Received: 28 January 2024 | Revised: 2 June 2024 | Accepted: 22 July 2024

DOI: 10.1002/hsr2.2285

ORIGINAL RESEARCH

Health Science Reports Open Access WILEY

Susceptibility weighted imaging for detection of thrombus in acute ischemic stroke: A cross-sectional study

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Abstract

Background and Aims: Susceptibility-weighted imaging (SWI) can help in the diagnosis of thrombus within the vessel in acute ischemic stroke, known as susceptibility vessel sign (SVS), and detection of SVS within the vessel can predict treatment modality and outcome. In this study, the purpose is to correlate the SVS on SWI with different parameters of stroke.

Methods: This prospective cross-sectional study enrolled consecutive stroke patients with vessel occlusion on magnetic resonance angiography (MRA) over 1 year. The relationship between SVS on SWI with risk factors, territory involved, and length of thrombus was correlated with the National Institutes of Health Stroke Scale (NIHSS).

Results: A total of 105 patients were enrolled in this study. Sixty-two percent (66 out of 105) of patients showed SVS on SWI with MRA-positive occlusion. A positive correlation was observed between SVS on SWI and the risk factor ($p = 0.003$, chi-square test), with 86% of patients with heart disease and 47% with hypertension exhibiting SVS. Additionally, a positive correlation was observed between SVS on SWI and territorial occlusion ($p = 0.000$, chi-square test). A moderate positive correlation was observed between the NIHSS and thrombus length ($p = 0.002$, Pearson's correlation coefficient), with a Pearson's coefficient of 0.367.

Conclusions: SWI can be useful in identifying the location of the thrombus, and NIHSS can determine the thrombus length in acute stroke. A higher incidence of SVS can be associated with risk factors, and it also depends upon the site of occlusion of the vessel.

KEYWORDS

MR angiography, stroke, susceptibility vessel sign, susceptibility weighted imaging, thrombus length

1 | BACKGROUND

Susceptibility-weighted imaging (SWI) is an MRI sequence that detects magnetic susceptibility differences among various compounds, such as blood and calcium, resulting from the distortion of the magnetic field.[1] It can identify thrombi within vessels in acute ischemic stroke (AIS) due to the paramagnetism of deoxygenated hemoglobin within trapped red blood cells (RBCs), manifesting as a distinct signal loss within the vessel.[2] Because of its superior spatial resolution, SWI exhibits a higher clot-detection rate and is considered a superior sequence for localizing blood products.[3]

SWI can reveal thrombi within occluded arteries, presenting as hypointense signals within the vessel, referred to as the "susceptibility vessel sign" (SVS).[4–6] Thrombi in strokes of cardiogenic origin are predominantly composed of RBCs, making them more commonly visible as SVS on SWI.[5]

Despite the growing utility of SWI in AIS, there remains a need for further investigation into its clinical implications and prognostic value. Understanding the relationship between SVS on SWI and various stroke parameters, such as risk factors, territory involved, and thrombus length, can enhance our ability to tailor treatment strategies and optimize patient care. In this study, we analyzed the relationship between SVS on SWI, various risk factors, and the territory involved. Additionally, we examined the length of the thrombus (TL) in relation to the National Institutes of Health Stroke Scale (NIHSS) score. The manuscript is in line with STROBE guidelines.[7]

Key points

- Sixty-two percent of patients showed susceptibility vessel sign (SVS) on susceptibility-weighted imaging (SWI) with magnetic resonance angiography (MRA)-positive occlusion, indicating the potential of SWI in assessing stroke severity.
- Positive correlations were observed between SVS and risk factors (heart disease, hypertension), territorial occlusion, and a moderate correlation between the NIH Stroke Scale (NIHSS) score and thrombus length.
- SWI is highlighted as a valuable tool due to its superior sensitivity in detecting blood products and vascular anomalies, emphasizing its role in identifying thrombus location and predicting treatment outcomes in acute ischemic stroke.

2 | METHODS

2.1 | Ethical consideration

The Institutional Review Committee of Upendra Devkota Memorial National Institute of Neurological and Allied Sciences approved the study with registration number 113/2021. All of our patients were informed about the nature of the study, and the written consent form was signed. All the patients were assured of confidentiality.

2.2 | Study design and setting

This is a prospective cross-sectional study done at Upendra Devkota Memorial National Institute of Neurological and Allied Sciences, a tertiary care hospital located in Kathmandu. All patients admitted to the hospital with stroke from July 2021 to 2022 were included in this study. The study criteria comprised individuals who met the following conditions: confirmation of anterior circulation stroke through diffusion-weighted imaging (DWI), MRI conducted within 72 h of the onset of the stroke, patients with evidence of vessel occlusion on magnetic resonance angiography (MRA), and MRI performed either before or during intravenous thrombolysis (IVT) or mechanical thrombectomy (MT). Cases of infarcts with hemorrhagic transformation were excluded from the study due to the suboptimal quantification of SVS.

2.3 | Study procedure

The MRI was conducted using a 1.5 T unit (Siemens, Magnetom, Essenza). Different parameters for SWI and MRA that was followed in the study are enlisted in Table 1.

TABLE 1 MRI protocol and parameters.

Parameter	Value/setting
SWI parameters	
Echo time (TE)	40 ms
Repetition time (TR)	29 ms
Slice thickness	0.7 mm
Flip angle	25°
Field of view (FOV)	184 × 200 mm
Intersection gap	0 mm
Matrix size	322 × 225
MRA parameters	
Echo time (TE)	7.15 ms
Repetition time (TR)	29 ms
Field of view (FOV)	168 × 200 mm
Slice thickness	0.7 mm
Flip angle	25°
Acquisition time	3 min

Abbreviations: MRA, magnetic resonance angiography; SWI, susceptibility-weighted imaging.

Two radiologists who were blinded to the clinical characteristics and other MRI images reviewed the SWI images independently. The criteria for detecting the SVS involved identifying a hypointense signal within the artery on SWI that exceeded the size of the diameter of the homologous contralateral artery (Figure 1B,D). The length of SVS within the M1 middle cerebral artery (MCA) was determined by the largest length of SVS at the particular slice. Signal loss within the vessel was termed vessel occlusion on MRA (Figure 1A,C). A vascular neurointerventionist, blinded to the clinical characteristics and other MRI images, reviewed the MRA for the detection of vessel occlusion.

2.4 | Analytical strategy

The data was analyzed in Statistical Package for Social Sciences (SPSS) software version 27.0. The statistical value was significant when as p-value was <0.05. A chi-square test was done to find out the correlation between SVS on SWI with patient risk factors and SVS on SWI with territory involved. The correlation was calculated between the size of the thrombus and the NIHSS score.

3 | RESULTS

A total of 105 patients were included in this study. The mean age of the patients in our cohort was 58 years (range: 22–87), and 62.8% of the patients were male. Hypertension was the most common associated risk factor (44 patients, 41.9%), followed by heart disease (30 patients, 28.5%). The M1 segment of the MCA was commonly involved in the study (42 patients, 40%), followed by M2 MCA (15 patients, 14.2%), and the combined M1 + M2 segment (15 patients, 14.2% each). Internal carotid artery (ICA) bifurcation (T occlusion) was observed in 19 patients (18.1%). The mean NIHSS score was 11 (range: 2–23). The baseline demographic data of the patients included in this study are shown in Table 2.

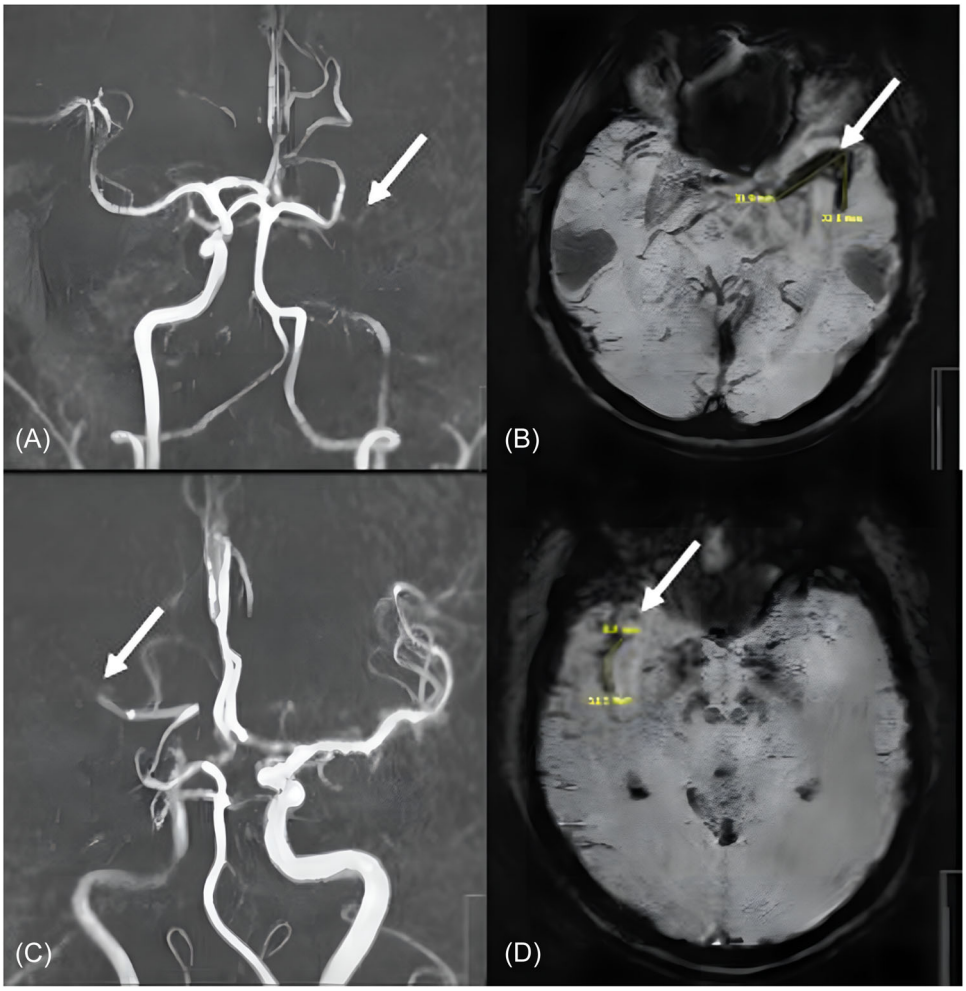

FIGURE 1 MRI of the brain showing SVS and occlusion in MRA. MRA (A) shows occlusion in distal ICA and left MCA segments. SWI (B) shows SVS in the M1 and M2 segments of the left MCA. MRA (C) shows occlusion in the M1 segment of the right MCA. SWI (D) shows SVS in distal M1 and M2 segments of the right MCA. MCA, middle cerebral artery; MRA, magnetic resonance angiography; SVS, susceptibility vessel sign; SWI, susceptibility-weighted imaging.

TABLE 2 Demographics of all the patients included in the study.

Total no of patients ($n = 105$)	Number of patients (%)
Sex	
Males	66 (62.8%)
Females	39 (37.2%)
Age (years)	
Mean age	58 years (range: 22–87)
Risk factor	
Hypertension	44 (41.9%)
Heart disease	30 (28.5%)
Tobacco use	22 (20.9%)
Type 2 diabetes mellitus	3 (2.8%)
Others	6 (5.7%)
Territory involved	
MCA M1	42 (40%)
MCA M2	15 (14.2%)
MCA M1 + M2	15 (14.2%)
T occlusion (ICA bifurcation)	19 (18.1%)
Others	15 (14.2%)
NIHSS score	
Mean	11 (range: 2–23)
SVS on SWI with MRA showing occlusion	
Present	66 (62.9%)
Absent	39 (37.1%)

Abbreviations: ICA, internal carotid artery; MCA, middle cerebral artery; MRA, magnetic resonance angiography; NIHSS, National Institutes of Health Stroke Scale; SVS, susceptibility vessel sign; SWI, susceptibility-weighted imaging.

TABLE 3 Demographics of the patients with SVS positive on SWI.

Total no of patients ($n = 66$)	No of patients (%)
Males	44 (66.7%)
Females	22 (33.3%)
Age (years)	
Mean age	56 years (range: 22–87)
Risk factor	
Hypertension	21 (31.8%)
Heart disease	26 (39.4%)
Tobacco use	14 (21.2%)
Type 2 diabetes mellitus	1 (1.5%)
Others	4 (6%)
Territory involved	
MCA M1	32 (48.4%)
MCA M2	9 (13.6%)
MCA M1 + M2	14 (21.2%)
T occlusion	1 (1.5%)
Others	10 (15.1%)
NIHSS score	
Mean	12 (range: 3–23)
Length of thrombus	
Mean (mm)	15.5 mm (range: 3–53)

Abbreviations: MCA, middle cerebral artery; NIHSS, National Institutes of Health Stroke Scale; SVS, susceptibility vessel sign; SWI, susceptibility-weighted imaging.

TABLE 4 Territory involved in patients with positive SVS on SWI.

Territory	Positive (%)
MCA M1	32/42 (76.2%)
MCA M2	9/15 (60%)
MCA M1 + M2	14/15 (93.3%)
T occlusion	1/19 (5.2%)

Abbreviations: MCA, middle cerebral artery; SVS, susceptibility vessel sign; SWI, susceptibility-weighted imaging.

In our study, SVS was present in 66 patients (62.9%) with MR angiography-positive vessel occlusion. On subgroup analysis with SVS, it was more commonly present in males (44 patients, 66.7%) than females (22 patients, 33.3%), with a mean age of 56 years (range: 22–87). Previous heart disease was more commonly associated with SVS signs in 26 patients (39.4%), followed by hypertension in 21 patients (31.8%). M1 MCA occlusion was more commonly associated with SVS in 32 patients (48.4%), followed by both M1 and M2 MCA in 14 patients (21.2%), and M2 MCA in 9 patients (13.6%). Only 1 patient (1.5%) with carotid T occlusion showed SVS in our cohort. The mean NIHSS score was 12 (range: 3–23), and the mean TL was 15.5 mm (range: 3–53) in these patients with positive SVS. Demographic analysis of the positive samples with SVS is described in Table 3.

In our cohort, 26 out of 30 patients (86%) with heart disease and 21 out of 44 patients (47%) with hypertension were found to be positive for SVS on SWI. There was a positive correlation between SVS on SWI and the patient's risk factor, as determined by the chi-square test, with a value of 11.631, a degree of freedom of 2, and $p = 0.003$. Hence, SVS on SWI can be dependent on risk factors in those patients.

Both M1 + M2 MCA occlusion showed more commonly positive for SVS in 14 out of 15 patients (93.3%), followed by M1 MCA in 32 out of 42 patients (76.2%), M2 MCA in 9 out of 15 patients (60%), and T occlusion in 1 out of 19 patients (5.2%) in our cohort. The details of the correlation were described in Table 4. A chi-square test

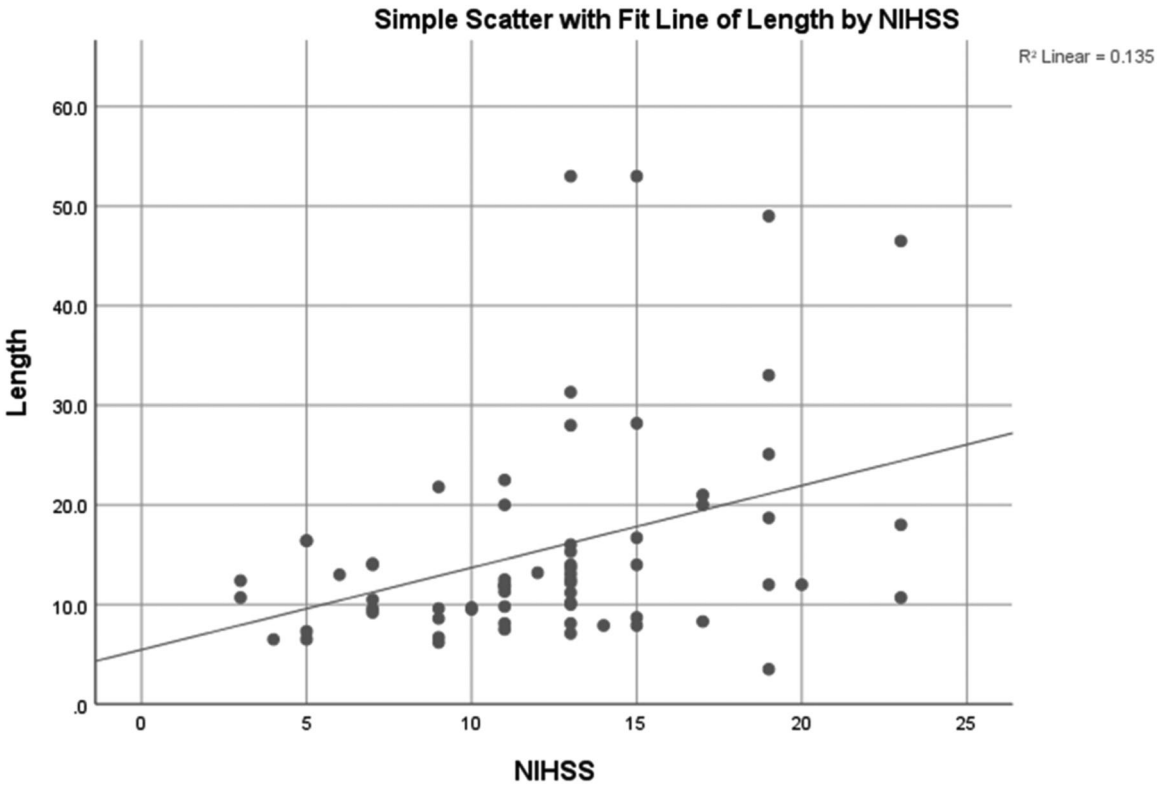

FIGURE 2 Relation of length with NIHSS score. NIHSS, National Institutes of Health Stroke Scale.

was done to find out the correlation between the SVS with territorial occlusion. The result showed a chi-square value of 35.980 with a degree of freedom of 4 and a *p*-value of 0.000, which was statistically significant. Hence, the SVS sign-on SWI is dependent on the territory involved, and since the $p < 0.01$, the result is highly significant.

The correlation between the NIHSS score and the TL was calculated using Pearson's test, and the result showed a Pearson's correlation coefficient of 0.367 and a *p*-value of 0.002. Since the value of 0.367 lies between 0.3 and 0.5, and the *p*-value is <0.05, there was a moderate correlation between the TL and NIHSS score. The details of the finding are shown in Figure 2.

4 | DISCUSSION

SWI has better sensitivity than the T2* sequence for detecting blood products and vascular anomalies such as developmental venous anomaly (DVA).[8] Therefore, it plays a significant role in the detection of thrombus within vessels in AIS, making it a major research field for stroke detection and intervention.[9]

In our study, SVS was observed in 62.8% of patients who had positive occlusion on MR angiography. SVS can be seen in 50%–85% of cases of hyperacute stroke, predominantly in RBC-rich thrombus, whereas a lack of SVS is an indicator for fibrin-rich thrombus.[10–15] Our results concluded that the SVS sign on SWI is dependent on the territory of the artery involved. In our cohort, 48% of total patients and 76% of patients with MRA positive occlusion at the level of M1 MCA territory, and 86% of total samples and 19% of total positive MRA at the level of MCA M1 + M2 territory, were found to have positive SVS on SWI.

In a similar study conducted by Bourcier et al., where 100 out of 143 (69.9%) patients were found to have positive SVS with occlusion on MCA M1 territory.[16] Another study showed that out of 217 patients, 76% of patients exhibited SVS signs, and a favorable outcome was observed with a stent retriever as a first-line procedure in that cohort.[17] Romero et al. correlated SVS with CT angiography, where 77% of patients showed SVS with CTA-positive occlusion, and M1 was the most common segment.[18] Zheng et al. studied 56 patients who presented with different stages of acute and subacute infarctions, and they observed that 39 out of 56 (55%) had M1 occlusion with SVS.[19] The reason for the lesser number of SVS in T occlusion in our study could be due to a smaller number of T occlusions or fibrin-rich clots.

In our study cohort, a significant association was found between SVS on SWI and cardioembolic stroke. Similar observations were noted in a study where GRE-SVS was frequently associated with cardioembolic stroke (77.5%) compared to strokes of other etiologies (25.5%) with $p < 0.001$.[5] Prominent vessel signs in SWI were independently associated with large vessel occlusion, anterior circulation stroke, and cardioembolism.[20] In a study conducted by Yan et al., the previous use of antiplatelets with negative SVS was inversely associated with a poor prognosis.[21]

In our study, a moderate correlation was observed between the NIHSS score and the TL, indicating a potential association with acute

stroke burden. Similar findings were reported in a study by Zheng et al., where susceptibility was positively correlated with admission to NIHSS.[19] Another study suggested that the length of SVS, with a cut-off value of 9.45 mm, could be associated with early neurologic deterioration.[22] Higher NIHSS scores with positive SVS were associated with poor outcomes[21]; however, contrasting results were found in another study, which showed that the presence of SVS on SWI was associated with better modified Rankin scale (mRS) scores at 3 months compared to cases without SVS ($p = 0.004$).[10] The presence of SVS after posttreatment is related to poor outcomes and significantly has higher NIHSS scores.[23]

The findings of this study highlight the utility of SWI in detecting thrombus location and assessing stroke severity, which could influence treatment decisions and predict outcomes in AIS. The association of SVS with cardioembolic stroke and the correlation between thrombus length and NIHSS scores suggest that SWI can be a valuable tool for personalized treatment planning.

This study had a few limitations. The sample size was relatively small, which may affect the generalizability of the findings. Selection bias could have been introduced as all patients were recruited from a single tertiary care hospital. All patients were studied using a 1.5T MRI, preventing a comparison of SVS incidence with higher field strength, such as a 3T MRI. SVS was not assessed in patients with MRA-negative strokes, and we did not evaluate SVS in the posterior circulation or after treatment in stroke cases. Future studies should aim to include larger, more diverse populations and utilize higher field-strength MRIs to validate these findings and explore the potential differences in SVS detection rates. Additionally, prospective studies could investigate the role of SVS in posterior circulation strokes and its impact posttreatment.

5 | CONCLUSION

SWI can be useful in identifying the location of the thrombus, and NIHSS can determine the thrombus length in cases of acute stroke. A higher incidence of SVS can be associated with risk factors and also depends upon the site of occlusion of the vessel. A higher length of SVS can be associated with early neurologic deterioration.

AUTHOR CONTRIBUTIONS

Subash Phuyal: Conceptualization; methodology; validation; visualization; writing—review and editing; writing—original draft; investigation; data curation; supervision; formal analysis. **Sushanta Paudel**: Conceptualization; investigation; writing—original draft; writing—review and editing; validation; visualization; methodology; formal analysis; data curation; supervision. **Suchit Thapa Chhetri**: Conceptualization; investigation; writing—original draft; methodology; validation; visualization; writing—review and editing; formal analysis; data curation; supervision. **Prakash Phuyal**: Investigation; writing—original draft; methodology; validation; visualization; writing—review and editing; formal analysis. **Sadina Shrestha**: Investigation; writing—original draft; methodology; validation; visualization; writing—review and editing. **Anzil Man Singh Maharjan**: Writing—original draft; methodology; validation; visualization; writing—review and editing.

ACKNOWLEDGMENTS

We would like to acknowledge the support and help we received from our colleagues.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Curated data that was analyzed is available from the corresponding author upon reasonable request.

TRANSPARENCY STATEMENT

The lead author Sushanta Paudel affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Phuyal S, Paudel S, Chhetri ST, Phuyal P, Shrestha S, Maharjan AMS. Susceptibility weighted imaging for detection of thrombus in acute ischemic stroke: a cross-sectional study. *Health Sci Rep*. 2024;7:e2285. doi:10.1002/hsr2.2285