Investigation of the Golden-Angle Radial DESS Sequence for Diffusion-Weighted MRI

Xia Zhao[1], Michael Langham[1], Cheng Li[1], and Hee Kwon Song[1]

[1] *Laboratory for Structural NMR Imaging, University of Pennsylvania, Philadelphia, PA, United States*

Introduction: The diffusion-weighted DESS (Dual-Echo Steady-State) sequence has gained attention as a possible alternative to the conventional DW-EPI, permitting relatively high spatial resolution without susceptibility-related or N/2 ghosting artifacts [1, 2]. In the presence of undesired motion, however, phase inconsistencies caused by the motion may degrade DESS image quality. With radial imaging, self-gating strategies could be employed to utilize only those views which are least affected by motion and to compensate for phase inconsistencies between k-space lines. In this work, we investigate and compare the performance of diffusion-weighted DESS sequence with radial acquisition with the standard DW-EPI sequence for imaging the brain.

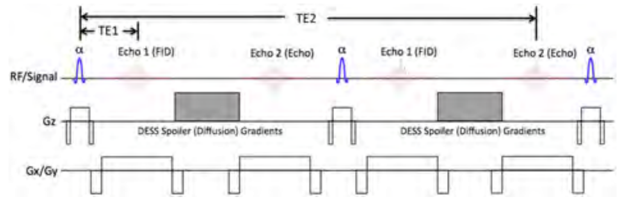

Figure 1 Diagram of a 2D radial DW-DESS sequence.

Methods: A 2D diffusion-weighted DESS sequence with radial readouts is shown in **Figure 1**. DW-DESS consists of two readouts separated by a diffusion encoding gradient. The FID (TE1) is T_1-weighted, while the Echo (TE2 = 2*TR-TE1) is more heavily T_2 and diffusion weighted.

Both phantom and in-vivo experiments were carried out. The phantom, consisting of 3 containers (pure and doped water, oil), were scanned with DW-DESS and DW-EPI with the following parameters: DW-DESS: TR/TE1/TE2=13.8/2.39/25.21ms, FOV=$(256mm)^2$, slice thickness=6mm, flip angle=10°, 128 readouts, golden angle view increment of 111.25°; DW-EPI: TR/TE=3000/133ms, slice thickness=5mm, 128 readouts, 128 PE steps, fat saturation. Two DW were applied: b-value=0 and $600s/mm^2$ for EPI; for radial DESS, a minimum DW gradient was needed to avoid banding artifacts, therefore, a DW equivalent to b-values of 35 and $\sim700s/mm^2$ were used. In-vivo scans of the brain were carried out using the same parameters as above for DW-DESS but with GRAPPA (accel. factor=2) for DW-EPI to shorten the TE (97ms).

Figure 2 Phantom images of radial DW-DESS and DW-EPI. Diffusion encoding was applied along the x-axis in these images, but due to isotropic diffusion in these phantoms, diffusion encoding along all 3 axes yield nearly identical results. Effective b-values are shown above each image.

Results and Discussion: Results from phantom scans are shown in **Figure 2**. This figure demonstrates the presence of susceptibility artifacts (red arrow) and N/2 ghosts (green arrow) in DW-EPI, which are absent in the DW-DESS acquisition. While the fat signal has been removed by saturation in EPI, the DESS acquisition is relatively insensitive to chemical shift effects and saturation is not required (blue arrow).

Figure 3 compares DESS with and without radial self-gating for cardiac pulsations with DW-EPI in the brain. Signal loss due to the pulsations [3] can be recovered by retrospective self-gating and phase correction which ensures that the center k-space points are consistent among all the views (yellow arrow). Similar diffusion contrasts due to fiber orientations can be observed between DESS and EPI data (blue arrows). Distortion near the frontal sinus is clearly seen in the EPI images (red arrow).

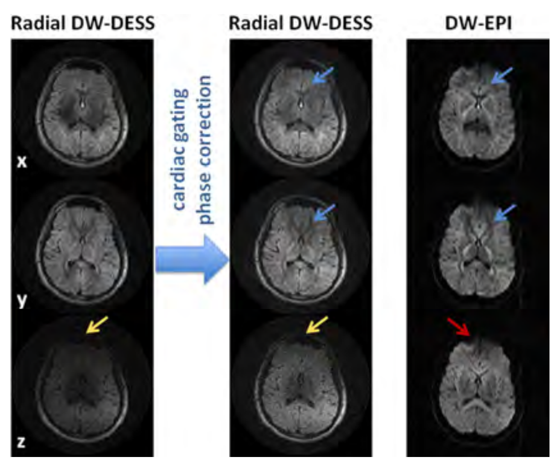

Figure 3 Effect of retrospective cardiac self-gating and phase correction on in-vivo scan using radial diffusion DESS and comparison with diffusion EPI.

Figure 4 displays a slice closer to the sinus demonstrating the severe susceptibility-related distortion in the EPI image (red arrow), which is absent in DESS. Not all motion is completely removed, however, and some signal loss does remain in the DESS images, including those due to motion of the eyes during the scan.

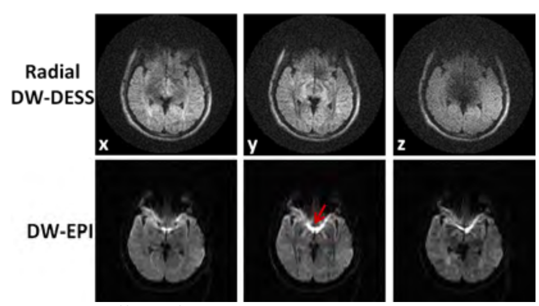

Figure 4 Effect of cardiac gating and phase correction on in-vivo scan using radial diffusion DESS and comparison with diffusion EPI.

Conclusion: The DESS sequence can potentially provide high resolution diffusion images without the problem of susceptibility-related artifacts and N/2 ghosting. With golden angle radial acquisition, self-gating techniques can be utilized to reject/accept certain views for reconstruction and to compensate for phase inconsistencies among views. Further study will be needed to more fully determine the advantages the DESS sequence may offer and the accuracy it is able to achieve.

References: [1] K.L.Granlund et al. MRI (2014) 32:330-341. [2] O.Bieri et al. MRM (2012) 68:720-729. [3] J. A. McNab et al. NMR in Biomedicine (2010) 23:781-793.

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