Isotropic Steady State Diffusion Weighted Imaging

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Introduction Steady-state diffusion-weighted imaging enables high-SNR, high-resolution diffusion images of brain and is potentially effective in the diagnosis of stroke location [1]. However, white matter anisotropic tissue contrast can mask out a real stroke location. In order to get rid of the anisotropic effect of diffusion, the whole diffusion tensor is acquired and its trace is derived. Alternately, in standard diffusion sequences such as diffusion weighted single shot EPI or diffusion weighted IEPI, isotropic diffusion weighting can be applied to acquire isotropic diffusion weighted images [2, 3]. Unlike the standard diffusion sequences, which use a bipolar gradient per TR, SS-DWI uses a single unbalanced diffusion gradient. Therefore, isotropic diffusion weighting cannot be created in a conventional way. In this work, we introduce a new method for creating isotropic diffusion weighting in steady-state free precession imaging.

Methods Steady-state DWI signal is a weighted summation of many diffusion-weighted echoes. Therefore, by repeatedly varying diffusion gradient, the signal will reach a steady state with a new diffusion weighting. In this work, the diffusion gradient direction alternates between A/P and L/R direction and each echo will have diffusion weighting both in A/P and L/R, which results in a quasi-isotropic diffusion weighting. As in steady-state DWI [4], the signal expression depends on T_1, T_2, D and flip angle (α), which is fairly complicated even after approximation. However, using the fact that most of the signal comes from recently excited echoes and their refocusing time in this method will be twice as long as that in steady-state DWI, we can use the eq.1 in [4] by substitute T_R by $2T_R$ and find the effective b-value.

A steady-state DWI sequence with alternating diffusion gradients was used to image the human brain on a 1.5T Signa EX scanner (GE Healthcare, Milwaukee, WI) using standard head coil. Figure 1 shows 4 T_Rs of the pulse sequence. The readout was 3DFT covering 20×20×8 cm^3 FOV in a 256×128×16 matrix for 0.78×1.56×5 mm^3 voxel resolution. The diffusion gradient of strength 21.5 mT/m was applied for 7.0ms alternating between Gx and Gy every other T_R. This causes signal attenuation equivalent to b = 540 s/mm^2. Flip angle was 25°, TE/TR was 17/34 and bandwidth was 31 kHz. In order to correct Nyquist ghosting, each phase encoding was acquired twice in two consecutive T_Rs and the data from odd T_Rs and those from even T_Rs were collected and reconstructed separately and then summed. Small spiral navigator was used to correct translational rigid body motion artifacts. Two averages were acquired for a total scan time of 4:45.

Results Figure 2 compares the conventional trace-weighted image acquired from steady-state DWI and the isotropic steady-state DWI. The first two images are diffusion weighted along the A/P and L/R directions and shows anisotropic effects in white matter. The third image from the left shows the trace-weighted image that combined the first two images and much of the anisotropy has been removed, although anisotropy in S/I still remained. The last image is acquired from isotropic steady-state DWI and it shows similar contrast to the trace-weighted image. Figure 3 shows two images from this method but with a different diffusion weighting direction. The second is diffusion weighted in the 45° rotated direction of the first. It has almost the same contrast as the first and verifies isotropic steady-state DWI sequence creates isotropic diffusion weighting.

Discussion As in steady-state DWI, isotropic steady-state DWI is fairly sensitive to motion. Translational rigid body motion was corrected with phase compensation using a spiral navigator but other motions such as rotation or higher-order non-rigid motions related to cardiac cycle degrade images. More sophisticated motion correction method such as least-square reconstruction and refocusing reconstruction [5] may be able to be applied. Directional diffusion sensitivity in even T_Rs and in odd T_Rs will be different because their diffusion gradients are different. Repeating the phase encoding was to remove Nyquist ghosting but will reduce directional diffusion sensitivity by averaging the sensitivities.

Conclusion We have presented a method for creating isotropic diffusion weighting in steady-state free precession imaging and calculated its effective b-value. 3D in vivo isotropic steady-state DWI of brain was performed and Nyquist ghosting was effectively removed.

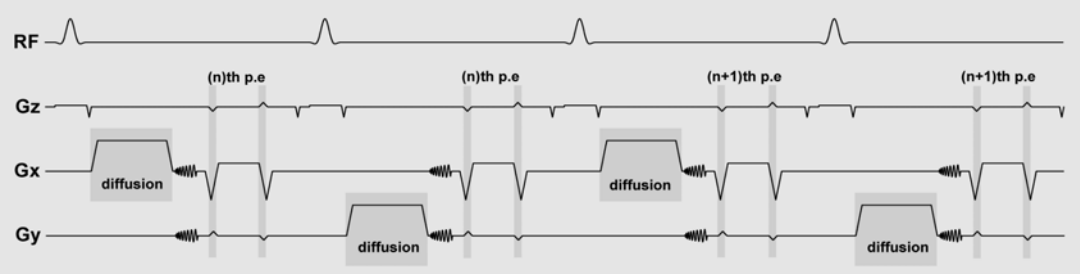

FIG. 1. Four T_Rs of the isotropic steady-state DWI pulse sequence with a 3DFT acquisition and a 2D spiral navigator. The diffusion gradient alternates between Gx and Gy. The phase encoding changes every other TR.

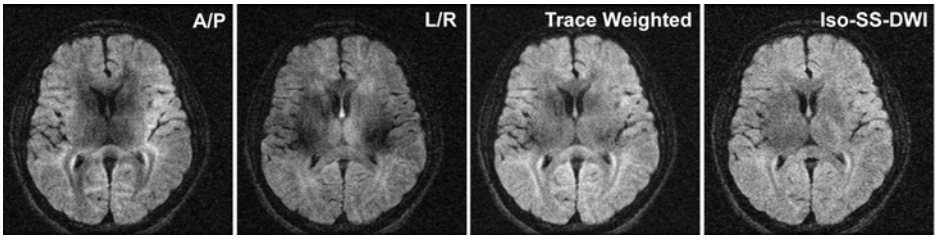

FIG. 2. Conventional steady-state DWI and isotropic steady-state DWI with the same effective b value (540 s/mm^2). The first two images were acquired from the conventional steady-state DWI with diffusion weighting in A/P and L/R and were combined to produce the trace-weighted image. Isotropic steady-state DWI shows similar contrast to the trace-weighted Image.

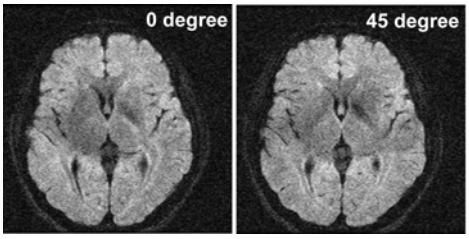

FIG. 3. Isotropic SS-DWI with diffusion gradients along A/P and L/R direction and diffusion gradients along the LA/RP and LP/RA (45° rotated)

References

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