Research Highlights

New vistas in clinical practice: susceptibility-weighted imaging

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Abstract: Susceptibility-weighted imaging (SWI) is a recently developed magnetic resonance imaging (MRI) technique where image contrast represents 'magnetic susceptibility effects'—a natural property of tissues. The applications of SWI are rapidly increasing, with much work being carried out to determine the usefulness of the technique in multiple disease states. Current clinical applications of the technique include detection of microbleeds, subarachnoid hemorrhage (SAH), ferromagnetic deposition in neurodegenerative disease, and characterization of cerebral tumors.

Keywords: Susceptibility-weighted imaging (SWI); microbleeds; neurodegeneration

Submitted Jan 04, 2015. Accepted for publication Feb 13, 2015.
doi: 10.3978/j.issn.2223-4292.2015.03.03
View this article at: http://dx.doi.org/10.3978/j.issn.2223-4292.2015.03.03

Introduction

Susceptibility-weighted imaging (SWI) is a relatively recently developed magnetic resonance imaging (MRI) technique where the image contrast is mainly based on 'magnetic susceptibility effects'—a natural property of tissues. This property reflects the magnetic response of a substance to an external magnetic field. The difference in susceptibility between substances leads to local magnetic field inhomogeneities, which results in faster T2* relaxation (*Box 1*), leading to signal loss on MR sequences sensitive to T2* effects (1). Substances that exhibit a strong susceptibility effect are more easily detected using SWI. Examples of substances that have a strong susceptibility effect include ferromagnetic substances such as iron, paramagnetic substances including blood products and gadolinium (MR contrast agent) and diamagnetic substances such as calcium.

Box 1 The T2* effect

Protons in the body exhibit a property known as spin—which can be pictured as a nucleus spinning around its axis—and have an associated magnetic field. In the presence of an external static magnetic field, these spinning nuclei align themselves in the direction of that static magnetic field, with the net magnetisation oriented in a longitudinal direction. The application of a 90 degree radiofrequency pulse flips net magnetisation into the transverse plane. However, this state is unstable and the spinning nuclei seek to realign themselves with the static magnetic field. These nuclei, which are in phase with each other after the application of the radiofrequency pulse, immediately start to dephase from each other because of variations in molecular interactions between neighbouring nuclei and inhomogeneities in the local magnetic field. This decay in transverse magnetisation leads to a loss of signal and is described by the time constant T2*

The SWI technique (*Box 2*)

SWI employs a high resolution 3D gradient-recalled echo sequence with a long echo time and flow compensation, utilising both magnitude and phase information (1), which allows for increased sensitivity in the detection of susceptibility effects.

Box 2 The generation of the susceptibility-weighted image (*Figure 1*)

The MR signal is a complex signal, which results in the formation of real and imaginary images. The combination of these real and imaginary parts is used to form magnitude images, which give information about the magnitude of the MR signal. This is given by the equation:

$M = (R^2 + I^2)^{½}$

Phase images, which contain information about differences in magnetic field strength of a voxel compared to the static magnetic field, are also derived from these real and imaginary components and are given by the equation:

$P = \tan^{-1}(I/R)$

Magnitude images are used in conventional MR images, but the phase images traditionally have been discarded as they are sensitive to both local field inhomogeneities as well as unwanted magnetic field inhomogeneities such as magnet effects and air-tissue interface effects (18). The use of high pass filtering techniques allows large scale inhomogeneities to be removed, thereby increasing the utility of the phase images (19)

The combination of both phase and magnitude images allows a single susceptibility-weighted image to be derived. In addition, thick slice minimum intensity projection images can be generated from the post processed susceptibility-weighted image, which allow better visualization of venous structures, which contain paramagnetic deoxyhaemoglobin

SWI can also differentiate blood products and calcium. Blood products are paramagnetic and increase the local magnetic field, whereas calcium is diamagnetic and reduces the magnetic field, thus appearing different on phase images

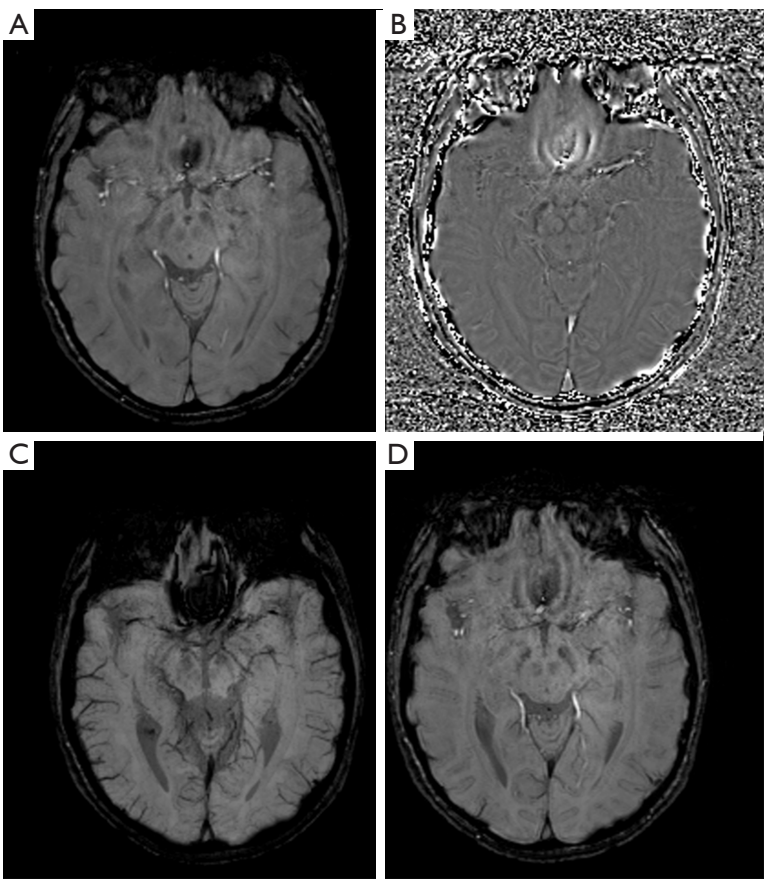

Figure 1 A normal susceptibility-weighted image. The combination of (A) magnitude and (B) phase images generates a (D) susceptibility-weighted image. The generation of (C) minimum intensity projection images allow for better visualisation of venous structures.

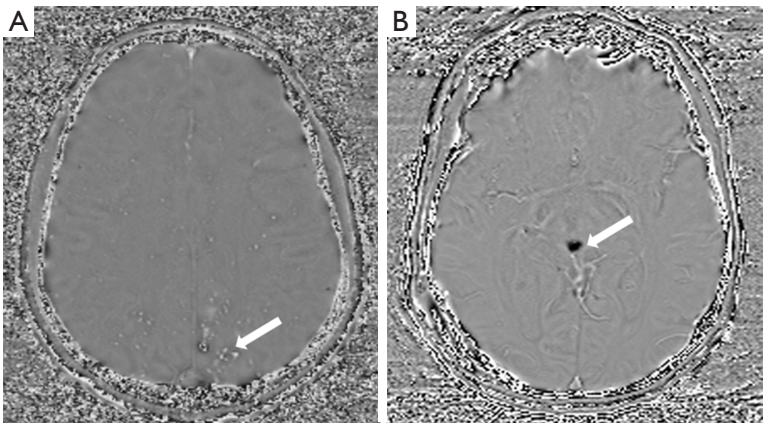

Figure 2 Phase images can be used to differentiate between (A) hemorrhage and (B) calcification (arrowed).

The phase information contains important information about differences in magnetic field strength in a particular MR voxel. As such the combination of both the phase and magnitude images into a single susceptibility-weighted image are of greater utility than magnitude images alone, for example in identifying blood products (2).

An added advantage of SWI over the current gradient echo sequences is the ability to differentiate between blood products and calcification or mineralization (3) (*Figure 2*).

Clinical applications of SWI

The applications of SWI are rapidly increasing, with much work being carried out to determine the usefulness of the technique in multiple disease states.

Cerebral microbleeds (CMBs)

The most common application of SWI currently is in the detection of CMBs. These are small rounded homogeneous foci of low signal on gradient echo sequences (4), which correlate histopathologically with blood-breakdown products (5). CMBs are commonly seen in the elderly population and tend to increase with age, affecting more than 40% of people over 80 (6).

CMBs are mainly associated with two forms of small vessel disease: hypertensive arteriopathy and cerebral amyloid angiopathy (CAA), the latter which is found commonly in Alzheimer's disease, dementia and ageing. SWI can be used to differentiate between these two forms based on the topographical distribution of CMBs. In hypertensive arteriopathy, the CMB distribution tends to be in the basal ganglia, thalamus and brainstem (*Figure 3*). In contrast, the CMBs in CAA tend to occur in a lobar distribution and at the grey-white matter interface (7) (*Figure 4*). SWI may further assist in identifying the presence of haemosiderin deposition and convexity subarachnoid hemorrhage (SAH), which are further identifying features of CAA (*Figure 4*).

The identification of CMBs in specific treatment settings is also of value in determining future risk of intracerebral hemorrhage (ICH). The presence of CMBs in patients treated with warfarin or antithrombotic drugs are at increased risk of ICH (8).

Neurodegeneration

The sensitivity of SWI to ferromagnetic substances makes it an appropriate tool to assess brain iron content (9). Elevated iron content is demonstrated in many neurodegenerative disorders including Parkinson's disease, Alzheimer's disease and Huntington's disease. In addition, iron accumulation in the basal ganglia is also seen in neurodegeneration with brain iron accumulation, a heterogeneous group of genetic extrapyramidal motor disorders that typically present at an early age.

Stroke

The use of SWI in the imaging of acute stroke may serve several purposes. By identifying underlying CMBs, it may be possible to predict the risk of developing an ICH after thrombolysis (10), as well as identifying areas of hemorrhage within an infarct (11). In addition, SWI may be useful in identifying intravascular thrombus during the acute event (12).

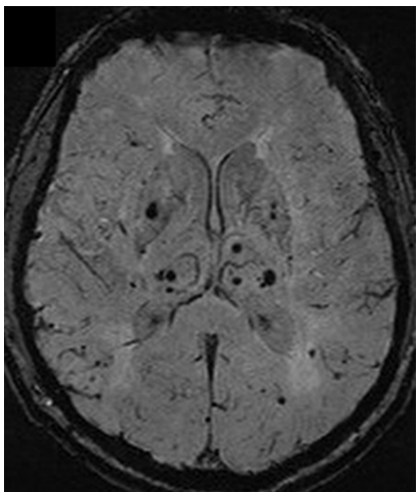

Figure 3 Cerebral microbleeds are demonstrated in an elderly patient with hypertension affecting predominantly the deep grey structures.

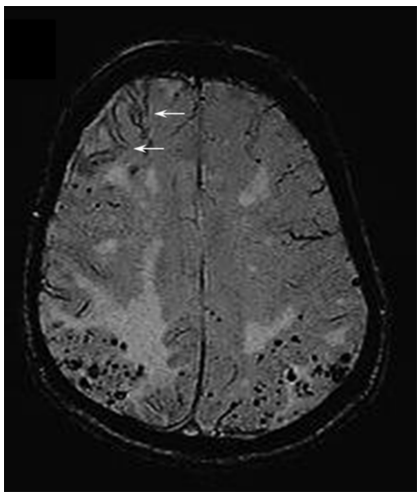

Figure 4 In a patient with cerebral amyloid angiopathy, the distribution of cerebral microbleeds is lobar. Haemosiderin staining of cortical sulci can also be seen (white arrows).

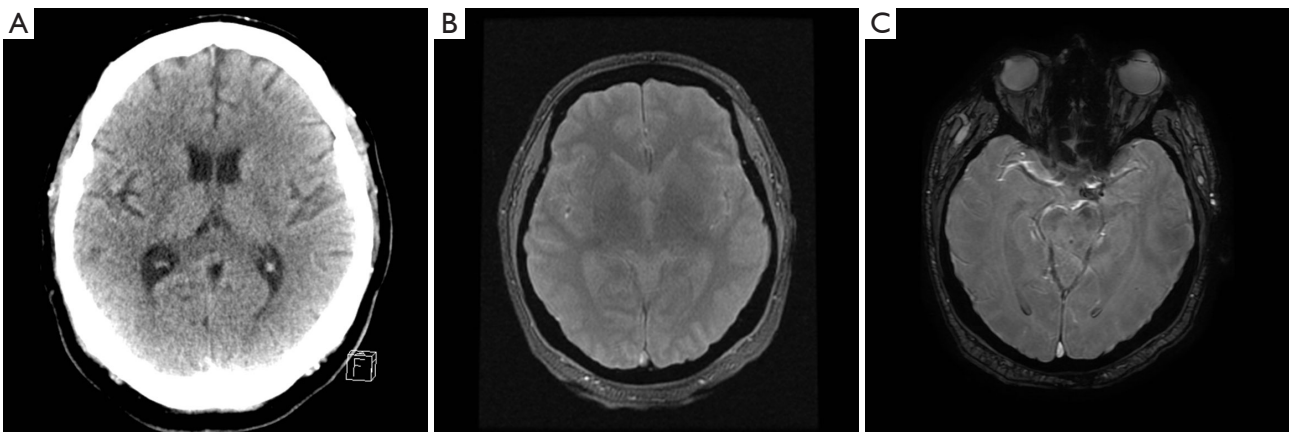

Figure 5 In a patient presenting with reduced GCS an initial CT is negative for SAH which was subsequently diagnosed by CSF photospectrometry. (A) Intraventricular blood is not evident on CT; (B) barely visible on T2* images; (C) clearly seen in both occipital horns on SWI. GCS, glasgow coma scale; SAH, subarachnoid hemorrhage; CSF, cerebrospinal fluid; SWI, susceptibility-weighted imaging.

Intracerebral tumours

SWI may be used to better characterize brain tumors, particularly in relation to the internal architecture and areas of calcification and/or intratumoral hemorrhage. This can provide additional information about the grading of a particular tumor (9).

Subarachnoid hemorrhage (SAH)

SWI has been utilized in the diagnosis of spontaneous cortical SAH (13,14) and as a diagnostic aid to localize the source of bleeding in patients with multiple cerebral aneurysms (15). SWI also appears to provide enhanced detection of traumatic SAH compared to CT (16). Our experience also indicates that SWI can identify spontaneous SAH in cases where the initial CT is negative (see *Figure 5*) supporting the findings of Verma *et al.*, 2013 (17). Further study is warranted to evaluate the effectiveness of the technique in this setting.

Conclusions

SWI has been shown to be useful in the investigation of multiple disease states, particularly in neurovascular and

neurodegenerative disorders. As such, this technique has becoming increasingly incorporated into routine MR neuroimaging protocols.

Disclosure: The authors declare no conflict of interest.

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Cite this article as: Krishnan AS, Lansley JA, Jäger HR, Mankad K. New vistas in clinical practice: susceptibility-weighted imaging. Quant Imaging Med Surg 2015;5(3):448-452. doi: 10.3978/j.issn.2223-4292.2015.03.03

