

# Interpretation of tissue contrast in a rapid black-blood gradient echo sequence with motion-sensitized driven equilibrium (MSDE) preparation (3D MERGE) for 3D isotropic high-resolution imaging of the vessel wall and its application for hemorrhage detection

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**Introduction:** High-resolution MRI of carotid atherosclerotic plaque allows identification of plaque composition associated with the risk of stroke. 3D sequences can potentially improve plaque component identification in all three dimensions compared to existing 2D sequences. A fast isotropic black-blood carotid MRI with motion-sensitized driven equilibrium (MSDE) preparation [1,2] was developed with excellent plaque component delineation in vivo [3]. However the T1, T2 contrast properties of the MSDE prepared TFE sequence (3D MSDE prepared Rapid Gradient Echo or 3D-MERGE) has not yet been elucidated. With this sequence design, proton density weighting due to low-angle FLASH-like readout in the non-steady-state regime, a variable degree of T1 weighting based on the TFE shot duration and phase encoding order and T2 effects of the MSDE preparation can simultaneously affect the behavior of magnetization. While the contrast properties of major plaque components have been established for standard turbo spin echo based T1 and T2 weighted images, these established contrast properties cannot be directly extrapolated to the new sequence. Therefore future applications of 3D-MERGE for identification of plaque components require characterization of its signal and contrast properties and effects of sequence parameters on tissue contrast.

**Aims:** The goals of this study were: 1) to develop a simulation model based on Bloch equations to describe contrast behavior of 3D-MERGE; 2) to validate the contrast properties of 3D-MERGE using phantoms with a variety of relaxation properties; and 3) to demonstrate the usefulness of 3D-MERGE for imaging of certain clinically important plaque components.

**Materials and Methods: Phantom experiments:** Reference T1 and T2 values of 11 vials with Gadolinium-doped solutions were determined on a Philips Achieva 3T scanner using a Look-Locker T1-mapping and multiple spin-echo T2-mapping methods, respectively. The vials also were scanned using 3D MERGE with MSDE preparation [2] and spoiled segmented FLASH (or turbo field echo, T1-TFE) readout with centric phase encoding (TR: 7.2ms, TE: 3.5 ms, Flip angle: 6°, TFE factor: 90). A sufficiently large spoiler gradient was added at the end of each 3D-MERGE MSDE shot to ensure complete spoiling of transverse magnetization [4]. **Simulations:** Bloch equation simulations of 3D-MERGE were carried out in MATLAB using experimental T1 and T2 values. Since each subsequent MSDE shot filters k-space based on T1 and T2 relaxation in 3D-MERGE, a multi-shot k-space filtration was simulated as follows. K-space of a homogenous circle with known T1 and T2 corresponding to the vial under measurement was filtered by the appropriate 3D-MERGE k-space

filter. Signal was then measured on the image produced by inverse fourier transform of filtered k-space. For describing tissue properties fibrous tissue/muscle (T1: 1000ms, T2: 40ms) was taken as reference tissue. Contrast behavior of in-vivo imaging parameters was simulated for T1 range: 100-3000 ms (T2:40ms) and T2 range: 10-300ms (T1:1000ms). **In vivo imaging:** 15 patients with carotid atherosclerosis (>16-79% stenosis by duplex ultrasound) were imaged with a standard 3T protocol (Ref) on a 3T Philips Achieva scanner with 4-array carotid surface coil. To test the capability of 3D MERGE to identify intraplaque hemorrhage based on described below contrast properties, the standard approach utilizing 3D TOF and 2D T1-weighted TSE was compared to 3D-MERGE. In both techniques, hemorrhage was interpreted as the area of hyperintense signal. **Statistical analysis:** Correlation was determined between simulated and measured signal for known T1 and T2 on the vials.

Agreement between conventional imaging protocol and 3D-MERGE for identification of intraplaque hemorrhage was assessed by Cohen's kappa.

**Results and Discussion: Contrast interpretation:** There was excellent correlation ( $R=0.98$ ,  $p<0.05$ ) between simulated and measured signal for known T1 and T2 (fig 1) reflecting the validity of the simulations. Contrast behavior simulations showed good T1 contrast and T2 contrast (fig 2) for 3D-MERGE with in vivo imaging parameters. The strong T1 contrast for  $T1<500$ ms suggests that the sequence can produce a high signal for hemorrhage. The management of T1-weighting in 3D-MERGE can primarily be accomplished by varying the shot duration, where the tradeoff between the desired T1 contrast and SNR should be maintained. At clinical scan parameters [3], the T1 contrast is the dominant mechanism for tissues with short T1. In addition to T1 contrast, 3D-MERGE also exhibits T2 contrast thus providing the opportunity to detect long T2 components such as loose extracellular matrix ( $T2\sim 50$ ms) using the same sequence. Our investigations based on Bloch simulations show that by varying the MSDE preparative sequence duration, the T2 effect may be increased especially for T2 in the range of 20-60ms which corresponds to the range of T2 in major plaque components. Changing MSDE prepulse duration has a minor effect on T1 contrast and can be adjusted independently of T1. However increasing MSDE duration reduces overall signal [3]. **In vivo hemorrhage detection:** An example of hemorrhage imaging with 3D-MERGE is shown in fig. 3. Good agreement was achieved between the reference method (3D TOF and 2D FSE) and 3D-MERGE with  $\kappa=0.73$ .

**Conclusion:** 3D-MERGE contrast is T1 weighted with a lesser degree of T2 weighting using current in vivo imaging parameters. Thus intraplaque hemorrhage can be readily visualized with 3D-MERGE. This study also suggests that the combination of contrast mechanisms inherent in 3D-MERGE makes it an ideal candidate for developing an all-in-one solution for fast black-blood carotid imaging, simultaneously providing angiographic lumen information and identification of high-risk plaque features, such as hemorrhage and rupture.

**References:** [1] Koktzoglou, Radiology 2007; 243:220-8, [2] Wang, MRM 2007; 58:973-81, [3] Balu, MRM, 2010, In Press, [4] Yarnykh, MRM, 2010, 63(6):1610-26, [5] Underhill, Radiology 2008; 248(2):550-60.

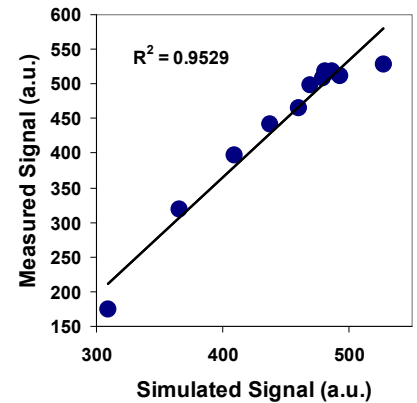


Fig 1: Comparison of bloch-equation simulated signal intensity vs measured signal intensity for known values of T1 and T2 measured on a phantom

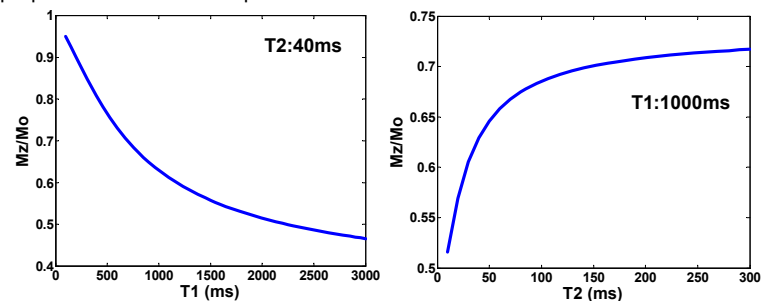


Fig 2: T1 contrast (left) and T2 contrast (right) of in vivo 3D-MERGE when TFE=90. TR/TE/flip was 10/4.8/6

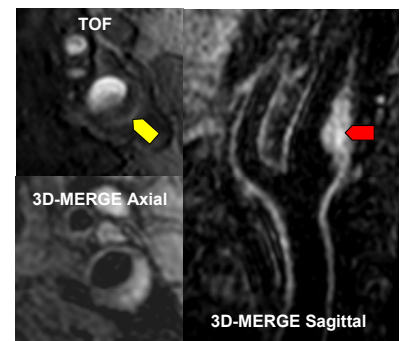


Fig 3: Intraplaque hemorrhage: Bright signal on TOF (yellow arrow) corresponds to hyperintensity on reformatted axial and sagittal 3D-MERGE images.