In Vivo singleshot T1 and T2* Measurements of Atherosclerosis Plaques in Symptomatic and Asymptomatic Patients Using 2D ss-SGSTEPI Technique

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INTRODUCTION: Atherosclerosis is a major cause of cardiovascular disease including acute coronary syndromes and ischemic strokes. Atherosclerotic plaque characterization by MRI is generally based on the signal intensities in multi-contrast images such as T1, T2 weighted and PD, but these conventional MRI are unable to provide the full quantification of high risk plaque components in vivo due to low sensitivity and specificity[1-4]. Iron has consistently been found in higher concentrations in atherosclerotic plaque compared to vessel tissue [5-6]. Iron may be incorporated into hemoglobin or bound to the storage proteins ferritin and hemosiderin, both of which cause measurable changes in local magnetic field homogeneity [7]. It has been reported that intraplaque T2* measurement distinguished symptom-producing from non-symptom plaques in patients with carotid atherosclerosis[8]. Recently, we have developed a 2D singleshot spin-/stimulated echo-EPI (2D ss-SESTEPI) sequence that can measure T_1 of water protons in a localized volume in a singleshot [9]. In this work we introduce simultaneous measurement of T_1 and T_2^* of human atherosclerotic plaque using a novel sequence, 2D ss-spin-/gradient-/stimulated- echo (2D ss-SGSTEPI).

METHOD: Figure 1 presents the 2D ss-SGSTEPI pulse. The longitudinal component undergoes T_1 decay during TM and is excited by the third 90° RF pulse. The signal difference between the spin echo (SEPI) and stimulated echo (STEPI) formed at TE is the T_1 decay by $e^{-TM/T1}$. The transverse magnetization further evolves with T_2^* decay by $e^{-\Delta TE/T2^*}$. The gradient echo (GEPI) provides the signal of T_2^* decay during ΔTE caused by T_2 and local field variation. The signal magnitudes of three images are described with following equations (1) to (3). To present the feasibility of 2D ss-SGSTEI sequence, MRI studies of five symptomatic and three asymptomatic patients with atherosclerosis were performed on a Siemens Trio 3T MRI scanner (Siemens Medical Solutions, Erlangen, Germany) with a home built four element bilateral phased array carotid coils. The imaging parameters for 2D ss SGSTEI were: $\Delta TE/TM=42/400ms$ TR=6500ms, imaging matrix = 160x41, 2 mm slice thickness. The in-plane spatial resolution for data acquisition was 1.0x1.0mm with display resolution 0.5x0.5 mm², after zero-filled interpolation. Scan time was 1:24 min for 10 magnitude averages. The T_1 and T_2^* maps were calculated and displayed using IDL. 3D MPRAGE and T1w images were acquired on the same slice locations shown in T1, T2* maps. ADC maps in same slice location were also created using 2D ss-IMIV-DWEPI [10].

Figure 1 2D ss-SGSTEPI pulse sequence diagram

$$S_{SE}(\vec{r},t) = S_0(\vec{r})\left(1 - e^{-\frac{\tau}{T_1(\vec{r},t)}}\right)e^{-\frac{TE}{T_2(\vec{r},t)}} \quad (1)$$

$$S_{GE}(\vec{r},t) = S_{SE}(\vec{r},t)e^{-\frac{\Delta TE}{T_2^*(\vec{r},t)}} \quad (2)$$

$$S_{STE}(\vec{r},t) = S_{SE}(\vec{r},t)e^{-\frac{TM}{T_1(\vec{r},t)}} \quad (3)$$

RESULTS: Table 1 Mean T_2^*, T_1 and ADC values from 8 patients

	Symptomatic	Asymptomatic
T2*(ms)	22±2.8	37±4.8
T1(ms)	321±12.8	420±12.8
ADC (10^{-3}mm²/s)	0.85±0.24	1.41±0.48

Figure 2. 3D MP RAGE and T1w images, T_2^*, T_1 and ADC maps from a patient with intramural hemorrhage. All maps demonstrate the clear wall and plaque definition.

Three ROIs per each patient were selected in visible plaque. The mean T1, T2* and ADC values for plaque obtained from the 8 subjects are summarized in Table 1. Symptomatic compared to asymptomatic patients had significantly lower plaque T2* values (22±2.8 vs. 37±4.8ms, respectively, p<0.002). This value is close to the T_2^* value reported previously [8]. Fig 2 displays 3D MPRAGE, T1w images, T_1, T_2^* and ADC maps from a symptomatic subject with intramural hemorrhage. The ROI drawn by the red lines in the maps Fig 2 demonstrate a typical ROI selection. The ADC value was measured as $0.91x10^{-3}$mm²/s. T_1, T_2^* were measured as 332, 24 ms, respectively.

DISCUSSION: We found that in symptomatic patients, a shift of the type of iron complexes present seemed to occur with shortening of T2* by using 2D ss-SGSTEPI. With T2*-shortening, these results suggest a shift to aggregate iron complexes that have greater local effects on magnetic susceptibility. The small sample size is a limitation of this study. Further study will include identifying changes in the amount, species, and chemistry of intra-plaque iron during the course of atherosclerosis development. Neovasculature, which plays another significant role in atherosclerotic plaque progression and destabilization, can be evaluated by using a kinetic microvessel model in conjunction with dynamic contrast enhanced (DCE)-MRI [11]. The kinetic model parameters, such as the transfer constant, can be quantified using DCE-MRI, which is based on T1-weighted dynamic imaging. Our 2D ss SGSTEPI sequence can provide the simultaneous measurement of relaxation times (T_1, T_2^*) in a singleshot. These relaxation measurements can be used to obtain more accurate perfusion and model parameters of neovasculature with only a single injection of Gd-CA.

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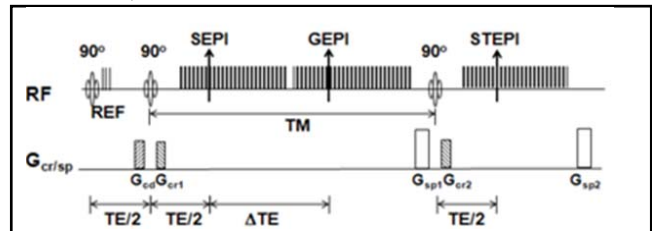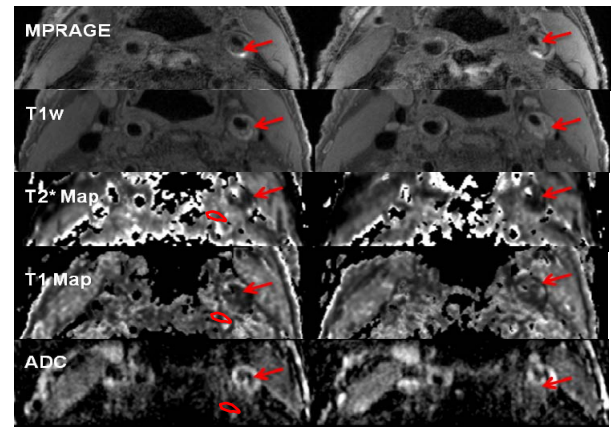10. Kim SE, et al. *J MRI* 2009;**30**,1068.   11. Moreno PR, et al. *Circulation* 2006;**113**:2245.