Measurement of $T_2$ and $T_2^*$ in Spin Echo Single Point EPR Imaging Using a Single Acquisition Method
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**Purpose** Electron paramagnetic resonance imaging (EPR) has surfaced as a promising technique that can allow quantitative imaging of tissue oxygenation. Owing to the extremely short spin-spin relaxation time of the spin probe (Oxo63), current EPR benefits from single point imaging (SPI) scheme where entire FID is phase encoded under static phase encoding gradients. Several methods have been proposed to overcome zoom-in effect (time-decreasing FOV) resulting from using static phase encoding gradients and thereby enable direct $T_2^*$/$pO_2$ estimation, such as the multiple acquisition method, a single acquisition method, and a spin echo-based method. Among the techniques, spin echo based SPI-EPR (ESPI-EPR) is worthy of study because it can allow simultaneous $T_2$ and $T_2^*$ estimation when combined with a single acquisition method. In EPR, $T_2/T_2^*$ parameters are used as a precursor to $pO_2$ quantification owing to their inversely proportional relation. In this study, the physical and physiological significance of $T_2$ and $T_2^*$ measures was explored through ESPI-EPRI.

**Methods** To obtain images with an equal FOV in ESPI, we extended a single acquisition method using gridding and k-space extrapolation (KSE). Since there are three independent segments in ESPI as seen in Fig. 1-a, KSE can be applied in two different ways, intra-segment or inter-segment extrapolation. In intra-segment KSE, k-spaces are extrapolated independently within each segment as shown in Fig. 1-b, whereas inter-segment KSE benefits from k-spaces in different segments as shown in Fig. 1-c. Once equal FOV images have been secured, $T_2$ and $T_2^*$ can be fit over a large amount of data points (typically 100-300 points) using the following piecewise signal equation:

$$M = M_0 \exp \left( -\frac{t}{T_2} - \frac{t}{T_2^*} \right)$$

, where TE denotes echo time. $T_2$ and $T_2^*$ can be directly fit if TE is known, and $T_2^*$ can be calculated by the equation, $T_2^* = 1/(1/T_2+1/T_2')$. We compared quantitative measurements of single acquisition ESPI and single acquisition FID-SPI on a 10 mT EPR scanner.

**Results** Inter-segment KSE (Fig. 1d-bottom) yields better imaging quality than intra-segment (Fig. 1d-top) because error propagated during extrapolation is alleviated by taking data from the first segment that has higher SNR. Fig. 2a shows the $T_2^*$ map estimated by applying single acquisition SPI-FID and Fig. 2b and Fig. 2c show the $T_2^*$ map and $T_2$ map estimated using the proposed method with ESPI data, respectively. Table 1 shows estimated $T_2/T_2^*$ in each tube and the resultant %O2-$R_2^*$ curve fits.

**Discussion and Conclusion** A new approach for single acquisition quantitative SPI has been presented. As shown in Table 1, similar estimates of $T_2^*$ were obtained between FID and ESPI approaches. While the observed $T_2$ is significantly larger (as expected), the slope of $T_2$ and $T_2^*$ with varying oxygenation is very similar, indicating similar sensitivity to oxygenation with either parameter. Future work is needed to evaluate the physiological significance between $T_2$ and $T_2^*$ measurements for in vivo tumor hypoxia imaging. Further, tradeoffs between the value of SPI, which offers a shorter TR and thus more rapid imaging, versus ESPI which allows estimation of both parameters and a higher intrinsic SNR should be examined.

**References**

**Target Audience** Researchers interested in quantitative oxygen imaging using electron paramagnetic resonance imaging.

![Figure 1. k-space extrapolation in ESPI.](image)

![Figure 2. Estimated $T_2^*$ maps. 19x19x19 SPI data was used for a, and 21x21x21 ESPI data was used for b. 2D slices are shown.](image)

<table>
<thead>
<tr>
<th>Tube</th>
<th>$T_2/T_2^*$ (ns)</th>
<th>%O2-$R_2^*$ curve fit</th>
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</thead>
<tbody>
<tr>
<td>Tube 1</td>
<td>625.7 ± 69.2</td>
<td>5.15 x10^{-5}</td>
</tr>
<tr>
<td>Tube 2</td>
<td>604.4 ± 48.9</td>
<td>1.61 x10^{-3}</td>
</tr>
<tr>
<td>Tube 3</td>
<td>534.9 ± 41.4</td>
<td>0.99</td>
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Table 1. Estimated parameters. A 3-tube phantom of Oxo63 bubbled with of 0%, 2%, 5% oxygen was used.