Estimating Amounts of Iron Oxide from Gradient Echo Images

W. T. Dixon[1], D. J. Blezek[2], L. A. Lowery[1], D. E. Meyer[1], A. M. Kulkarni[1], B. C. Bales[1], D. L. Petko[1], and T. K. Foo[1]
[1]GE Global Research, Niskayuna, NY, United States, [2]Mayo Clinic, Rochester, Minnesota, United States

Introduction

Iron oxide contrast agents accumulate in specific regions providing image contrast and raising the question, how much? Traditionally, one looks at the labeled region, dividing the agent induced change in relaxation rate by known relaxivity to find agent concentration. For SPIO, relaxivity in vivo is not the same as in vitro and is not usually known. The labeled region may be quite small, its signal difficult to determine, and aligning it for comparisons with pre-injection control images difficult.

Because of its susceptibility, SPIO affects signals coming from unlabeled tissue surrounding the labeled region. Several methods for using these signals for detecting or estimating SPIO indirectly (see references) have been presented as new pulse sequences. Here, we present results derived from conventional, multislice, 2D, gradient-echo images.

Methods

We injected SPIO (110 emu/g) directly into legs of rat carcasses obtained through an IACUC approved protocol, estimating total iron three ways. Assuming any voxel with 360° across it is dark, the dark volume predicts m, the magnetization in emu to be

$$m = \frac{1}{4\gamma \mathrm{TE}} \left(\frac{3v^4}{\pi p_x p_y p_z} \right)^{1/3} \qquad [1],$$

with p_x, p_y, and p_z pixel dimensions in cm, v the black volume in cm^3, and γ, the gyromagnetic ratio, in radians/s/Gauss. Alternatively, in the higher intensity region around the dark spot the SPIO contributes to the pixel phase

$$\Delta\varphi(r) = m\gamma \frac{(3\cos^2\theta - 1)}{|r|^3} \mathrm{TE} \qquad [2],$$

which can be least square fitted to the observed phase images for the magnetization, m. Finally, generalizing eq 2 slightly gives another observable, the difference in phase between echo 1 and echo 2 images.

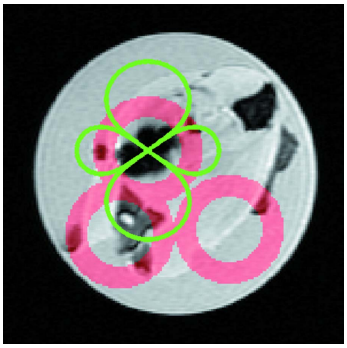

Fig 1 Fitting regions for dipole (red). Upper one contains 3ug SPIO in 10 microliter injectate.

Results

Figure 1, a magnitude image of a leg injected with 3microgram SPIO, shows the location of the assumed dipole (green). The red, spherical shells are phase fitting regions, the lower 2 in iron-free, control regions. Figure 2 shows best fit iron masses as a function of TE, sample orientation, and a read/phase encode axis swap. Black volume gave inaccurate estimates that depended on both TE and sample orientation. Phase difference analysis gave -90 and -140 nanogram estimates in the control regions.

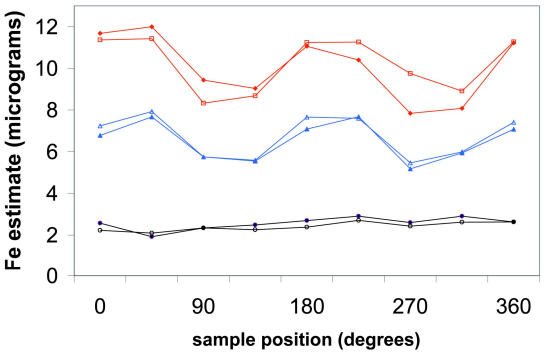

Fig 2 Iron estimate based on black volume on TE=25ms image (top), 10 ms (middle) and phase difference (bottom). Solid and hollow symbols have read and phase axes interchanged.

Discussion

Both black spot and phase based analyses rely on voxel sizes and distances between voxels. Since susceptibility artifacts distort positions in the read but not phase encode direction, we estimated iron before and after swapping these axes. All iron estimates were immune to this swap (Fig 2).

Our estimation methods assume the SPIO is concentrated at a point or is spherically distributed in a small volume. The labeled region, however, is not spherical; the black volume depends on the sample orientation (Fig 2) and the dark region looks irregular in every view. Despite the irregular shape of the labeled region, the phase difference method gave good estimates of the mass of iron injected.

References

Cunningham CH, et al. MRM 2005; 53:999-1005.
Stuber M, et al. ISMRM. Miami, 2005; 2608.
Gilson WD, et al. ISMRM, 2005; 2621.
Bakker CJ, et al. MRM 2006; 55:92-97.
Mani V, et al. MRM 2006; 55:126-135.
Liu W, et al. NMR Biomed 2007; 21:242-250.