Importance of Susceptibility Effects in the Determination of Fractional Regional Blood Volume (fRBV)

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Introduction

In the MR measurement of fractional regional blood volume (fRBV) in a capillary bed using a ferromagnetic nanoparticle contrast agent [1], it is important to know whether or not susceptibility effects at the boundary between the vascular and extravascular compartment effect the measurement. By comparing the fractional volume of saline (fV) in a model system—a dialysis canister—oriented with its tubing parallel and perpendicular to B_0, and at different B_0 values, the effects of susceptibility can be quantitatively evaluated.

Method

A renal dialysis canister [Fresenius Medical Inc. model F8] was used as a phantom. The canister contains a series of tubes (~ 200 μm diameter) connected in parallel and constructed of semi-permeable membranes, which were filled with either pure saline solution or a dilution of 1 ml of Feridex^{TM} in one liter of saline. The volume surrounding the tubes was filled with saline solution only. The tubes serve as a model of a capillary bed (intravascular region), while the solution surrounding the tubes can be thought of as the tissue (extravascular region). Feridex, [Advanced Magnetics Inc, Cambridge, MA] is a well-characterized supermagnetic nanoparticle MR contrast agent. At a concentration of 1 mL Feridex per 1 L of saline, the ^{1}H T_1 of the Feridex solution is approximately 200 ms.

The dialysis canister and two syringes, one filled with pure saline solution the other with Feridex solution, were imaged in two orientations—with canister and hence the tubes aligned parallel and perpendicular to the main magnetic field. Two sets of images were taken in each orientation, before and after the tubes were filled with Feridex solution. A spoiled gradient echo sequence (SPGR) was used for imaging, with TR/TE 19/6 ms, NEX 32, and flip angle 30°. The experiments were performed in a 0.2 T GE Profile and a 1.5 T GE Signa scanners, which allowed us to compare the susceptibility effects due to Feridex at a low and a mid-field value.

The fractional volume of the tubes for a region of interest can be calculated according to [2]:

$$fV = (S_{canister+Fe} - S_{canister})/(S_{syringe+Fe} - S_{syringe}),$$

where $S_{canister}$ is the signal from the dialysis canister when filled with saline only, $S_{canister+Fe}$ is the signal once the tubes are filled with Feridex solution, $S_{syringe}$ is the signal from the saline-filled syringe and $S_{syringe+Fe}$ is the signal from syringe of Feridex solution.

Results

At 0.2 T, the MR measurement of fV for tubes oriented perpendicular to the main magnetic field gives a value of 0.200 ± 0.003. An independent measurement of fV using confocal microscopy on the same canister yielded a value of 0.202 ± 0.001. Using a different canister, experiments at 0.2 T yielded fV measurements for the parallel and perpendicular orientations of the canister that agree within the experimental error. At 1.5 T, the fV obtained when the tubes are oriented parallel to the main field is approximately twice that obtained when in the perpendicular orientation.

Discussion

The factor of two change in fV with canister orientation at 1.5 T are likely due to T_2* effects induced by magnetic susceptibility gradients in the heterogeneous phantom. The fV changes do not result from magnetic field-dependent change in T_1 of Feridex solution, because such an effect is accounted for in the normalization of the measured canister signals to the syringe signals. Furthermore, because our results are based on computing the difference between the signal strengths in Feridex solution and saline in the canister, T_2* effects due to magnetic field inhomogeneities and susceptibility differences between outer solution and the tubes are eliminated. Therefore, we conclude that the orientation dependence at 1.5 T of the MR fV measurement results from a magnetization gradient that develops across the tube inner boundary (i.e., between the superparamagentic Feridex solution and the diamagnetic tube wall) when the tube is perpendicular to the applied magnetic field. The lower magnetization of Feridex at 0.2 T, known to be 90% at 0.6 T [3], is the likely cause of the lack of an orientation dependence for the MR fV measurements at 0.2 T.

Conclusion

In this work we have demonstrated a method to determine the importance of susceptibility effects due to Feridex as they relate to our previously developed technique [1] for measuring fractional regional blood volume in the lung capillary bed. As such, we are developing a greater understanding of the role of applied field strength and orientation on MR fRBV measurements in the lungs.

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References

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