Target audience: Radiologists and MR physicists who are interested in black blood carotid vessel wall imaging optimization.

Purpose: Blood suppression is essential for black blood vessel wall imaging, and unsuppressed intra-luminal blood leads to plaque mimicking artefacts. Double inversion-recovery (DIR) methods have become the de facto standard for blood suppressed vessel wall imaging. However, this method is sensitive to the rate of flow replenishment which leads to plaque-mimicking artefacts in the presence of slow or complex flow that often occur around the carotid bifurcation. Improved motion-sensitized driven-equilibrium (iMSDE) provides better blood suppression than DIR methods. However, it induces signal loss and inherent T1 decay which may not be suitable for T1 imaging. 3D variable flip angle FSE has inherent blood suppression but can still demonstrate residual blood flow artefacts in some situations. Delay Alternating with Nutation for Tailored Excitation (DANTE) shows strong blood suppression ability and only induces small T1/T2 weighting. However, DANTE has rarely been studied in multi-contrast 2D/3D carotid vessel wall imaging. This study aims to evaluate the efficiency of DANTE blood suppression and SNR performance in 2D T2 and T2 weighted FSE sequences and 3D variable flip angle FSE (CUBE, GE Healthcare) sequence in comparison with DIR and iMSDE preparation.

Methods: (a) Study population: Six healthy volunteers underwent black-blood 2D T1w and T2w FSE with DIR, iMSDE and DANTE preparation of the carotids in a 1.5T MRI system (MR450, GE Healthcare, Waukesha, WI) using a 4 channel phased-array neck coil. Another six volunteers underwent 3D isotropic resolution T1w CUBE with iMSDE/DANTE preparation. (b) Scan protocol: 2D scan parameters were: TR/TE (T1w): 800ms/10ms; TR/TE (T2w): 2500ms/52ms; 14cm*14cm FOV, 256*192 matrix, 3mm slice thickness, 4 slices to cover the bifurcation; NEX = 2; ETL (T1): 10; ETL (T2): 12. A single and multi-slice DIR sequence was prescribed as defined previously [2]. One slice was acquired per TR in the T1w protocol and four slices were acquired per TR in the T2w protocol. Optimised first order moments (m1) 487 mTm2/m for T1w and 1518 mTm2/m for T2w were used for the iMSDE preparation as defined previously [6]. 3D CUBE parameters were: TR/TE: 440ms/10ms; 14cm*14cm FOV; 224*224 matrix; 40 coronal slices; 1.2mm slice thickness (interpolated to 0.6mm); ETL 24. A 487 mTm2/m was used for T1w iMSDE CUBE. DANTE parameters used for both 2D and 3D imaging were adopted from previous publications [7; 8]: DANTE train length: 150; gap between each RF pulse: 1ms; preparation time: 150ms; flip angle of RF pulse: 11°; gradient amplitude: 20 mT/m. (c) Image and data analysis: Lumen and adjacent muscle SNR was measured in order to quantify the blood suppression and SNR performance of the different methods. In total, 48 locations are analyzed in both 2D and 3D images. Non-parametric Wilcoxon paired tests were performed to test within group differences in SNR using the different sequences.

Result: In 2D T1w and T2w imaging, both iMSDE and DANTE provided better blood suppression compared to the DIR method (p<0.001) (Figure 1 and Table 1). In 2D T1w imaging, the use of iMSDE/DANTE preparation caused significant muscle SNR loss (p<0.001). DANTE yielded better blood suppression and muscle SNR than iMSDE (p<0.001). In 2D T2w imaging, DANTE preparation reduced the muscle SNR (p<0.001) whilst iMSDE increased the muscle SNR (p<0.001). DANTE provided comparable blood suppression performance to iMSDE method (p=0.14). In 3D T2w CUBE imaging, both iMSDE and DANTE removed the flow artefacts in black blood CUBE images with a lower lumen SNR (p<0.001) (Figure 2 and Table 1). DANTE and iMSDE reduced the muscle SNR (p<0.001) but DANTE yielded a much higher SNR than iMSDE.

Discussion: In this study we have shown both iMSDE and DANTE can improve blood suppression performance than traditional DIR methods in both 2D and 3D multi-contrast imaging of carotid artery wall, albeit at the cost of a reduction in SNR. In T1w imaging, DANTE provided a higher SNR. In T2w imaging, iMSDE provided the highest SNR. This is due to that the inherent T1 decay during iMSDE preparation being included in the effective TE. The effective TE were not exactly matched and iMSDE T2w had a slightly shorter TE (47.2ms) than DIR T2w sequence (52.3ms), resulting a higher muscle SNR. In this study we found the DANTE preparation used in CUBE can removed all the flow artefacts. Due to the inherent black blood effect of CUBE, it is possible that a weaker DANTE module may also be sufficient. Therefore, DANTE CUBE can be further optimized (i.e., reduce flip angle and train length) to achieve better SNR performance.

Conclusion: Both DANTE and iMSDE preparation can improve the blood suppression performance in both 2D DIR prepared FSE sequences and 3D black blood CUBE sequences. DANTE is optimal for T2w 2D and 3D imaging for improved SNR. iMSDE is optimal for T1w imaging.