MRI Artifact Reduction and Quality Improvement in the Upper Abdomen with PROPELLER and Prospective Acquisition Correction (PACE) Technique

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OBJECTIVE. The purpose of this study was to evaluate the effectiveness of the periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER [BLADE in the MR systems from Siemens Medical Solutions]) with a respiratory compensation technique for motion correction, image noise reduction, improved sharpness of liver edge, and image quality of the upper abdomen.

SUBJECTS AND METHODS. Twenty healthy adult volunteers with a mean age of 28 years (age range, 23–42 years) underwent upper abdominal MRI with a 1.5-T scanner. For each subject, fat-saturated T2-weighted turbo spin-echo (TSE) sequences with respiratory compensation (prospective acquisition correction [PACE]) were performed with and without the BLADE technique. Ghosting artifact, artifacts except ghosting artifact such as respiratory motion and bowel movement, sharpness of liver edge, image noise, and overall image quality were evaluated visually by three radiologists using a 5-point scale for qualitative analysis. The Wilcoxon's signed rank test was used to determine whether a significant difference existed between images with and without BLADE. A p value less than 0.05 was considered to be statistically significant.

RESULTS. In the BLADE images, image artifacts, sharpness of liver edge, image noise, and overall image quality were significantly improved ($p < 0.001$).

CONCLUSION. With the BLADE technique, T2-weighted TSE images of the upper abdomen could provide reduced image artifacts including ghosting artifact and image noise and provide better image quality.

In upper abdominal MRI, artifacts impair image quality and lead to loss of diagnostic information. One of the main causes of artifacts is physiologic motion such as respiratory motion, cardiovascular pulsation, bowel movement, and physical movement of subjects. Motion artifacts, especially ghosting artifact, can lead to a loss of image clarity and reduction of anatomic detail, thus limiting detection of pathologic findings in the abdominal region [1–3]. Also, artifacts frequently blur the liver edge and obscure the depiction of intrahepatic vessels, making it difficult to recognize liver lesions in the left lobe or under the diaphragm [4, 5].

To overcome these problems, a new and promising method for motion control has been investigated [6–8]. Although some techniques, such as respiratory-ordered phase encoding [9], gradient-moment nulling [10], and breath-hold acquisition [11], have been used to control or reduce image artifacts, the clinical success has been limited. The navigator-echo method [12] is used to identify motion-corrupted measurements and reacquire these measurements when the anatomy is close to the baseline position [13]. Although it improves the image quality, such navigator-gated acquisition results in unpredictably long acquisition time when the subject does not return sufficiently close to the baseline position, and multiaveraged navigator-gated acquisitions are rarely practical. The prospective acquisition correction (PACE) method alleviates this problem; however, it cannot perfectly overcome the motion artifacts.

Recently, the periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER) MR technique [14] that is known to be a type of self-navigated data acquisition technique has been introduced in clinical practice. It acquires k-space data in blades and enables shorter acquisition time compared with former navigator-gated sequences [12, 15]. The PROPELLER method

Keywords: image artifact, MRI, periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER), prospective acquisition correction (PACE), upper abdomen

DOI:10.2214/AJR.07.3657

Received January 10, 2008; accepted after revision May 5, 2008.

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AJR 2008; 191:1154–1158

0361–803X/08/1914–1154

(BLADE in the MR system of Siemens Medical System) acquires N blades (N = number of blades) that are rotated around the center of k-space. Each blade consists of the lowest phase-encoding lines of a conventional rectilinear k-space trajectory that are filled with the multiple echo-trains acquisition after a single radiofrequency excitation (Fig. 1). The BLADE method is a variant of the radial scanning techniques and enables correction of in-plane motions by using the data at the k-space center, which are acquired by every blade. The BLADE MR image offers a significant advantage because it offers targeted correction for the major in-plane movements of rotation and translation. The method can be used with other methods for motion correction and yields a better signal-to-noise ratio (SNR) by oversampling data at the center of the k-space [14, 16].

Although the utility of MRI with the BLADE technique has been reported clinically [16–19], there has been little evaluation in the upper abdomen [20, 21]. Hence, the aim of this study was to evaluate the advantage of the BLADE method in conjunction with PACE acquisition for the improvement of MR images of the upper abdomen.

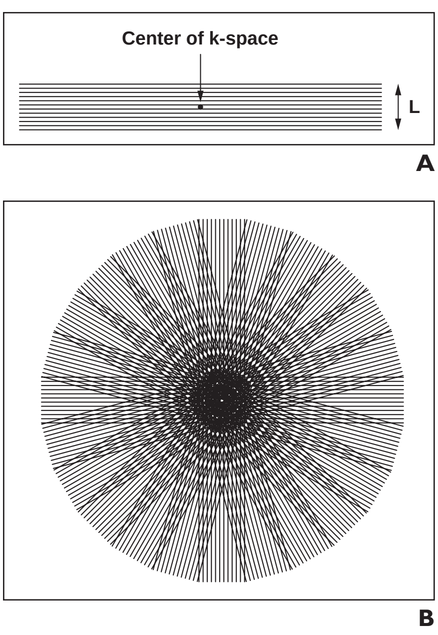

Fig. 1—Illustration of BLADE (proprietary name for periodically rotated overlapping parallel lines with enhanced reconstruction [PROPELLER] in MR systems from Siemens Medical Solutions) k-space data acquisition.
A, Single blade in k-space, composed of *L* phase encoded lines corresponds to full image set with very low resolution in phase-encoding direction.
B, Each blade contains phase-encoding lines. Graphic shows complete set of trajectories for BLADE data, composed of rotated stripes.

Subjects and Methods

Volunteers

This was a prospective study approved by the institutional review board (IRB). Twenty healthy adult volunteers (12 men and eight women; mean age, 28 years; age range, 23–42 years) were enrolled. All volunteers showed no contraindications for MRI. In compliance with local IRB guidelines, informed written consent was obtained from each volunteer before the study.

MRI

The volunteers underwent upper abdominal MRI examinations with a 1.5-T system (Magnetom Symphony, Siemens Medical Solutions) equipped with a six-channel body phased-array coil. In each subject, fat-saturated T2-weighted turbo spin-echo (TSE) images with PACE for respiratory compensation were acquired with and without applying the BLADE method. In both acquisitions, the parameters, except for the BLADE technique, were the same: TE, 85; flip angle, 150°; bandwidth, 425 Hz/pixel; echo-train length, 31; field of view, 32 cm; section slice, 6 mm; matrix, 256 × 256; and voxel size, 1.25 × 1.25 × 6.00 mm^3. The acquisition with the BLADE technique required scanning times of 305 ± 55 seconds, whereas those without BLADE were acquired in 242 ± 52 seconds. Each blade was evenly rotated 14 times to cover the k-space completely.

Image Data Analysis

Irrespective of usage of the BLADE technique, all images were presented at random by one experienced abdominal radiologist with 7 years of experience and evaluated by three experienced abdominal radiologists with 19, 16, and 7 years of experience, respectively, separately with workstations (Centricity, version 2.0; GE Healthcare). The evaluators were not informed of the subject data and MR acquisition conditions. The readers independently checked all 54 MR images including both BLADE and non-BLADE acquisitions from each subject (total of 1,080 images) and scored images on ghosting artifact, artifacts except ghosting artifact such as respiratory and cardiovascular pulsation, sharpness of liver edge, image noise, and overall image quality using a 5-point scale. Disagreements on evaluation were resolved by the third investigator.

Qualitative Analysis

The readers evaluated the severity of ghosting artifact and artifacts except ghosting artifact and rated images with a 5-point scale: 0 = severe image artifact (nondiagnostic), 1 = from moderate to severe image artifact (between scores 0 and 2, but still diagnostic), 2 = moderate image artifact, 3 = minimal image artifact (between scores 2 and 4), and 4 = no image artifact. They also rated sharpness of liver edge, image noise, and overall image quality with a 5-point scale. Sharpness of liver edge was scored as follows: 0 = unacceptable, 1 = poor and blurred severely, 2 = moderate (between scores 1 and 3), 3 = clearly depicted with slight blur, and 4 = excellently depicted without blur. Image noise was rated as follows: 0 = unacceptable, 1 = above-average increase, 2 = average and acceptable, 3 = less-than average, and 4 = minimum or nothing. Evaluation of overall image quality was ranked as follows: 0 = nondiagnostic, 1 = poor, 2 = fair, 3 = good, and 4 = excellent.

Statistical Analysis

For descriptive results of qualitative analysis, the Wilcoxon's signed rank test was used to determine significant differences between images with and without the BLADE technique. A p value less than 0.05 was considered to indicate a statistically significant difference. Percentage disagreement between readers was calculated; reader agreement was assessed using the Cohen's kappa test; kappa value of 0.21–0.40 implied fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; and 0.81–1.0, almost perfect agreement. Statistical analysis was performed using SPSS statistical software, version 15.0.

TABLE 1: Mean Values and SD for T2-Weighted Images With and Without BLADE

Parameter	With BLADE	Without BLADE	p[a]
Ghosting artifact	4.00 ± 0.00	1.17 ± 0.45	< 0.001
Artifacts other than ghosting artifact	3.05 ± 0.47	1.60 ± 0.42	< 0.001
Sharpness of liver edge	3.10 ± 0.48	1.32 ± 0.44	< 0.001
Image noise	3.12 ± 0.42	1.26 ± 0.40	< 0.001
Overall image quality	3.20 ± 0.43	1.15 ± 0.43	< 0.001

Note—BLADE is the proprietary name for periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER) in MR systems from Siemens Medical Solutions. Except for p value, data are mean ± SD.
[a]Statistically significant for all parameters.

TABLE 2: Interobserver Agreement

Parameter	Disagreement (%)	κ	Interobserver Agreement
Ghosting artifact	8	0.90	Almost perfect
Artifacts other than ghosting artifact	15	0.74	Substantial
Sharpness of liver edge	20	0.67	Substantial
Image noise	18	0.72	Substantial
Overall image quality	18	0.72	Substantial
Total	16	0.74	Substantial

Results

The comparative visual assessments showed that ghosting artifact, artifacts except ghosting artifact, sharpness of the liver edge, image noise, and overall image quality were better in T2-weighted images with BLADE ($p < 0.001$) than those without it (Table 1). The analysis of interobserver agreement of all the evaluated items indicated substantial or almost perfect agreement (Table 2).

Discussion

MRI is widely used as a part of medical diagnosis because of its advantageous features such as high-resolution capability, the ability to produce an arbitrary anatomic cross-sectional image, and high tissue contrast. However, there are many potential sources of image artifacts associated with MRI that can potentially degrade images to the extent that they are insufficient for accurate diagnosis. Especially in the upper abdomen, MR images are easily affected by image artifacts because of respiratory motion, cardiovascular pulsation, or bowel movement as well as physical movement of subjects. Consequently the quality of the generated MR image is deteriorated [22]. As a method to overcome these problems, the BLADE technique is expected to reduce image artifacts and improve anatomic depiction in the upper abdomen. It also contributes to better SNR compared with acquisition without it [14, 16].

In this study, image artifacts were shown to be reduced by the BLADE technique (Fig. 2). MRI with the BLADE technique did not generate ghosting artifact and also showed reduction of other artifacts including respiratory motion and cardiovascular pulsation. In all cases, image artifacts were fewer in the images with the BLADE technique. From our results, better depiction of abdominal lesions that are likely to be affected by image artifacts can be expected. The BLADE technique involves a series of rotating blades containing phase-encoding lines, with each blade sampling a common central k-space data set. It enables correction of motion and also achieves motion averaging by oversampling, which thereby offers significant advantages in terms of imaging artifacts. In BLADE MRI, the number of excitations (blades) needed to adequately cover k-space is

$N = \pi / 2 \times M / L$ = blade coverage $\times M / L$, where N is the number of blades, M is the matrix size, and L represents echo-train length [16].

As specified in the equation, data collection with the BLADE technique requires an additional factor of $\pi / 2$ imaging time over conventional scanning [14]. It leads to more sampling of the k-space and results in increased SNR, which can reduce image noise and provide better image quality to improve abdominal lesion conspicuity and clarity of vessels. We confirmed image noise reduction

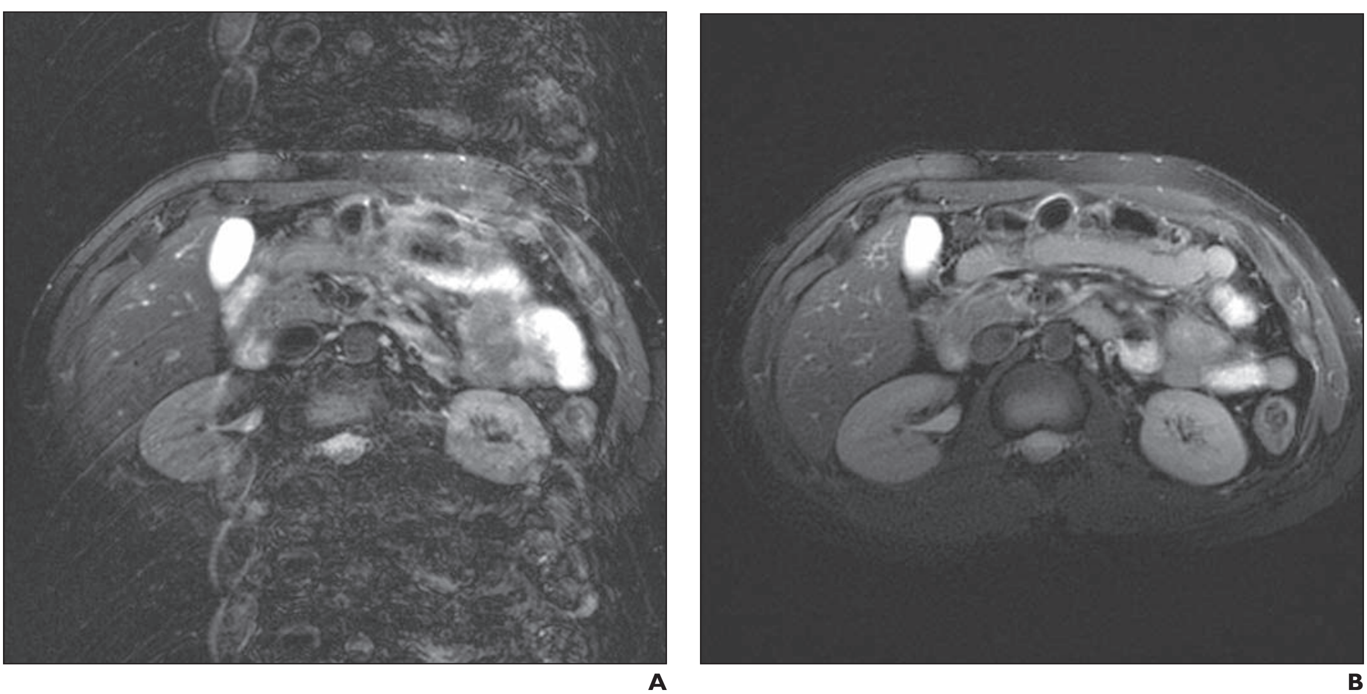

Fig. 2—25-year-old healthy volunteer.
A and **B**, Conventional fat-saturated T2-weighted turbo spin-echo axial image with respiratory-triggered acquisition (**A**) shows marked artifacts including ghosting artifact. Artifact is markedly improved after motion correction on the BLADE (proprietary name for periodically rotated overlapping parallel lines with enhanced reconstruction [PROPELLER] in MR systems from Siemens Medical Solutions) MR image (**B**).

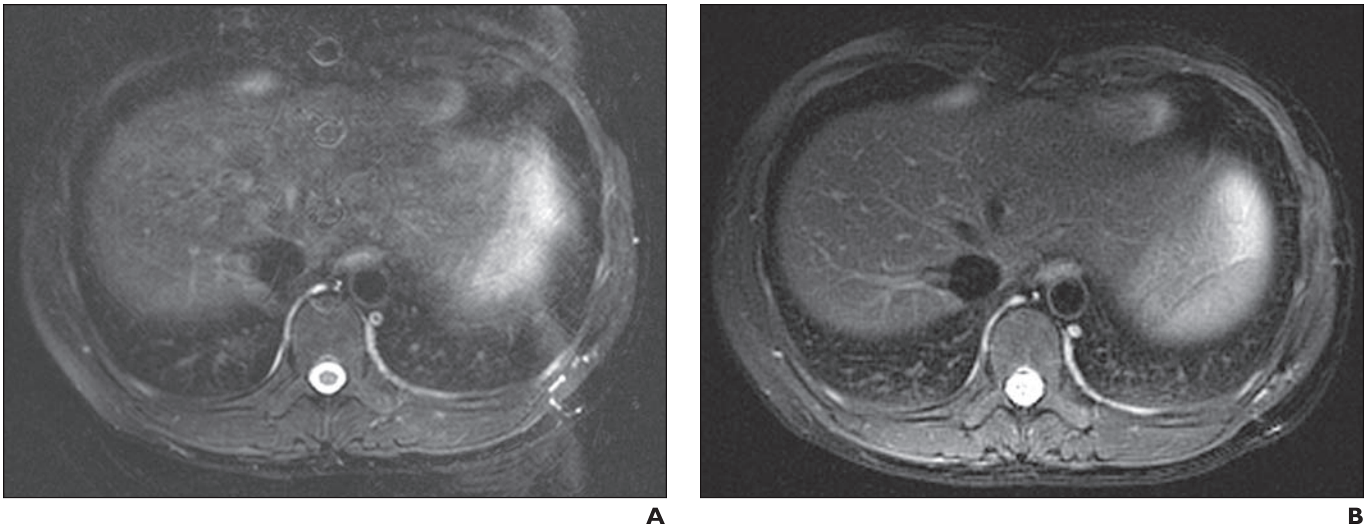

Fig. 3—38-year-old healthy volunteer.
A and **B,** Conventional fat-saturated T2-weighted turbo spin-echo axial image with respiratory-triggered acquisition (**A**) shows blurred resolution of liver edge and poor depiction of intrahepatic vessels. Much better sharpness of liver edge and clearer depiction of intrahepatic vessels were seen on BLADE (proprietary name for periodically rotated overlapping parallel lines with enhanced reconstruction [PROPELLER] in MR systems from Siemens Medical Solutions) MR image (**B**).

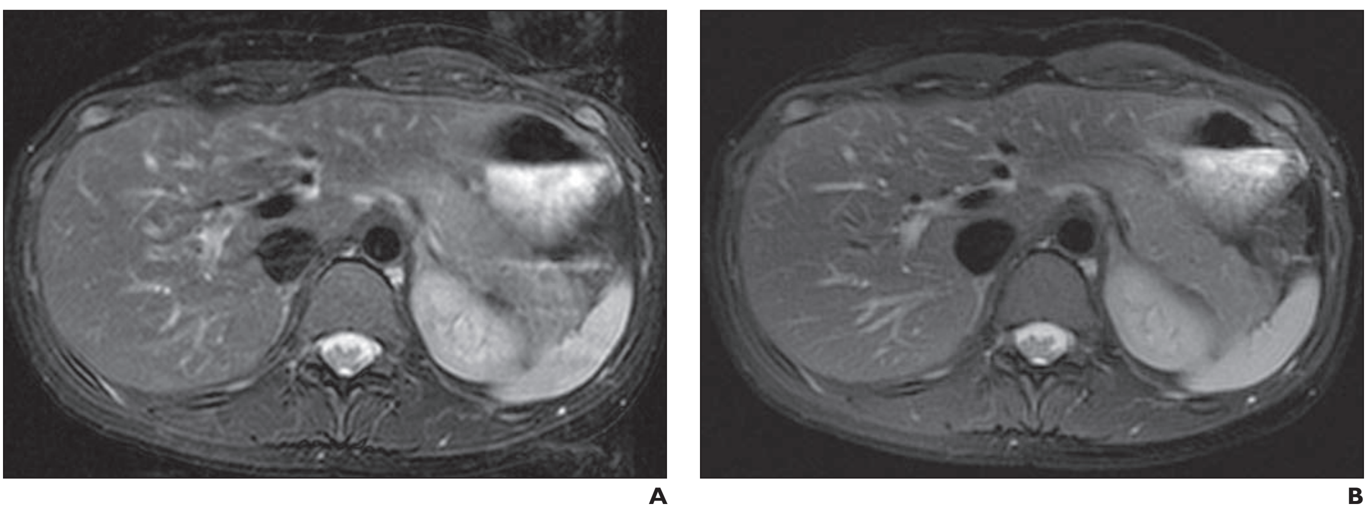

Fig. 4—32-year-old healthy volunteer.
A and **B,** Conventional fat-saturated T2-weighted turbo spin-echo axial image with a respiratory-triggered acquisition (**A**) shows obscure depiction of organs such as spleen, kidney, pancreas, and intestine. Depiction of organs was improved on BLADE (proprietary name for periodically rotated overlapping parallel lines with enhanced reconstruction [PROPELLER] in MR systems from Siemens Medical Solutions) MR image (**B**).

qualitatively, but the quantitative analysis was not feasible because placement of the region of interest (ROI) in the same place was difficult due to differences in slice positions and artifacts between images with and without application of the BLADE technique. In the upper abdomen, MR images with the BLADE technique may not only provide diagnostic anatomic information but also help to detect lesions that are obscured by image artifacts.

Respiratory-triggered acquisition techniques, such as PACE, are used to improve the image quality and allow high-resolution examinations with thinner slice thickness. They are especially useful for patients who have difficulty undergoing breath-hold examination or those under sedation, although the acquisition in breath-hold would yield adequate diagnostic images in less than 1 minute [23–25]. The respiratory-triggered acquisition depends on the cooperation of the subject, and motion artifacts caused by a mismatch in the respiratory rhythm appear occasionally [26]. This would lead to blurring of the liver edge and poor depiction of the intrahepatic vessels. Consequently, it might be difficult to diagnose lesions in the subdiaphragm or liver edge. In the current study, sharpness of liver edge showed significant improvement. The BLADE technique is thought to compensate for the failure of PACE correction and improve depiction of the liver edge (Fig. 3) and other organs as well (Fig. 4).

Our study has some limitations. First, the number of subjects was small ($n = 20$), and images were acquired from volunteers. Therefore, the clinical utility for evaluating lesions remains to be validated. We should confirm the results regarding abdominal lesions by investigating larger patient populations through further studies. Second, the image reconstruction time was increased for the BLADE technique compared with the conventional method. BLADE scanning time is slightly longer than the matched standard sequence. That may lead to slightly better SNR, but it also creates additional time for inadvertent patient movement. The use of applications such as the parallel acquisition technique might reduce the acquisition time. Third, the various parameters were not fully investigated and may not be optimized.

In summary, MRI using the BLADE and PACE technique is promising for reducing image noise and artifacts and obtaining better image quality in the upper abdomen. Future clinical studies are required to evaluate abdominal imaging with malignancy, including lesion detection and therapy assessment with the use of the optimized BLADE technique, especially for patients with difficulties in breath-holding or those under sedation.

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