Breath-hold FSE for Accurate Imaging of Myocardial and Hepatic R_2

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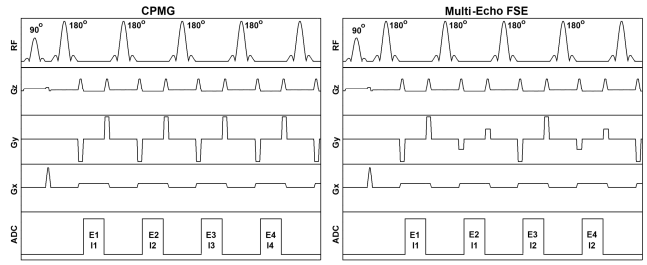

Fig. 1. Pulse sequence diagram of (left) CPMG and (right) multi-echo FSE with TF of 2. E: echo; I: image.

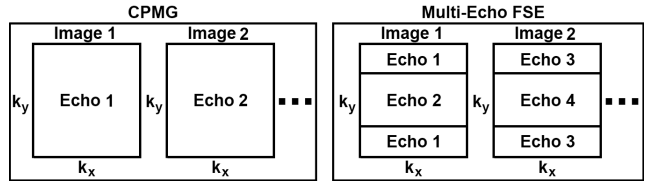

Fig. 2. Corresponding k-space of (left) CPMG and (right) centric k-space reordering of the FSE sequence with TF =2.

Introduction: For patients with transfusional iron overload, improved non-invasive methods for monitoring iron-chelating therapy are needed. MRI provides a means to non-invasively assess tissue iron concentration in both liver and heart by exploiting the paramagnetic effects of iron on the relaxation rates of solvent protons, such as R_1, R_2, or R_2^*. At present, the most widely used method is breath-hold R_2^* imaging [1], which has been shown to detect myocardial iron deposition [2]. Limitations of this method are (i) sensitivity to non-iron related magnetic field (B_0) inhomogeneities which can confound R_2^* measurements within the whole heart [3] and liver and (ii) insensitivity to ferritin iron, the storage iron fraction in equilibrium with the low molecular weight cytosolic iron pool accessed by iron-chelating agents [4]. We have developed an alternative method, R_2 imaging based on spin echo pulse sequences, which is relatively insensitive to B_0 inhomogeneity while providing a measure of RR_2, the "reduced R_2" that provides a measure of ferritin iron [5]. Compared with gradient echo sequences, spin echo sequences are slower and more sensitive to motion and heart rate variability. Consequently, spin echo sequences for hepatic and myocardial R_2 measurement in thalassemia patients are generally performed during free breathing with respiratory gating [6-8], and their low data acquisition efficiency make them impractical for performing both myocardial and hepatic R_2 imaging within a clinically acceptable examination time. The purpose of this study was to develop a breath-hold fast spin echo (FSE)[9] sequence for more accurate imaging of myocardial and hepatic R_2.

Methods: Figure 1 shows schematic diagrams of the navigator-gated Carr-Purcell-Meiboom-Gill (CPMG)[10, 11] and the breath-hold FSE sequences. In CPMG, each spin echo forms an image. In practice, the radio-frequency (RF) field (B_1) inhomogeneity produces flip angle error that result in asymmetry of amplitude between odd and even echoes. Note that phase-cycling corrects the flip angle error only for even echoes. Given this fact, the multi-echo FSE with turbo factor (TF) of 2 was designed with centric k-space reordering, such that two successive echoes form an image with the even and odd echoes filling the inner and outer halves of k-space, respectively (Fig. 2). Compared with even echo CPMG, this FSE should provide comparable accuracy with an acceleration factor of 2, which will then be utilized to perform breath-hold imaging. Both the CPMG and FSE sequences were implemented on a 1.5T whole-body MR scanner (Avanto, Siemens) for comparison. Relevant imaging parameters for both CPMG and FSE include: FOV = 340 x 276 mm, matrix = 128 x 78, GRAPPA acceleration factor = 1.8, slice thickness = 10 mm, BW = 500 Hz/pixel, ESP = 5.6 ms, number of images = 10, echo-train duration ~ 120 ms, and double-inversion black-blood preparation pulse. Image acquisition was repeated for two additional different inter-echo spacing (ESP) of 7 (BW = 295 Hz/pixel; number of images =8) and 10 ms (BW = 155 Hz/pixel; number of images =6), respectively, in order to quantify non-monoexponential T_2 decay in the presence of soluble (ferritin) and particulate (hemosiderin) iron [5]. To minimize stimulated echoes, the slice thickness of the refocusing pulse was set to three times that of the excitation pulse [12]. Agarose gel phantom containing different concentrations of iron (0, 0.02, 0.04, 0.06, 0.08, and 0.10 mg Fe/ml) were imaged with TR = 1000 ms. The liver and heart of two patients with thalassemia major were imaged. The breath-hold duration of the FSE was 20-22 s, and the scan duration of the navigator-gated CPMG was typically on the order of 5-7 min. The region-of-interest (ROI) was manually drawn for each object. The reduced R_2 (RR_2), a measure of the true solution relaxation rates and thus able to detect ferritin iron levels independently of hemosiderin iron levels [5], was calculated by non-linear least square fitting of the three sets of non-monoexponential relaxation curves with different ESPs [13]. The RR_2 values of the phantom and subjects were pooled for linear correlation and Bland-Altman analyses.

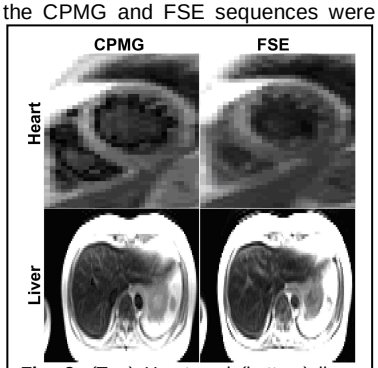

Fig. 3. (Top) Heart and (bottom) liver images acquired using (left) even echo CPMG and (right) multi-echo FSE.

Results: Figure 3 shows representative heart and liver images that compare the image quality produced by the two sequences. For pooled data (Fig. 4), the RR_2 values were strongly correlated (slope = 1.01; bias = -0.75; R^2 = 0.99) and in good agreement (mean difference = 0.37; 95% limits of agreement were -1.61 and 2.34).

Discussion: This study demonstrated the feasibility of performing breath-hold FSE for myocardial and hepatic R_2 imaging within a clinically acceptable breath-hold duration of 20-22s. The initial evaluation showed that breath-hold FSE produces an accuracy comparable to that of navigator-gated even echo CPMG. This FSE sequence provides two advantages over the previously described FSE sequence with TF = 3 [14]. First, the latter provides shorter ESP, which is necessary to perform reliable data fitting. Second, the latter provides immunity to asymmetry of amplitude between odd and even images. The higher efficiency of breath-hold FSE provides a means to extend the sampling of the liver and heart, which in turn will permit evaluation of spatial variability in iron distribution. Future work will validate the FSE sequence more thoroughly.

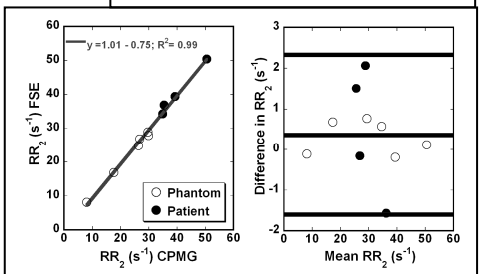

Fig. 4. (Left) Correlation and (right) Bland-Altman plots. Black and Gray lines in right represent mean and 95% limits of agreements, respectively.

References

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