Single-shot isotropic diffusion weighting with eddy current compensation

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Introduction: In clinical settings, it is often desirable to acquire diffusion weighted images where the diffusion contrast is isotropic[1]. One method is to repetitively acquire an image, with each acquisition having one of three orthogonal diffusion directions and multiply the images together. Another method is to design the *k*-space trajectory of the diffusion weighting such that it efficiently produces isotropic weighting in a single image acquisition[2]. The latter method has also been extended to incorporate single-refocused spin echo imaging[3]. We present a method here to incorporate isotropic diffusion weighting into a twice-refocused spin-echo (TRSE) preparation. The gradient design is optimized to compensate for eddy current effects of a given time constant and to minimize the TE.

Methods: To determine the timing and scaling on the diffusion lobes, we started with the solution given in [4] as a starting point for the G_x axis. For the G_y axis we desire the weighting to have *k*-space trajectory that is even and orthogonal to the *k*-space trajectory of the G_x axis. We iteratively scaled the G_x middle lobes until these criteria were satisfied. The G_z axis was determined through convex optimization. We created a relaxed problem to

$$\underset{g}{\text{maximize}}\ \tilde{b} = \gamma^2 \int_0^{TE} \left[\int_0^t g_1(t')dt' \right] dt$$

This was subject to the scanner hardware limitations (max gradient amplitudes of 40 mT/m and 100 T/m/s). The k_z trajectory was also constrained to be an odd waveform, thereby keeping G_z orthogonal to G_x and G_y. This optimization was done using the CVX platform[5]. The gradients were scaled such that each of the *b*-values were equal. Imaging was done by using an EPI readout. Simulations of the eddy currents follow what was done in [4] with eddy currents being modeled as single exponentials with a time constant of 100ms. Scans were performed on a GE Signa 1.5T scanner with an 8CH High Resolution head coil on a healthy volunteer. The image was 128x128 with FOV = 23mm. Slice thickness was 5mm. TE was sequence dependent and is listed in Figure 3. TR was 3s. Acquisition acceleration was used through ASSET reconstruction with R = 2.

Results: Simulations of the eddy current response are shown in Fig. 2a for the single spin-echo preparation scheme presented in [3] and in Fig. 2b for our TRSE isotropic weighting scheme. In every axis, there is superior eddy current suppression. Fig. 3 shows the norm of the eddy current simulation values computed for a range of eddy current constants immediately after the gradients are turned off for both the diffusion weighting scheme in [3] and the proposed method. We notice here that for every time constant there is a superior response with the proposed method. Figure 4 shows *in vivo* images of various acquisition schemes. Figure 4.d shows the SS-TRSE isotropic weighting image to have the lowest SNR, which is expected since it is acquired in one third of the time of the traditional acquisition. The SS-TRSE is also noisier than the image using the preparation from [3] (Fig. 4.c) because of longer TE (62ms compared to 99.4ms). Inspection shows better contrast uniformity, image sharpness and fewer geometric distortions, which is attributed to better eddy current suppression.

Discussion: We have implemented a new isotropic diffusion weighting scheme that also suppresses eddy current artifacts. This technique is an alternative to current strategies as it can acquire isotropic diffusion weighted images in one third of the time. It also serves as an improvement over previously established methods [2,3] in its ability to capture better edge sharpness and minimize geometric distortions.

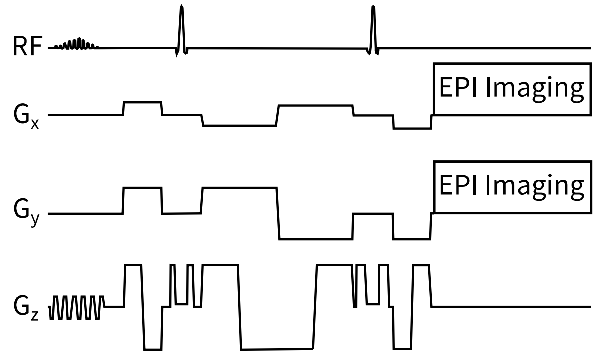

Figure 1: SS-TRSE isotropic diffusion sequence

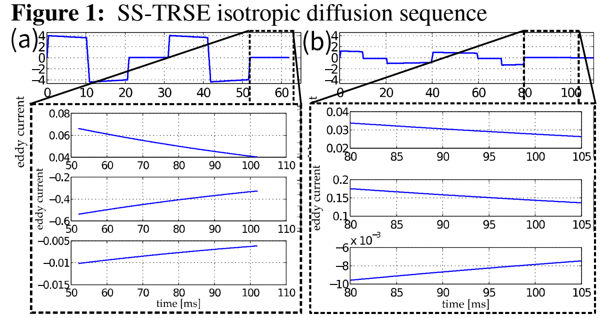

Figure 2: Eddy current fall-off simulations for (a) single-refocused isotropic and (b) twice-refocused isotropic preparations

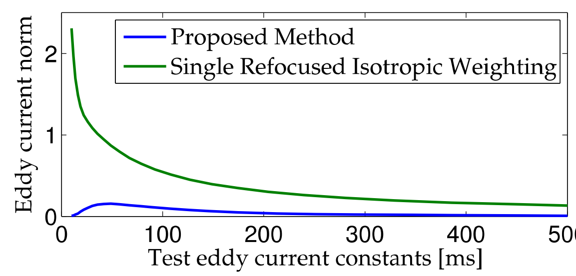

Figure 3: Norm of the simulated eddy current response immediately after the gradients are turned off for various eddy current time constants. Responses from both isotropic single-shot weighing schemes are shown.

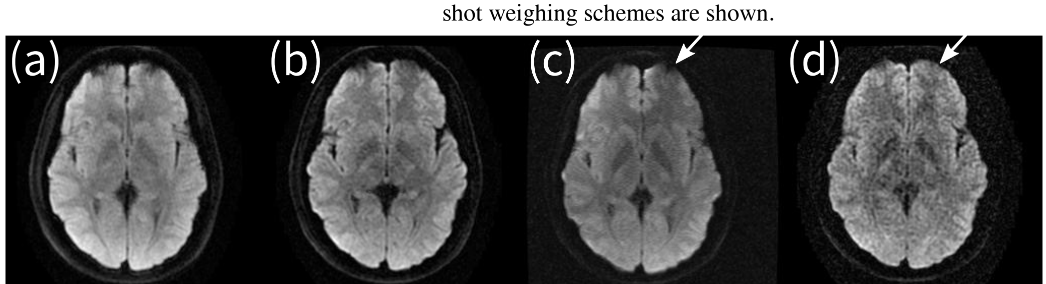

Figure 3: Axial slices with isotropic diffusion weighting with b = 500 s/mm^2 (a) Stejskal-Tanner (TE = 53.5ms), (b) standard twice-refocused (TE = 71.3ms), (c) single-shot single-refocused (TE = 62ms) , and (d) single-shot twice-refocused (TE = 99.4ms)

References: [1] Van Gelderen, MRM, 1994. [2] Wong, MRM, 1995. [3] Butts, MRM, 1997. [4] Reese, MRM, 2003. [5] Grant, Online, 2013.

[This work partly supported by NIH P41 RR09784, NSF GRFP, and GE Healthcare]