

Asian Forum Session 1: SWI/QSM/Iron Quantification

SY07-1

## **Basic Physics of SWI and Relaxation**

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Magnetic susceptibility imaging is a clinically important imaging methodology that helps to visualize tissue iron and calcium in the brain. Recently, new methods have been developed to measure tissue magnetic susceptibility more accurately and quantitatively. In this presentation, I will review the basic physics of magnetic susceptibility and susceptibility induced relaxation. Additionally, a conventional post-processing method for SWI, which takes the advantages of both magnetic susceptibility weighted magnitude images and magnetic susceptibility weighted phase images in order to create substantially improved susceptibility contrast, will be explained in detail. Lastly, the origins of such magnetic susceptibility sources in the brain will be detailed, providing a complete picture of magnetic susceptibility imaging.

**Keywords :** SWI

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## Basic Physics of Quantitative Susceptibility Mapping (QSM)

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Magnetic susceptibility is an important biomarker for characterizing biological tissue, for example, iron deposition, calcification, fraction of oxy-/deoxy-hemoglobin in blood, and myelination of neurons. Principle of susceptibility effect in MRI signal is well known. Materials having different susceptibility in a static magnetic field alters strength of surrounding magnetic fields, and thus, resonant frequency and phase of surrounding magnetization. This susceptibility effect in phase distribution is calculated by convolving dipole kernel to susceptibility distribution.

The susceptibility effect has been used to produce image contrast: T2\*-weighted imaging (T2\*WI) and susceptibility-weighted imaging (SWI). T2\*WI reflects phase dispersion due to susceptibility in a voxel. SWI uses image processing to enhance the contrast of T2\*WI by additionally weighting phase shift due to susceptibility. These techniques has a problem that phase shift and dispersion do not show local susceptibility property but show qualitative value reflecting sum of surrounding susceptibility properties.

To overcome this problem, quantitative susceptibility mapping (QSM) has been proposed to estimate spatial distribution of susceptibility from acquired phase map. The concept of QSM is simple; however, highly accurate QSM has not been developed until recent years. The reason is that inverse problem, deconvolving the dipole kernel from phase map to generate susceptibility map, is ill-posed, because the phase shift due to susceptibility shrinks around magic angle direction and the acquired phase map is insufficient to estimate background materials. Inefficient estimation sometimes produces streaking artifacts along the magic angle direction or blurs structures of biological tissues. Recent improvements of MRI systems, especially computers and software, has been improving QSM.

QSM includes two techniques to solve the each ill-posed problem: background field removal (BFR) and field-to-susceptibility inversion (FSI). BFR is to remove susceptibility effect from material in the background and inhomogeneity due to the MRI system. There have been presented several techniques using prior knowledge about produced phase map: projection onto dipole fields (PDF), sophisticated harmonic artifact reduction for phase data (SHARP) and regularization-enabled SHARP (RESHARP). FSI is to solve ill-posed inverse problem to produce susceptibility map from background-removed phase map. There have been presented several techniques using generalized deconvolution: truncated singular value decomposition (TSVD) and morphology enabled dipole inversion (MEDl).

Although QSM has been largely improved, there remain several issues: underestimation of fine structures, streaking artifacts around materials with highly different susceptibility, chemical shift induced errors caused by fat contamination, and estimation errors at boundary regions. In order to improve accuracy in fine structures such as small veins, we have developed some techniques. One technique is multiple dipole-inversion combination with k-space segmentation (MUDICK) which applies different regularization to divided three k-space domains: low-/high-frequency and magic angle domains. Another technique is adaptive edge-preserving filtering which applies the filters in processing susceptibility map. Both technique has been demonstrated efficiency in reducing streaking artifacts while preserving accuracy in fine structure by numerical simulation and volunteer study.

Recently improved QSM have shown its usefulness in some clinical studies. Considering the current status in both technical developments and clinical application, QSM will provide useful biomarkers for diagnosing several diseases.

**Keywords :** Susceptibility, Phase, Inverse problem, Dipole

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## SWI/QSM in brain tumor

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High-grade glioma accounts for approximately 50 % of primary malignant cerebral tumors and includes glioblastoma [World Health Organization (WHO) grade IV], anaplastic astrocytoma, mixed anaplastic oligoastrocytoma and anaplastic oligodendroglioma (WHO grade III). Tumor resection followed by postoperative chemotherapy and radiation therapy (RT) is recommended as the standard of care for high-grade glioma. RT has been recognized as a potent local treatment of brain tumors, but RT also damages normal brain tissue and results in radiation-related changes seen on follow-up magnetic resonance imaging (MRI) after the completion of radiation treatment.

Several characteristic imaging features of radiation-related changes on MRI have been identified, including diffuse white matter edema-like changes, cysts and contrast-enhancing lesions. Among these changes, newly appearing contrast-enhancing lesions, usually termed as pseudoprogression or radionecrosis, receive the attention of both clinicians and neuroradiologists because these MRI lesions can mimic the recurrence of tumors. Pseudoprogression refers to acute to subacute radiation-related changes; it typically occurs within 12 weeks and may occur up to 6 months after post-irradiation. Radionecrosis, on the other hand, encompasses late radiation-related changes occurring months to years' post-irradiation. Radionecrosis is clinically different from pseudoprogression in their late onset and possible progression with requirement for additional intervention to mitigate the effect. The incidence of radionecrosis is reported between 3 % - 24 %.

Several studies have attempted to differentiate recurrence from radionecrosis by using dynamic susceptibility contrast (DSC) perfusion-weighted imaging (PWI). DSC PWI has been used to characterize tumor vascular physiology and hemodynamics. Tumor recurrence accompany with the formation of complex networks of abnormal blood vessels with increased permeability that appear as regions of hyper perfusion with higher blood volume. On the other hand, radionecrosis is associated with hypo perfusion because of treatment-induced vascular endothelial damage and coagulation necrosis. Relative cerebral blood volume (rCBV) measurements of enhancing lesions reflect an assessment of perfusion; these measurements have been correlated with vascularity, which tends to be higher in recurrence than in radionecrosis. Furthermore, DSC PWI derived parameters even can be used as significant prognosticators of response in glioblastoma.

Susceptibility-weighted magnetic resonance imaging sequences (SWMRI) are an advanced MRI sequences which encompass susceptibility-weighted angiography (SWAN, General Electric), susceptibility weighted imaging (SWI, Siemens) and venous blood oxygen level dependent (VenoBOLD, Philips) that exploit the susceptibility differences between tissues to provide contrast in different regions of the brain, allowing for much better visualization of blood and microvessels. According to preliminary reports, post-radiation changes in the brain have been related to histopathologic vascular injury or cavernous hemangioma formation. These radiation-induced vascular alterations may result in hemorrhages, which has been reported as a fatal event in association with radiation induced temporal lobe necrosis with adjacent multiple micro hemorrhages. We therefore assumed that SWMRI could thus provide additional information to differentiate recurrence from radionecrosis.

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## SWI and QSM in Stroke and Misery Perfusion

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Oxygen extraction fraction (OEF) provides information about the relative deficiencies in cerebral blood supply with the tissue's demand for oxygen, so called misery perfusion. Positron emission tomography (PET) is generally considered to be the gold standard method for OEF measurements; however, PET has several disadvantages such as limited availability and radiation exposure.

Several new approaches have been introduced to measure OEF using MRI, such as  $T2^*/T2'$  based, spin tagging, and phase based method. All of them rely on the presence of paramagnetism of deoxy-Hb, which causes spin dephasing and phase shift.

Based on SWI phase images, we have developed relative OEF map in the brain. Significant changes in OEF were seen with respiratory or acetazolamide challenges in normal subjects; however, this technique requires two SWI scans and only relative change in OEF was estimated. Recently, we have successfully developed quantitative OEF map utilizing quantitative susceptibility mapping (QSM). This technique was applied in patients with internal carotid or middle cerebral artery stenosis or occlusion, and the significant increase in OEF was clearly shown. This change had good correlation with gold standard PET-OEF images.

In conclusion, OEF measurement by MRI is feasible. QSM-based method is our novel technique and can generate absolute OEF map with single acquisition. QSM-OEF has a good correlation with PET-OEF in patients with chronic major artery stenosis or occlusive disease.

**Keywords :** SWI, QSM, Stroke, OEF, Misery perfusion