An Optimized 3D Spoiled Gradient for Hemorrhage Assessment Using INversion Recovery and Multiple Echoes (3D SHINE) for Carotid Plaque Imaging

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Introduction

Intraplaque hemorrhage into the carotid atherosclerotic plaque has been shown to create instability and progression. Moody et al. developed a $T_1$-weighted magnetization-prepared 3D gradient echo sequence to detect the hemorrhagic carotid plaque at 1.5T with a good sensitivity and specificity (1). We have also developed a similar optimized 3D inversion recovery prepared fast spoiled gradient recalled sequence (IR FSPGR) on a 3T scanner for carotid plaque imaging and have achieved a good level of success (2). Then we further enhanced the single-echo IR FSPGR, with an inclusion of multiple echo acquisitions. This sequence is called 3D SHINE (Spoiled Gradient for Hemorrhage Assessment Using INversion Recovery and Multiple Echoes) (3). The 3D SHINE sequence has been optimized in scan time, coverage and black-blood effect. With this optimized protocol, four patients with hemorrhagic carotid plaques have been studied. The $T_2^*$ values appear to be promising in characterizing the hemorhagic type (4,5). This hemorrhagic type characterization may provide additional information on plaque vulnerability.

Methods

In this optimized protocol for 3D SHINE, four echoes are acquired after each RF excitation pulse at each slice phase-encoding step. By properly selecting the time of inversion ($T_{i}$), receiver bandwidth (rBW), as well as the rest time after the sequence of slice phase encoding steps, the slice flow can be minimized to reach the maximum contrast between the carotid vessel lumen and the vessel wall. This protocol was optimized on four normal subjects and was evaluated on five patients (four with plaque hemorrhage). The data were collected on a 3T Signa® HDx MR scanner (GE Healthcare, Waukesha, WI) using a dedicated 4-channel carotid surface coil. The followed optimized protocol was applied to patients (commonly with the single-echo IR FSPGR protocol): fat saturation, flip angle = $15^\circ$, field of view = 16 cm, number of slices = 40, slice thickness = 1 mm, matrix size = 256 x 192. Other parameters are shown in Table 1 below:

### Table 1. Other Imaging Parameters for IR FSPGR and 3D SHINE

<table>
<thead>
<tr>
<th></th>
<th>rBW (kHz)</th>
<th>1st TE (ms)</th>
<th>2nd TE (ms)</th>
<th>3rd TE (ms)</th>
<th>4th TE (ms)</th>
<th>tr (ms)</th>
<th>Effect TI (ms)</th>
<th>Rest time (ms)</th>
<th>TR (ms)</th>
<th>Number of Excitation</th>
<th>Scan time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-echo IR FSPGR</td>
<td>± 31.25</td>
<td>3.2</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>13.7</td>
<td>318</td>
<td>0</td>
<td>591</td>
<td>2</td>
<td>3 min 50 sec</td>
</tr>
<tr>
<td>4-echo 3D SHINE</td>
<td>± 41.7</td>
<td>2.7</td>
<td>6.1</td>
<td>9.6</td>
<td>13</td>
<td>22.4</td>
<td>510</td>
<td>250</td>
<td>1208</td>
<td>1</td>
<td>3 min 54 sec</td>
</tr>
</tbody>
</table>

$\text{tr} =$ time of repetition for each phase encoding step, $\text{TR} =$ the time of repetition with respect to the non-selective inversion, and $\text{Rest time} =$ the extra rest time after the sequence of slice phase encoding steps.

The $T_2^*$ was calculated based on the semi-log linear regression of the voxel signal values and the corresponding $TE$s (time of echo).

Specifically, $1/T_2^* = -\ln(S_n - S_m)/(TE - TE_m)$, where $S_n$ and $S_m$ are voxel signal intensity values at $TE$ values of $TE_n$ and $TE_m$.

More traditional quadruple inversion-recovery $T_1$-weighted (6), double inversion-recovery $T_2$-weighted (7) and time-of-flight (TOF) images for carotid plaque imaging were also collected to confirm whether the hemorrhagic regions were Type I or II as previously validated by histological evaluation of carotid endarterectomy specimens (4,5). Single-echo IR FSPGR images with protocol shown in Table 1 were also acquired for comparison.

Regions of interests (ROI) were identified as Type I and Type II based on $T_2^*$ values for Type I hemorrhage is $11.3 \pm 2.9$ ms and for Type II hemorrhage is $22.4 \pm 8.3$ ms. They are statistically different from each other ($P < 0.001$). However, when there is calcification next to the hemorrhagic region as in one of our cases, the $T_2^*$ for non-Type I hemorrhagic tissue can be reduced to the range of Type I hemorrhage and leads to false characterization. This case was excluded in the $T_2^*$ value calculated above. Fig. 1 shows results from one patient data. The hemorrhagic region can be easily identified by its high contrast. The carotid plaque region and its associated $T_2^*$ map can be easily visualized due to the good black-blood effect and the 3D reformatting capability. Further patient evaluation is ongoing. Our 3D SHINE technique appears to add great value in carotid plaque hemorrhagic detection and characterization.

### Results and Discussion

The optimized 3D SHINE sequence maintains the similar scan time as the single-echo IR FSPGR sequence. The $T_2^*$ values for Type I hemorrhage is $11.3 \pm 2.9$ ms and for Type II hemorrhage is $22.4 \pm 8.3$ ms. They are statistically different from each other ($P < 0.001$). However, when there is calcification next to the hemorrhagic region as in one of our cases, the $T_2^*$ for non-Type I hemorrhagic tissue can be reduced to the range of Type I hemorrhage and leads to false characterization. This case was excluded in the $T_2^*$ value calculated above. Fig. 1 shows results from one patient data. The hemorrhagic region can be easily identified by its high contrast. The carotid plaque region and its associated $T_2^*$ map can be easily visualized due to the good black-blood effect and the 3D reformatting capability. Further patient evaluation is ongoing. Our 3D SHINE technique appears to add great value in carotid plaque hemorrhagic detection and characterization.

### References


