Original Article

Evaluation of the role of susceptibility-weighted imaging (SWI) as a new complementary sequence in routine brain MRI

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Abstract

Background: Susceptibility-weighted imaging (SWI), an advanced MRI technique, has a high sensitivity in detecting microvascular changes, hemorrhages, and calcifications, thereby improving the diagnosis and management of various neurological pathologies. This study evaluated the frequency of abnormal findings in SWI sequence in patients with brain pathologies referred to Loghman Hakim Hospital.

Materials and Methods: This cross-sectional study was conducted on patients with various brain pathologies who underwent brain MRI with SWI sequence at Loghman Hakim Hospital from October 2021 to October 2022. The frequency of different brain pathologies in the SWI sequence was assessed.

Results: A total of 157 brain pathologies were evaluated. In 129 cases (82.2%), the most probable lesion diagnosis was only found in the SWI sequence. Thrombosis in veins was found in all cerebral venous thrombosis (CVT) patients in SWI and other sequences. Hemorrhage in venous infarct was observed in 20% of CVT cases. In patients with vascular malformations, the diagnosis of cavernoma was made in 9 patients (81.8%) and capillary telangiectasia in 2 patients (18.2%).

Conclusion: The findings of this study demonstrated the significant role of SWI in evaluating various brain pathologies, especially in cases where routine MRI sequences are not diagnostic. Therefore, we recommend using SWI in routine brain MRI.

Keywords: Brain, Magnetic resonance imaging, Pathology

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Introduction

The Susceptibility Weighted Imaging (SWI) sequence is an advanced 3D MRI sequence based on gradient-recall echo[1]. The SWI sequence has a higher ability to detect cases such as microhemorrhages and microvascular changes[2-5]. This sequence is highly sensitive to identifying and displaying magnetic substances such as deoxygenated hemoglobin, hemosiderin, ferritin, and calcium. This ability is especially useful in evaluating neurological diseases, grading tumors, and the assessment of the progress of the disease and the treatment process[6-9].

In recent years, SWI has found many applications in neurosurgery, neurooncology, vascular neurosurgery, and neurotraumatology[10-12]. Various studies have shown that SWI has a higher sensitivity than routine MRI (such as T1, T2, FLAIR, Proton Density (PD), Diffusion-weighted imaging (DWI), Apparent diffusion coefficient (ADC), and Contrast-Enhanced (CE) T1) in detecting the vessels, internal structure, and bleeding of tumors[12-13].

The SWI sequence is also helpful in identifying and characterizing traumatic brain injury (TBI) and hemorrhagic and non-hemorrhagic diffuse axonal injury (DAI) cases[14]. Studies conducted on the functions of SWI show that this sequence is more sensitive in detecting vascular malformations than other MRI sequences[15, 16].

Although SWI has many advantages over routine MRI, especially in vascular and hemorrhage evaluation, this technique is associated with limitations, such as a long time duration for performing the sequence, which may cause discomfort and movement of the patient, resulting in increased artifact. Also, the SWI sequence is prone to air-tissue and bone structure artifacts. There are limited studies about the frequency of SWI abnormal findings[17-19]. In the present study, we evaluated the frequency of abnormal findings of SWI sequence in brain pathologies to conclude that SWI is necessary for the correct diagnosis of various CNS pathologies and should be performed in routine brain MRI studies.

Methods

This is a cross-sectional study. This study was conducted on patients diagnosed with brain pathologies in Loghman Hakim Hospital from October 2021 to October 2022. The inclusion criteria were involvement with cerebral pathologies, including demyelinating disorders, stroke, malignancies, brain trauma, cerebral vascular thrombosis, vascular malformation, and cerebral micro-bleeds. The exclusion criteria were lack of SWI sequence for the patient, a time gap between the SWI sequencing and other sequences, and lack of access to the MRI.

After identifying the eligible cases to enter the study, two expert radiologists extracted and recorded the patient's SWI sequence and other available sequences. If there was a difference in radiologists' ideas, a third expert radiologist decided about the imaging.

The assessed diseases in this study were as follows:

1. Demyelinating

a. Central vessel sign in multiple sclerosis (MS)

b. Peripheral rim sign in MS

c. Hypointense rim in progressive multifocal leukoencephalopathy (PML)

2. Stroke (arterial)

a. Susceptibility vessel sign in arterial stroke

b. Asymetrically prominent cortical veins in arterial stroke

c. Hemorrhagic transformation in arterial stroke

3. Neoplasms

a. Intratumoral hemorrhage (grade 0-1-2-3)

4. Infective

a. Dual rim sign in brain abscess

5. Trauma

a. Superficial siderosis

b. Diffuse axonal injury (DAI)

6. CVT

a. Hemorrhage in venous infarct

b. Thrombosis in veins

7. Vascular malformation

a. Cavernoma (single-multiple)

b. Developmental venous anomalies (DVA)

c. Capillary telangiectasia

8. Cerebral microbleeds

a. Hypertensive encephalopathy

b. Amyloid angiopathy

Finally, after extracting the data, data were analyzed to determine the frequency of abnormal findings in the SWI sequence.

Data analysis: Data were recorded and analyzed by SPSSv.25 software. To describe the qualitative data, we used the frequency and frequency percentage, and to describe the quantitative data, if it followed the normal distribution, we used the mean and standard deviation; otherwise, we used the median and the interquartile range. The significance level was considered 0.05.

Ethical consideration: This study was approved by the ethical committee of Shahid Beheshti Medical University (IR.SBMU.MSP.REC.1402.601).

Results

In this period, 157 patients were enrolled in the study. The frequency of pathologies is seen in Table 1.

Out of 157 brain pathologies, in 129 cases (82.2%), the lesion was diagnosed only by regarding the findings on SWI. In 28 cases, the SWI sequence confirmed findings in other sequences and was unnecessary for a clear diagnosis. In other words, its findings were obvious in other sequences. In 6 cases (21.4%), using SWI helped confirm the diagnosis.

Table 1. Frequency of brain pathologies in MRI.

Brain pathologies	Frequency
Demyelination	33
stroke	67
Neoplasms	25
Infectious	9
Trauma	2
Cerebral venous thrombosis (CVT)	10
Vascular malformation	11

The description of SWI status in different conditions is described in the following:

Demyelination: The type of sign observed in the SWI of all patients in the demyelination group was the Central vessel sign in MS. The mentioned lesion was seen only in the SWI sequence in all these patients.

Stroke: A total of 176 MRIs with evidence of stroke were found, of which 67 patients showed ischemic stroke with hemorrhagic transformation that was obvious on SWI. The data are seen in Table 2. Axial images of T1, SWI, and DWI of a patient with ischemic stroke and hemorrhaghic transformation in left PCA are shown in Figure 1. SWI showed hemorrhagic transformation, which was not evident in other sequences (Figure 1).

Table 2. The frequency of signs observed in the SWI of patients with ischemic stroke.

Sign	Number (%)	Only observed in SWI sequence
Susceptibility vessel sign in arterial stroke	5 (7.5)	5 (100)
Asymmetrically prominent cortical veins in arterial stroke	2 (3.0)	2 (100)
Hemorrhagic transformation in arterial stroke	42 (62.7)	35 (83.3)
Hypertensive encephalopathy	18 (26.9)	18 (100)

Neoplasms: Twenty-five brain tumor pathologies with evidence of bleeding were found in MRI. In all of these patients, the sign of intratumoral hemorrhage was seen in the SWI sequence. The lesion was metastatic in 2 patients (8%). The grade of intratumoral hemorrhage in SWI in tumoral lesions was as follows (grade 0: 1, grade 1: 5, grade 2: 6, grade 3: 9 patients). Intratumoral hemorrhage was seen in 17 (68%) of patients only in SWI. Intratumoral hemorrhage was seen in 7 patients in the T1 sequence and one patient in the T1 and T2 sequences, in addition to SWI. Among these 8 patients, the SWI sequence helped to diagnose or better characterize the lesion in one patient (12.5%) (Figure 2).

Infectious: The sign of infectious disease was observed in 8 patients (88.9%) as dual rim signs in brain abscess and in one patient (11.1) as hemorrhagic encephalitis following COVID-19. In 8 patients (88.9%), SWI is key in diagnosis because dual rim or hemorrhage was seen only on SWI. However, in one patient with a brain abscess (11.1%) with a dual rim sign, this sign was seen in other T1, T2, FLAIR, and T1+Gad sequences, and the SWI sequence helped to diagnose better or characterize the lesion (Figure 3).

Trauma: There were two patients with brain trauma, and the findings were compatible with DAI in one patient and Superficial siderosis in the other. The mentioned findings were found only in SWI in both patients. so diagnosis is impossible without a SWI sequence.

CVT: A sign of vein thrombosis was found in SWI of all 10 patients with CVT. The sign of hemorrhage in venous infarct was found in 2 patients (20%). Hemorrhage in venous infarct sign was observed only in the SWI sequence. The sign of Thrombosis in veins was observed in 2 patients (20%) only in SWI, and in the remaining 8 patients, it was found in other sequences.

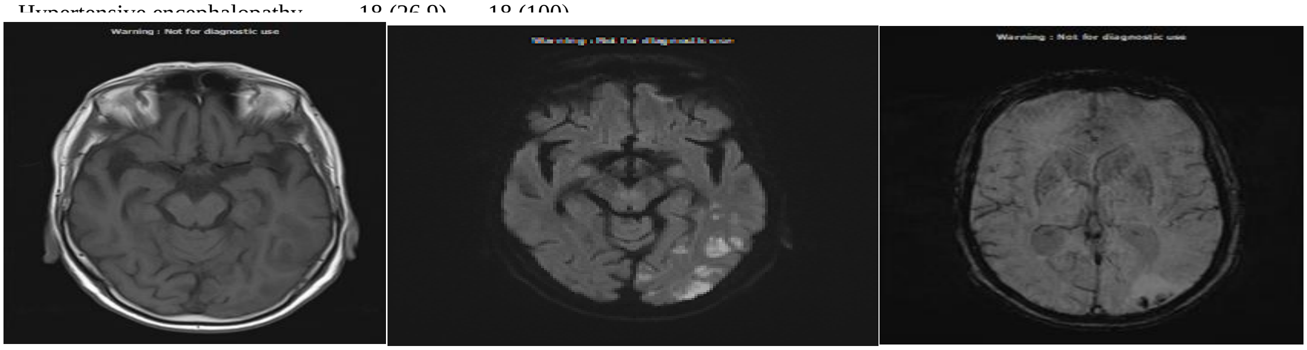

Figure 1. Axial view of T1W, DWI and, SWI sequences of a patient with ischemic stroke in the left PCA territory, SWI showed hemorrhagic transformation which was not evident on other sequences.

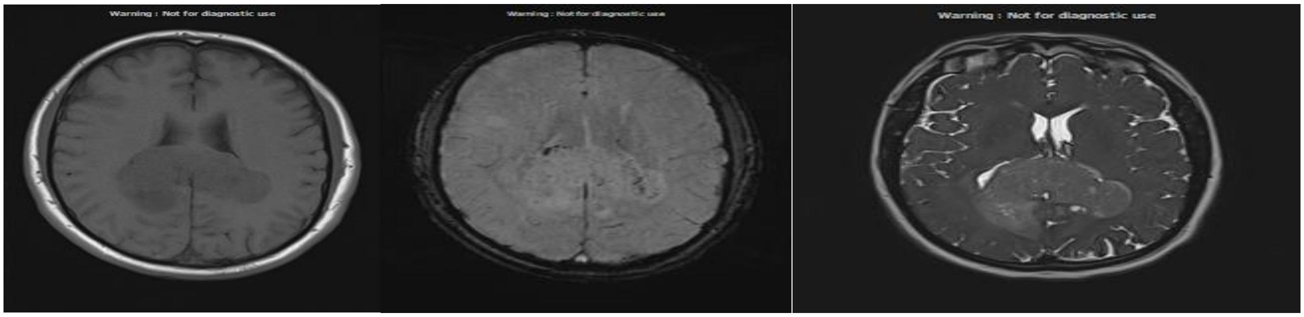

Figure 2. Axial views of T1W, T2W, and SWI sequences in a patient with tumoral lesion in the corpus callosum. Hemmorhagic changes are seen in SWI and not on the other sequences.

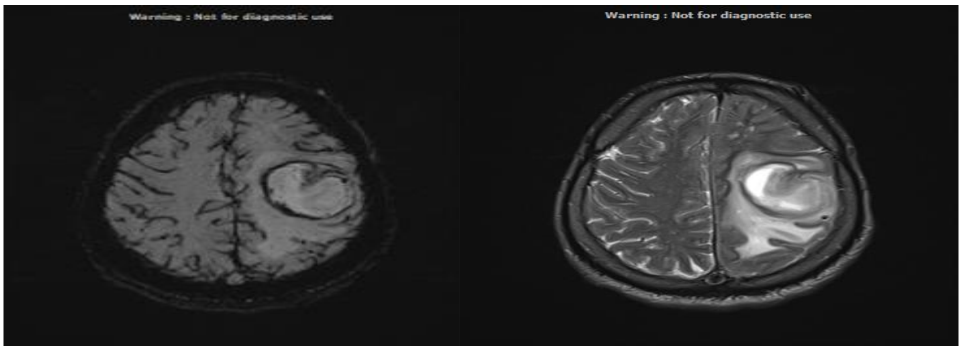

Figure 3. Brain abcess in T2W and SWI views. Dural rim sign in lateral aspect is obvious on both T2W and SWI.

Figure 4. Axial views of T2W,T1W,DWI and SWI sequences in a patient with multiple cavernomas. Two foci of blooming artifacts on SWI sequence are seen in right thalamus and right temporal lobe which were not evident on DWI, T1W, and T2W sequences.

Thrombosis in veins was observed in one patient in the T1 sequence, 2 in FLAIR, 4 in T1+Gad, and one in T2 and T1+Gad. Among these 8 patients, the SWI sequence helped to diagnose or better characterize the lesion in 3 patients (37.5%).

Vascular malformation: Of 11 patients with vascular malformations, 9 patients had cavernoma (81.8%) (7 cases single and 2 multiple), and capillary telangiectasia was found in 2 patients (18.2%). Capillary telangiectasia lesion was observed only in SWI. Cavernoma lesions were found in 4 patients in other sequences, 3 in T1, T2, and FLAIR sequences, and one in T1 and T2 sequences. In one of these 4 patients (25%), the SWI sequence helped to diagnose or characterize the lesion better. Multiple cavernomas and three single cavernomas were seen only in the SWI sequence (Figure 4).

Discussion

In the current study, we assessed the frequency of different pathologic findings in SWI sequence, and we also assessed the ability of SWI to increase the rate of correct diagnosis or help to better diagnose in brain MRI studies. We found that the SWI sequence is a helpful method for diagnosing several brain pathologies. In 82.2% of cases with brain pathologies, the pathologic signs mandatory for correct diagnosis are obvious only in the SWI sequence.

We found that hemorrhagic transformation was found in 63% of ischemic strokes in the SWI sequence. Hemorrhagic transformation can occur spontaneously or as a result of reperfusion syndromes, such as thrombolysis and thrombectomy. The main mechanism of hemorrhagic transformation is the outflow of blood from the disturbed blood-brain barrier (BBB) to the infarcted area. It is an important complication because it can worsen the patient's condition and increase the risk of disability or death. Early detection of hemorrhagic transformation is crucial for appropriate management of the patient. This transformation can range from small petechial hemorrhage to more extensive bleeding. Due to its high sensitivity to blood products, SWI is valuable in detecting and characterizing hemorrhagic transformation in ischemic infarction[20]. This finding can be seen in 3-40% of strokes[20]. The selective referral of suspected patients for brain MRI and SWI can cause a high percentage of hemorrhagic transformation in the patients of this study. Except for hemorrhagic transformation, other signs accompanied by ischemic stroke on SWI include susceptibility vessel sign and prominent vessel sign[21]. Thrombus or clot formation within a blood vessel is only seen on SWI or GRE sequences. It is clinically important and may require immediate intervention to restore blood flow to the infarcted zone and prevent further damage to brain tissue. Detection of an occluded vessel is crucial in managing acute stroke, so using SWI as a reliable method for diagnosing susceptibility vessel signs is necessary during routine brain MRI. There are 5 patients in our cases who show this sign on SWI (7/5%). Prominent vessel sign refers to the visualization of abnormal dilated blood vessels adjacent to infarcted zone which shows the presence of salvageable ischemic tissue that will become infarcted if blood perfusion cannot be established in time. This finding is depicted in 2 (3%) of our patients. There are also evidence of micro bleeding in brain parenchyma due to hypertensive microangiopathy or amyloid angiopathy which are not identified in conventional MRI sequences. SWI or GRE sequences are necessary for identification of these situations in brain MRI. There are 25 patients including these features in our study which were only obvious in SWI sequence[22].

All patients with brain neoplasms in the current study who had evidence of hemorrhage had signs of intratumoral bleeding, which could mostly be detected only by SWI sequence. This finding is important because it emphasizes the sensitivity of SWI in identifying hemorrhagic components of tumors, a feature often underrepresented in other routine MRI sequences. Intratumoral hemorrhages are often in microbleeding, which is very difficult to detect in conventional MR sequences, including T2 and T1 with contrast[23]. Areas identified as hemorrhage on conventional sequences can be necrosis areas[24]. In this study, these hemorrhages were not visible on T1 and T2 sequences in 68% of patients with brain neoplasms, indicating the superiority of SWI contrast resolution for blood-containing products. Similar to the current study, previous studies showed the higher sensitivity of SWI in detecting micro-bleedings and calcifications in brain neoplasms, which potentially helps to distinguish tumor types and grades[24, 25]. SWI can provide additional or better information than conventional sequences, such as border definition, blood-containing products, venous positioning status, tumor architecture, and edema[24, 26]. In the present study, intratumoral hemorrhage was visible in other sequences in 12.5% of cases. SWI sequence helped confirm the diagnosis or better characterization of the lesion, emphasizing the SWI potency to help more comprehensively characterize brain neoplasms. The enhanced detail provided by SWI can help clinicians understand the heterogeneity and complexity of brain tumors, which is crucial for treatment planning and prognosis assessment. Our findings support the growing evidence that SWI should be considered a routine protocol for evaluating brain neoplasms on MRI[26]. We also used the ITSS program to grade the severity of intratumoral hemorrhage in SWI, which is based on the number of linear or dot-like structures in the maximum cross-section of tumors on SWI. The severity of hemorrhage is increased from grade 0 to grade 3. The results were as follows in our patients (grade 0: 1, grade 1: 5, grade 2: 6, grade 3: 9 patients). Despite having severe intratumoral hemorrhage in most of our patients, the hemorrhage was not recognizable in conventional MRI sequences. Therefore, SWI helped us to characterize the tumoral lesions better.

Multiple sclerosis is a demyelinating disease, and diagnosis may be challenging. There is no single laboratory test to prove or exclude MS, thus MR is beneficial in reaching a definitive diagnosis. Differentiating MS from various CNS pathologies, mainly white matter lesions due to small vessel ischemia, is sometimes impossible or difficult. As WM lesions in MS are typically perivenular, the presence of the central vein sign visible on SWI within the demyelinating plaques helps confirm MS diagnosis. This sign is obvious in all of our patients with multiple sclerosis. Also, there is signal hypointensity on SWI due to iron deposition in multiple sclerosis plaques at the lesion's edge in a ringlike fashion or the center, indicating nodular iron-laden lesions correlated with cognitive impairment and brain atrophy in MS patients. This sign is not identified in our patients[27].

In our study, 8 patients with brain abscesses and one patient with COVID-19 encephalitis were assessed by MRI, and the dual rim sign was observed in all patients with brain abscesses and hemorrhagic encephalitis in the patient with COVID-19 encephalitis[28]. The dual rim sign is mainly observed only in the SWI sequence, which helps distinguish an abscess from a glioblastoma, which is in line with the findings of Toh et al.[29]. In glioblastomas, the low signal rims are irregular and incomplete which represent hemorrhagic products, in brain abscess immediately internal to the low-intensity rim is a high-intensity line which is known as the dual rim sign. Therefore, using SWI along with other standard MRI sequences can provide additional information about the nature of the lesion, potentially influencing the diagnosis, clinical management, and prognosis of the disease. Additionally, the results of our study emphasize the importance of performing SWI in patients suspected of infectious brain pathologies. In patients suspected of encephalitis, detecting hemorrhage in SWI is a prognostic factor for poor outcomes.

Thrombosis in veins was found in SWI of all patients with CVT. In addition, the sign of Hemorrhage in venous infarct was observed in 20% of our cases, which could only be detected in the SWI sequence. Although in 80% of cases, the sign of Thrombosis in veins could be detected in other sequences, in 37.5% of these patients, SWI helped diagnose or better characterize the lesion. These results were mentioned in the previous studies[30, 31] and emphasize the substantial role of SWI in diagnosing and describing CVT. A recent retrospective study of 51 CVT patients and 27 controls showed that the high-resolution SWI sequence offered the best sensitivity and accuracy among standard MRI sequences for the independent detection of acute and subacute venous thrombi[30]. Kashyap et al. found that SWI can be useful in diagnosing CVT, and it should be done because the diagnosis of CVT is challenging compared to other sequences[32].

The findings of our study highlighted the importance of SWI in the diagnosis and identification of brain vascular malformations, especially cavernoma and capillary telangiectasias. Our results showed the predominant presence of cavernoma in most patients (82%) with a combination of single and multiple manifestations. Multiple cavernomas are hereditary and cannot be diagnosed by conventional MRI sequences. Identifying these lesions has an important role in patient management and follow-up. Thus, SWI has a crucial role in diagnosing multiple cavernomas, especially. Capillary telangiectasia, which accounted for 18.2% of our cases, was detected exclusively through SWI, underscoring the sensitivity of this imaging modality in identifying smaller or subtle vascular abnormalities. Previous studies have shown that SWI is more efficient than gradient-echo imaging in identifying brain capillary telangiectasias[33, 34]. Sparacia et al. emphasized the usefulness of SWI in patients with cavernoma and its superiority over other standard MRI sequences[35]. The high sensitivity of SWI in detecting these abnormalities emphasizes its value as a suitable clinical imaging method. Further research is needed to investigate the potency of SWI in diagnosing and managing other types of cerebral vascular malformations.

Conclusion

The findings of this study indicated the important role of SWI in evaluating various brain pathologies, especially in cases where routine MRI sequences are insufficient. Our findings support the integration of SWI into standard diagnostic protocols for a more comprehensive assessment of neurological diseases. However, there is a need for further research to exploit the capabilities of SWI in clinical imaging fully.

Acknowledgment

None.

Conflict of interest

The authors further declare that they have no conflict of interest.

References

1. Di Ieva A, Lam T, Alcaide-Leon P, Bharatha A, Montanera W, Cusimano MD. Magnetic resonance susceptibility weighted imaging in neurosurgery: current applications and future perspectives. Journal of neurosurgery. 2015;123(6):1463-75.
2. Ashwal S, Wycliffe ND, Holshouser BA. Advanced neuroimaging in children with nonaccidental trauma. Developmental neuroscience. 2011;32(5-6):343-60.
3. Bian W, Hess CP, Chang SM, Nelson SJ, Lupo JM. Susceptibility-weighted MR imaging of radiation therapy-induced cerebral microbleeds in patients with glioma: a comparison between 3T and 7T. Neuroradiology. 2014;56:91-6.
4. Di Ieva A, Matula C, Grizzi F, Grabner G, Trattnig S, Tschabitscher M. Fractal analysis of the susceptibility weighted imaging patterns in malignant brain tumors during antiangiogenic treatment: technical report on four cases serially imaged by 7 T magnetic resonance during a period of four weeks. World Neurosurgery. 2012;77(5-6):785. e11-. e21.
5. Di Ieva A, Tschabitscher M, Galzio RJ, Grabner G, Kronnerwetter C, Widhalm G, et al. The veins of the nucleus dentatus: anatomical and radiological findings. Neuroimage. 2011;54(1):74-9.
6. Li C, Ai B, Li Y, Qi H, Wu L. Susceptibility-weighted imaging in grading brain astrocytomas. European Journal of Radiology. 2010;75(1):e81-e5.
7. Colbert CA, Holshouser BA, Aaen GS, Sheridan C, Oyoyo U, Kido D, Ashwal S. Value of cerebral microhemorrhages detected with susceptibility-weighted MR Imaging for prediction of long-term outcome in children with nonaccidental trauma. Radiology. 2010;256(3):898-905.
8. Grabner G, Nöbauer I, Elandt K, Kronnerwetter C, Woehrer A, Marosi C, et al. Longitudinal brain imaging of five malignant glioma patients treated with bevacizumab using susceptibility-weighted magnetic resonance imaging at 7 T. Magnetic resonance imaging. 2012;30(1):139-47.
9. Zeng Q-S, Kang X-S, Li C-F, Zhou G-Y. Detection of hemorrhagic hypointense foci in radiation injury region using susceptibility-weighted imaging. Acta radiologica. 2011;52(1):115-9.
10. Hemeda YH. Positive Susceptibility Vessel Sign on SWI-MRI Sequence Imaging Might Differentiate Patients Had Silent Brain Ischemia among Apparently Neurologically-Free Patients. The Egyptian Journal of Hospital Medicine. 2022;86(1):437-46.
11. Haller S, Haacke EM, Thurnher MM, Barkhof F. Susceptibility-weighted imaging: technical essentials and clinical neurologic applications. Radiology. 2021;299(1):3-26.
12. Abu-samra MF, Amin MF, Yassen AM, Fath El-Bab AK, Gabr MF. SWI as a promising tool comparable to CT perfusion in evaluation of acute cerebral infarction. Egyptian Journal of Radiology and Nuclear Medicine. 2021;52:1-10.
13. Löbel U, Sedlacik J, Sabin ND, Kocak M, Broniscer A, Hillenbrand CM, Patay Z. Three-dimensional susceptibility-weighted imaging and two-dimensional T2*-weighted gradient-echo imaging of intratumoral hemorrhages in pediatric diffuse intrinsic pontine glioma. Neuroradiology. 2010;52:1167-77.
14. Toth A, Kovacs N, Perlaki G, Orsi G, Aradi M, Komaromy H, et al. Multi-modal magnetic resonance imaging in the acute and sub-acute phase of mild traumatic brain injury: can we see the difference? Journal of neurotrauma. 2013;30(1):2-10.
15. El-Koussy M, Schroth G, Gralla J, Brekenfeld C, Andres R, Jung S, et al. Susceptibility-weighted MR imaging for diagnosis of capillary telangiectasia of the brain. American journal of neuroradiology. 2012;33(4):715-20.
16. Deistung A, Schweser F, Wiestler B, Abello M, Roethke M, Sahm F, et al. Quantitative susceptibility mapping differentiates between blood depositions and calcifications in patients with glioblastoma. PloS one. 2013;8(3):e57924.
17. Deistung A, Schäfer A, Schweser F, Biedermann U, Güllmar D, Trampel R, et al. High-resolution MR imaging of the human brainstem in vivo at 7 Tesla. Frontiers in human neuroscience. 2013;7:710.
18. Hunter JV, Wilde EA, Tong KA, Holshouser BA. Emerging imaging tools for use with traumatic brain injury research. Journal of neurotrauma. 2012;29(4):654-71.
19. Wang M, Dai Y, Han Y, Haacke EM, Dai J, Shi D. Susceptibility weighted imaging in detecting hemorrhage in acute cervical spinal cord injury. Magnetic resonance imaging. 2011;29(3):365-73.
20. Spronk E, Sykes G, Falcione S, Munsterman D, Joy T, Kamtchum-Tatuene J, Jickling GC. Hemorrhagic Transformation in Ischemic Stroke and the Role of Inflammation. Frontiers in neurology. 2021;12:661955.
21. Rubin A, Waszczuk Ł, Trybek G, Kapetanakis S, Bladowska J. Application of susceptibility weighted imaging (SWI) in diagnostic imaging of brain pathologies–a practical approach. Clinical Neurology and Neurosurgery. 2022;221:107368.
22. Rashid AMA, Yaakob MNM, Kamis MFA-K, Noh MSFM. The prominent hypointense vessel sign on susceptibility-weighted imaging (SWI) as a potential imaging biomarker for poor clinical outcome in acute ischemic stroke (AIS). Radiology Case Reports. 2022;17(11):4268-71.
23. Mohammed W, Xunning H, Haibin S, Jingzhi M. Clinical applications of susceptibility-weighted imaging in detecting and grading intracranial gliomas: a review. Cancer imaging : the official publication of the International Cancer Imaging Society. 2013;13(2):186-95.
24. Löbel U, Sedlacik J, Sabin ND, Kocak M, Broniscer A, Hillenbrand CM, Patay Z. Three-dimensional susceptibility-weighted imaging and two-dimensional T2*-weighted gradient-echo imaging of intratumoral hemorrhages in pediatric diffuse intrinsic pontine glioma. Neuroradiology. 2010;52(12):1167-77.
25. Ceballos-Ceballos J, Loza-Gallardo DA, Barajas-Romero MA, Cantú-Brito C, Valdés-Ferrer SI. Recognition of Brain Metastases Using Gadolinium-Enhanced SWI MRI: Proof-of-Concept Study.

Frontiers in neurology. 2020;11:5.
26. Halefoglu AM, Yousem DM. Susceptibility weighted imaging: Clinical applications and future directions. World journal of radiology. 2018;10(4):30-45.
27. Al-Zandi SH, Fayadh NA, Al-Waely NK. Central vein sign detected by SWI at 3 T MRI as a discriminator between multiple sclerosis and leukoaraiosis. The Egyptian Journal of Radiology and Nuclear Medicine. 2018;49(1):158-64.
28. Conklin J, Frosch MP, Mukerji SS, Rapalino O, Maher MD, Schaefer PW, et al. Susceptibility-weighted imaging reveals cerebral microvascular injury in severe COVID-19. Journal of the neurological sciences. 2021;421:117308.
29. Toh CH, Wei KC, Chang CN, Hsu PW, Wong HF, Ng SH, et al. Differentiation of pyogenic brain abscesses from necrotic glioblastomas with use of susceptibility-weighted imaging. AJNR American journal of neuroradiology. 2012;33(8):1534-8.
30. Boukerche F, Balakrishnan S, Kalapos P, Thamburaj K. Detection of cerebral cortical vein thrombosis with high-resolution susceptibility weighted imaging- A comparison with MR venography and standard MR sequences. Neuroradiology. 2023;65(5):885-92.
31. Sadik JC, Jianu DC, Sadik R, Purcell Y, Novaes N, Saragoussi E, et al. Imaging of Cerebral Venous Thrombosis. Life (Basel, Switzerland). 2022;12(8).
32. Kashyap PV, Kashyap M, Dhiran A, Yadav A. Missed Cerebral Venous Thrombosis: A Diagnostic Challenge. Annals of Neurosciences. 2023;30(3):197-204.
33. Chaudhry US, De Bruin DE, Policeni BA. Susceptibility-weighted MR imaging: a better technique in the detection of capillary telangiectasia compared with T2* gradient-echo. AJNR American journal of neuroradiology. 2014;35(12):2302-5.
34. El-Koussy M, Schroth G, Gralla J, Brekenfeld C, Andres RH, Jung S, et al. Susceptibility-weighted MR imaging for diagnosis of capillary telangiectasia of the brain. AJNR American journal of neuroradiology. 2012;33(4):715-20.
35. Sparacia G, Speciale C, Banco A, Bencivinni F, Midiri M. Accuracy of SWI sequences compared to T2*-weighted gradient echo sequences in the detection of cerebral cavernous malformations in the familial form. The Neuroradiology Journal. 2016;29(5):326-35.