TECHNICAL NOTE

Dual Gradient-echo In-phase and Opposed-phase Magnetic Resonance Imaging to Evaluate Lipomatous Metaplasia in Patients with Old Myocardial Infarction

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We present an alternative method for evaluating cardiac fat tissue—dual gradient-echo in-phase and opposed-phase magnetic resonance imaging (IPOP-MRI) with electrocardiographic (ECG) gating. Conventional IPOP-MRI can be used to evaluate small amounts of fat and is widely used for abdominal imaging, but cardiac motion artifacts make its use difficult for cardiac imaging. Using ECG gating prior to IPOP-MRI, we evaluated lipomatous metaplasia after myocardial infarction. The areas of lipomatous metaplasia measured by IPOP-MRI with ECG gating correlated well with those areas on black-blood T₁-weighted imaging ($r = 0.82$, $P < 0.0001$, mean bias -0.29 cm^2 , limit of agreement $\pm 2.06 \text{ cm}^2$).

Keywords: *dual-gradient-echo MRI, fat, out of phase, T₁WI, water*

Introduction

Dual gradient-echo in-phase and opposed-phase magnetic resonance imaging (IPOP-MRI) is widely used to image several abdominal organs, and its clinical usefulness in evaluating the severity and distribution of steatosis in the liver has been established.^{1,2} Signals from water and fat within the same voxel are additive on in-phase images and counteractive on opposed-phase, also termed out-of-phase, images. Thus, opposed-phase images depict small amounts of fat tissue as areas of low signal intensity (SI), and images prepared by subtracting opposed-phase images from in-phase images clearly depict only pure fat tissue as areas of high SI. Cardiac motion artifacts make IPOP-MRI of the heart difficult, but we could examine fat tissue in the heart using electrocardiographic (ECG) gating prior to IPOP-MRI. We describe the evaluation of lipomatous metaplasia after myocardial infarction (MI) using IPOP-MRI with ECG gating.

Subjects and Methods

At 10.9 ± 6.3 years after MI onset (infarction location: 2 anterior, 2 anteroseptal, 2 inferior), 6 patients (5 men, one woman) aged 72.7 ± 7.4 years underwent MR imaging using a 1.5-tesla MR scanner (Avanto; Siemens, Erlangen, Germany) with an 8-element phased-array body coil. Flow compensation and automatic shimming were performed.

The imaging protocol for dual gradient-echo sequence with ECG gating was: repetition time (TR)/echo time (TE), 700/2.4 ms (opposed phase) and 700/4.8 ms (in phase); flip angle, 30°; field of view (FOV) read, 340 mm; FOV phase, 100%; base resolution, 128; phase resolution, 90%; and generalized autocalibrating partially parallel acquisitions (GRAPPA) factor, 2.

The protocol for T₁-weighted black-blood turbo spin-echo sequence was: TR/TE, 700–1000/37 ms; TR, 1 cardiac cycle [1 RR interval]; flip angle, 180°; FOV read, 340 mm; FOV phase, 81.3%; base resolution, 256; phase resolution, 60%; GRAPPA factor, 2; and turbo factor, 11. A frequency-selective fat-saturation pulse was added to the T₁-weighted sequence for fat suppression.

All images were acquired at the end diastole dur-

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ing inspiratory breath holding from the same 8 to 10 contiguous short-axis planes with 8-mm section thickness and 2-mm inter-slice gap covering the entire left ventricle (LV) from base to apex. Water images were reconstructed by adding the in-phase and opposed-phase images, and fat images were constructed by subtracting opposed-phase images from in-phase images. Areas of lipomatous metaplasia were manually traced and compared between the reconstructed fat images and black-blood T_1 -weighted images (T_1 WI).

We followed the clinical research protocols approved by our institutional ethics committee in accordance with the Helsinki Declaration of 1975.

Results

ECG-gated IPOP-MRI provided evaluable cardiac images for all subjects. The time required to acquire all the LV images was significantly shorter for ECG-gated IPOP-MRI (5.1 ± 1.3 min) than black-blood T_1 -WI with and without fat suppression (10.1 ± 2.5 min) (paired t test, $P < 0.01$).

Figures 1 and 2 show typical images from a 73-year-old man with an old anteroseptal MI who was referred to our hospital for evaluation of myocardial viability and left ventricular function by cardiac MR imaging. He had undergone percutaneous coronary intervention for chronic total occlusion of the proximal left anterior descending artery 6 years earlier. Since then, he had had no cardiac symptoms, such as chest pain, dyspnea, palpitation, faintness, or syncope, and his exercise ECG showed no signs of ischemia. Cine MR images showed severe hypokinesia in the anteroseptal wall with a focal dark band (Fig. 1a,b). A black-blood pre-con-

trast T_1 WI with turbo spin-echo sequence (conventional T_1 WI) showed areas of high SI in the anteroseptal wall and pericardial fat (Fig. 2a), which appeared with low SI during fat-saturation pulses (Fig. 2b). A pre-contrast phase-sensitive reconstructed inversion-recovery true fast imaging with steady-state precession (true FISP) image also showed areas of high SI in the above-mentioned regions (Fig. 2c). Thus, lipomatous metaplasia after MI was recognized in the anteroseptal wall. ECG-gated IPOP-MRI was also performed. Areas of high SI in the heart and pericardial fat on an in-phase image (Fig. 2e) showed significantly less SI on an opposed-phase image and were identified as areas of lipomatous metaplasia and pericardial fat on conventional T_1 WI (Fig. 2f). A reconstructed water image also showed areas of low SI in the region of lipomatous metaplasia and pericardial fat (Fig. 2g). A reconstructed fat image clearly showed only lipomatous metaplasia and pericardial fat as areas of high SI (Fig. 2h). Finally, a phase-sensitive reconstructed inversion-recovery true FISP image acquired about 10 min after injection of gadodiamide (0.15 mmol/kg) showed areas of high SI areas in the anteroseptal wall, which were identified as infarcted myocardium (Fig. 2d).

Figure 3 shows the correlation and Bland-Altman analyses of the comparison of the areas of lipomatous metaplasia between the reconstructed fat images and black-blood T_1 -WI. The areas of lipomatous metaplasia correlated well ($r = 0.82$, $P < 0.0001$) between the 2 imaging methods. The mean bias was -0.29 cm² and limits of agreement, ± 2.06 cm². Although the reconstructed fat images tended to overestimate the size of the area of lipomatous metaplasia (3.53 ± 1.78 cm²) on the black-blood T_1 -

Fig. 1. Short-axis cine images show severe hypokinesia in the anteroseptal wall and a focal dark band (arrows; **a**: diastolic phase, **b**: systolic phase).

Fig. 2. Short-axis view. Black-blood pre-contrast T_1 -weighted image with a turbo spin-echo sequence shows areas of high signal intensity (SI) in the anteroseptal wall (**a**, white arrows), which appear as areas of low SI during application of a fat-saturation pulse (**b**, white arrows). A pre-contrast phase-sensitive reconstructed inversion-recovery true fast image with steady-state precession shows areas of high SI in the above-mentioned regions (**c**, white arrows), and a post-contrast image shows anteroseptal myocardial infarction (**d**, black arrows). Thus, lipomatous metaplasia after myocardial infarction is present in the anteroseptal wall. In- and opposed-phase gradient-echo magnetic resonance images were simultaneously acquired before the contrast study. The in-phase image shows areas of high SI in the heart (**e**), whereas the opposed-phase image (**f**, white arrows) and additive image of the in- and opposed-phase images (**g**, white arrows) show areas of low SI in the region of lipomatous metaplasia. Images prepared by subtracting in-phase images from opposed-phase images clearly depict lipomatous metaplasia as areas of high SI (**h**, white arrows).

Fig. 3. Comparison between the 2 imaging methods of areas of lipomatous metaplasia. Correlation (left) and Bland-Altman analyses (right) showing comparison of the areas of lipomatous metaplasia between the reconstructed fat images and black-blood T_1 -weighted images. The bias (solid line) equals the mean difference between the 2 techniques. The limits of agreement (dashed lines) are equal to the mean ± 2 standard deviation (SD) of the difference and include approximately 95% of the data points.

weighted images ($3.24 \pm 1.44 \text{ cm}^2$), no significant differences were observed between the 2 imaging methods (paired *t* test, $P=0.28$).

Discussion

Cardiologists are increasingly recognizing the importance of evaluating cardiac fat. Subendocardial fat deposition, also called lipomatous metaplasia, is related to a history of MI.^{3,4} Although the clinical significance of lipomatous metaplasia has not been sufficiently established in patients with old MI, the detection of subendocardial fat deposition by non-contrast MR imaging could at least aid diagnosis of old MI, especially in patients with renal failure, who should not receive gadolinium contrast agents. Fat infiltration in the right ventricular free wall is an important finding for diagnosing arrhythmogenic right ventricular dysplasia/cardiomyopathy.⁵ Moreover, pericardial fat is a marker of adiposity and cardiovascular risk.⁶

Cardiac MR imaging involving black-blood T₁WI and a turbo spin-echo sequence with or without chemical-shift imaging for the selection of fat suppression is a noninvasive and accurate technique for evaluating cardiac fat.⁷⁻¹¹ However, conventional T₁WI is occasionally inconvenient for patients because it requires prolonged resting in a supine position and frequent breath holding for image acquisition during separate breath holds. Moreover, image acquisition during separate breath holds can cause misregistration between corresponding images with and without fat suppression, making difficult the reconstruction of the additive and subtractive images. Our IPOP-MRI technique with ECG gating solves these problems by allowing simultaneous acquisition of in- and opposed-phase images in the same breath hold. In other words, IPOP-MRI with ECG gating can yield cardiac images with and without fat suppression in significantly less time than black-blood T₁WI with and without fat suppression. Moreover, opposed-phase images enable accurate evaluation of small amounts of fat, and subtraction images enable the visualization of pure fat tissue only. Thus, IPOP-MRI with ECG gating may improve the evaluation of fat tissue volume and display the details of fat distribution in the heart.

Triple gradient-echo MR imaging for the heart has recently been reported¹² and is expected to enable more accurate evaluation of fat tissue by the 3-point Dixon method than that achieved by dual gradient-echo MRI. However, this technique requires a relatively long scan time, high-performance MR imaging scanner, and post-processing

software, and it is not commonly used. Until these problems with triple gradient-echo MR imaging are resolved, IPOP-MRI with ECG gating may be a useful alternative to conventional T₁WI for the evaluation of cardiac fat tissue.

The present study is potentially limited by the very small number of subjects and because the gradient-echo sequence lacks the 180° refocusing pulses of spin-echo sequences, which may result in loss of signal intensity from magnetic susceptibility effects and local magnetic field inhomogeneities that produces subsequent artifacts. Research is needed to evaluate cardiac morphology by IPOP-MRI with ECG gating, and multicenter studies of a larger number of subjects are needed to confirm our results.

In the present study, IPOP-MRI with ECG gating enabled clear visualization of lipomatous metaplasia after MI. We believe that this technique is a good alternative to conventional T₁WI for evaluating fat tissue in the heart.

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