

Time-efficient Diffusion-weighted Black Blood Imaging Based on iMSDE

Haining Liu¹, Zechen Zhou², Jinnan Wang³, Shuo Chen², Balu Niranjan⁴, and Chun Yuan^{2,4}

¹Bioengineering Department, University of Washington, Seattle, WA, United States, ²Bioengineering Department, Tsinghua University, Beijing, China, ³Philips Research North America, NY, United States, ⁴Radiology Department, University of Washington, WA, United States

Purpose

In addition to luminal stenosis, components like lipid core, intraplaque hemorrhage and calcifications are important indicators of high-risk atherosclerotic plaque. Multi-contrast vessel wall MRI techniques allow comprehensive analysis of atherosclerotic plaque. Detection of lipid core with high specificity requires Gadolinium contrast since the lipid core may present heterogeneous appearance in non-contrast MRI. However gadolinium administration is limited in patients with kidney disease due to risk of nephrogenic systemic sclerosis. Diffusion weighted imaging has great potential for *in vivo* lipid core imaging without gadolinium injection. DWI combined with DIR preparation was recently proposed^[2,3]. This method requires long preparation time (over 700ms) to generate sufficient b-value and blood suppression. Improved Motion-Sensitized Driven-Equilibrium (iMSDE) is a black blood (BB) sequence which has advantages in regions with complex and slow flow without long presaturation time by using the first-order moment (m_1) of the flow-sensitizing gradient pair as well as the intravoxel spin velocity distribution to suppress blood^[1]. In this study, we propose the diffusion-weighted iMSDE (DiMSDE) that can generate strong diffusion weighting on black blood images without compromising blood suppression efficiency while maintaining a short preparation duration.

Methods

DiMSDE Sequence: In the preparative pulse, the four radiofrequency (RF) pulses of iMSDE^[1] are preserved and TE_{prep} is defined as the duration between the two 90° RF pulses. Turbo Spin Echo (TSE) is used for image acquisition. To generate strong diffusion weighting and preserve blood suppression efficiency, the gradients were designed with the following rules: 1) the m_0 of gradients along all three directions should be zero. 2) the selection of m_1 value should balance the needs between flow suppression and less motion sensitivity. m_1 generated from diffusion gradients should be largely compensated to avoid sensitivity to motion artifacts. At the same time, the gradient duration within each bipolar gradient pair (d_1 and d_2 in FIG. 1) should be slightly different so as to introduce moderate m_1 effect for flow suppression. 3) To reduce the T_2 effects on the signal strength and contrast of components, the amplitude of diffusion-weighted gradients should be the maximum value allowed by the scanner and its shape should be optimized so that for a given TE_{prep} and m_1 value the biggest b value can be achieved. 4) To avoid the severe motion artifacts caused by high b value,

motion sensitizing gradients with moderate m_1 and small gradient amplitude were applied in the slice selection direction.

MRI Scan: Scans were all conducted on healthy volunteers with a 3T whole body scanner (Philips Achieva, R3.21, the Netherlands). The benefit of generating a moderate m_1 for flow suppression was first evaluated at b value of 300. Based on our previous experience in black blood iMSDE imaging, in

this study, the m_1 in each direction is about $800mTms^2/m$. The coil used in this study was a 36-channel neurovascular coil. The scan parameters for DiMSDE were: TR/TE: 2000/8.1ms, FOV: $160 \times 160 \times 3mm^3$, acquired voxel size: $0.6 \times 0.6 \times 3mm^3$, interpolated to $0.3 \times 0.3 \times 3mm^3$, TSE factor: 13. Scan time: 42s. A fully compensated m_1 design has $d_1=d_2$ and $m_1=0$, while our design has $d_1 \neq d_2$ and $m_1=-800$ along three directions. We then compared DiMSDE with DWI/EPI sequence on the brain to evaluate the diffusion weighting using a 8-channel head coil. The FOV is $198 \times 198 \times 4mm^3$. For DiMSDE, TR/TE: 2000/6.4ms, reconstructed matrix size: 640×640 , acquisition time: 40s. For DWI/EPI: reconstructed matrix size: 256×256 , acquisition time: 13s.

Results and Discussion

DiMSDE was found to provide improved blood suppression compared to fully compensated m_1 design. In FIG. 2a, although m_2 and higher moments can also suppress flow to some extent, there are still flow artifacts (marked by red arrow in FIG. 2a) appearing in the image acquired with compensated m_1 and these flow artifacts are suppressed in the image acquired with DiMSDE (FIG. 2b). Based on our simulation, to satisfy the third rule in the method part, shifting the center of the bipolar diffusion weighted gradients ($d_1 \neq d_2$) will generate the biggest b value when TE_{prep} and m_1 are constant. As to the DWI imaging, FIG.3 shows that when b is 300, DiMSDE and DWI/EPI exhibit comparable diffusion contrasts in the brain and the difference is due to the different acquisition methods. Since DiMSDE is TSE based, it can achieve higher resolution with better image quality compared with DWI/EPI scheme as can be seen in FIG. 3.

Conclusion

In this study, the DiMSDE technique was proposed to generate strong DWI contrasts for black blood lipid core detection. DiMSDE has great potential to become the first-line imaging method that assist physicians to treat the atherosclerosis patients.

References

[1] Wang, Jinnan, et al. JMRI. 31.5 (2010): 1256-1263. [2] Yibin Xie, et al. MRA Club meeting (2013). [3] Kim S, et al. JMRI 34.5 (2011): 1167-1175.

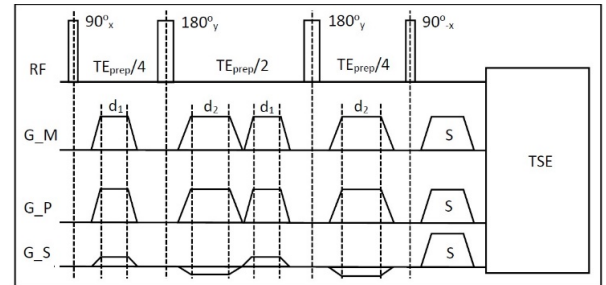


FIG.1. Diagram of DiMSDE preparative pulse sequence. The spoiling gradients are marked by 'S'. This preparative pulse is executed before a standard TSE acquisition sequence.

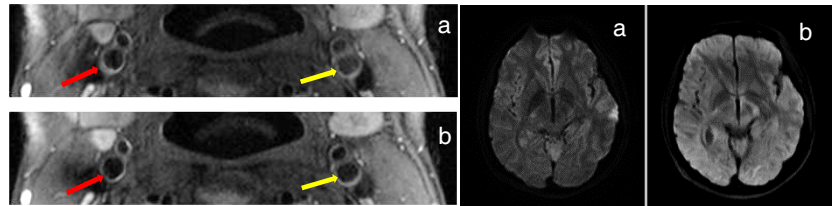


FIG.2 Comparison of flow suppression effects between a) DiMSDE with $m_1=0$ and b) $m_1>0$ in three directions when $b=300$. The arrows shows that the flow artifacts in a) have been suppressed in b).

FIG.3. The DWI brain imaging comparison between a) DWI-EPI and b) DiMSDE when $b=300$. DiMSDE shows similar DWI prosperities with better SNR.