Spatially-variant $B_0$ field gradients in the liver: implications for $R_2^*$ mapping for iron quantification

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Introduction: $R_2^*$ relaxometry is a promising technique for liver iron quantification. However, measured $R_2^*$ values are affected by several confounding factors, including the presence of macroscopic $B_0$ field inhomogeneities due to susceptibility effects, e.g., near the dome of the liver. Susceptibility effects introduce errors in the apparent $R_2^*$, and these errors can be highly protocol-dependent. The purpose of this work is to characterize the $B_0$ distribution in the liver in order to optimize acquisition strategies.

Methods: After IRB approval, 6 patients with no known iron overload underwent chemical shift-based MR imaging of the liver acquired at 3T using an investigational multi-echo 3D spoiled gradient echo, with two protocols with different image parameters. Protocol 1: sagittal slab, TR=9.0 ms, 6 echoes/TR (1 shot), TE=0.8 ms, $\Delta T E=1.2$ ms, with slice thickness = 3.0 mm. Protocol 2: axial slab, TR=8.0 ms, 3 echoes/TR (2 shots), TE=1.2 ms, $\Delta T E=1.0$ ms, with slice thickness = 8.0 mm. Separated water and fat images, an $R_2^*$ map, and a $B_0$ field map were obtained using a chemical shift-based water-fat separation algorithm. The spatial gradient of the $B_0$ field map (in $\hat{x}$, $\hat{y}$, $\hat{z}$) was computed from the sagittal data. ROIs were placed in the 9 Couinaud segments of the liver by a radiologist with >5 years experience in liver imaging, in order to measure the 3 components of the gradient. Theoretical $B_0$ field maps were calculated for each subject based on known susceptibility values of water/fat/air, and an anatomically specific susceptibility distribution (derived from the fat-water separation described above), in order to characterize the source of $B_0$ field inhomogeneities. Finally, theoretical $B_0$ gradients were obtained from the calculated $B_0$ field for each segment in each subject, and compared with the measured $B_0$ field gradients.

Results: Segment 2 has the highest gradients with an average of 22.0 Hz/cm for the measured gradients, and also the highest standard deviation at an average of $\pm13.6$ Hz/cm (Fig. 3). Segments 4A, 7, and 8 also have large gradients in the $\hat{z}$ direction (all above 15 Hz/cm). The measured and simulated average gradients have correlations of 0.79 for $\hat{x}$, 0.91 for $\hat{y}$, and 0.83 for $\hat{z}$, demonstrating good agreement. In contrast to the agreement between theoretical and measured average gradients in Fig. 3, Fig. 4 demonstrates that the simulated gradients do not predict the measured gradients well for an individual segment of a particular liver.

Discussion and Conclusion: The difference in the behavior between the average gradients in Fig. 3 and the individual gradients in Fig. 4 may be explained by the relative simplicity of the susceptibility model used in the simulation. Rapid field variations along $\hat{z}$ near the liver dome (segments 4A, 7, 8) result in an increase in the apparent $R_2^*$, as often observed in scans acquired axially with thick slices. Thus, sagittal or coronal acquisitions, rather than axial, may be preferable if localized $R_2^*$ measures near the liver dome are required. The methods presented in this work may be used to optimize acquisition parameters to minimize the field variation within a voxel to avoid susceptibility-related errors in $R_2^*$ measurement for liver iron quantification.


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