Effect of Capillary Orientation and Oxygenation on Myocardial Signal

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Background

Capillaries in myocardium are like small cylinders of inhomogeneity in that the susceptibility of blood, particularly deoxygenated blood, differs from that of the myocardium. The effect of this inhomogeneity on the induced field and thus on the image signal depends on the orientation of the capillaries with respect to the applied magnetic field. If capillary orientation is random, then the effects are likewise random. However, capillary orientation is not random in myocardium but is organized and follows the orientation of the myocardial fibers [1]. Recent advances in cardiovascular imaging apply blood oxygen level dependent (BOLD) imaging to the myocardium yet regional BOLD results are likely to be affected by capillary orientation effects. In this work, the effect of capillary orientation and blood oxygenation on myocardial signal were studied with simulations and experiment.

Methods

We created a capillary phantom in Matlab (The MathWorks, Natick, MA) with a single 8 micron diameter [2] cylinder embedded in a (72 micron)^3 volume of myocardial tissue to correspond with an average distance of approximately 24 microns from any point to the nearest capillary [3]. Using the simulator developed by Yoder et al. [4], the induced field was calculated when a capillary of completely deoxygenated blood is oriented from 0° to 90° in 15° increments to the applied magnetic field. Using the induced fields, gradient echo images of slices perpendicular to those capillaries were simulated. To measure the effects of oxygenation levels on the signal produced by the phantom, we calculated the induced field of and simulated gradient echo images of a capillary oriented at 90° with respect to the applied magnetic field (i.e., the orientation with the most severe susceptibility effects) with blood oxygenation levels from 0-100%, focusing on the physiological range of 50-100% oxygenated blood. To quantify the inhomogeneity effects on myocardial signal, the mean signal of the entire slice was divided by the standard deviation in the signal to give a pseudo SNR.

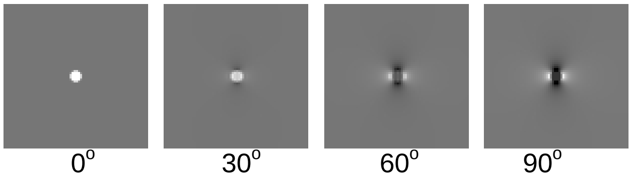

Figure 1. Induced field for a capillary filled with deoxygenated blood surrounded by myocardium. Angles are those between the capillary and the applied field. Black is the minimum (-4.27 ppm) and white is the maximum (-2.02 ppm) induced field change. Note the increase in field inhomogeneity as angle increases.

Multiecho gradient echo images were obtained of an excised mouse heart in a doped-water solution at 4.7T with the heart at different orientations with respect to the applied field (TR=300ms, TE=3.7ms*n, n=1-12). T2* maps were then computed.

Results and Discussion

As shown in Figure 1, the field perturbation within the myocardium is minimal when the capillary is parallel to the applied field and maximal when perpendicular to the applied field. As the field effects become stronger (i.e. as angle increases), the deleterious effect on the image SNR increases, as shown in Figure 2. This illustrates that identically composed myocardium in regions with differing orientations will give different SNRs. The slight increase in SNR at 45° is a consequence of phase cancellation at the vessel boundary declining more rapidly with angle than the rate at which susceptibility effects propagate into the myocardium. Similarly, as the levels of deoxygenated hemoglobin increase, the SNR decreases, as shown in Figure 3. Empirical data, shown in Figure 4, reveals an angle dependence to T2* in the myocardium.

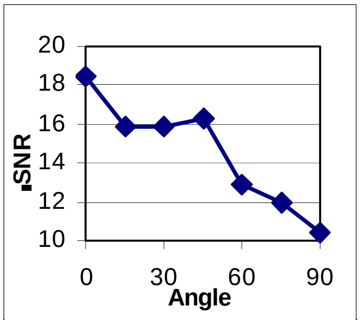

Figure 2. SNR for myocardium surrounding a dO_2Hb-filled capillary oriented 0-90 degrees with respect to the applied field. (GE: B_o=3T, TE=30ms, TR=20s).

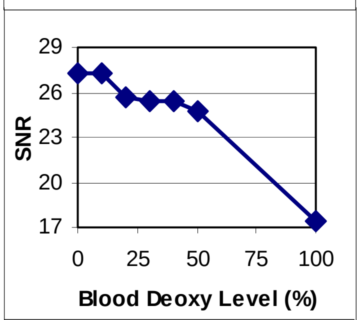

Figure 3. SNR for myocardium surrounding a capillary oriented 90° with respect to the B_o field at various dO_2Hb levels. (GE: B_o=3T, TE=30ms, TR=20s).

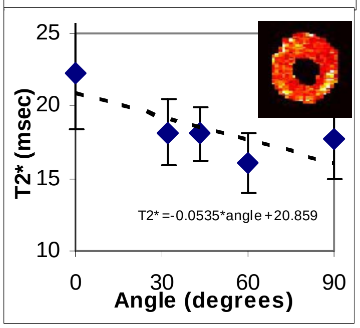

Figure 4. T2* for a ventricular ROI vs. the angle of the whole heart w.r.t. B_o. Note that whole heart orientation is not the same as capillary orientation even for a small ROI. Regardless, note the change in T2* as a function of orientation.

Conclusion

Simulation and experiment support the hypothesis that capillary orientation and oxygenation affect myocardial signal and T2* measurements.

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