Original Article

Susceptibility weighted magnetic resonance imaging of brain: A multifaceted powerful sequence that adds to understanding of acute stroke

Deepti Naik, Sanjaya Viswamitra, Ashok A. Kumar, M. G. Srinath

Department of Radiodiagnosis, MS Ramaiah Medical College and Hospitals, Bangalore, Karnataka, India

Abstract

Context: To evaluate the additional information that susceptibility weighted sequences and datasets would provide in acute stroke. **Aims:** The aim of this study were to assess the value addition of susceptibility weighted magnetic resonance imaging (SWI) of brain in patients with acute arterial infarct. **Materials and Methods:** All patients referred for a complete brain magnetic resonance imaging (MRI) between March 2010 and March 2011 at our institution had SWI as part of routine MRI (T1, T2, and diffusion imaging). Retrospective study of 62 consecutive patients with acute arterial infarct was evaluated for the presence of macroscopic hemorrhage, petechial micro-bleeds, dark middle cerebral artery (MCA) sign and prominent vessels in the vicinity of infarct. **Results:** SWI was found to detect hemorrhage not seen on other routine MRI sequences in 22 patients. Out of 62 patients, 17 (10 petechial) had hemorrhage less than 50% and 5 patients had greater than 50% area of hemorrhage. A "dark artery sign" due to thrombus within the artery was seen in 8 out of 62 patients. Prominent cortical and intraparenchymal veins were seen in 14 out of 62 patients. **Conclusions:** SWI has been previously shown to be sensitive in detecting hemorrhage; however is not routinely used in stroke evaluation. Our study shows that SWI, by virtue of identifying unsuspected hemorrhage, central occluded vessel, and venous congestion is additive in value to the routine MR exam and should be part of a routine MR brain in patients suspected of having an acute infarct.

Key Words

Deoxyhaemoglobin, hemorrhage, infarct, ischemia, magnetic resonance imaging, susceptibility weighted imaging

For correspondence:
Dr. Deepti Naik, Department of Radiodiagnosis, MS Ramaiah Medical College and Hospitals, MSRIT Post, Bangalore - 560 054, Karnataka, India.
E-mail: drdeepti2004@hotmail.com

Ann Indian Acad Neurol 2014;17:58-61

Introduction

Magnetic susceptibility is the magnetic response of a tissue when in a magnetic field. Susceptibility weighted magnetic resonance imaging (SWI) is a relatively new MR sequence described in 2004 by Haacke *et al*.[1] that accentuates susceptibility differences in tissues such as deoxygenated blood in veins, acute hemorrhage, acute thrombus, calcium, hemosiderin, and iron exhibit susceptibility differences from their surroundings. The first three tissue states are commonly associated with acute stroke and SWI can thus improve evaluation of stroke. SWI differs from gradient echo (GRE) related susceptibility by using both magnitude and phase information and can increase the susceptibility differences, and specifically increase the conspicuity of hemorrhage almost six fold compared to GRE.

Access this article online	
Quick Response Code:	Website: www.annalsofian.org
	DOI: 10.4103/0972-2327.128555

Diffusion weighted Magnetic Resonance Imaging (MRI) has significantly improved the ability to detect stroke and continues to be the mainstay in the diagnosis of acute stroke by MRI. While SWI is not a part of the routine MR imaging of brain in most imaging centers, this technique can offer additional information such as the presence of intra-cerebral hemorrhage or micro-bleeds and the presence of spontaneous blood oxygen level dependent (BOLD) effects, which may reflect tissue viability.[2-4] The thrombosed artery, not commonly seen on a routine MRI brain with diffusion and GRE can be seen with SWI akin to bright middle cerebral artery (MCA) sign on computed tomography (CT), and appears as a "dark vessel."

This study aimed at evaluating the presence of unsuspected macroscopic hemorrhage, petechial micro-bleeds on SWI and also to evaluate for the presence of an occluded artery.

Materials and Methods

A retrospective evaluation of 88 consecutive patients with acute arterial infarcts on MRI, defined by area of diffusion restriction, was performed from March 1st 2010 to March 1st 2011. A total of 62 patients had SWI as part of a complete brain MRI exam and were included in the study.

MRI scan

Non-contrast MRI brain was performed using an 18 channel 1.5 T MRI scanner (Avanto, Siemens, Erlangen, Germany) with a head coil. The sequences performed were sagittal T1, axial T2, axial Turbo inversion recovery magnitude (TIRM), diffusion weighted imaging with B values of 0 and 1000, and SWI. The imaging parameters for SWI were repetition time of 50 ms, time to echo of 40 ms, flip angle 15°, slice thickness 2.5 mm, bandwidth 80 kHz, and field of view of 230 mm^2, and took an additional 4 min of scan time. The SWI sequence generated four sets of images: Phase, magnitude, SWI axial, and thick minimum intensity projection (mIP) images.

MRI evaluation

The MR exam was evaluated for the location of infarct, presence or absence of hemorrhage on SWI and other sequences, presence of dark vessel, presence of prominent cortical and/or intramedullary veins in the vicinity of infarct. Hemorrhage associated with stroke was further categorized as acute petechial hemorrhage if less than 50% of the infarct size and macrohemorrhage if involving more than 50% of the infarcted area as compared to the area of diffusion restriction.

Results

Of 62 patients with acute infarct included in the study, 50 were men and 12 were women, mean age of 60.5 years (29 years to 92 years). A total of 40 patients had no acute hemorrhage even on SWI. The distribution of the infarcts with hemorrhage was: Middle cerebral artery-11, posterior cerebral artery-5, anterior cerebral artery-1, superior cerebellar artery-3, anterior inferior cerebellar artery-1, and posterior inferior cerebellar artery-1. Of the 22 patients with hemorrhage, 5 patients had macro hemorrhage [Figure 1] and 17 had petechial hemorrhage within the infarct bleeds [Figure 2]. The dark artery sign [Figure 3a and c] was seen in eight patients and prominent venous vessels in the vicinity of the infarct [Figure 3b] were noted in 14 patients.

Discussion

Our results show that SWI is able to give critical information regarding hemorrhage and vessel thrombosis that could be significant in the assessment of acute stroke. The imaging assessment of stroke has evolved considerably with the use of diffusion MRI and perfusion CT and MRI leading to improved assessment of the patient particularly for thrombolytic therapy. The decision algorithm for such therapy, in addition to history and clinical assessment, commonly uses a non-contrast CT scan of the head, primarily by virtue of availability, and timeliness of acquisition of the exam. CT is used to not only assess the visualization of the stroke, but also critically for the presence of hemorrhage. MRI is however, the imaging gold standard in the diagnosis of acute infarct due to its superior ability of diffusion to depict the infarct and vessels without the need for intravenous contrast.[5-7] Both CT and MRI can give perfusion data following contrast administration. Furthermore, MRI is being looked at critically beyond the hyperacute phase of less than 3 h to extend the window for thrombolysis up to even 9 h.[5] Hence, the purpose of this study was to evaluate the additional information that susceptibility weighted datasets would provide in the setting of acute stroke.

In imaging, susceptibility is the interaction of tissue with the magnetic field with resultant loss of local signal and hence an area of low signal or "black" area on GRE sequences or SWI. SWI imaging is a relatively new tissue contrast sequence that offers several benefits. It was first proposed and patented by Haacke in 1997 and implemented on commercial scanner after 2004. SWI is a unique combination of high-resolution 3D gradient-echo imaging with full flow compensation in all three orthogonal directions to avoid unwanted background field T2* signal loss. 4 image sets are generated by this approximately 3.5 min scan. The first is a magnitude image,

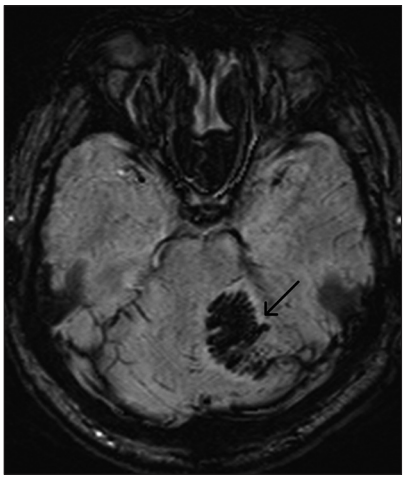

Figure 1: Susceptibility weighted magnetic resonance imaging shows hemorrhage (> 50%) (arrow) within the left cerebellar infarct

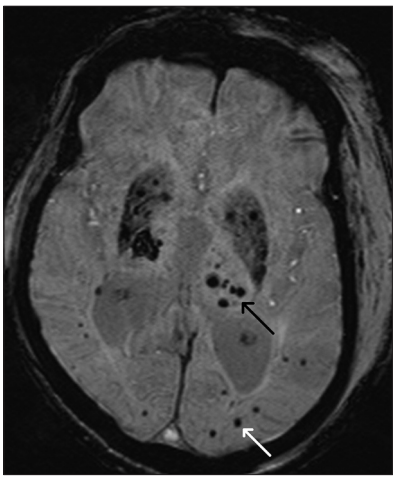

Figure 2: Susceptibility weighted magnetic resonance imaging image shows multiple micro-bleeds in basal ganglia, left thalamus (black arrow) and at the gray-white matter junction (white arrow)

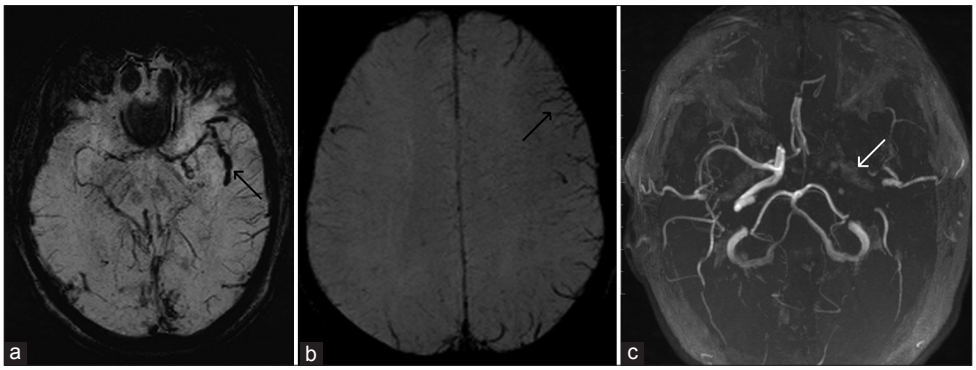

Figure 3: (a-c) Susceptibility weighted magnetic resonance imaging, (a) Dark left MCA (arrow) suggestive of thrombus in left MCA. SWI (b) Image at a higher level shows prominent cortical veins (arrow) in left cerebral hemisphere. Magnetic resonance angiography, (c) Occlusion of left MCA (arrow) with the paucity of left MCA branches

which reflects susceptibility changes similar to GRE, but almost 3-6 times more conspicuous. The phase image uses phase information (that routine MRI sequences discard), to show the phase of the susceptibility and is useful for differentiating calcification from hemorrhage. Calcium, being a diamagnetic substance, has a phase that is reverse of the hemoglobin moieties and will appear dark on a phase image opposite in contrast to that of hemorrhage, which is bright on the phase image. The phase mask is combined with the magnitude image to create the susceptibility weighted dataset, which is also depicted in a mIP is used to provide a global mIP overview.

Calcium and iron are the two other commonly deposited substances in the brain which also distort local fields and appear to be of low signal on the SWI image and can mimic hemorrhage. Calcium is differentiated on the phase images while the iron is found in predictable locations such as the globus pallidus and substantia nigra. The BOLD effect of deoxygenated hemoglobin makes it possible to visualize slow-flowing blood in small cerebral vessels on SWI images, difficult to do with current time-of-flight and phase-contrast magnetic resonance angiography (MRA) techniques.[4] The mIPs are used to establish continuity of tortuous structures; therefore gives a venogram effect to the veins allowing better appreciation of their characteristics and differentiating them from adjacent hemorrhage.

Perhaps, one of the most important determinants of thrombolytic treatment and prognosticator of improvement is the presence or absence of intra-parenchymal hemorrhage. This may be found either at the time of acute infarct or post-treatment, after reperfusion and is a feared complication of thrombolysis in acute stroke therapy. While the significance of pre-procedure hemorrhage is not clear when seen on MRI, its presence would likely grow in importance when stroke therapy is offered after 3 h of onset of symptoms.

MRI evaluation for hemorrhage has traditionally been performed with GRE imaging. All forms of hemoglobin other than oxyhemoglobin are paramagnetic with unpaired electrons with resultant susceptibility. SWI is 3-6 times better at depicting hemorrhage than GRE sequences,[8] and has been used to detect diffuse axonal injury to great success by enhanced visualization of micro-bleeds.[4,8-10] 35% of our patients had unsuspected hemorrhage. 22 of 60 patients (35.5%) of our patients had hemorrhage. (Approximately three quarters (17 of 22) had a hemorrhage in less than 50% and one quarter of our patients had a hemorrhage in more than 50% of the area of the infarct. Although, one limitation of this study was its retrospective nature and hence the clinical significance of these hemorrhages was not ascertained, the presence of unsuspected hemorrhage in our study was not an insignificant number.

Multiple cerebral micro-bleeds are seen in various micro-angiopathies most commonly hypertensive angiopathy and amyloid angiopathy. Multiple chronic micro-bleeds in the cortical-subcortical interface suggests cerebral amyloid angiopathy whereas those in basal ganglia and thalamus are more commonly seen in chronic hypertension.[11] Chronic hemorrhages in a patient with stroke may reflect the vulnerability of the vascular system and has been suggested as a predictor for future bleed particularly in patients undergoing thrombolytic therapy by some authors,[2,12,13] while others feel that this may be less of a risk when the number of micro-bleeds are small.[14] Our study found co-existing micro-bleeds away from the site of the infarct in six patients without hemorrhagic infarct and in four patients with hemorrhagic infarct.

The same physics principle of susceptibility discussed above allows for thrombus to demonstrate susceptibility and hence SWI to show thrombus within an artery at the same time allow for venous imaging from the BOLD effect.[4,11,15-18]

A potential benefit of SWI may be the detection of distally located clots, which may be missed by routine MR angiogram.[2,19] Thrombus is often not picked up in partially occluded vessels on bright blood imaging such as time of flight, which show only a narrowed artery and not the adjacent thrombus. The demonstration and accurate localization of arterial occlusion may have prognostic and therapeutic implications in acute stroke patients.[3] However, clots limited to the intracranial internal carotid artery may be overlooked because of susceptibility artefacts generated by the paranasal sinuses and the skull base and would more frequently be seen as the absence of flow voids on a T2 fast spin echo sequence. In our study, the dark vessel sign was seen in 10 out of 62 patients with acute arterial infarct with visualization of thrombus in central as well as distal arteries.

SWI can also demonstrate venous changes at an infarct. Multiple prominent hypointense veins in the vicinity of infarct thought to be due to increased oxygen extraction, increased deoxyhemoglobin concentration, and uncoupling of oxygen supply and demand in hypoperfused tissue in the vessels near infarcted area and in the penumbra.[3,17,20] In our study, multiple prominent hypointense veins were seen in 14 out of 62 cases. This could be of importance in predicting tissue at risk in the penumbra and the presence of such vessels has suggested the need for additional imaging such as dynamic contrast perfusion to estimate vascular reserve from cerebral blood flow and volume.[3]

The limitations of this study were the non-availability of clinical follow-up and relatively small sample size. To the best of our knowledge, there are only a few articles in the literature which have specifically evaluated the SWI in acute stroke using samples of patients, though there are several review articles, which discuss the use of SWI in multiple clinical conditions. We believe that our article is unique in evaluating all facets of SWI in acute stroke in a sample volume. The absence of angiographic confirmation of distal thrombus may be thought of as a limitation; however, as noted above MRA may falsely miss a thrombus that is non-occlusive in nature. We also did not perform perfusion imaging to assess the significance of the venous prominence, which the literature has described is an area of penumbra.

Conclusion

SWI is available routinely on many MRI scanners and takes only 3-5 min to perform, however, its use in acute stroke is variable. Based on our study, we believe that it needs to be part of the routine protocol for stroke. SWI has the ability to identify several parameters, which may be of prognostic value or in making therapeutic decisions such as unsuspected hemorrhage sometimes larger than 50% of the infarcted volume; the presence of arterial thrombus even when not central; concomitant micro-bleed. The identification of prominent veins in and adjacent to an area of infarct adds to our understanding of penumbra and viability.

References

1. Haacke EM, Xu Y, Cheng YC, Reichenbach JR. Susceptibility weighted imaging (SWI). Magn Reson Med 2004;52:612-8.
2. Haacke EM, Mittal S, Wu Z, Neelavalli J, Cheng YC. Susceptibility-weighted imaging: Technical aspects and clinical applications, part 1. AJNR Am J Neuroradiol 2009;30:19-30.
3. Hermier M, Nighoghossian N. Contribution of susceptibility-weighted imaging to acute stroke assessment. Stroke 2004;35:1989-94.
4. Mittal S, Wu Z, Neelavalli J, Haacke EM. Susceptibility-weighted imaging: Technical aspects and clinical applications, part 2. AJNR Am J Neuroradiol 2009;30:232-52.
5. Sehgal V, Delproposto Z, Haacke EM, Tong KA, Wycliffe N, Kido DK, *et al*. Clinical applications of neuroimaging with susceptibility-weighted imaging. J Magn Reson Imaging 2005;22:439-50.
6. Schellinger PD, Thomalla G, Fiehler J, Köhrmann M, Molina CA, Neumann-Haefelin T, *et al*. MRI-based and CT-based thrombolytic therapy in acute stroke within and beyond established time windows: An analysis of 1210 patients. Stroke 2007;38:2640-5.
7. Rosso C, Drier A, Lacroix D, Mutlu G, Pires C, Lehéricy S, *et al*. Diffusion-weighted MRI in acute stroke within the first 6 hours: 1.5 or 3.0 Tesla? Neurology 2010;74:1946-53.
8. Röther J. CT and MRI in the diagnosis of acute stroke and their role in thrombolysis. Thromb Res 2001;103:S125-33.
9. Tong KA, Ashwal S, Holshouser BA, Shutter LA, Herigault G, Haacke EM, *et al*. Hemorrhagic shearing lesions in children and adolescents with posttraumatic diffuse axonal injury: Improved detection and initial results. Radiology 2003;227:332-9.
10. Tong KA, Ashwal S, Obenaus A, Nickerson JP, Kido D, Haacke EM. Susceptibility-weighted MR imaging: A review of clinical applications in children. AJNR Am J Neuroradiol 2008;29:9-17.
11. Tong KA, Ashwal S, Holshouser BA, Nickerson JP, Wall CJ, Shutter LA, *et al*. Diffuse axonal injury in children: Clinical correlation with hemorrhagic lesions. Ann Neurol 2004;56:36-50.
12. Haacke EM, DelProposto ZS, Chaturvedi S, Sehgal V, Tenzer M, Neelavalli J, *et al*. Imaging cerebral amyloid angiopathy with susceptibility-weighted imaging. AJNR Am J Neuroradiol 2007;28:316-7.
13. Kidwell CS, Saver JL, Villablanca JP, Duckwiler G, Fredieu A, Gough K, *et al*. Magnetic resonance imaging detection of microbleeds before thrombolysis: An emerging application. Stroke 2002;33:95-8.
14. Nighoghossian N, Hermier M, Adeleine P, Blanc-Lasserre K, Derex L, Honnorat J, *et al*. Old microbleeds are a potential risk factor for cerebral bleeding after ischemic stroke: A gradient-echo T2*-weighted brain MRI study. Stroke 2002;33:735-42.
15. Derex L, Nighoghossian N, Hermier M, Adeleine P, Philippeau F, Honnorat J, *et al*. Thrombolysis for ischemic stroke in patients with old microbleeds on pretreatment MRI. Cerebrovasc Dis 2004;17:238-41.
16. Ayaz M, Boikov AS, Haacke EM, Kido DK, Kirsch WM. Imaging cerebral microbleeds using susceptibility weighted imaging: One step toward detecting vascular dementia. J Magn Reson Imaging 2010;31:142-8.
17. Haacke EM, Tang J, Neelavalli J, Cheng YC. Susceptibility mapping as a means to visualize veins and quantify oxygen saturation. J Magn Reson Imaging 2010;32:663-76.
18. Cho KH, Kim JS, Kwon SU, Cho AH, Kang DW. Significance of susceptibility vessel sign on T2*-weighted gradient echo imaging for identification of stroke subtypes. Stroke 2005;36:2379-83.
19. Chalela JA, Haymore JB, Ezzeddine MA, Davis LA, Warach S. The hypointense MCA sign. Neurology 2002;58:1470.
20. Barnes SR, Haacke EM. Susceptibility-weighted imaging: Clinical angiographic applications. Magn Reson Imaging Clin N Am 2009;17:47-61.

How to cite this article: Naik D, Viswamitra S, Kumar AA, Srinath MG. Susceptibility weighted magnetic resonance imaging of brain: A multifaceted powerful sequence that adds to understanding of acute stroke. Ann Indian Acad Neurol 2014;17:58-61.

Received: 04-02-13, **Revised:** 28-02-13, **Accepted:** 25-04-13

Source of Support: Nil, **Conflict of Interest:** Nil