Rapid 3D Vessel Wall Imaging at 3T: Optimization of Diffusion Preparation and Comparison to other Protocols

M. K. Makhijani[1], G. S. Pohost[2], and K. S. Nayak[1]

[1]Electrical Engineering, University of Southern California, Los Angeles, CA, United States, [2]University of Southern California, United States

Introduction: Multi-contrast MRI is widely used to image the vessel wall and characterize the composition of atherosclerotic plaques. Standard protocols use 2D multi-slice fast spin echo (FSE) with double inversion recovery (DIR) [1]. 2D methods lack contiguous coverage and suffer from partial voluming affecting plaque quantitation. 3D methods cannot be robustly combined with DIR preparation due to lingering signal from stagnant flow. An alternative preparation dubbed "diffusion sensitizing gradients" (DSG, also known as DPDE, DW-prep, and MSDE) causes significant dephasing of flowing spins [2], and has also been applied in the carotids with 3D SSFP imaging [3] (which has a restricted set of contrast variations) and 2D-FSE imaging [4]. In this work, we optimize and evaluate the performance of DSG+DIR prep in conjunction with 3D inner volume imaging (IVI) FSE [5-7] and compare it to standard protocols and 3D SSFP imaging approach at 3T. The rationale for applying DSG and DIR prep simultaneously is to minimize the vessel wall signal loss during long DSG prep times due to diffusion effect, T_2 contamination, and eddy currents.

Methods: Experiments were performed on a Signa Excite 3T scanner (GE Healthcare) using a 4-channel carotid array coil. The imaging sequence consisted of 3 modules: DSG and DIR preparation, fat saturation and 3D-IVI FSE imaging. Relevant scan parameters are summarized as [FOV-Matrix-Resolution-TE(/eff)-ESP-TR-ETL-Acq-time]: 3D IVI FSE [16x3.2cm^2-320x64x20-0.5x0.5x2.5mm^3-11ms-11ms-1RR-12-100s], 2D Multislice [16x12.8cm^2-320x256-0.5x0.5x2.5mm^3-6.2ms-6.2ms-1RR-8-30s], and 3D SSFP [16x12.8cm^2-320x256x20-0.5x0.5x2.5mm^3-6.8-3.4ms-1RR-60-80s]. DSG preparation consists of 3 hard pulses 90_x-180_y-90_{-x} with gradients before and after the 180º pulse applied on all three axes, and spoiler gradients. The 3D IVI FSE imaging module is a variant of typical FSE imaging with excitation and refocusing pulses applied along orthogonal axes.

Optimization of DSG: Increasing the DSG gradient area (and hence the b-value) increases the dephasing of flowing spins, but also increases the T2 weighting (reducing vessel wall signal). There is a known tradeoff between maximizing vessel wall signal and minimizing the luminal blood signal. In this study we optimized the contrast between the vessel wall and luminal blood as function of the b-value based on in-vivo measurements in 2 healthy volunteers.

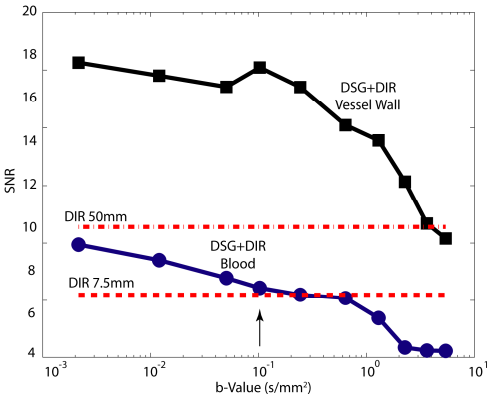

Figure 1: The effect of DSG+DIR prep on blood and vessel wall signal. The 2 red lines indicate the DIR blood signal with inversion slab thicknesses of 50 mm (used in 3D mode) and 7.5 mm (used in 2D mode). Blood signal (blue) decreases with higher b-value and is comparable to DIR blood signal (red) at 7.5 mm inversion slab thickness when b > 0.1 s/mm2. Vessel wall signal (black) experiences the expected attenuation due to T_2 decay at low b-values, and greater attenuation when b > 1 s/mm^2. Arrow on the b-value axis indicates the optimal sensitization. A similar approach was utilized for optimizing DSG prep for SSFP imaging, with an optimal b-value of 2.26 s/mm^2

Results and Discussion: The plot containing wall-lumen contrast as a function of the b-value is shown in Figure 1. The optimal DSG prep time when used with DIR prep was under 8ms and T_2 contamination was restricted to 4ms. Figure 2 contains a single T1-weighted slice of the carotid arteries just above the bifurcation from a healthy volunteer. Table 1 contains measurements of the luminal and vessel wall SNR along with wall-lumen CNR. Luminal suppression and CNR was better using the proposed DSG+DIR approach as compared to the DIR only methods. The SSFP-DSG approach demonstrated better vessel wall SNR but blood suppression at the bifurcation was visibly poor (see slice # 10 and 11). Further increase in the b-value (>10 s/mm^2) associated with SSFP-DSG method for better suppression resulted in significant vessel wall signal loss. We speculate this is more due to eddy currents rather than T_2 contamination or diffusion effect.

Conclusion: We demonstrate bilateral 3D FSE carotid-wall imaging with a 5cm FOV in the S/I direction within 100-seconds, with 0.5x0.5x2.5 mm^3 resolution, and with vessel wall-lumen CNR > 18. DSG and DIR preps are combined for robust blood suppression during 3D acquisitions. The CNR of proposed approach was better than DIR only methods and comparable to SSFP-DSG approach while FSE offers a more flexible range of contrast variations.

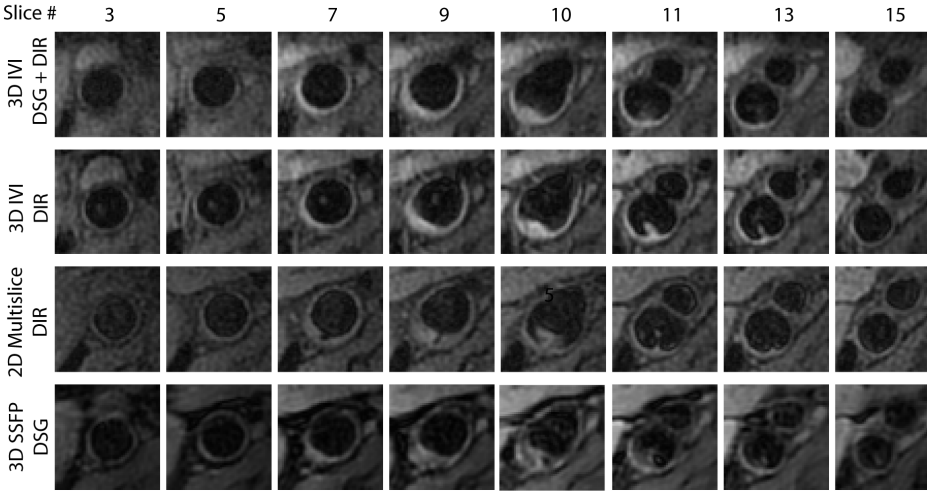

Figure 3: T1 weighted images from a healthy volunteer at the bifurcation of the left carotid artery using the proposed 3D IVI FSE-DSG+DIR, 3D IVI FSE-DIR, 2D Multislice, and 3D SSFP-DSG. The DIR only preps and SSFP-DSG method suffers from artifacts due to incomplete blood suppression at the bifurcation (see slice # 10 and 11).

Table 1	**3D IVI-FSE DSG+DIR**	**3D IVI-FSE DIR**	**2D Multislice DIR**	**3D SSFP DSG**
Wall SNR	23.32	24.32	14.96	31.05
Lumen SNR	4.93	7.58	5.5	11.8
CNR	18.38	16.75	9.45	19.2

References:

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