Orientation effects on the local magnetic field or phase and T2*-weighted hypointensity of gradient echo imaging and their removal in quantitative susceptibility mapping

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Introduction

Gradient-recalled echo (GRE) is a commonly used pulse sequence in MRA, perfusion, fMRI, high field imaging. GRE may provide T_2^* weighted magnitude image sensitive to intravoxel dephasing of field variation, phase contrast caused by susceptibility induced local average magnetic field [1], or susceptibility weighted image [2]. T_2^* hypointensity is very sensitive to imaging parameters, particularly echo time, field strength, and voxel size. Both T2*-weighted hypointensity and phase depend on relative orientation with respect to B_0, relative geometry between observation voxel and susceptibility source. The well known blooming artifacts refers to that the signal intensity loss extends beyond the susceptibility source. A new approach, quantitative susceptibility map (QSM), reveals the susceptibility source by solving the field source inverse problem, removes the blooming artifacts [3]. We here illustrate the geometric relationship between susceptibility source, induced local field, T_2^* hypointensity, and phase.

Materials and Methods

MRI experiments. Healthy volunteers and agar phantoms that contained a small cylindrical section of agar doped with an iron oxide were imaged at multiple orientations with respect to B_0 on a 3T system using a 3D multi-echo spoiled gradient echo sequence. Imaging parameters were: TEs = 3.5, 7.0, 10.5, 14.0, 17.5, 21.0, 24.5, 28, 31.5ms; TR = 41ms; BW = 320Hz/pixel, FA = 15° , NEX = 1, voxel size of 0.94×0.94×2.5 mm^3 for the subject and 1.2×1.2×1.2 mm^3 for the phantom. QSM was computed from multiple echo phase data and unwrapped using a magnitude image guided region-growing unwrapping algorithm [4]. A projection onto dipole fields method was used to remove the background field [5]. For both phantom and human scans, the noise standard deviation (SD) was estimated over a background air region. The original ill-posed field to source inverse problem was solved by imposing a consistency with the magnitude images, where uniform regions were favored to have uniform susceptibilities.

Magnetic field simulation. The field maps of a phantom mimicking the agar phantoms with varying orientations were simulated by convoluting the dipole kernel with the susceptibility distribution according to Maxwell's Equation for magnetism. These computed fields were compared with MRI multiple orientations

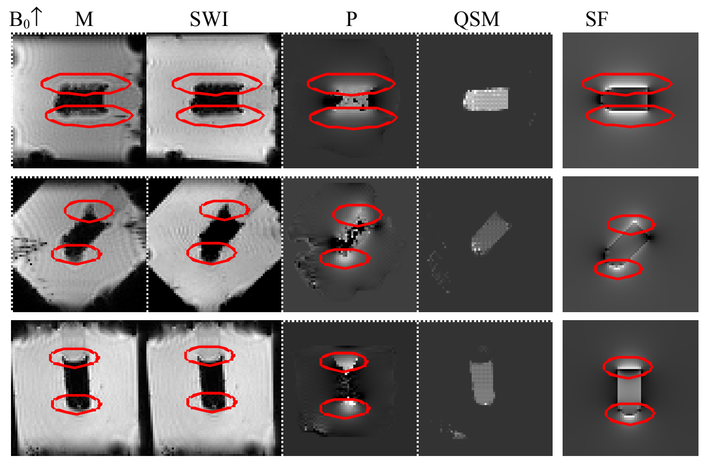

Fig.1. GRE magnitude image (M), susceptibility weighted imaging (SWI), phase map (P), and quantitative susceptibility map (QSM) of the phantom at 0^0 (top row) 45^0 (mid row) and 90^0 (bottom row), and corresponding simulated field map (SF). Red circles indicate locations of strong blooming artifacts

Results

Fig. 1 shows the effect on experimented GRE magnitude (M) image, susceptibility weighted imaging (SWI), phase (P) map, quantitative susceptibility map (QSM) of a phantom at approximately 0^0, 45^0 and 90^0 orientations in the magnet, and corresponding simulated field map of a mimicking phantom. The strong blooming artifacts in the M and SWI images were associated with strong phase variations (P and SF), identified by red circles. The observed phases differed from the simulated field inside the Fe_2O_3 doped agar cylinder because of poor SNR. Compared to QSM that had no blooming artifacts, the sensitive orientation dependence of the blooming artifacts was visually obvious (the three rows were from similar but not identical sections of the phantom due to rotations). When the agar cylinder axis was $\perp B_0$ (top row in Fig.1, 0^0), the blooming artifacts were the largest.

The marked orientation dependence of phase was also observed in human brain imaging (Fig.2), with slight orientation dependence of magnitude images (red circles in Fig.2)

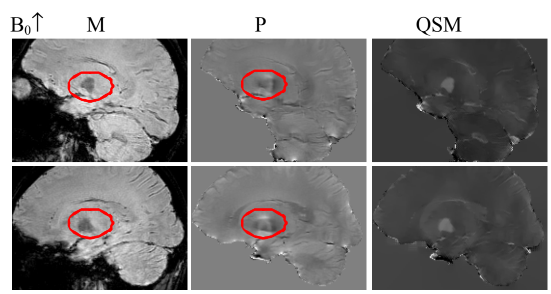

Fig.2. GRE magnitude image (M), phase map (P), and quantitative susceptibility map (QSM) of a human brain at two orientations. Red circles indicate locations of strong orientation dependence.

Discussion and Conclusion

Consistent with Maxwell's Equation, the induced local field pattern of a magnetic susceptible object strongly depend on the object orientation in an external uniform B_0 field. Consequently, the blooming artifacts associated with spatial variations of the local field and demonstrated in the gradient echo magnitude and phase images depend on the object orientation.

References

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