Specialty area: Methods En Vogue - How Have They Fared Over Time?

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Highlights

- SWI is based on gradient echo imaging and utilizes both magnitude and phase information to enhance susceptibility variations between tissues
- SWI visualizes veins, hemorrhages, iron deposition and calcification
- SWI provides images with high spatial resolution and excellent contrast-to-noise ratio
- Newer developments allow overcoming some limitations of SWI and provide quantitative susceptibility maps

Title: Susceptibility Weighted Imaging (SWI)

TARGET AUDIENCE: MR researchers and clinicians who are interested in understanding the basic principle of susceptibility weighted imaging, its clinical impact and newer developments.

OBJECTIVES: To review the fundamental principles of susceptibility weighted imaging and clinical applications and explore recent developments

PURPOSE: Susceptibility weighted imaging has become a fast growing field allowing to highlight tissue structures and compounds that may be difficult to detect by conventional MRI, including iron, calcifications, small veins, blood, and bones (1–6). Since its inception in 1997 (1), SWI has proven useful in a multitude of applications relating to high resolution MR venography, imaging hemorrhages from trauma, visualizing blood products and vascularization of tumors as well as relating to assessing iron deposits.

METHODS: Magnetic susceptibility is a fundamental physical property that can significantly affect MR image contrast. Using T_2*-weighted gradient echo imaging, variations of tissue magnetic susceptibility typically lead to local signal cancellations in magnitude images and causes frequency shifts in the phase. In SWI, the magnitude and the phase are combined into a single image, called the susceptibility weighted image. One particular problem with phase images, however, is that they often show phase wraps and may be dominated by non-tissue-specific background fields. By filtering the phase to remove the influence of these background fields and combining the filtered phase with the corresponding magnitude via multiplication followed by subsequent minimum intensity projection, SWI is able to dramatically enhance the contrast in a qualitative manner between tissues of differing magnetic susceptibility. More recently, impressive progress has been made in even quantifying tissue susceptibility *in vivo* by solving the inverse problem (QSM) (7-11). In fact, QSM seeks to collapse the blooming field distortions (a non-local and indirect effect) into the underlying material susceptibility itself. First clinical susceptibility mapping studies are already available and the field of new clinical applications is growing rapidly (12-14).

RESULTS: Since, in principle, SWI data can be acquired with any generic 2D or 3D gradient echo sequence, the technique can be used with all common clinical MRI scanners, making it highly robust for routine clinical work. As the contrast is based on small susceptibility differences, and the method uses gradient echo imaging with low SAR limitations, it is particularly suited for high field applications. Optimizing sequence parameters (e.g., flip angle, TR, TR, bandwidth) allows to shorten the acquisition times at higher field strengths or to trade SNR gain at higher fields against spatial resolution. Clinical applications of SWI are broad and have been continuously growing over the years. These applications involve imaging of vascular malformations, intracranial hemorrhage, iron deposition and calcifications. For example, SWI has considerably increased microbleed detection rates compared with gradient echo sequences (15) although the ultimate sensitivity to detect microbleeds also depends on slice

thickness and magnetic field strength. Common diseases where SWI has made significant impact include traumatic brain injuries (TBI), stroke, venous anomalies, multiple sclerosis (MS) and brain tumors (16-26). QSM, which represents the quantitative advancement of SWI, is also a rapidly developing and growing field that is at the cusp of translating into scientific and clinical applications (27-33).

DISCUSSION: Susceptibility-weighted imaging (SWI) has continued to develop into a powerful clinical tool. Taking advantage of phase information induced by local susceptibility changes between tissues and veins MR imaging contrast is enhanced. Although applications of SWI have so far mainly focused on the evaluation of various neurologic disorders, there appear to be also many possibilities for extending SWI to other body parts as well, including imaging vessel walls, imaging nerves, imaging calcium and imaging iron deposition in the heart and liver. Part of the success of SWI is certainly rooted in its robustness of data acquisition and its extreme high-field compatibility. Limitations of its sometimes low specificity due to hypointensities on the images (microbleeds *vs*. small veins), ambiguities between diamagnetic and paramagnetic contributions (calcifications *vs*. microhemorrhages) and the orientation-dependent, non-local phase information may be overcome by the newer development of quantitative susceptibility mapping.

CONCLUSION: Over the years SWI has found broad clinical applications, particularly in neuroimaging, but with recent extensions into imaging further body parts. Having been considered in the beginning as a highly specialized application of gradient echo imaging for delineating venous vessels only, the technique has been meanwhile adopted by major MRI vendors under different acronyms, such as SWI (Susceptibility Weighted Imaging), SWAN (Susceptibility Weighted Angiography), or PADRE (Phase Difference Enhanced Imaging) (34).

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