Fast Relaxation Time Mapping in Human Carotid Artery Wall Using Black Blood DANTE 2D Turbo Spin Echo

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Introduction: Quantitative evaluation of T_1 and T_2 is very useful in clinical detection and classification of atherosclerotic plaques in imaging of human carotid artery wall[1]. Because of the small size of arteries and the local field inhomogeneity, caused by the complex composition of plaque and susceptibility differences between blood and vessel wall, a fast and robust black blood (BB) imaging technique is required to deliver high resolution T_1 and T_2 maps on pixel-by-pixel basis. Candidates for fast T_1 and T_2 mapping are the DESPOT1 and DESPOT2 imaging techniques[2]. However, these techniques cannot be used for T_1 and T_2 mapping of human carotid arteries due to their inherent blood signal enhancement. In addition, sensitivity to field inhomogeneity and magnetization transfer effects further compromise the use of DESPOT2 in T_2 mapping. DANTE (Delays Alternating with Nutation for Tailored Excitation) pulse trains are a rapid series of low flip angle RF pulses interspersed with gradients. It has previously been demonstrated that during application of DANTE as preparation pulses for 2D turbo spin echo (TSE) imaging, the longitudinal magnetization of flowing spins is largely attenuated in contrast to static tissue, whose longitudinal magnetization is mostly preserved[3].

In this work, we first derived a highly simplified linear equation $M=M_0[1-1/2(T_1/T_2)^{1/2}]$ from the longitudinal Bloch equation at steady state case in the presence of DANTE pulses. This equation was then verified to be applicable in the case that the DANTE pulse train is interspersed with readout modules. Finally, preliminary in-vivo BB experiments for T_1 and T_2 mapping demonstrate that DANTE-TSE has the potential to be applied as a fast (3 measurements in 10 minutes with 39 slice coverage), high resolution (0.6×0.6×2mm) and robust (insensitive to susceptibility in both preparation and readout module) imaging tool for relaxation time mapping of human carotid artery walls.

Theory: First the simplest case is considered in Fig. 1a where a single infinite long DANTE pulse train with gradient G, interspersed between RF pulses, is applied. The gradient G must be larger than $2\pi/\gamma t_D\Delta r$ to avoid banding artefacts (i.e. to render them subpixel or sub-slice thickness). In the equations shown in Fig. 1a, γ is the gyromagnetic ratio, t_D is duration between DANTE pulses, α the DANTE flip angle and Δr the pixel size or the slice thickness. M_{zss} is the longitudinal signal at steady state when the number of pulses, N_p, is a large number. Under the condition $G>2\pi/\gamma t_D\Delta r$ the equation's integral yields a closed-form expression for the longitudinal steady-state magnetization, i.e. a longitudinal Bloch equation[4]. Given DANTE parameters of small α (0-15°) and t_D (typically 1-5ms, much smaller than tissue T_1 and T_2), the integration of the equation can be solved and simplified into a linear equation $M_{zss}=M_0[1-1/2(T_1/T_2)^{1/2}]$. The more practical case, where the DANTE pulse train is interspersed with readout modules, is considered in Fig. 1b. It was found that when T_D, the readout module duration (typically <100ms), is small compared with the tissue T_1, the equation derived in Fig. 1a may be still valid.

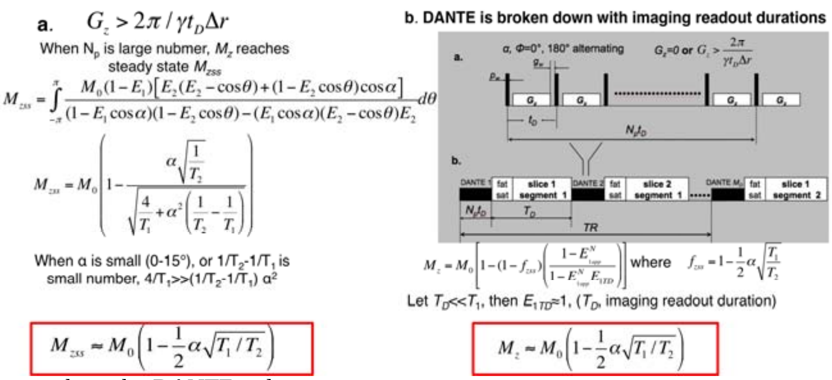

Fig 1. M_z solutions for constant and intermittent DANTE

Methods: A Siemens 3T Verio along with a 4-channel neck coil was used for experiments. A healthy volunteer (male, 24-35 years) underwent DANTE prepared TSE. Minimally, three measurements are required to yield both T_1 and T_2 maps. Measurements 1 and 2, implemented with DANTE α=4° and 8°, respectively, and a TSE echo time of 19ms. These two measurements can generate a T_1/T_2 ratio map. Measurement 3 was undertaken with TE=60ms and a DANTE α=4°. Pixel-based calculation of images from Measurements 1 and 3 yield a T_2 map. From these data a T_1 map can also be calculated. To verify the derived linear equation in-vivo, additional measurements were implemented with DANTE α=0°,2°,6° along with a readout TSE TE=19ms. For all images a matrix of 256×256×39 was used with FOV 150mm, yielding 0.6×0.6×2mm resolution. Each measurement took 3 minutes (turbo factor=7, bandwidth/Px=391Hz, T_D=70ms, DANTE N_p=32, t_D=1ms, and a gradient G_z=18mT/m, iPat=2, NEX=2).

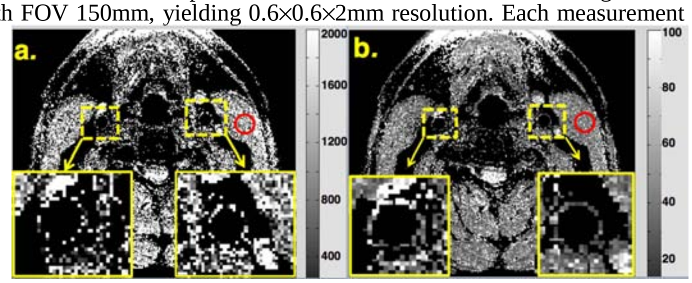

Fig 3. T_1 (a) and T_2 (b) maps extracted from three imaging measurements

Results: Bloch equation simulations according Fig. 1b, were implemented under the assumed parameters shown in Fig.2 as an initial verification of linear equation. The solid lines in Fig. 2a show the longitudinal signal of static tissue with different DANTE α. The blood signal is shown as dashed lines demonstrating that when α>4° the blood signal may be ignored. Extracted static tissue signal from these Bloch simulations is shown in Fig. 2b (blue circles). For comparison, the red crosses in Fig. 2b are calculated from the linear equation with varying α. This shows good agreement between Bloch simulation and the prediction of the simplified equation. For in-vivo assessment, T_1 and T_2 maps of the carotid artery wall are shown in Fig 3a and 3b, respectively. They are created from the three image measurements described in Methods. In order to demontrate the linear relationship of true tissue signal versus α, signal from the muscle ROIs shown in Fig. 3 (red circles) was extracted from meausements with α= 0, 2, 4, 6, 8° all with TSE TE=19ms. The fitting results in Fig. 4 show that the T_1/T_2 ratio of muscle is 31. Given that the T_2 in the ROI is determined to be 40 ms, this implies a T_1 of 1240 ms. Independent single-slice inversion recory T_1 measurements determined T_1 at the same location as 1108ms, which agrees reasonably with our fitting results. **Conclusions:** We have demonstrated the use of blood suppressed 2D DANTE-TSE for fast relaxation time mapping in human carotid artery wall.

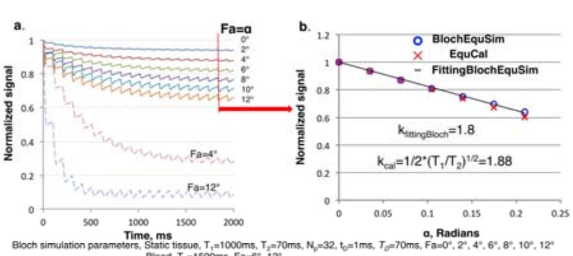

Fig 2. Bloch simulations for verification of the derived signal equations

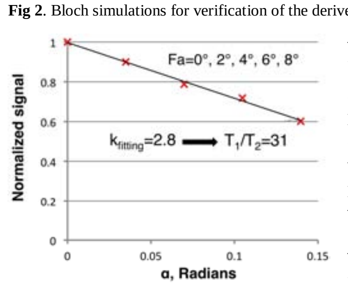

Fig 4. Muscle signal linearly vs DANTE α.

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References: 1. Yuan C. et al. Radiol. 2001; 2. Deoni S.C.L. et al. Magn. Reson. Med. 2003; 3. Li L. et al. Magn. Reson. Med. 2012; 4. Freeman R, et al. J Magn Reson. 1971.