Error propagation in Vessel Size Index Imaging

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Introduction

The vessel size index (VSI) provides information on the distribution of vessel radii in a voxel (1). Experimentally, it can be estimated by quantifying the changes in VSI, and VSI\textsuperscript{2} induced by the injection of an intravascular susceptibility contrast agent, the variation of the susceptibility difference between blood and tissue before and after contrast injection (\(\Delta\chi\)), and the apparent diffusion coefficient (ADC). VSI is then computed according to the expression

\[
VSI = 0.424 [ADC/T_2^* B_0] VSI^2 (\Delta R'_2/\Delta R_2)
\]

The present study aims to characterize the contribution of each of the experimentally derived parameters mentioned above to the error on VSI. This analysis should allow evaluating the smallest change in VSI that can be detected across images in a given experimental protocol. Also, it should be possible to identify the most important directions for acquisition scheme optimization.

Material and Methods

The experimental protocol essentially followed the approach described in (1). Data were acquired on anesthetized (isoflurane, 2%) rats (n=5) bearing a brain tumour. Animals received 200µmol Fe/kg of Sinerem® (Guerbet laboratories). MR images were obtained at 2.35T (SMIS console) on 1mm thick slices with a voxel size of 312x312 µm. Signal value was taken as the average signal intensity over a region of interest (ROI) placed on the normal brain.

Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Signal / Noise</th>
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<tr>
<td>For (\Delta R_2)</td>
<td>before: 34.3, after: 23.4</td>
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<tr>
<td>For (\Delta R'_2) (first echo):</td>
<td>before: 116.6, after: 116.4</td>
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<tr>
<td>For ADC:</td>
<td>X: 23.4, Y: 22.7, Z: 26.8, No diff: 54.0</td>
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Table 1. Signal-to-noise ratios.

For ADC, an error of 5% was obtained. Fig 1b shows that \(\Delta R'_2\) is measured with an error smaller than 10% in the range of 10 to 60 s\(^{-1}\) (Fig. 1a). The error on \(\Delta R_2\) is 9% at best and is less than 15% over a range of 3 to 15s\(^{-1}\) (Fig. 1b). Simulations also shows that the relative influence of ADC error on VSI is half of the relative influences of \(\Delta R_2\) and \(\Delta R'_2\) errors, which are identical (data not illustrated here). Fig. 1c shows the error on VSI, which ranges between 21% and 55%. Since a same value of VSI can be obtained from different combinations of \(\Delta R'_2\) and \(\Delta R_2\), multiple error values are obtained for a single VSI value. In Fig. 1c, points highlighted in red (largest errors) can be obtained with a \(\Delta R_2\) smaller than 5s\(^{-1}\), which is not measured properly with our approach (\(\Delta (\Delta R_2)\) greater than 10%, Fig. 1b). These points represent the largest error values.

Conclusion

VSI quantification could be improved (i) by reducing the first gradient echo times to improve the \(\Delta R'_2\) measurement (ii) but mostly by improving the \(\Delta R_2\) measurement (e.g. by acquiring multiple spin-echoes), which appears to be the largest contributor to VSI error (2). The results also suggest that, in normal tissue where VSI ~4.8 µm (1), the smallest VSI detectable is about 2.4 µm (considering a 25% error and an increase of two times the error). This suggests that VSI could be used as an early indicator of tumour angiogenesis.

References


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