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Susceptibility-based Imaging, Mapping, and Applications in High Field MRI

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Tissue exposed to an external magnetic field generates its own internal magnetization or internal field. The internal field is determined by the product of the external field and its susceptibility. The internal field is a few tenths of ppm of the external field for most of tissues, thus it may be considered as a small perturbed field or simply a tissue-dependent magnetic field inhomogeneity. Although the susceptibility field affects the magnitude and phase of MRI, it is usually measured by the phase.

The phase generated by the susceptibility field is used to enhance image contrast in susceptibility-weighted imaging (SWI). The SWI is obtained by multiplying a sigmoidal function of the phase to the magnitude image. The SWI is an effective diagnostic method, for example, detecting brain tumor, traumatic brain injury, iron deposition, multiple sclerosis, stroke, Parkinson's disease, etc. Since the susceptibility changes the field of surrounding regions, its point spread function has broad widths with a zero mean property. These are different from other point spread functions due to T_1, T_2, or diffusion.

To overcome the nonlocal character of the phase by the susceptibility, quantitative susceptibility mapping (QSM) is suggested by solving an inverse problem from the measured phase to quantify the local susceptibility of the tissue. The QSM has also been applied to diagnoses. For example, QSM can detect the intracranial hemorrhage which causes the acute stroke and traumatic brain injury, estimate iron concentration in the brain to diagnose various neurodegenerative disorders, and visualize veins and venous oxygenation, etc.

There are, however, many sources of phase in MRI, e.g., blood flow, various chemical frequencies, main field inhomogeneity, etc. A phased array coil introduces spatially varying phase, and eddy currents induce spatially and temporally varying phase as well. Phase wrapping is an obstacle to finding a true phase. Lack of signal in the background is a limiting factor to solve QSM.

In this talk, physical principles of the susceptibility will be addressed, mostly combined with MRI. Contrast mechanism of the susceptibility will be analyzed as a function of the field strength. Susceptibility-weighted imaging will be discussed in comparison with T_1, T_2, and diffusion weighted imaging. Principles of QSM will be discussed mostly from a signal processing view point. Emphasis will be given on how to separate susceptibility-induced phase from other phase sources, especially from main field inhomogeneity. Since the susceptibility field is less than 0.2 ppm of the main field in the brain tissue, it can easily be distorted by main field inhomogeneity. We introduce a technique called Simultaneous Unwrapping Phase and Error Recovery from inhomogeneity (SUPER) for QSM, to unwrap phase and to remove inhomogeneity simultaneously. Some simulation and experimental results obtained for 3.0 Tesla and 7.0 Tesla MRI systems are shown. Potential applications of the susceptibility-based imaging in high field MRI will be discussed.

Keywords : Susceptibility, SWI, QSM, Inhomogeneity