A fast spin-echo multi gradient-echo sequence to reduce distortions on T2-weighted images at high field

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INTRODUCTION

Susceptibility-induced magnetic field and chemical shift increase image distortion at high field[1]. For a 2D fast spin echo (FSE) sequence used to obtain T2 contrast, the anatomy is distorted in the readout direction generating hypo- and hyper-intense signals close to interfaces limiting the precision for morphological studies as well as generating an ambiguous contrast[2]. Increasing the acquisition bandwidth is a typical way to reduce these artifacts. However, in order to maintain the SNR per unit time, the number of 180 pulses (the echo train length) has to be increased, rapidly reaching specific absorption rate limits at high field[1]. In addition, to limit angle inhomogeneity effects (slice profile), 180 pulses are surrounded by crusher gradients resulting in a significant RF pulse pattern duration which reduces the observation time *TO* available between pulses, and that can reach the gradient amplifier duty cycle limits if repeated rapidly for thin slices. Altogether, any increase in sampling bandwidth will rapidly decrease the ratio *TO*/*ESp* (echo spacing) that is directly linked to the scan efficiency. For a given echo spacing, we propose to replace the single readout by a train of gradient echoes acquired with a larger bandwidth avoiding the use of an increased number of 180 pulses while reducing image distortion. It is shown in vivo on rat brain that susceptibility induced distortions are suppressed by this approach while preserving SNR and contrast.

MATERIAL AND METHODS

MR system Experiments were performed on a horizontal 7T/40cm system (Varian, Palo Alto, CA) equipped with a 12cm ID gradient coil (700 mT/m). A 4-channel receive brain surface coil and an actively decoupled volume transmit coil were used.

Animal handling Two 300g male Sprague Dawley rat were anesthetized using ~2% isoflurane and immobilized in a prone position using ear rods and tooth bar.

Pulse sequence After shimming and scout imaging, 20 horizontal 2D slices were acquired with a standard FSE and the fast spin-echo multi gradient-echo sequence (FSEMGE) depicted in Fig.1. The FSE sequence efficiency was first optimized (TO/ESp ~ 0.75) considering the previously mentioned RF and gradient limitations in our system. Parameters were: 200x200 µm in plane resolution (38.4x38.4 mm FOV, 192x192MTX), 300 µm slice thickness, frequency direction along B_0, TR = 4 s, spin echo train length SETL = 6, ESp = 19 ms, SW = 14 kHz (TO=13.7 ms), TE = 57 ms and 4 signal accumulations. The FSEMGE sequence was then applied with the same parameters except for SW = 156 kHz and a gradient echo train length GETL = 11 resulting in the same TO.

Image reconstruction k-space signals from each coil were zero-filled to 256x256 and Fourier transformed (FFT). Coil images were combined with weighted least-squares for which the relative complex weights were generated from low resolution images (gauss filtered central echo images). Reversed echoes were flipped and phase centered (echo shifting). A FFT along the gradient-echo time was performed on 128 points. For each pixel, the largest spectrum component and the corresponding frequency were kept.

RESULTS

FSE images provided a T2 contrast within the brain but suffered from strong distortions. Hyper-signals in entorhinal cortex (arrows in slice 1 and 2) or at the brain boundaries can be confounded with higher T2 contrast without further information. The FSEMGE images provided the same SNR and contrast in most part of the brain (CSF, WM/GM in the cerebellum). However, in the regions with rapidly varying B0 such as close to interfaces (e.g. flocculus and paraflocculus), artifacts were suppressed and a much clearer anatomy was depicted. The brain and cerebellum contours drawn in the FSEMGE images and reported in the FSE images further indicate the drastic reduction of the brain deformation using a gradient-echo train.

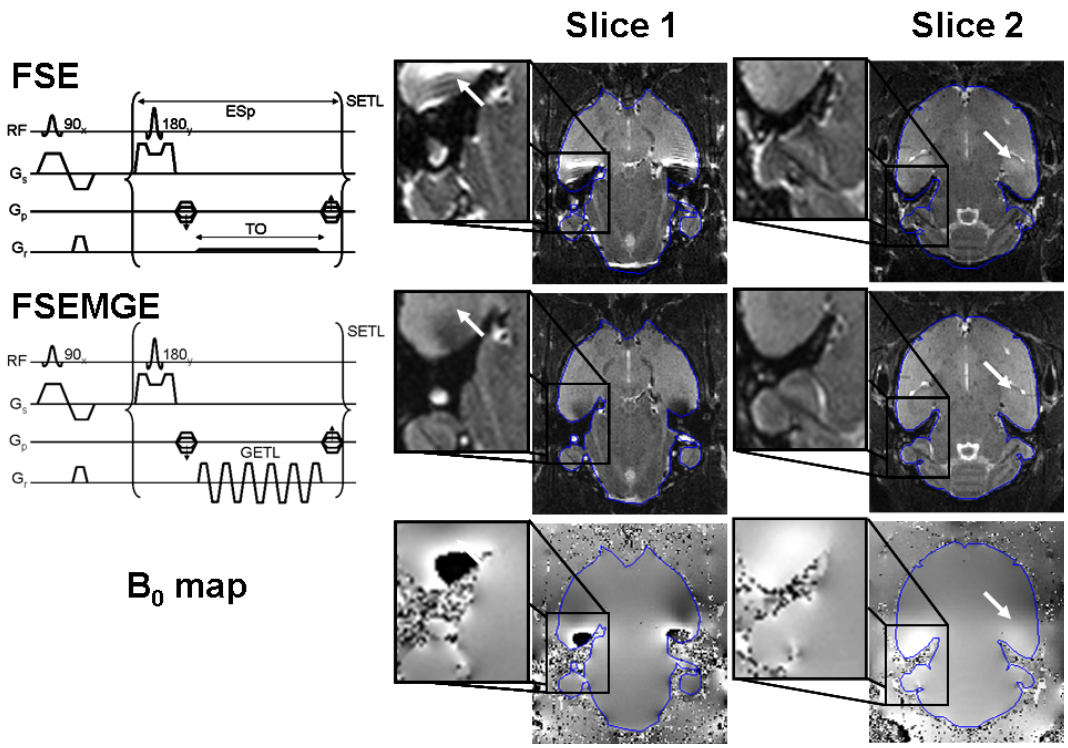

Fig. 1: Typical results for 2 slices for the FSE (top row) and FSEMGE (middle row) sequences. The FSEMGE acquires multiple gradient echoes with an increased bandwidth but the same TO providing the same SNR and T2 contrast, an additional B0 map (bottom row) and a suppression of distortion artifacts.

DICUSSION AND CONCLUSION

We have shown that image distortions can be greatly reduced in a FSE sequence by using a gradient echo train with a larger bandwidth instead of the single readout with the same scan efficiency. Image quality was enhanced with a bandwidth 11 times greater reducing artifacts by the same amount in region with rapidly varying frequencies. This framework is particularly adapted for high field imaging considering SAR limitation and increased susceptibility effects. Additively, the technique simultaneously performs a fast frequency mapping. The use of the FFT along the time direction is a simple way to estimate the main frequency component for each pixel. More sophisticated reconstruction algorithms could allow the extraction of information such as spectral width and T2. The principle can be generalized to gradient echo sequences for which an echo train should provide similar artifact reduction compared to a single echo.

REFERENCES 1. Ultra high field magnetic resonance imaging, PM Robitaille, L Berliner, Springer **2.** MR artifacts: a review, Bellon et al., Am. J. Roentgenol 147:1271.