

The Role of Susceptibility Weighted Imaging in Evaluating Intra-Arterial Thrombus for Acute Ischemic Stroke

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Abstract: Background: Ischemic stroke is a significant cause of death and long-term disability. Thrombolytic therapy is effective for ischemic strokes treated within 4.5 hours of symptom onset. While arterial occlusions are commonly identified using digital subtraction angiography (DSA), magnetic resonance angiography (MRA), and computed tomography angiography (CTA), these methods do not provide detailed information on thrombus composition and formation time. Susceptibility weighted imaging (SWI) is gaining attention for its ability to detect thrombi in acute ischemic stroke, revealing them as hypointense susceptibility vessel signs (SVS) in the affected regions.

Results: In our study, 97 patients were found to have thrombi using MRA, with the M1 segment of the middle cerebral artery (MCA) being the most frequently affected (57.6%). SWI detected intra-arterial thrombi in 122 patients, significantly more than the 97 detected by MRA ($P = 0.0002$). All patients with thrombi identified by SWI exhibited a positive susceptibility sign. Among these patients, 88.8% had a solitary thrombus, and 11.2% had multiple thrombi. MRA did not identify any distant thrombi. Additionally, 81% of patients with an abnormally prominent vessel sign (APVS) on SWI showed parenchymal changes in these regions. The caudate nucleus, internal capsule, and lentiform nucleus were the least affected areas. All patients with an APVS had arterial occlusion, compared to only 9 patients without an APVS ($P = 0.0001$).

Conclusion: SWI is highly effective in detecting peripheral thrombi in acute ischemic stroke patients. SWI and MRA together improve the visualization of occluded vessels. We recommend incorporating SWI into routine MRI protocols for acute stroke assessment.

Keywords: MRI, Susceptibility Weighted Imaging, Magnetic Resonance Angiography, Acute Ischemic Stroke, Thrombus Detection

BACKGROUND:

Ischemic stroke is a leading cause of death and disability. Thrombolytic therapy is the only proven treatment for ischemic stroke within 3 to 4 hours of symptom onset. The nature of the thrombus may influence recanalization success, with red thrombi being more amenable to thrombolytic therapy. Additionally, the site and size of the thrombus are crucial in determining the treatment strategy. While digital subtraction angiography (DSA), magnetic resonance angiography (MRA), and computed tomography angiography (CTA) can detect intra-arterial thrombi, they do not provide information on thrombus composition and formation time.

Susceptibility weighted imaging (SWI) is a magnetic resonance imaging (MRI) technique that enhances image contrast based on tissue susceptibility differences. SWI is particularly effective in identifying hemorrhage, calcium, and non-heme iron due to its susceptibility artifacts. Although SWI is well-established in pediatric neuroimaging, its application in visualizing thrombi in acute ischemic stroke is gaining significant interest. In SWI, an intravascular thrombus appears as an abnormal dark signal known as a susceptibility vessel sign (SVS), typically presenting as a thick vessel with a dark signal. This SVS indicates locally elevated deoxyhemoglobin from trapped red blood cells in blocked vessels, suggesting an acute or sub acute thrombus.

The presence of SVS provides valuable information about the site, multiplicity, and structure of the thrombus, signifying arterial occlusion, which resolves upon recanalization. Given that thrombus composition varies, and only acute thrombi display SVS on SWI, we hypothesize that susceptibility imaging reflects both the structure and the formation time of thrombi.

The aim of this study is to evaluate the effectiveness of susceptibility weighted imaging in assessing intra-arterial thrombi in correlation with MRA and diffusion weighted imaging in patients with acute ischemic stroke.

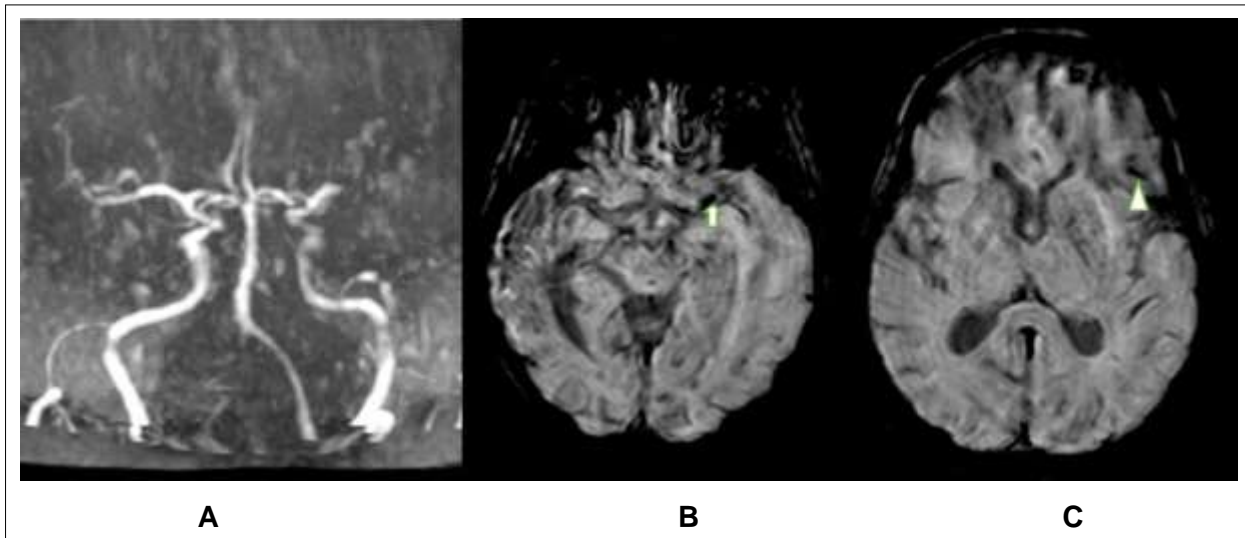
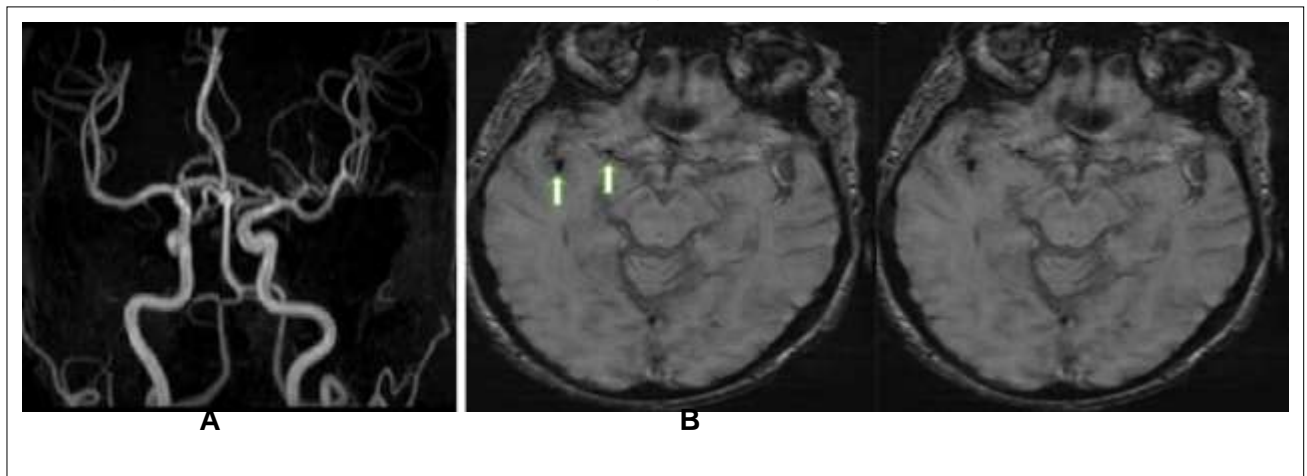


Fig. 1 MRA A shows abrupt interruption of left MCA at the level of M1 segment. SWI B, C shows two susceptibility vessel sign along M1 (white arrow), and M3 (arrow head) segments of left MCA representing two thrombi in a 61-year old woman.

Fig.2 An 52-year-old man, MRA A reveals normal filling of cerebra vessels at both sides, SWI B shows two



susceptibility vessel sign at M1 and M2 segments of right MCA

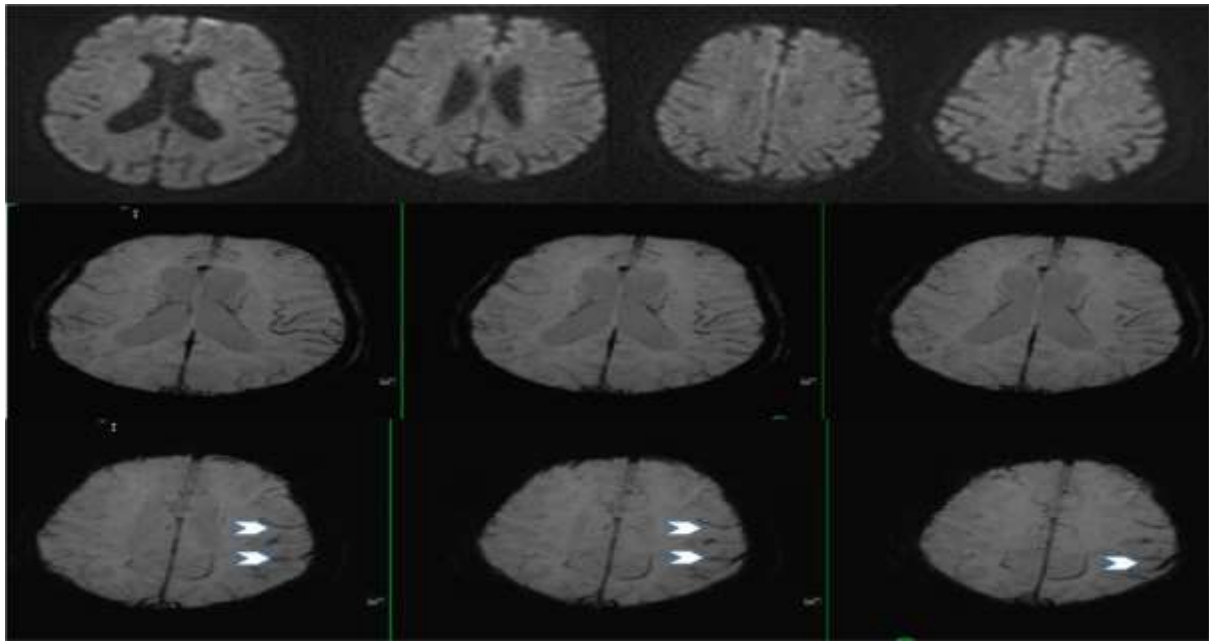


Fig.3 An 56-year-old male. DWI A shows no definite abnormality. SWI B, C revealed asymmetrical susceptibility vessel sign in the form of prominent cortical veins (arrow head) on the left cerebral hemisphere along (M1–M6) representing an area at risk.

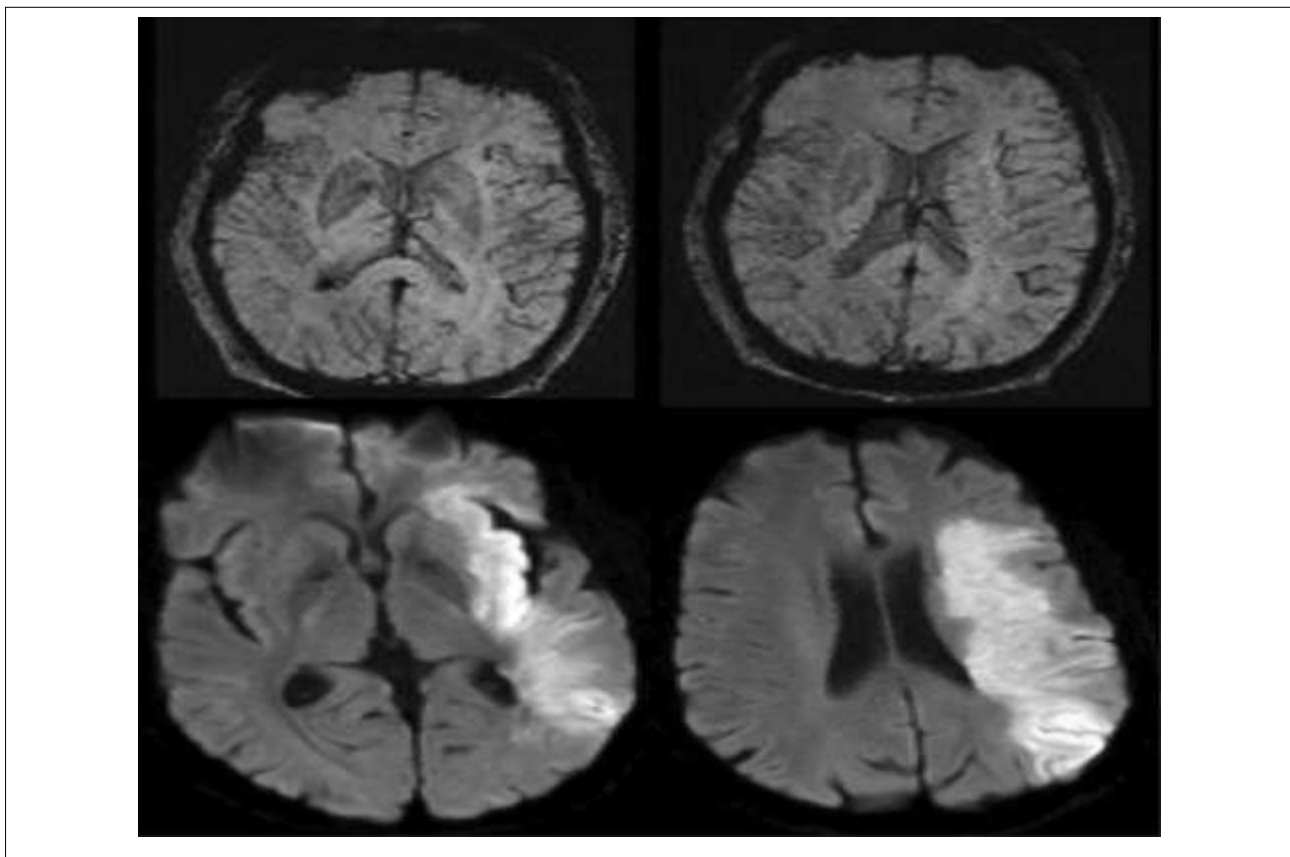


Fig.4 An 62-year-old male. SWI A, B shows abnormally prominent vessel signs.

DWI C, D shows acute left cerebral infarction.

Methods

Study Design and Population

This retrospective study included 150 patients diagnosed with ischemic stroke, aged between 30 and 70 years, with a mean age of 39.5 ± 10.4 years. The study was conducted from August 2023 to April 2024. All patients were referred for imaging to Department of RadioDiagnosis, Maharajah's Institute of Medical Sciences (MIMS), Nellimarla, Vizianagaram, within the first 24 hours of symptom onset, with a mean referral time of approximately 18 hours

INCLUSION AND EXCLUSION CRITERIA

Inclusion Criteria

- Diagnosed with acute stroke.
- Stroke symptoms persisting for more than one hour.

Exclusion Criteria

- General contraindications to MRI, such as the presence of paramagnetic substances.
- Claustrophobic patients.

MRI Technique:

Magnetic resonance imaging studies were conducted using a 1.5-Tesla Siemens Avanto Magnetom MR system magnet. Each patient underwent MRI scanning including axial fast field echo (FFE) T1, axial turbo spin-echo (TSE) T2, FLAIR (Fluid Attenuated Inversion Recovery), and diffusion-weighted imaging (DWI), in addition to the susceptibility weighted imaging (SWI) sequence and magnetic resonance angiography (MRA).

The SWI sequence was acquired with the following parameters: TR (Repetition Time) = 34 ms; TE (Echo Time) = 24 ms; flip angle = 15° ; slice thickness = 0.5 mm with 240 slices per slab; voxel size = $1.1 \times 1.1 \times 0.5$ mm; and matrix size = 208×173 . The acquisition time for SWI was 7 minutes and 57 seconds. Post-processing involved generating minimum intensity projection (minIP) images with a thickness of 10 mm to assess venous collaterals, and maximum intensity projection (MIP) images to evaluate cerebral vessels.

Image Interpretation

Images were interpreted by a Radiologist, blinded to clinical data. Intra-arterial thrombus was identified using the susceptibility vessel sign (SVS), characterized by an abnormal low signal intensity within the artery, appearing larger than the vessel size on the contra lateral side. Thrombus detection was feasible within the first week of symptom onset, with measurement taken on the slice displaying the longest SVS sign. Results were compared with findings from MRA.

Statistical Analysis

Statistical analysis was performed using SPSS software version 20 (SPSS Inc., Chicago, IL). For tests of significance (repeated measures ANOVA, Cochran's Q tests, Kappa statistics, and ROC curve analysis), p-values less than 0.05 (5%) were considered statistically significant.

RESULTS

- **Thrombus Detection:** Ninety-seven patients exhibited thrombus on MRA, with the M1 segment of the middle cerebral artery (MCA) being the most affected, representing approximately 57.6% of cases. SWI detected intra-arterial thrombus in 122 patients, significantly more than the 97 patients detected by MRA ($P = 0.0002$). All patients with thrombus displayed a positive susceptibility sign, as shown in Table 1.
- **Thrombus Characteristics:** Among patients with positive thrombus in SWI, 88.8% had solitary thrombi, while 11.2% had multiple thrombi. MRA failed to detect any distant thrombi, as shown in Table 2.
- **Segmental Analysis:** The M4, M5, and M6 segments were the most affected, while the M5 segment was the least affected. Of note, 81% of patients with an abnormally prominent vessel sign (APVS) exhibited parenchymal changes in these areas. Conversely, deep structures such as the caudate nucleus, internal capsule, and lentiform nucleus were the least affected. All patients with an APVS had arterial occlusion, whereas only 9 patients without an APVS showed arterial occlusion ($P = 0.0001$), as shown in Table 3.

- Mismatch Analysis:** A total of 102 patients demonstrated a mismatch between SWI and DWI, representing about 68% of cases. Forty-eight patients had a negative mismatch, accounting for 32% of cases, as shown in Table 4.

Table 1: SWI versus MRA in Detection of Intra-Arterial Thrombus

	Occlusion on MRA	Non-occlusion on MRA	Total
SVS	97 (100%)	25 (41.6%)	122
Non-SVS	0 (0%)	28 (58.4%)	28
Total	97	53	150

p-value: <0.0001

Table 2: SWI versus MRA in Detection of Multiple Intra-Arterial Thrombi

	Solitary thrombus	Multiple thrombi	Total
MRA	97	0	97
SWI	103	19	122

Table 3: Prominent Vessel Sign and Arterial Occlusions

	Arterial Occlusion	No Arterial Occlusion	Total
PVS	112 (91.6%)	0 (0%)	112
No PVS	10 (8.4%)	28 (100%)	38
Total	122	28	150

p-value: <0.0001

Table 4: SWI/DWI Mismatch (Penumbra)

	Positive	Negative	Total
SWI/DWI Mismatch	102	48	150

DISCUSSION:

1. **SWI in Acute Cerebral Ischemia:**

- SWI emerges as a pivotal imaging modality in acute cerebral ischemia due to its ability to provide crucial insights into the pathophysiological processes underlying ischemic stroke.
- Beyond merely detecting ischemic lesions, SWI excels in delineating the extent of tissue at risk (the ischemic penumbra) and identifying areas prone to hemorrhagic transformation. This multifaceted capability enhances its diagnostic utility and aids clinicians in making informed treatment decisions.

2. **Assessment of Intra-arterial Thrombus:**

- One of the key strengths of SWI lies in its capacity to characterize intra-arterial thrombi comprehensively.
- By leveraging the susceptibility vessel sign (SVS), SWI facilitates the identification and characterization of thrombi based on their location, length, and multiplicity.
- The SVS manifests as a distinct hypointense signal within the lumen of occluded arteries, appearing larger in diameter compared to the contra lateral vessel. This hallmark feature enables precise localization and quantification of thrombi burden, crucial for treatment planning and prognostication.

3. **Comparative Advantage Over Traditional Imaging:**

- SWI's superiority over conventional imaging modalities, such as T2* sequences and MRA, underscores its growing significance in clinical practice.
- Compared to T2* GRE, SWI demonstrates enhanced sensitivity and superior contrast resolution, particularly in detecting thrombo-embolic events across the anterior and posterior circulations.
- While MRA remains a valuable diagnostic tool, our study suggests that SWI may offer distinct advantages, particularly in defining thrombus location within specific vascular segments and identifying multiple thrombi with greater accuracy.

4. **Insights into Thrombus Distribution Patterns:**

- Our study sheds light on the varying distribution patterns of thrombi along the MCA segments, revealing a predilection for involvement in certain segments over others.
- The observed predominance of thrombi in the M1 segment underscores the importance of segment-specific analysis in understanding thrombus pathogenesis and guiding targeted therapeutic interventions.

5. **Prognostic Implications:**

- The correlation between DWI/SWI mismatch and subsequent infarction growth underscores the prognostic value of SWI in predicting stroke progression.
- Patients exhibiting a positive DWI/SWI mismatch, characterized by asymmetrical prominent vessel signs on SWI, are identified as having a higher risk of infarction growth, highlighting the utility of SWI as a prognostic indicator.

6. **Clinical Implications and Future Directions:**

- The findings advocate for the integration of SWI into routine acute stroke MRI protocols, aiming to enhance diagnostic accuracy and prognostic assessment.
- Future research endeavors may focus on validating the prognostic value of SWI in larger patient cohorts and exploring its utility in guiding personalized treatment strategies tailored to individual patient profiles.

By elaborating on these points, we provide a comprehensive understanding of SWI's role in acute cerebral ischemia, emphasizing its diagnostic and prognostic significance in clinical practice.

LIMITATIONS:

- The absence of a gold standard imaging modality poses a limitation to the current study. Consequently, we relied on the correlation of SWI findings with patient clinical data, diffusion imaging, and follow-up studies to validate our observations. While this approach provides valuable insights, it underscores the need for further validation through larger-scale studies with established gold standards.

CONCLUSIONS:

- Our study underscores the superior sensitivity of SWI over TOF angiography in detecting peripheral thrombi in patients with acute ischemic stroke. We advocate for the integration of SWI into routine acute stroke MRI protocols, as it complements existing techniques and enhances the visual detection of occluded vessels. This recommendation is based on the robust evidence presented in our study, which highlights the diagnostic utility and clinical significance of SWI in acute stroke management.

ABBREVIATIONS:

- MRI: Magnetic resonance imaging
- MRA: Magnetic resonance angiography
- SWI: Susceptibility weighted Imaging
- SVS: Susceptibility vessel sign
- APVS: Abnormally prominent vessel sign
- MCA: Middle cerebral artery
- DWI: Diffusion weighted imaging
- GRE: Gradient echo
- TOF: Time of flight
- DSA: Digital subtraction angiography
- MIP: Maximum intensity projection

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AVAILABILITY OF DATA AND MATERIALS:

- The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

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