Efficacy of RADial Acquisition Regime (RADAR) for shoulder MR imaging

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Aims and objectives

In MR examinations, motion artifacts caused by patient's body motion have an influence on accurate diagnosis. Periodically Rotated Overlapping Parallel Lines with Enhanced Reconstruction (PROPELLER) sequence has been reportedly to reduce motion artifacts and B0-related artifacts [1-5]. PROPELLER is a general term, and the MR manufactures named it in their peculiar name such as PROPELLER [GE Healthcare], Multi Vane [Philips Medical Systems], BLADE [Siemens Medical Systems], RADial Acquisition Regime (RADAR) [Hitachi Medical Systems], JET [Toshiba Medical Systems]. PROPELLER is a technique invented to reduce motion artifacts with radial k-space coverage. There have been reports in brain, abdomen and shoulder MR imaging with PROPELLER [1-6]. In the report of shoulder MR imaging, diagnostic impairment due to motion artifacts could be reduced by using PROPELLER technique [4]. However, there have been very few reports on shoulder MR imaging with PROPELLER. In addition, there has been no report on RADAR applied for shoulder MR imaging. As we indicated above, PROPELLER has advantages in the reduction of motion artifacts. On the other hand, PROPELLER has a disadvantage of streak artifacts. Streak artifacts appear in the gridding process that adjusts the position of acquired data by complementary processing from oblique trajectory to the accurate grid of k-space, and it was indicated that streak artifacts are attributable to undersampling [5, 6]. There have been reports on the streak artifacts in brain and abdomen [5, 6]. However, there has been no report on this artifact in shoulder region or the comparison between motion artifacts and streak artifacts. Thus, the purpose of this study was to elucidate the utility of RADAR for motion artifacts reduction of shoulder MR imaging, and to examine the influence of streak artifacts for diagnosis.

Methods and materials

This study was composed of the anterior half of healthy volunteers' study and the latter half of clinical study for patients.

Subjects

Healthy volunteers and patients

In the healthy volunteer study, 15 healthy volunteers (8 male and 7 female; age range, 20-25 years old; mean, 22.8) were enrolled. All volunteers had no present illness or past history for shoulder region. In the clinical study, 48 patients (27 male and 21 female; age range, 13-80 years old; mean, 52.6) with a chief complaint of shoulder pain and a
limitation in range of motion were included. This study was approved by our institutional review board, and written informed consent was obtained from all volunteers or patients.

**MRI examination**

Both of the volunteer and clinical studies were performed at 1.5T-MRI (Echelon Vega, Hitachi Medical Corporation) with 5-channel RAPID shoulder coil. The following sequences were obtained with and without RADAR; sagittal oblique T2-weighted fast-spin-echo (FSE) and coronal oblique proton density (PD)-FSE sequences. All sequences were obtained with fat suppression. Imaging protocols of these sequences were shown in Table 1 on page 5 and Table 2 on page 5.

In the volunteer study, the right shoulders of all healthy volunteers were imaged, and all sequences were performed in both static and exercise-loaded conditions. The exercise-loaded condition was performed in the following manner; each volunteer rotated the right upper arm from anatomical position to 90 degrees internally, and he or she repeated this exercise every 20 seconds at intervals of a few seconds.

In the clinical study, the symptomatic shoulders (right, 27; left, 21) of patients were examined.

**MR image evaluation**

Two board-certified radiologists (H.Y., observer 1, with 25 years of experience in skeletal radiology; Y.Y., observer 2, with 7 years of experience in skeletal radiology) evaluated independently artifacts and detectabilities of anatomical structures in the volunteer study, and motion and streak artifacts in the clinical study. They were not informed of exercise-loaded status of volunteers, clinical information of patients, and the usage of RADAR. All images were displayed at random order in both volunteer and clinical studies.

(a) Volunteer study

**Comparison of sequences with and without RADAR on artifacts and detectabilities of anatomical structures**

Two radiologists independently evaluated artifacts and detectabilities of anatomical structures (oblique coronal view, rotator cuff and articular labrum; oblique sagittal view, supraspinatus and infraspinatus muscle tendons) on 4-point scales. The score and evaluative standard were depended on as follows: Artifacts, 0 = severe artifacts and undiagnosed case, 1 = moderate artifacts and complicated diagnosis, 2 = slight artifacts
and diagnostic uncertainty, 3 = nothing and easily-diagnosed case; detectabilities of anatomical structures, 0 = unobservable and undiagnosed case, 1 = observable case and complicated diagnosis, 2 = observable case and diagnostic uncertainty, 3 = good and easily-diagnosed case.

(b) Clinical study

**Comparison of motion artifacts and streak artifacts between sequences with and without RADAR**

They evaluated motion and streak artifacts on 3-point scales. The score and evaluative standard were depended on as follows: motion and streak artifacts, 0 = appearance of artifacts and diagnostic obstacle, 1 = appearance of artifacts but diagnosable case, 2 = nothing and easily-diagnosed case.

**Comparison between motion artifacts and streak artifacts**

After comparison of motion artifacts and streak artifacts between sequences with and without RADAR, the scores of motion artifacts that more frequently appeared on the sequence were compared with the scores of streak artifacts that more frequently occurred on the sequence.

**Statistical analysis**

(a) Volunteer study

The mean scores of artifacts and those of detectabilities of anatomical structures were compared between sequences with and without RADAR in both static and exercise-loaded conditions.

(b) Clinical study

The mean scores of motion and streak artifacts were compared between sequences with and without RADAR. In addition, the mean scores of motion artifacts were compared with those of streak artifacts.

The Wilcoxon signed-rank test was used in all comparisons. P < 0.05 was considered a significant difference. The assessment of interobserver agreement was performed
by using # statistics [7]. The relation between values and assessments was indicated as follow: 0.21-0.40 = fair agreement; 0.41-0.60 = moderate agreement; 0.61-0.80 = substantial agreement; 0.81-1.00 = most perfect agreement. A computer software (JMP Pro 9.0.2; SAS, Cary, NC) was used to analyze the raw data by the Wilcoxon signed-rank test.

Images for this section:

<table>
<thead>
<tr>
<th>Imaging Protocols about sagittal oblique T2-FSE sequences</th>
<th>RADAR (-)</th>
<th>RADAR (+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOV [mm]</td>
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<td>160</td>
</tr>
<tr>
<td>TR/TE [ms]</td>
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<td>1</td>
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<td>256 × 172</td>
</tr>
<tr>
<td>NSA</td>
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<td>2</td>
</tr>
<tr>
<td>BW [Hz]</td>
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<tr>
<td>Scanning time [min:s]</td>
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<td>3:37</td>
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</tbody>
</table>

Table 1: Imaging Protocols of oblique sagittal T2-FSE Sequences. * Rapid Acquisition through a Parallel Imaging Design
<table>
<thead>
<tr>
<th></th>
<th>RADAR (-)</th>
<th>RADAR (+)</th>
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<tbody>
<tr>
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<td>160</td>
</tr>
<tr>
<td>TR/TE [ms]</td>
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<td>2200/45</td>
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<td>4:05</td>
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</tbody>
</table>

**Table 2:** Imaging Protocols of oblique coronal PD-FSE Sequences. * Rapid Acquisition through a Parallel Imaging Design
Results

(a) Volunteer study

Comparison of artifacts and detectabilities of anatomical structures between sequences with and without RADAR

In exercise-loaded condition, both oblique sagittal T2-FSE and oblique coronal PD-FSE sequences with RADAR significantly reduced motion artifacts compared with those without RADAR (P < 0.05) (Fig. 1 on page 8, Fig. 7 on page 15, and Fig. 8 on page 16). In addition, sagittal oblique T2-FSE with RADAR significantly improved the delineations of supraspinatus and infraspinatus muscle tendons compared with those without RADAR (P < 0.05) (Fig. 2 on page 8 and Fig. 7 on page 15). On the other hand, the delineations of rotator cuff and articular labrum did not significantly improve with use of RADAR (Fig. 3 on page 9 and Fig. 8 on page 16). In static condition, artifacts and the delineations of rotator cuff in oblique coronal images significantly improved with use of RADAR (P < 0.05) (Fig. 1 on page 8, Fig. 3 on page 9, and Fig. 8 on page 16). Observer 2 alone indicated that artifacts and detectabilities of anatomic structures in oblique sagittal images and the delineations of articular labrum in oblique coronal images significantly improved (P < 0.01) (Fig. 1 on page 8, Fig. 2 on page 8, and Fig. 3 on page 9). The assessment of interobserver agreement resulted in most perfect agreement on all comparisons (Table 3 on page 10 and Table 4 on page 11).

(b) Clinical study

Comparison of motion artifacts and streak artifacts between sequences with and without RADAR

Both sagittal oblique T2-FSE and oblique coronal PD-FSE sequences with RADAR significantly reduced motion artifacts (P < 0.05) (Fig. 4 on page 12 and Fig. 9 on page 17). The assessment of interobserver agreement resulted in moderate agreement about both oblique sagittal and oblique coronal images without RADAR (oblique sagittal images, # = 0.54; oblique coronal images, # = 0.57). On the other hand, these results with RADAR indicated most perfect agreement (oblique sagittal images, # = 0.94; oblique coronal images, # = 0.94).

Streak artifacts dominantly appeared on both oblique sagittal and oblique coronal images with RADAR (P < 0.05) (Fig. 5 on page 13 and Fig. 9 on page 17). The assessment of interobserver agreement resulted in substantial agreement for oblique sagittal images
with RADAR (# = 0.72) and most perfect agreement (oblique sagittal images without RADAR, # = 0.97; oblique coronal images without RADRA, # = 0.98; oblique coronal images with RADAR, # = 0.86) besides oblique sagittal images with RADAR.

**Comparison of motion artifacts with streak artifacts**

The mean scores of streak artifacts tended to be higher than those of motion artifacts on both oblique sagittal and oblique coronal images (Fig. 6 on page 14). Therefore, streak artifacts less influenced on diagnosis than motion artifacts.

**Images for this section:**

![Bar graphs](image)

**Fig. 1:** Bar graphs show the mean scores evaluated for motion artifacts on sequences with and without RADAR in the volunteer study. A and B show the results of oblique sagittal T2-FSE sequences. C and D show the results of oblique coronal PD-FSE sequences. (*: p < 0.05, **: p < 0.01, n.s.: not significant)
Fig. 2: Bar graphs show the mean scores evaluated for detectabilities of anatomic structure on sequences with and without RADAR in volunteer study. A and B show the results of supraspinatus muscle tendons on oblique sagittal T2-FSE sequences. C and D show the results of infraspinatus tendons on oblique sagittal T2-FSE sequences. (*: p < 0.05, **: p < 0.01, n.s.: not significant)
Fig. 3: Bar graphs show the mean scores evaluated for detectabilities of anatomic structure on sequences with and without RADAR in volunteer study. A and B show the results of rotator cuff on oblique coronal PD-FSE sequences. C and D show the results of articular labrum on oblique coronal PD-FSE sequences. (*: p < 0.05, **: p < 0.01, n.s.: not significant)
### Table 3: The assessment of interobserver agreement about detectabilities of anatomic structures.

<table>
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<tr>
<th>Oblique sagittal image</th>
<th>Exercise-loaded condition</th>
<th>Static condition</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>with RADAR</td>
<td>without RADAR</td>
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<tr>
<td>Supraspinatus muscle tendons</td>
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<td>0.96</td>
</tr>
<tr>
<td>Infraspinatus muscle tendons</td>
<td>0.96</td>
<td>0.95</td>
</tr>
<tr>
<td>Oblique coronal image</td>
<td></td>
<td></td>
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<tr>
<td>Rotator cuff</td>
<td>0.98</td>
<td>0.96</td>
</tr>
<tr>
<td>Articular labrum</td>
<td>0.90</td>
<td>0.97</td>
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</table>
### Table 4: The assessment of interobserver agreement about motion artifact

<table>
<thead>
<tr>
<th>Motion artifact</th>
<th>Exercise-loaded condition</th>
<th>Static condition</th>
</tr>
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<tbody>
<tr>
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<tr>
<td></td>
<td>with RADAR</td>
<td>without RADAR</td>
</tr>
<tr>
<td>Oblique sagittal image</td>
<td>0.94</td>
<td>0.96</td>
</tr>
<tr>
<td>Oblique coronal image</td>
<td>0.95</td>
<td>0.98</td>
</tr>
</tbody>
</table>
**Fig. 4:** Bar graphs show the mean scores evaluated for motion artifacts on sequences with and without RADAR in the clinical study. A and B show the results of oblique sagittal T2-FSE sequences. C and D show the results of oblique coronal PD-FSE sequences. (**: p < 0.01)**
**Fig. 5:** Bar graphs show the mean scores evaluated for streak artifacts on sequences with and without RADAR in the clinical study. A and B show the results of oblique sagittal T2-FSE sequences. C and D show the results of oblique coronal PD-FSE sequences. (**: p < 0.01)
Fig. 6: Bar graphs show the mean scores evaluated for motion artifacts on sequences without RADAR and streak artifacts on sequences with RADAR in the clinical study. A and B show the results of oblique sagittal T2-FSE sequences. C and D show the results of oblique coronal PD-FSE sequences. (*: p < 0.05, **: p < 0.01, n.s.: not significant)
Fig. 7: The shoulder MR images of the oblique sagittal T2-FSE sequences without RADAR (A and C) and those with RADAR (B and D) in the volunteer study. (A, B: in static condition, C, D: in exercise-loaded condition)
**Fig. 8:** The shoulder MR images of the oblique coronal PD-FSE sequences without RADAR (A and C) and those with RADAR (B and D) in the volunteer study. (A, B: in static condition, C, D: in exercise-loaded condition)
Fig. 9: The shoulder MR images of the oblique sagittal T2-FSE sequences (A and B) and oblique coronal PD-FSE sequences (C and D) in the clinical study. (A, C: with RADAR, B, D: without RADAR)
Conclusion

In both volunteer and clinical studies, RADAR significantly reduced motion artifacts in both oblique sagittal and oblique coronal images. These results are consistent with those of Dietrich et al [4]. Therefore, we think that these results could have a positive impact on the detectabilities of anatomic structure of oblique sagittal images in exercise-loaded condition in the volunteer study. On the other hand, RADAR did not significantly improve the detectabilities of anatomic structure on oblique coronal images. For this reason, we assume that streak artifacts tended to appear around subacromial bursa and glenoid cavity overlapping the rotator cuff and superior labrum on oblique coronal images (Fig. 10 on page 20) that correspond to the periphery of the field of view of the images where the gradient strengths fall off. Streak artifacts appear in the gridding process that adjusts the position of acquired data by complementary processing from oblique trajectory to the accurate grid of k-space, and it was indicated that streak artifacts are attributable to undersampling [5, 6]. Therefore, it is recommended to increase the projection data covering the k-space; however, it requires prolonged scanning time. Our protocol with RADAR cost 3 minutes and 37 seconds in oblique sagittal T2-FSE and 4 minutes and 5 seconds in oblique coronal PD-FSE, respectively. Thus, the further prolongation of imaging time might not be acceptable in a clinical practice. Precise investigation on improved protocol using parallel imaging is therefore need in a future study.

In the clinical study, the mean scores of streak artifacts tended to be higher than those of motion artifacts on both oblique sagittal and oblique coronal images. These results reveal that streak artifacts influenced little on diagnosis than motion artifacts. Streak artifacts occur in the periphery of the field of view because of weakened gradient strength and radiate from the point [8]. Therefore, we think that streak artifacts had little effect on diagnostic regions of the image compared with motion artifacts. We assume that this difference of the two types of artifacts attributed the less influence on diagnosis of streak artifacts.

This study has some limitations. First, volunteers in our study were relatively small in number, and were limited to early twenties. This selection bias might affect the results, because elderly volunteers might show various degree of motion artifacts even in a static condition. Second, the diagnostic accuracy was not compared between sequences with RADAR and without RADAR, because there was not always a gold standard available such as arthroscopic or intraoperative findings for all patients. Finally, we could not measure signal-to-noise ratio (SNR) because we used a parallel imaging technique (Rapid Acquisition through a Parallel Imaging Design) for both oblique coronal and oblique sagittal images without RADAR [9].

In conclusion, RADAR could reduce motion artifacts in shoulder MR imaging. It concurrently causes streak artifacts; however, it might have little effect on the diagnosis.
Fig. 10: The shoulder MR image of the oblique coronal PD-FSE sequences with RADAR in the volunteer study. White arrows indicate streak artifacts.
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References


