Original Research Article

THREE-DIMENSIONAL SUSCEPTIBILITY WEIGHTED IMAGING AT 3 TESLA MRI: EVALUATION OF NORMAL DEEP CEREBRAL VENOUS ANATOMY AND CLINICAL APPLICATIONS IN NEUROIMAGING

S. Sreenivas[1]*, Sabarinath Eada[2], Venutharla Samson[3]

[1,2,3]Assistant Professor, Department of Radiodiagnosis, MNR Medical College and Hospital, Sangareddy, Telangana, India

A B S T R A C T

Background: Susceptibility Weighted Imaging is an advanced magnetic resonance technique that exploits magnetic susceptibility differences to enhance visualization of venous structures, hemorrhage, iron deposition, and calcification. With the advent of 3 Tesla MRI systems, SWI provides superior spatial resolution and improved signal-to-noise ratio, expanding its role in neuroimaging. This study was designed to evaluate normal deep cerebral venous anatomy using 3D SWI at 3 Tesla and to assess its clinical utility in a spectrum of intracranial pathologies.

Materials and Methods: This prospective cross-sectional study included 100 patients with clinically suspected intracranial lesions and 30 healthy volunteers. All subjects underwent MRI brain on a 3T scanner including T1, T2, FLAIR, DWI, and 3D SWI sequences. SWI images were reconstructed using filtered phase data and minimum intensity projection techniques. Imaging findings were correlated with conventional MRI sequences, and venous anatomical variants were analysed.

Results: SWI demonstrated superior sensitivity in detecting cerebral microbleeds, haemorrhagic transformation in stroke, cortical vein thrombosis, diffuse axonal injury, intratumoral hemorrhage, and developmental venous anomalies. Additional occult lesions were identified in cavernomas and traumatic brain injury cases. Evaluation of deep venous anatomy revealed predominance of Type I thalamostriate vein configuration and single-trunk anterior caudate vein pattern.

Conclusion: 3D SWI at 3 Tesla significantly enhances diagnostic accuracy in neuroimaging by improving detection of hemorrhage, thrombus, and venous anatomy. Incorporation of SWI into routine MRI protocols provides valuable clinical and preoperative information.

Keywords: Susceptibility Weighted Imaging, 3 Tesla MRI, Cerebral microbleeds, Venous anatomy, Stroke, Neuroimaging.

INTRODUCTION

Susceptibility-weighted imaging (SWI) is a high-resolution, three-dimensional gradient-echo MRI technique that combines magnitude and filtered phase information to exploit local magnetic susceptibility differences between tissues. Originally described by Haacke and colleagues, SWI produces contrast that is sensitive to paramagnetic and diamagnetic compounds and to venous blood, enabling visualization of venous architecture, microhaemorrhages, and iron deposition with far greater conspicuity than conventional T2* sequences.[1]

Clinical interest in SWI has grown substantially with higher-field scanners (3T and above) and improved coil technology, because increased field strength amplifies susceptibility effects and improves signal-to-noise ratio, permitting thinner sections and finer spatial resolution essential for detecting small lesions and vessels.[2,3] Modern SWI protocols typically generate both voxelwise susceptibility-enhanced

images and minimum-intensity-projection (minIP) slabs that reveal the continuity of tortuous veins across slices an important advantage for mapping normal venous anatomy and its variants prior to surgical or endovascular procedures.[4]

From a diagnostic perspective, SWI has proven highly valuable across a wide range of neuroimaging indications. Its sensitivity for cerebral microbleeds (CMBs) and chronic blood products exceeds that of conventional 2-D T2* GRE imaging, leading to higher lesion counts and improved detection of clinically occult haemorrhagic foci in cerebral amyloid angiopathy, hypertensive small-vessel disease, and traumatic brain injury. These differences are driven by SWI's use of phase information and thinner sections at higher field strengths.[2]

In acute cerebrovascular disease, SWI identifies characteristic vascular signs of ischemia for example, the susceptibility sign, prominent/cortical vessel sign (PVS), and asymmetrical venous prominence that reflect intraluminal thrombus, increased oxygen extraction fraction, or slow flow in hypoperfused territories. Several studies have shown that the presence and extent of these SWI signs correlate with arterial occlusion, predict infarct growth, and provide complementary information to diffusion and perfusion imaging without the need for contrast agents.[5]

Beyond stroke and microbleeds, SWI enhances characterization of developmental and acquired vascular lesions, improves detection of diffuse axonal injury and small haemorrhagic shearing in trauma, and helps differentiate tumoral calcification from hemorrhage. Quantitative post-processing methods such as quantitative susceptibility mapping (QSM) further enable estimation of iron content and oxygenation metrics, opening avenues in imaging of neurodegenerative disease and tumor microenvironment assessment.[6,7]

Given these capabilities, incorporation of high-resolution 3D SWI into routine 3 T neuroimaging protocols is increasingly advocated. This study documents the normal venous and gray white-matter susceptibility anatomy at 3 T, and evaluates the clinical utility of 3D SWI in a spectrum of cerebrovascular, traumatic, and neoplastic conditions providing practical imaging parameters and illustrative examples that emphasize how SWI complements conventional MRI sequences and informs patient management.

MATERIALS AND METHODS

This prospective cross-sectional study was conducted in the Department of Radiodiagnosis at Maheshwara Medical College and Hospital, Isnapur from January 2025 to December 2025. A total of 130 subjects were included in that 100 patients with clinically suspected intracranial pathology and 30 healthy volunteers for evaluation of deep cerebral venous system anatomy. Patients were referred for MRI brain for conditions including stroke, cerebral venous sinus thrombosis, cerebral amyloid angiopathy, cavernoma, chronic hypertensive encephalopathy, trauma, tumors, and developmental venous anomalies.

Inclusion Criteria
- Patients undergoing MRI brain including SWI on a 3T scanner
- Clinically significant intracranial lesions or cerebrovascular pathology

Exclusion Criteria
- MRI contraindications like pacemakers, metallic implants, claustrophobia
- Significant motion artifacts
- Lack of informed consent

All scans were performed on a 3 Tesla MRI system. Imaging was conducted using a Philips Healthcare Achieva TX 3T scanner with 8-channel or 16-channel phased-array head coils. The MRI protocol included T1-weighted, T2-weighted, FLAIR, DWI with ADC mapping, and 3D Susceptibility Weighted Imaging (SWI).

Table 1: Parameters for SWI Parameters.

Parameters	SWI
Recovery time (TR) ms	15 ms
Echo time (TE) ms	21 ms
Flip angle (deg)	100
Slice thickness(mm)	1 mm
Interslice spacing	Contiguous slices
Acquisition matrix	220 x 222
Scan duration	4 min 15 sec

Post-Processing and Image Analysis
SWI data were reconstructed using filtered phase images and minimum intensity projection (minIP, 3-10 mm). Images were correlated with conventional MRI sequences.

Two experienced radiologists independently evaluated for hemorrhage and microbleeds, Thrombus and cortical vein involvement, intratumoral hemorrhage/calcification, diffuse axonal injury, and venous architecture and variants (TSV and ACV types).

Statistical analysis: Descriptive statistics were used to summarize findings. A p-value <0.05 was considered statistically significant where applicable.

RESULTS

Table 1: Demographic and clinical profile of study participants.

Parameters	Total no of participants (n=100)	
	Frequency	Percentage
Age (In years)		
Up to 20	09	9%
21-40	29	29%
41-60	33	33%
61-80	28	28%
Above 80	01	1%
Gender		
Male	35	35%
Female	65	65%
Categories of brain lesions		
Cerebral sinus venous thrombosis	10	10%
Cerebral amyloid angiopathy	15	15%
Cavernoma	21	21%
Chronic hypertensive encephalopathy	09	9%
Trauma	07	7%
Tumours	20	20%
Stroke	14	14%
Developmental venous anomaly	04	4%
Stage of the condition		
Acute	09	9%
Early subacute	01	1%

Table 2: Anatomical variations of TSV and ACV.

Parameters		Frequency	
		Left	Right
TSV			
Type I	Venous angle	22	20
Type II	False venous angle	08	10
ACV			
Type I	Single trunk	27	28
Type II	Two trunks	03	0
Terminal variations of ACV			
Type-A		24	21
Type-B		05	07
Type-C		02	01
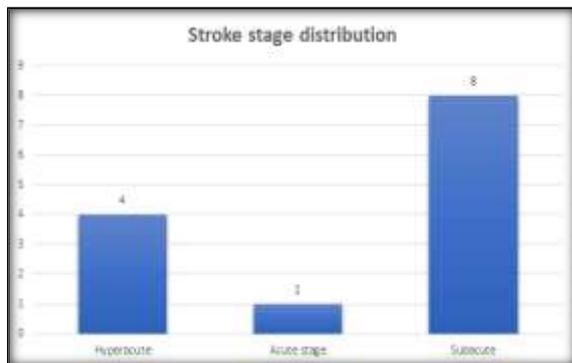
Graph 1: Stroke stage distribution.

Figure 2: MR image showing cavernoma with developmental venous anomaly in 32 years old male with complaints of headache on and off associated with redness of left eye.
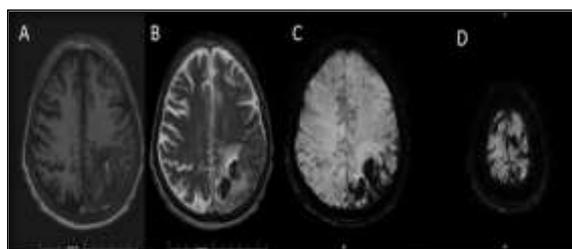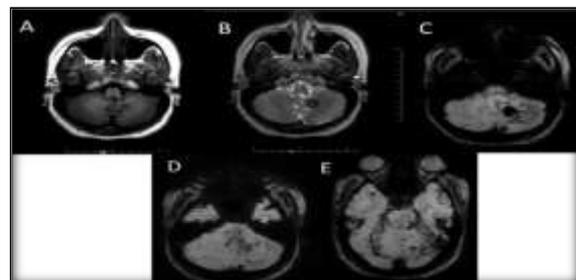
*A-Axial T1; B-Axial T2; C, D, E-SWI minIP.

Figure 1: MR image of Cerebral sinus venous thrombosis on conventional (T1, T2, and FLAIR) and susceptibility weighted sequences in 42 years old female with seizures.
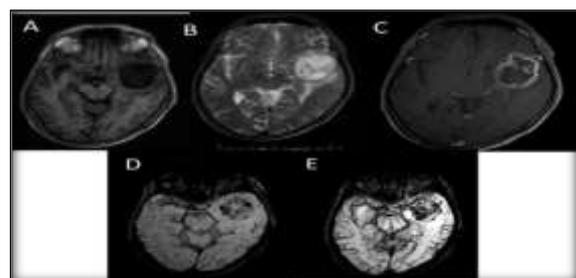
*A-Axial T1; B-Axial T2; C, D-SWI minIP

Figure 3: MR image showing tumours in 60 years old male with chief complaints of giddiness, decreased memory and slurring of speech.

*A-Axial T1; B-Axial T2; C, Axial T1 post gadolinium image; D, E- SWI minIP.

DISCUSSION

The demographic profile in our cohort showed a predominance of patients in the 41-60-year age group (33%), followed by 21-40 years (29%), consistent with epidemiological data suggesting increasing cerebrovascular and neoplastic burden in middle-aged populations. A female preponderance (65%) was observed, largely attributable to higher representation in cerebral amyloid angiopathy (CAA) and venous thrombosis cases. Similar demographic trends have been described in large neuroimaging series evaluating SWI in cerebrovascular disorders.[8]

Cerebral venous sinus thrombosis: In our study, SWI demonstrated hypointense blooming within thrombosed sinuses and cortical veins in all cases of cerebral sinus venous thrombosis (CSVT), with better depiction of haemorrhagic transformation than conventional sequences. These findings align with Idbaih et al. (2006), who reported superior visualization of thrombosed cortical veins using susceptibility-sensitive sequences. SWI exploits the paramagnetic properties of deoxyhemoglobin and methemoglobin, thereby accentuating thrombus conspicuity.[9] Our results reinforce the growing consensus that SWI should be integrated into routine MRI protocols for suspected venous thrombosis, particularly when MR venography findings are equivocal.

Cerebral amyloid angiopathy and chronic hypertensive encephalopathy: Among patients with CAA and chronic hypertensive encephalopathy, SWI identified multiple microbleeds not visualized on T1, T2, or FLAIR imaging. The lobar distribution in CAA and deep gray nuclei involvement in hypertensive microangiopathy observed in our cohort corresponds with established pathophysiological patterns.[2] The sensitivity of SWI in detecting cerebral microbleeds has been shown to be nearly double that of conventional GRE sequences, improving diagnostic confidence and risk stratification for anticoagulation therapy. Goos et al. (2011) similarly reported higher prevalence rates of microbleeds on SWI compared with GRE, underscoring its clinical relevance.[10]

Cavernomas and developmental venous anomalies: Cavernomas represented 21% of cases in our series. SWI detected additional occult lesions and better delineated associated developmental venous anomalies (DVA) [Figure 2]. These findings are consistent with de Souza et al. (2008), who demonstrated significantly higher lesion counts using SWI compared to T2-weighted imaging. The blooming effect seen on SWI enhances visualization of hemosiderin-laden lesions, improving detection of small or familial cavernomas.[11] The ability to demonstrate venous architecture in DVAs noninvasively provides additional surgical planning value.

Traumatic brain injury: In trauma patients, SWI revealed multiple punctate microhaemorrhage consistent with diffuse axonal injury (DAI) that were inconspicuous on conventional imaging. Liu et al. (2015) reported similar superiority of SWI over T2*WI in detecting haemorrhagic foci in mild traumatic brain injury.[12] The detection of microbleeds in the corpus callosum and gray-white matter junction, as seen in our cohort, has prognostic implications, correlating with clinical severity and outcome.

Intracranial tumors: SWI added significant diagnostic value in tumor characterization. In glioblastomas, multiple intratumoral blooming foci corresponded to hemorrhage and neovascularity, paralleling observations by Sehgal et al. (2006). Metastatic lesions also demonstrated haemorrhagic components more clearly on SWI. Conversely, primary CNS lymphomas showed minimal susceptibility effects, aiding differentiation from high-grade gliomas.[13] This differential blooming pattern may serve as a non-invasive biomarker in preoperative assessment.

Acute and subacute stroke: In stroke patients, SWI identified susceptibility vessel sign in hyperacute cases and haemorrhagic transformation in subacute infarcts, consistent with Wycliffe et al. (2004). Early detection of intraluminal thrombus and microhaemorrhage is clinically critical, particularly in patients undergoing thrombolytic therapy.[14] Kidwell et al. (2002) highlighted the prognostic importance of microbleeds prior to thrombolysis.[15] Our findings corroborate the role of SWI in acute stroke protocols.

Deep cerebral venous anatomy: Evaluation of deep venous system variants in 60 hemispheres demonstrated predominance of Type I thalamostriate vein (TSV) configuration (70%), comparable to frequencies reported by Zhang et al. (2015).[16] The high incidence of single-trunk anterior caudate vein (ACV) (94.8%) and Type A terminal variation align with previously published anatomical studies. Preoperative identification of venous angles and tributary patterns is essential during transcallosal or third ventricular surgical approaches. SWI, through high-resolution minIP reconstruction, provides detailed venographic mapping without contrast administration.

The strengths of this study include the use of high-field 3T MRI, standardized SWI parameters, and independent evaluation by experienced radiologists. However, limitations include a single-center design and lack of histopathological correlation in all tumor cases.

CONCLUSION

This study demonstrates that 3D Susceptibility Weighted Imaging (SWI) at 3 Tesla significantly enhances the detection and characterization of intracranial pathologies compared with conventional

MRI sequences. SWI proved highly sensitive in identifying microbleeds, haemorrhagic transformation, cortical vein thrombosis, intratumoral hemorrhage, and diffuse axonal injury. It also provided superior visualization of developmental venous anomalies and detailed assessment of deep cerebral venous system variants, offering valuable preoperative information. The integration of SWI into routine neuroimaging protocols improves diagnostic accuracy, aids therapeutic decision-making, and contributes to better patient management across cerebrovascular, traumatic, and neoplastic brain disorders.

REFERENCES

1. Haacke EM, Xu Y, Cheng YC, Reichenbach JR. Susceptibility weighted imaging (SWI). Magn Reson Med. 2004;52(3):612-618.
2. Nandigam RN, Viswanathan A, Delgado P, et al. MR imaging detection of cerebral microbleeds: effect of susceptibility-weighted imaging, section thickness, and field strength. AJNR Am J Neuroradiol. 2009;30(2):338-343.
3. Nair JR, Van Hecke W, De Belder F, et al. High-resolution susceptibility-weighted imaging at 3 T with a 32-channel head coil: technique and clinical applications. AJR Am J Roentgenol. 2010;195(4):1007-1014.
4. Halefoglu AM, Yousem DM. Susceptibility weighted imaging: Clinical applications and future directions. World J Radiol. 2018 Apr 28;10(4):30-45.
5. Chen CY, Chen CI, Tsai FY, Tsai PH, Chan WP. Prominent vessel sign on susceptibility-weighted imaging in acute stroke: prediction of infarct growth and clinical outcome. PLoS One. 2015 Jun 25;10(6):e0131118.
6. Cheng AL, Batool S, McCreary CR, Lauzon ML, Frayne R, Goyal M, Smith EE. Susceptibility-weighted imaging is more reliable than T2*-weighted gradient-recalled echo MRI for detecting microbleeds. Stroke. 2013;44(10):2782–6.
7. Schaefer PW, Huisman TA, Sorensen AG, Gonzalez RG, Schwamm LH. Diffusion-weighted MR imaging in closed head injury: high correlation with initial glasgow coma scale score and score on modified Rankin scale at discharge. Radiology. 2004; 233:58-66.
8. Greenberg SM, Vernooij MW, Cordonnier C, Viswanathan A, Al-Shahi Salman R, Warach S, et al. Cerebral microbleeds: A guide to detection and interpretation. Neurology. 2009;72(11):995-1002.
9. Idbaih A, Boukobza M, Crassard I, Porcher R, Bousser MG, Chabriat H. MRI of clot in cerebral venous thrombosis: High diagnostic value of susceptibility-weighted imaging. Neurology. 2006;66(7):1007-8.
10. Goos JDC, van der Flier WM, Knol DL, Pouwels PJW, Scheltens P, Barkhof F, et al. Clinical relevance of improved microbleed detection by susceptibility-weighted magnetic resonance imaging. Stroke. 2011;42(7):1894-900.
11. de Souza JM, Domingues RC, Cruz LCH Jr, Domingues FS, Iasbeck T, Gasparetto EL. Susceptibility-weighted imaging for the evaluation of patients with familial cerebral cavernous malformations. AJNR Am J Neuroradiol. 2008;29(1):154-8.
12. Liu G, Bales JW, Lee S, Wong C, Yan Y, Li Y, et al. Susceptibility-weighted imaging and quantitative susceptibility mapping in traumatic brain injury. J Clin Neurosci. 2015;22(6):1016-21.
13. Sehgal V, Delproposto Z, Haacke EM, Tong KA, Wycliffe N, Kido DK, et al. Clinical applications of neuroimaging with susceptibility-weighted imaging. AJNR Am J Neuroradiol. 2005;26(10):2521-31.
14. Wycliffe ND, Choe J, Holshouser B, Oyoyo U, Haacke EM, Kido DK. Reliability in detection of hemorrhage in acute stroke by susceptibility-weighted imaging compared with conventional MR imaging. AJNR Am J Neuroradiol. 2004;25(9):1578-84.
15. Kidwell CS, Chalela JA, Saver JL, Starkman S, Hill MD, Demchuk AM, et al. Comparison of MRI and CT for detection of acute intracerebral hemorrhage. Stroke. 2004;35(8):1826-31.
16. Zhang X, Wang J, Liu T, Dai Y, Chen Y, Wang Y. Three-dimensional susceptibility-weighted imaging of the deep cerebral veins: Normal anatomy and variations. PLoS One. 2015;10(5): e0127199.