T2* and ADC Simultaneous Measurements of in vivo Symptomatic and Asymptomatic carotid atherosclerotic plaques Using 2D ss-SGE-DWEPI Technique

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INTRODUCTION: Many Studies have shown that hemorrhage is highly correlated with neurologic events in patients with carotid stenosis(1-2). Hemorrhage is therefore an important plaque component and can be detected with MR thrombus imaging (3). It has been reported that Type I (fresh) hemorrhage occurred more often in patients with symptomatic plaques (4). A previous ex vivo DWI study reported that the ADC in hemorrhage varies according to the processes that occur during the successive phases of aging (5). Our 2D-IMIV-DWEPI sequence has demonstrated the ability of in vivo DWI to separate hemorrhage, lipid and arterial wall (6). Iron has consistently been found in higher concentrations in atherosclerotic plaque compared to vessel tissue (7). 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 (6). It has been reported that intraplaque T2* measurement distinguished symptom-producing from non-symptom-producing plaques in patients with carotid atherosclerosis (8). We have developed a novel 2D singleshot spin-/gradient echo- diffusion weighted EPI (2D ss-SGE-DWEPI) sequence that can measure simultaneously the diffusivity and T2* (p<0.001) and ADC (p=0.003) values. Our T2*values for plaque obtained from the 10 s 180° gradient echo (GE EPI) as shown in Fig.1.

METHOD: 2D ss-IMIV-DWEPI was modified to create the additional readout of a gradient echo (GE EPI) as shown in Fig.1. A pair of refocusing and inversion (RI) 180° RF pulses immediately follows the excitation 90° pulse to confine the reduced phase FOV for interleaved multiple slice imaging (IMIV). The diffusion sensitized gradients were applied before and after the RI pulses. After a diffusion weighted spin echo (SE EPI) is formed at TE, this signal further evolves with T2* decay. A gradient echo (GEPI) provides the signal of T2* decay during ATE caused by local field variation. The signal equations of two echoes are described in Eqs (1) and (2). To evaluate the feasibility of T2* measurement with 2D ss-SGE-DWEPI, MRI studies of five symptomatic and five asymptomatic patients with hemorrhage positive atherosclerosis were performed on a Siemens Trio 3T MRI scanner with home built carotid coils. The imaging parameters for 2D ss-SGE-DWEPI were: ΔTE=42ms TR=3000ms, imaging matrix = 160x40, 2 mm slice thickness. The in-plane spatial resolution for data acquisition was 1.0x1.25mm. Scan time was 2:24 min for 42 magnitude averages. DWI with b=0 and 500 s/mm² were interleaved. The ADC and T2* maps were calculated and displayed using IDL. While ADC maps were created only using SE DWI, T2* maps were created using two echoes images with b=0. 3D MPRAGE and T1w images were acquired at the same slice locations as the ADC and T2* maps.

\[ S_{GE}(f, t) = S_{0}(f) e^{-b-f} e^{-\frac{TE}{T2^*}} \]  
\[ S_{SE}(f, t) = S_{0}(f) e^{-f} e^{-\frac{\Delta TE}{T2^*}} \]  

RESULTS: Table 1 Mean T2*, T1, and ADC values from 10 patients

<table>
<thead>
<tr>
<th></th>
<th>Symptomatic</th>
<th>Asymptomatic</th>
<th>P value</th>
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<tbody>
<tr>
<td>T2*(ms)</td>
<td>23±3.8</td>
<td>39±5.8</td>
<td>p&lt;0.001</td>
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<tr>
<td>ADC (10^-3/mm²/s)</td>
<td>0.85±0.24</td>
<td>1.41±0.48</td>
<td>p=0.003</td>
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Three ROIs per each patient were selected in visible plaque. The mean T2* and ADC values for plaque obtained from the 10 subjects are summarized in Table 1. Symptomatic compared to asymptomatic patients had significantly lower plaque T2* (p<0.001) and ADC (p=0.003) values. Our T2* value is close to the value reported previously (9). Fig 2 displays 3D MPRAGE, T1w images, T2* and ADC maps from a symptomatic and an asymptomatic subject, each with intraplaural hemorrhage. The T2* and ADC values obtained from the red ROIs in Fig. 2 were 24/35 ms and 0.91/1.25x10^-3mm²/s, respectively.

DISCUSSION: We found that symptomatic plaque has a significantly lower ADC compared to values obtained from asymptomatic plaque. Previous ex vivo study reported that the ADC of fresh hemorrhage (0.72x10^-3mm²/s) is lower than the ADC (1.33x10^-3mm²/s) of organized hemorrhage (7). Our ADC results are thus consistent with the expectation that the fresh hemorrhage is found significantly more often in patients with symptomatic plaques. The observation of a shortened T2* in symptomatic patients is also consistent with the expectation that symptomatic subjects should show a shift of the type of iron complexes present. The shortened T2* suggests 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. The measurements of T2* and ADC obtained from 2D ss-SGE-DWEPI in our study revealed significant differences in the hemorrhage morphology of symptomatic and asymptomatic plaques. This approach might be used to characterize high-risk plaque and ultimately identify at-risk patients.

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REFERENCES: