# Should Susceptibility-weighted Imaging be Included in the Protocol for Evaluation of Acute Ischemic Stroke Patients?

Ranoji Shivaji Mane, Anand Kale Gowda[1], Sanath G Kamte[1], B Mohan[1], Vishnumurthy Hedna[1], Fathima Zohra[1], Umesh Krishnamurthy[1], Ashok A Kumar[1]

Department of Radiology, Gulbarga Institute of Medical Sciences, Kalaburagi, [1]Department of Radiology, M. S. Ramaiah Medical College, Bengaluru, Karnataka, India

**Correspondence:** Dr. Ranoji Shivaji Mane, #8-1545, Shivaji Building, Shivaji Nagar, Humnabad Road, Kalaburagi - 585 104, Karnataka, India. E-mail: ranoji22@gmail.com

## ABSTRACT

**Context:** Stroke is one of the leading causes of death globally and is a major cause of long-term disability. **Aims of Study:** (1) To identify hemorrhagic foci in patients with acute ischemic stroke by susceptibility-weighted imaging (SWI). (2) To compare the detection of hemorrhagic foci in patients with acute ischemic stroke by SWI versus conventional magnetic resonance imaging (MRI) (T1-weighted, T2-weighted, and fluid-attenuated inversion recovery [FLAIR]). **Materials and Methods:** Two-hundred and fifty patients, who clinically presented with neurological deficit, were evaluated using 1.5 Tesla MRI scanner from October 2011 to September 2013 with the above sequences. Detection of hemorrhage in acute infarct was evaluated and compared. **Results:** Of 250 patients evaluated in this study, 232 cases were arterial infarcts and 18 cases were venous infarcts. Hemorrhage was detected in 86 (34.4%) patients, of which 68 cases were from arterial infarcts and 18 were from venous infarcts. SWI was significantly sensitive and specific ($P < 0.004$) for the detection of hemorrhage in acute infarct compared to T1-weighted, T2-weighted, and FLAIR. **Conclusion:** SWI is a very sensitive sequence for the detection of hemorrhage in acute stroke patients. Therefore, its use is recommended in the protocol for evaluation of these patients.

**Key words:** Hemorrhage; magnetic resonance imaging; stroke; thrombolysis

## Introduction

Stroke is one of the leading causes of death globally and is a major cause of long-term disability.

The recommended standard WHO stroke definition is as follows:

"A focal (or at times global) neurological impairment of sudden onset, and lasting more than 24 h (or leading to death), and of presumed vascular origin."

Normal cerebral blood flow is in the range of 50–55 mL/100 g brain tissue/min. Experimental models have demonstrated that neuronal electrical activity ceases within the seconds of arterial occlusion.[1]

Experimental models have also shown that this loss of function generally occurs when the cerebral blood flow falls to a level of 15–20 mL/100 g/min.[2-4]

The loss of function due to ischemia can be reversible. The window of opportunity for reversing ischemic symptoms is directly related to the level to which the blood flow has dropped. A severe perfusion deficit with cerebral blood

| Access this article online | |
|---|---|
| Quick Response Code: | Website: www.wajradiology.org |
| | DOI: 10.4103/1115-3474.172094 |



**How to cite this article:** Mane RS, Gowda AK, Kamte SG, Mohan B, Hedna V, Zohra F, *et al*. Should susceptibility-weighted imaging be included in the protocol for evaluation of acute ischemic stroke patients?. West Afr J Radiol 2016;23:59-63.

flow values below 10 mL/100 g/min may lead to infarction within a matter of minutes, whereas more moderate levels of ischemia (10–20 mL/100 g/min) may be reversible for a period of hours after the start of the ischemic insult.[5]

An infarct can undergo hemorrhagic transformation with extravasation of small amounts of red cells, resulting in petechial hemorrhage, or a larger amount of blood, resulting in frank hematoma within the area of infarction. Old microbleeds have also been identified as a risk factor for bleeding after ischemic stroke. Microbleeds are probably an indicator of vascular vulnerability and contribute to cerebral bleeding.[6] Anticoagulant therapy and the use of thrombolytic agents increase the incidence of hemorrhagic transformation.

Magnetic resonance imaging (MRI) provides critical information in the diagnosis and treatment of acute stroke. Susceptibility-weighted imaging (SWI) is a novel technique that maximizes sensitivity to susceptibility effects by combining a long time to echo (TE), fully velocity-compensated three-dimensional gradient-echo (GRE) sequence with filtered phase information in each voxel to enhance the contrast in magnitude images and to add a new source of information, i.e. the susceptibility difference between tissues.[7]

### Objectives of study

- To identify hemorrhagic foci in patients with acute ischemic stroke by SWI
- To compare the detection of hemorrhagic foci in patients with acute ischemic stroke by SWI versus conventional MRI.

## Materials and Methods

### Study design

A cross-sectional study conducted in the Department of Radiology, M. S. Ramaiah Medical College and Hospitals, Bengaluru during October 2011–September 2013.

Two-hundred fifty patients, who clinically presented with neurological deficit, were evaluated using 1.5 Tesla MRI scanner (Magnetom Avanto; Siemens Erlangen, Germany).

All ages groups, sexes, and those patients with acute symptoms of stroke in whom MRI was done within 7 days were included in this study.

Causes of hemorrhage other than acute ischemic stroke such as cerebral amyloid angiopathy, follow-up MRI of asymptomatic known cases of patients with stroke or chronic stroke patients, and those patients in whom MRI is contraindicated such as cardiac pacemaker, cochlear implants were excluded from this study.

### Statistical methods

Data were entered in Microsoft Excel and were analyzed using SPSS version 17. All quantitative variables in the study were expressed in terms of descriptive statistics such as mean and standard deviation. All qualitative variables such as presence of hypertension, diabetes mellitus, gender, etc., were expressed in terms of proportion. Detection of hemorrhagic foci in patients with acute ischemic stroke by SWI versus conventional MRI was compared. $P < 0.05$ was considered statistically significant.

### Magnetic resonance imaging protocol

The following sequences were performed, sagittal T1-weighted images (WIs), axial T2-WIs, fluid-attenuated inversion recovery (FLAIR), diffusion-WI (DWI) including apparent diffusion coefficient (ADC), and SWIs. The parameters were as follows:

- T1-WI: Time to repeat (TR): 480 ms, TE: 8.7 ms; slice thickness: 5 mm; matrix size: 320 × 80; field of view (FOV): 230 mm
- T2-WI: TR: 5000 ms, TE: 92 ms; slice thickness: 5 mm; matrix size: 448 × 70; FOV: 230 mm
- FLAIR: TR: 9000 ms; TE: 92 ms; slice thickness: 5 mm; matrix size: 256 × 85; FOV: 230 mm; inversion time: 2500 ms; flip angle (FA): 150°
- DWI: Echo-planar imaging (EPI) spin-echo (SE); TR: 3600 ms; TE: 102 ms; slice thickness: 5 mm; matrix size: 192 × 100; FOV: 230 mm; b values: 0 and 1000 s/mm$^2$
- SWI: TR: 48 ms, TE: 40 ms, FA: 15°, slice thickness: 2.5 mm, inter-slice gap: 0.5 mm, bandwidth: 80 kHz and FOV: 230 mm × 200 mm, matrix: 256 mm × 192 mm, acquisition time 3 min 29 s. Four sets of images were generated including phase, magnitude, SWI, and minimum intensity projections and analyzed.

Hypointense blooming in the infarct area on SWI was considered as hemorrhage. Hyperintense areas on T1-weighted sequence, heterogeneous increased signal intensity in the infarct area on T2-weighted and FLAIR was considered hemorrhage.

The data such as patient's age, sex, clinical history, territory and type of infarct, extent of infarct, and presence or absence of hemorrhage in SWI along with extent of hemorrhage were recorded.

## Results

In this study that included 250 patients, 156 patients were male (62.4%) and 94 (37.6%) were females. In this study, the peak incidence of neurological deficits in males occurred in the age group between 60 and 69 years that is 34 cases (13.6%). In females, the peak incidence occurred in the age group between 70 and 79 years that is 29 cases (11.6%) [Table 1].

Hemorrhage was detected in 86 cases, of which 68 cases were arterial infarcts, and 18 were venous infarcts [Table 2].

Hemorrhage was seen in 56 (35.8%) of 156 male patients and 30 (31.9%) of 94 female patients. In this study of 250 cases, 232 (92.8%) patients had infarcts in the arterial territory, and 18 (7.2%) patients had venous infarcts.

**Table 1: Distribution of Age and Sex of the patients**

| Age in years | Gender *n* (%) | | Total *n* (%) |
|---|---|---|---|
| | Female | Male | |
| <20 | 6 (2.4) | 4 (1.6) | 10 (4.0) |
| 20-29 | 8 (3.2) | 14 (5.6) | 22 (8.8) |
| 30-39 | 4 (1.6) | 19 (7.6) | 23 (9.2) |
| 40-49 | 6 (2.4) | 20 (8.0) | 26 (10.4) |
| 50-59 | 16 (6.4) | 22 (8.8) | 38 (15.2) |
| 60-69 | 25 (10.0) | 34 (13.6) | 59 (23.6) |
| 70-79 | 29 (11.6) | 31 (12.4) | 60 (24.0) |
| >80 | 4 (1.6) | 8 (3.2) | 12 (4.8) |
| Total | 98 (39.2) | 152 (60.8) | 250 (100.0) |

**Table 2: Number of patients with hemorrhage in this study**

| Hemorrhage | *n* (%) |
|---|---|
| Absent | 164 (65.6) |
| Present | 86 (34.4) |
| Total | 250 (100.0) |

In this study, 30 (12%) cases had heterogeneous signal intensities in the areas of infarct, on T2-weighted and FLAIR sequences that were suggestive of hemorrhage [Figures 1 and 2].

SWI detected hypointense blooming in the areas of infarct in 86 (34.4%) of 250 cases. No hypointense blooming was seen in 164 (65.6%) cases in this study [Figures 1-3].

## Discussion

SWI is a new technique that exploits susceptibility differences in different tissues to provide a different type of tissue contrast. It is exquisitely sensitive to blood products, even more than the GRE technique, partly because of its inherent sensitivity, increased spatial resolution, and the thinner slices acquired.[8,9]

In this study that includes 250 patients, 232 cases were of arterial infarct and 18 cases of venous infarct.

Hemorrhage was detected in 86 (34.4%) patients, of which 68 cases were arterial infarcts and 18 were venous infarcts. Hemorrhage was seen in 56 (35.8%) of 156 male patients and 30 (31.9%) of 94 female patients.

It was observed that of the 232 arterial infarcts, 122 (52.5%) infarcts were present in the middle cerebral artery (MCA) territory, 62 (26.7%) in the vertebra-basilar territory,

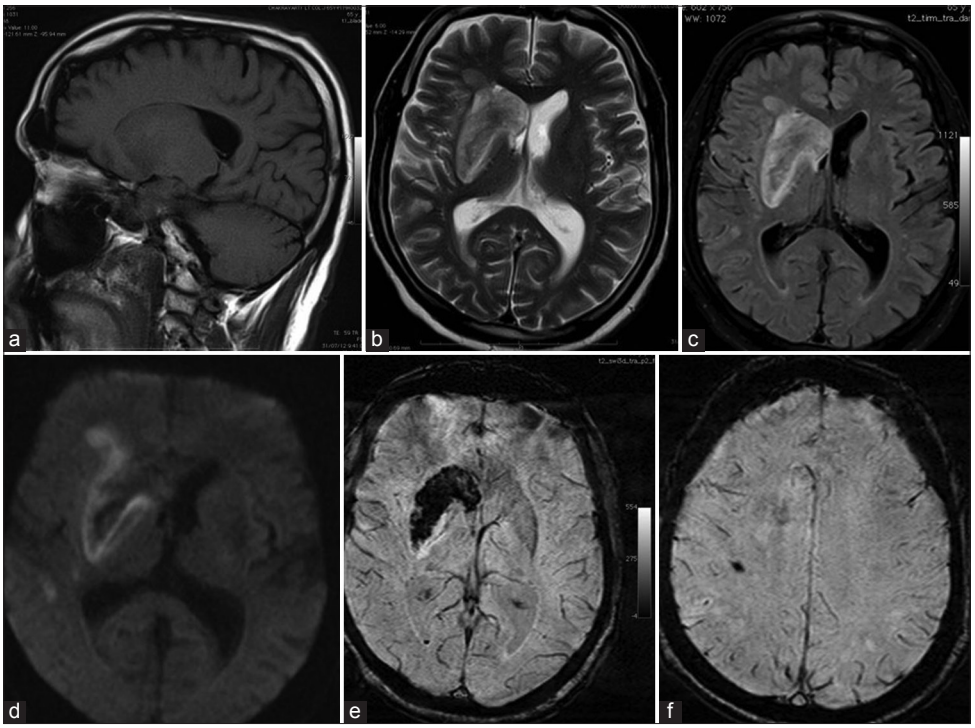


**Figure 1:** (a-f) T2 weighted and FLAIR sequence image showing heterogeneous lesion in the right basal ganglia with diffusion restriction. Susceptibility-weighted imaging shows hypointense blooming area in the right basal ganglia suggestive of hemorrhage

12 (5.1%) in the anterior cerebral artery (ACA) territory, 20 (8.6%) in the ACA-MCA watershed territory, and 16 (6.8%) in the MCA-posterior cerebral artery (PCA) territory. Of the 122 infarcts in the MCA territory, 36 (29.5%) infarcts showed hemorrhage, 18 (29.03%) of the 62 infarcts in the vertebra-basilar territory, 8 (40%) of the 20 infarcts in the ACA-MCA watershed territory, and 6 (37.5%) of the 16 infarcts in the MCA-PCA watershed territory showed hemorrhages. No hemorrhage was seen in the 12 infarcts in the ACA territory. Overall, the hemorrhagic infarcts were more common in the supratentorial region than the infratentorial region.

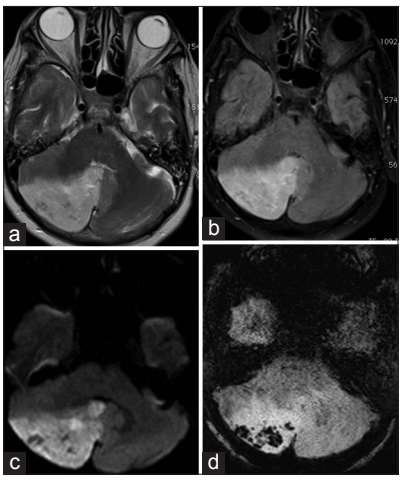


**Figure 2:** (a-d) T2 weighted and FLAIR sequence showing hyperintense lesion in the right cerebellar hemisphere with diffusion restriction. Susceptibility-weighted imaging shows hypointense blooming area in the right cerebellar hemisphere suggestive of hemorrhage

Characterization of the hemorrhage by the signal changes seen on T1-weighted, T2-weighted, FLAIR, and SWI was done. The sensitivity and specificity for the detection of hemorrhage by the above sequences were calculated and compared. Hypointense blooming in SWI sequence that is suggestive of hemorrhage was seen in 86 (34.4%) patients. Heterogeneous signal intensity on T2-weighted and FLAIR that is suggestive of hemorrhage was seen in 30 (12%) patients. Hyperintense areas on T1-weighted sequence that is suggestive of hemorrhage was seen in 12 patients (4.8%). SWI was significantly superior ($P$ = 0.003) to the T1-weighted, T2-weighted, and FLAIR sequences for the detection of the hemorrhage. Use of MRI to investigate acute parenchymal and intraventricular hemorrhage in a dog model showed that GRE was more sensitive than conventional SE T1- and T2-weighted sequences in depicting hyperacute hemorrhage. Hypointensity on GRE images appeared within 1 h of hematoma production. GRE was also superior to computed tomography (CT) in detection of these hemorrhages.[10]

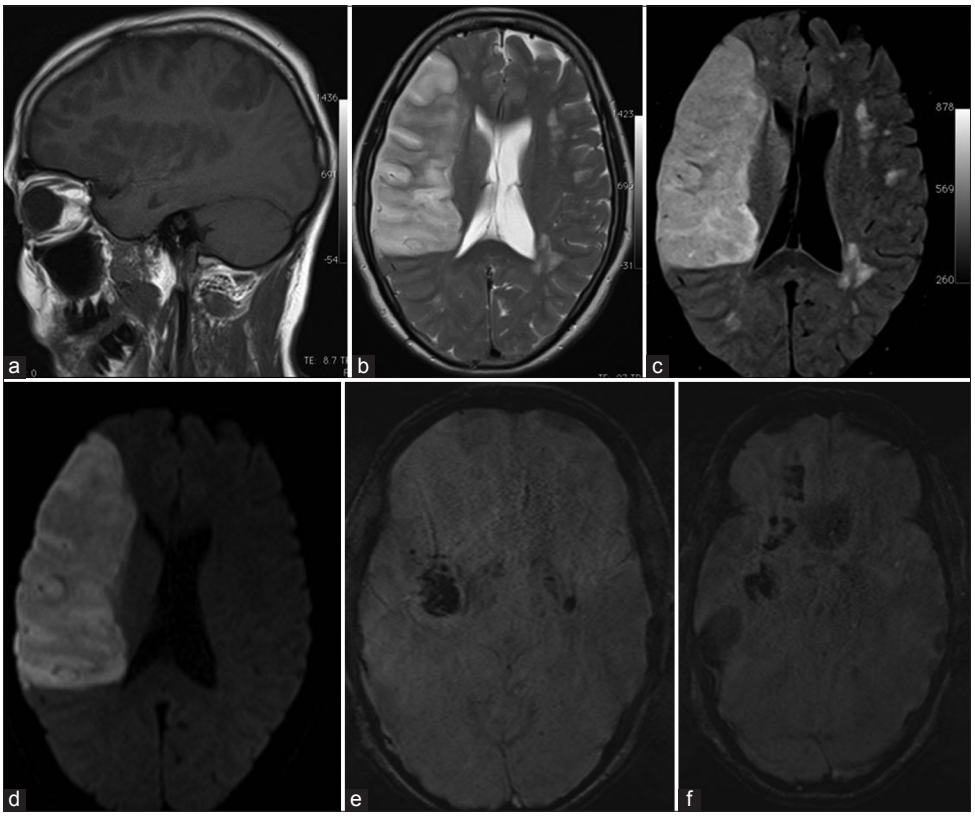


**Figure 3:** (a-e) Acute infarct in the right fronto-temporal lobe shows hypointense blooming on susceptibility-weighted imaging suggestive of hemorrhage

In another study, which compared findings from an animal model with clinical examinations, intracerebral hematoma of <24 h duration was shown to have a characteristic hypointense rim surrounding variable, heterogeneous hyperintensity on T2-weighted SE images.[11] In this study, also areas of heterogeneous signal intensity on T2-weighted and FLAIR sequences were suggestive of hemorrhage. DWI does not seem to be as specific for hemorrhage as it is for ischemic stroke, and the diagnosis of hemorrhage should be based on other sequences. Attempts to measure the ADC in intracerebral hemorrhage (ICH) are inherently flawed and systematically underestimated since any susceptibility effect will cause dephasing (i.e. lower signal intensity) at all values. Therefore, in an acute ICH, because of the susceptibility effect of deoxyhemoglobin, it would be difficult to measure correctly the ADC.[12]

The SE-EPI, turbo spin-echo (TSE) imaging, half-Fourier single-shot TSE (HASTE) imaging, and segmented HASTE (s-HASTE) imaging were inferior as compared to SWI sequence for the detection of the chronic hemorrhage.[13] SWI is sensitive for the detection of hemorrhage in hyperacute and chronic stages.

Venous infarcts are frequently hemorrhagic and SWI assists in detecting even small hemorrhages in venous infarcts. In this study, 18 venous infarcts were detected, and SWI could detect hemorrhage in all the cases.

Intra-arterial thrombolytic therapy has become a common technique for the treatment of acute ischemic stroke in tertiary care centers. However, there is inherently a risk of hemorrhagic transformation following such treatment. A prospective blinded randomized trial has confirmed that T2*GE images can detect hemorrhagic transformation within 6 h after intra-arterial thrombolysis. Because SWI is sensitive to deoxyhemoglobin, in theory, SWI could detect hemorrhagic transformation as early as several minutes after blood extravasation. Indeed, studies show that SWI can detect hemorrhagic transformation earlier than CT.[6,14,15] In our study, also SWI detected hemorrhagic transformation following intra-arterial thrombolytic therapy in 16 patients, the earliest being within 10 h of treatment.

Limited studies have evaluated the utility of SWI in acute stroke patients. Most of the studies done so far had a small sample size in evaluating the usefulness of SWI. Furthermore, studies with larger sample size can help assess the utility of SWI in acute infarct more accurately. The limitation of this study was small sample size.

## Conclusion

SWI is a novel technique that maximizes the sensitivity to susceptibility effects. SWI is very sensitive for the detection of hemorrhage in acute stroke. Therefore, SWI should be recommended in the protocol for evaluation of acute stroke. SWI can also be used for screening of intracranial hemorrhage before and after thrombolytic therapy.

### Financial support and sponsorship
Nil.

### Conflicts of interest
There are no conflicts of interest.

## References

1. Garcia JH, Mitchem HL, Briggs L, Morawetz R, Hudetz AG, Hazelrig JB, *et al.* Transient focal ischemia in subhuman primates. Neuronal injury as a function of local cerebral blood flow. J Neuropathol Exp Neurol 1983;42:44-60.
2. Bell BA, Symon L, Branston NM. CBF and time thresholds for the formation of ischemic cerebral edema, and effect of reperfusion in baboons. J Neurosurg 1985;62:31-41.
3. Hossmann KA, Schuier FJ. Experimental brain infarcts in cats. I. Pathophysiological observations. Stroke 1980;11:583-92.
4. Schuier FJ, Hossmann KA. Experimental brain infarcts in cats. II. Ischemic brain edema. Stroke 1980;11:593-601.
5. Heiss WD, Rosner G. Functional recovery of cortical neurons as related to degree and duration of ischemia. Ann Neurol 1983;14:294-301.
6. 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.
7. Reichenbach JR, Venkatesan R, Schillinger DJ, Kido DK, Haacke EM. Small vessels in the human brain: MR venography with deoxyhemoglobin as an intrinsic contrast agent. Radiology 1997;204:272-7.
8. 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.
9. Santhosh K, Kesavadas C, Thomas B, Gupta AK, Thamburaj K, Kapilamoorthy TR. Susceptibility weighted imaging: A new tool in magnetic resonance imaging of stroke. Clin Radiol 2009;64:74-83.
10. Weingarten K, Zimmerman RD, Deo-Narine V, Markisz J, Cahill PT, Deck MD. MR imaging of acute intracranial hemorrhage: Findings on sequential spin-echo and gradient-echo images in a dog model. AJNR Am J Neuroradiol 1991;12:457-67.
11. Atlas SW, Thulborn KR. MR detection of hyperacute parenchymal hemorrhage of the brain. AJNR Am J Neuroradiol 1998;19:1471-7.
12. Linfante I, Llinas RH, Caplan LR, Warach S. MRI features of intracerebral hemorrhage within 2 hours from symptom onset. Stroke 1999;30:2263-7.
13. Liang L, Korogi Y, Sugahara T, Shigematsu Y, Okuda T, Ikushima I, *et al.* Detection of intracranial hemorrhage with susceptibility-weighted MR sequences. AJNR Am J Neuroradiol 1999;20:1527-34.
14. 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.
15. Hermier M, Nighoghossian N, Derex L, Berthezène Y, Blanc-Lasserre K, Trouillas P, *et al.* MRI of acute post-ischemic cerebral hemorrhage in stroke patients: Diagnosis with T2*-weighted gradient-echo sequences. Neuroradiology 2001;43:809-15.