overall image quality were independently evaluated by two oral and maxillofacial radiologists using a five-point scale. The score graded by the two observers was averaged.

Results: The inter-observer agreement was almost perfect for all evaluated items ($\kappa \geq 0.81$). The T2W-PROPELLER images showed significantly fewer ghosting artifacts than T2W-FSE images in subjects performing the mandibular movements throughout MR scanning ($P < .001$). T2W-PROPELLER images also showed significantly fewer pulsation artifacts than T2W-FSE images, regardless of the performance of a movement, throughout MR scanning ($P < .001$). Finally, the T2W-PROPELLER images showed a significantly better overall image quality than T2W-FSE images in subjects performing movements 2 or 3 throughout MR scanning ($P < .001$).

Conclusion: The PROPELLER technique was found to be effective in reducing the motion artifacts caused by mandibular movements on fat-suppressed T2W MR images in the oral and maxillofacial regions.

1. Introduction

The periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER) technique enables motion correction using data acquired at the k-space center by every blade. Clinical applications have shown the benefit of the PROPELLER technique for brain [1–5], neck [6,7], cervical spine [8], abdomen [9–11], lumber spine [12], shoulder [13,14], and knee [15] MR imaging. However, to our knowledge, there have been no reports of the application of the PROPELLER technique to the oral and maxillofacial regions.

We sometimes encounter patients in clinical practice who suffer from involuntary movement of the jaw, mouth or tongue, such as those

Abbreviations: MR, magnetic resonance; PROPELLER, periodically rotated overlapping parallel lines with enhanced reconstruction; T2W, T2-weighted; FSE, fast spin-echo

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with oral dyskinesia. These movements result in motion-induced "ghosting" artifacts and reduce the diagnostic image quality in the target regions. Furthermore, a broad spectrum of artifacts caused by the pulsatile flow of vessels and the cerebrospinal fluid (CSF), swallowing or tongue movement can also occur, even in cooperative patients [16].

We hypothesized that the PROPELLER technique might be effective in reducing motion artifacts caused by mandibular movements on MR images in the oral and maxillofacial regions. Although T2-weighted spin-echo sequences are extremely sensitive for the detection of pathologic conditions, their relatively long acquisition times are a disadvantage [17]. This can lead to the degradation of images as a result of motion. For this reason, T2-weighted fast spin-echo (T2W-FSE) sequences are frequently used in clinical practice. In addition, eliminating fat signal using fat-suppression techniques can increase the value of T2W-FSE sequences, as fat has a high signal intensity on these images [18].

The aim of this study was to compare a fat-suppressed T2-weighted PROPELLER (T2W-PROPELLER) sequence with a fat-suppressed T2W-FSE sequence in the oral and maxillofacial regions with respect to the evaluation of the presence of motion artifacts caused by mandibular movements.

2. Materials and methods

2.1. Patients

Fifty-six healthy adult volunteers (34 males, 22 females; median age, 27 years; age range, 24–50 years) were enrolled in this prospective study. The study was approved by our institutional review board, and all volunteers gave their informed consent after the nature of the procedure had been fully explained.

2.2. MR imaging

All subjects were examined using a 1.5-T MR imaging scanner (Signa HDxt 1.5 T; GE Healthcare, Milwaukee, WI, USA) equipped with an 8-ch neurovascular array coil. The fat-suppressed T2W-PROPELLER sequence acquired in the axial plane using the blade data sampling scheme was matched to a fat-suppressed T2W-FSE sequence using rectilinear k-space sampling with respect to sequence parameters (Table 1). The subjects were examined in a closed mouth position (no movement) and then with three different rhythmical mandibular movements throughout MR scanning: open-close movement (movement 1), lateral movement (movement 2) and open-close and lateral movement (movement 3). The procedure of the movements was fully explained, and the subjects practiced sufficiently until they had mastered the movements before MR scanning.

In movement 1, the subjects were required to open their mouth as wide as possible and then close it at a rate of one stroke per second throughout MR scanning. In movement 2, the subjects were required to move their mouth from side to side as far as possible in a lateral movement at a rate of one side per second throughout MR scanning. In movement 3, the subjects were required to perform movement 1 and then movement 2; they moved their mouth repeatedly with one set of the two movements per 3 s throughout MR scanning. All subjects were scanned first with T2W-FSE and then with T2W-PROPELLER while performing the same movements.

Table 1
Imaging parameters for a 3 types of diffusion weighted imaging sequence.

Parameter	T2W-FSE	T2W-PROPELLER
Repetition time (ms)	5000	5000
Echo time (ms)	76.6	76.6
Field of view (cm)	24	24
Matrix	256 × 256	256
Slice thickness (mm)	5	5
Spacing (mm)	1	1
Band width (kHz)	50	50
Number of excitations	1	1
Echo train length	24	24
Scan time (min)	1:05	1:00
Number of slices	27	28

T2W-FSE: T2-weighted fast spin-echo, T2W-PROPELLER: T2-weighted PROPELLER.

2.3. Image analyses

All MR imaging data were presented at random and had any information related to the patient or examination technique removed by one oral and maxillofacial radiologist (1st author with 13 years of experience). The data sets were then independently evaluated by two experienced oral and maxillofacial radiologists (observer 1 with 21 years of experience and observer 2 with 9 years of experience) using a software program (Advantage Workstation 4.4; GE Healthcare).

The following five imaging categories were analyzed for oral and maxillofacial region by using a five-point scale according to a previous article [6]: ghosting artifacts, pulsation artifacts, streak artifacts, susceptibility artifacts and the overall image quality. We defined pulsation artifacts as phase-encoded artifacts from arteries, veins or CSF. Ghosting artifacts were defined as motion-induced phase-encoded artifacts, except for pulsation artifacts [19]. Streak artifacts were defined as sun-burst-like artifacts [20]. Susceptibility artifacts were defined as image degradation caused by tissue-air interfaces, including maxillary sinus and dental metal prostheses [21]. A classification system of five grades was used: 4 = imperceptible, 3 = mild, 2 = moderate, 1 = severe and 0 = profound, except for the overall image quality, where the grades were 4 = excellent, 3 = good, 2 = fair, 1 = poor and 0 = non-diagnostic. In advance, a consensus reading was repeated using five cases until the scores graded by the two observers corresponded sufficiently with each other. The score graded by the two observers was averaged.

2.4. Statistical analyses

To compare the average score between T2W-FSE images and T2W-PROPELLER images for the same mandibular movements, Wilcoxon's signed rank test was performed. To compare the average score among different mandibular movements, the Kruskal Wallis test was performed. A P value of $< .05$ was considered a significant difference. A post hoc pair-wise analysis was performed using the Mann-Whitney U test with Bonferroni's correction, with a P value of $< .05/4$. For the evaluation of the inter-observer agreement between the two radiologists, the quadratic weighted Cohen's kappa test was performed. A kappa value of 0–0.20 indicates slight agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement and 0.81–1.0, almost perfect agreement. All statistical analyses were performed using a commercially available software package (IBM SPSS Statistics for Mac, version 22; IBM Corp., Armonk, NY, USA).

3. Results

Kappa value was > 0.81 at lowest, indicating that inter-observer agreement of the visual evaluation in this study was almost perfect for all evaluated items (Table 2).

Table 3 shows the image degradation due to artifacts or the overall image quality. With respect to the comparison of the average score between T2W-FSE images and T2W-PROPELLER images in same mandibular movements, the T2W-PROPELLER images showed significantly fewer ghosting artifacts than T2W-FSE images in performing the mandibular movements during MR scanning ($P < .001$) (Table 3 and Fig. 1). The T2W-PROPELLER images also showed significantly fewer pulsation artifacts than T2W-FSE images, regardless of the presence of