A Mini Literature Review on the Application of Susceptibility Weighted Imaging in Neuroradiology

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ABSTRACT

Objectives: Susceptibility-weighted imaging (SWI) is a recent and robust advancement in magnetic resonance imaging (MRI) technique that exploits the magnetic susceptibility differences of several tissues such as calcification, deoxygenated blood, and blood products iron. This study aims to highlight the principle and clinical application of SWI in different brain pathologies such as traumatic brain injury, arterial stroke, neurodegenerative disease, and brain tumor.
Key findings: SWI is continuously employed in the differential diagnosis of numerous neurological disorders, these advancements in SWI made it an integral part of brain MRI protocol routine in evaluating various neurological diseases such as neurodegenerative and neurovascular diseases.
Conclusion: SWI provides an exceptional technique that offers valuable information on neurological disorders as well as cerebral diamagnetic and paramagnetic substances.
Implication for practice: The advent of SWI has enormously improved numerous applications in research and clinical neuroradiology such as the detection and assessment of hemorrhage, TBI, and neurodegenerative disease. SWI is a very useful alternative imaging tool in the management of stroke patients, via the facilitation and differentiation of calcium from a brain hemorrhage.

Keywords: susceptibility weighted imaging; Magnetic resonance imaging; Traumatic brain injury; Calcification; Acute stroke.

1.0 Introduction

Susceptibility-weighted imaging (SWI) is a novel magnetic resonance imaging (MRI) technique that was initially referred to as "High-Resolution Blood Oxygen level-dependent (BOLD) Venography" which provides increased visibility of the venous vasculature of the brain [1]. SWI exploits the magnetic susceptibility differences of different tissues, such as blood, iron, and calcification [2–4]. MRI has numerous approaches for investigational anatomic, functional, and metabolic imaging with each method focusing on a new issue [1,4]. SWI is continuously employed in the differential diagnosis of numerous neurological disorders. These advancements in SWI made it an important component of routine brain MRI protocols in evaluating numerous neurological diseases such as neurodegenerative and neurovascular diseases [3,5]. SWI technique has proven to provide an essentially useful clinical alternative source of information to normal MRI sequences, thus, via post-processed quantitative susceptibility mapping (QSM) SWI sequences permit quality data research in evaluating compounds that can interfere with magnetic field in the brain, an approach that is very useful in neurodegenerative disorders [2,6–8]. This review article is aimed at highlighting the principle and clinical application of SWI in different brain pathologies.

2.0 Principles and Technical Aspect of SWI

Magnetic susceptibility denotes the degree of magnetization of a body in response to external magnetic field intensity within or around the voxel [9,10]. Conversely, paramagnetic substances such as gadolinium-containing contrast, deoxyhemoglobin, fat, air, and hemosiderin, play a significant role in the magnetic field [11,12] resulting in a positive shift on the adjacent parenchyma in a left-handed system such as the Avanto system of Siemens magnets (Erlangen, Germany) (**See Table 1**) and a negative shift in right-handed systems [2,3].

However, ferro-calcinosis could lead to confusion in signaling intensity patterns with basal ganglia calcification a more or less a mixture of paramagnetic iron and diamagnetic calcium [2,13]. Thus, cortical veins containing blood practically could serve as a reference in determining the probable intensity of phase image

(high or low) of paramagnetic constituents [3]. SWI sequences are attributed with several disadvantages such as undesirable magnetic susceptibility sources which could lead to artifacts appearing at air-tissue interfaces such as areas lining side by side to the temporal bone and sinuses which could limit investigations. In addition, a blooming artifact is a vital sign for detecting inhomogeneity in the magnetic field, which could sometimes result in extreme tissue signal cancellation and loss of anatomical borders [14].

Local magnetic field heterogeneity resulting in T2 shortening could be brought by ferromagnetic, diamagnetic, and paramagnetic substances which subsequently could lead to loss of signal on T2* weighted gradient-echo (GE) sequences [2]. Conversely, the susceptibility effect is most visible in non-refocused GE techniques via high field strength, short flip angles, and long echo times (TE), even though SWI depend on GE sequences with higher susceptibility sensitivity when compared with the conventional T2* weighted GE sequences due to its high-resolution, long TE, flow-compensated, 3D GE imaging technique containing filtered phase information in each voxel [14].

Noteworthy, the magnitude and phase MR data in SWI are brought together and a phase mask is produced, thus by multiplying these with the original image magnitudes results in a final SWI dataset with both phase and magnitude information vital for proper tissue characterization, hence a high-quality SWI image is created [15]. Lastly, these images are processed further with a minimum intensity projection algorithm (minIP) to get a 3-10 mm thick high signal to noise minIP slabs, hence these minIP images show continuousness within tortuous veins across the slices whereas attenuating the upcoming signal from the brain tissue [14].

Table 1: **Susceptibility weighted imaging sequences work specific Resume for 1.5 T Siemens Magnetom Avanto syngo magnet.**

Slab Group 1	
Slabs	1
Dist. factor	20%
Position	L0.0 A16.0 H37.8
Orientation	T > C -6.9
Phase enc. dir.	R >> L
Rotation	90.00 deg
Phase oversampling	0%
Slibe oversampling	23.10%
Slices per slab	104
FoV read	230 mm
FoV phase	75%
Slice thickness	1.50 mm
TR	28 m/s
TE	20.00 m/s
Averages	1
Concentrations	1
Filter	Prescan normalize
Matrix size	256 x 256
TA	4.44
Voxel size	1.0 mm x 0.9 mm x 1.5 mm
Flip angle	15 deg
Dimension	3D
Bandwidth	120 Hz/Px
Slice resolution	100%
Coil elements	HEI-4

3.0 Clinical application

3.1 Traumatic brain injuries

Traumatic brain injury is linked with momentous morbidity and mortality. Even though CT remains the principal imaging modality for the diagnosis and detection of trauma-related brain injuries, nevertheless MRI has proven to provide a valuable assessment tool in the detection of TBI [16]. However, limiting factors such as the availability of potential motion artifacts and feasibility make MRI a drawback in TBI assessment [3]. Another important advantage of MRI to CT scan in the detection of TBI is the ability of MRI to identify and localize smaller hemorrhages in more severe cases such as punctate microhemorrhage [16].

Diffuse axonal injury (DAI) is a result of traumatic shear-strain forces with subsequent damage, which typically occurs within the periventricular regions, deep white matter, gray-white matter junctions, brainstem, hippocampus, and as well as the corpus callosum [17]. It is worth noting that, SWI could detect hemorrhagic DAI and its degree of severity by way of microhemorrhages which are seen as focal areas of low signal intensity, which is difficult to be detected on normal conventional MRI sequences or CT scans [2,18]. Accordingly, SWI is considered more robust than other sequences in the demonstration of quantity, extent, and site of hemorrhagic DAI lesions, hence SWI detects about four times as many hemorrhagic DAI lesions as T2*-weighted imaging in traumatic patients [3,19,20]

In addition, SWI could be employed in evaluating chronic subdural hematoma (SDH) extra-axial intracranial bleeding, although it can be well-demonstrated via a CT scan [21]. A chronic SDH is associated with continuous bleeding episodes along the membranes, thus various amounts of blood proteins and other blood products are deposited [22]. Cramer et al., (2016), their study described a case series of four pediatric patients with chronic subdural hemorrhage (SDH) neo-membranes, with very subtle or absent hemosiderin staining along the neo-membranes in two (2) cases.

Contusions are associated with the commonest form of intra-axial traumatic injuries due to forceful interaction and sudden deceleration between the brain and tentorium cerebelli or fax cerebri [16]. Although, there is a paucity of knowledge on the impact of SWI in assessing hemorrhagic brain contusions although CT scan could be beneficial in detecting brain contusions [2].

Noteworthy, cerebral fat embolism is one of the rare complications of polytrauma which could present symptoms similar to hypoxemia and encephalopathy, hence could be misinterpreted due to petechial hemorrhages and traumatic brain injury on MRI which can mimic DAI [23,24]. Equally fat embolism and DAI could present dropsical changes on T2/FLAIR sequence, though, SWI demonstrates an elaborate distribution of small petechial hemorrhage as seen in basal ganglia, cerebellum, and white matter, in fat embolism [23].

In conclusion, SWI could be considered helpful clinically in postoperative care after a neurosurgical procedure, however, more studies on the potential role of SWI in follow-up recovery of post-operative pneumocephalus in neurosurgical patients are paramount.

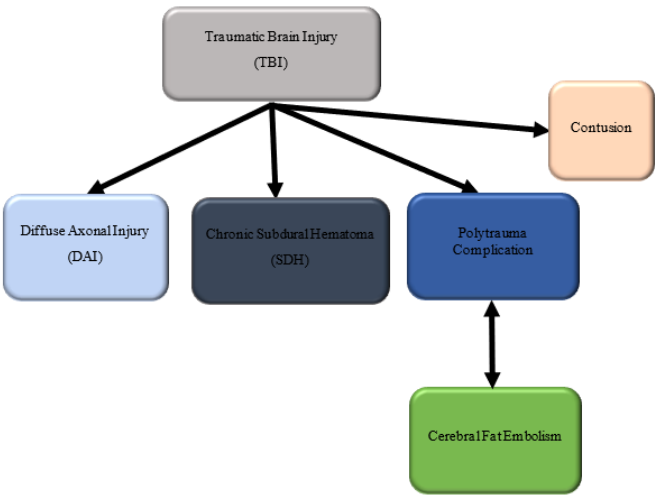

Figure 1: Schematic Diagram of the Clinical Application of SWI in TBI

3.2 CNS vascular malformation/Arterial stroke

Neurovascular malformation or diseases such as cerebrovascular ischemia may occur as a result of arteriosclerotic stenosis or thromboembolism and could lead to acute infarction with or without bleeding [3]. Several imaging modalities are used to evaluate a suspected acute stroke such as computed tomography (CT), diffusion-weighted imaging (DWI), perfusion-weighted imaging (PWI), and MR angiography (MRA), conversely, SWI provides an exceptional advantage in the management of stroke such as highlighting cerebral veins signal drop in healthy individuals after hyperventilation and caffeine ingestion which denotes a decline in oxygen and cerebral blood flow (Chang, 2014).

Thromboembolism or atherosclerotic stenosis of vascular vessels is associated with the occurrence of acute cerebral infarction with or without hemorrhage [2]. Importantly, vascular occlusion results in susceptibility change leading to decrease arterial flow and upsurge pooling of deoxygenated blood, hence resulting in a high concentration of deoxyhemoglobin with such conversion occurring as early as 2 hours after inception of the symptoms [26].

SWI assists immensely in the identification of hemorrhages within the infarct region. SWI enables the differentiation of a hemorrhage from a bland ischemic stroke, with several studies providing evidence that SWI is more sensitive in detecting hemorrhage within the acute infarct regions when compared to CT scans and 2D GE T2* weighted sequences [27,28].

Moreso, SWI is very sensitive and suitable for detecting chronic subarachnoid and subacute hemorrhages. Thus, is an upgrade since these advantages are often deficient in CT and FLAIR [29]. Worthy to note is that microhemorrhages within the infarct region can be detected correctly using SWI when compared to other imaging modalities such as T2* GE sequences [2].

3.3 Neurodegenerative disease

Neurodegenerative diseases are associated with increased deposition of iron primarily in the form of ferritin and ferro-calcinosis, particularly in the region of the basal ganglia (Fig 2). Consequently, increase in iron levels in the brain are attributed to several neurodegenerative diseases such as Parkinson's disease, Huntington's disease, Alzheimer's disease, Multiple sclerosis (MS), Amyotrophic lateral sclerosis, Wilson's Disease, Hallervorden-Spatz syndrome and Pantothenate Kinase-associated neurodegeneration (PKAN) [30–32]. Conversely, the ability to detect and quantify the amount of ferritin in the brain plays a vital role in the prediction, prognosis, and treatment outcomes of neurodegenerative diseases [3].

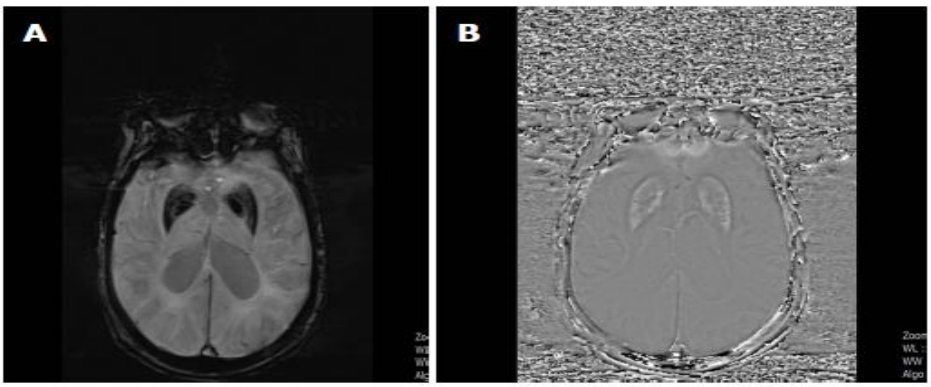

Figure 2: SWI Sequences of a 79-year-old woman diagnosed with Alzheimer's Disease: (A) SWI minor image revealing hypointense signal intensity in the globus pallidus and putamen showing amplified iron deposition (B) SWI phase image revealing hyperintense signal in the basal ganglia due to the positive shift effect of paramagnetic iron [2].

The application of SWI in mild cognitive impairment (MCI) shows variances in stable and progressive MCI with a greater content of iron in the right substantia nigra in progressive MCI and the right pallidum when compared with stable MCI [33,34]. However, Barnaure et al., (2017) in their study found no significant differences between both groups concerning severity, distribution, and cerebral microbleed prevalence.

MS affects the Central Nervous System (CNS) and is naturally imaged using FLAIR, although the precision

and sensitivity of MRI in detecting MS lesions in the CNS are minimal. However, SWI assists in detecting demyelination lesions of perivenular distribution indicating the MS plaque within the minor veins. [35]. Even though, Rudko et al., (2014) indicated that the deposition of iron levels in MS patients relates better with disability than MS plaque volume with amplified iron content in patients with the clinically isolated syndrome (CIS) [3].

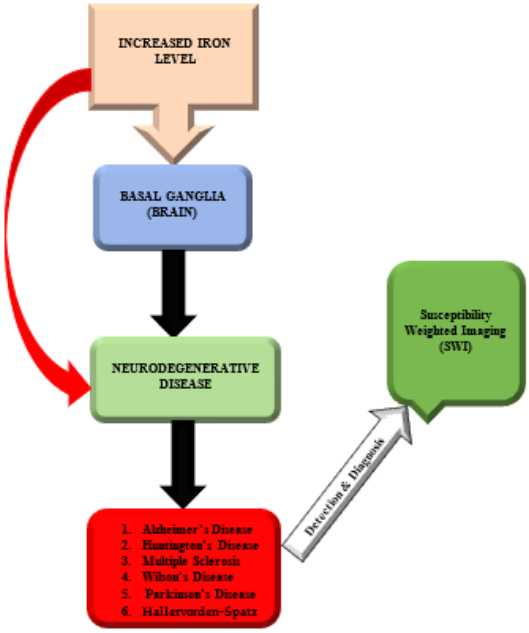

Figure 3: Schematic Diagram of the Clinical Application of SWI in Neurodegenerative Diseases

3.4 Brain tumors

SWI plays a vital role in the identification and diagnosis of hemorrhagic and calcified foci within tumors which makes it easy to the assessment of internal angioarchitecture of the tumors in detail, thus, high-grade tumors are mostly associated with intralesional hemorrhage [2,3].

Noteworthy, in the assessment of brain tumors, a significant pointer is calcification, which is diamagnetic, hence, hemorrhage is paramagnetic consequently leading to contradictory signal strengths on SWI phase images [37]. Zulfiqar reported that the determination of calcification in brain tumors such as oligodendroglioma using SWI sequences led to an important enhancement in the detection of intratumoral calcification by 53%, although no changes in specificity [2].

SWI also assists in identifying fat-containing masses, such as ruptured intracranial dermoid cysts via diagnosing the blooming fatty components (Fig 4). However, the low-intensity sign in SWI is moderately attributed to the shift in chemical artifacts between water and fat other than magnetic susceptibility [38]. SWI could be useful in differentiating cerebellopontine angle meningiomas from vestibular schwannomas [39].

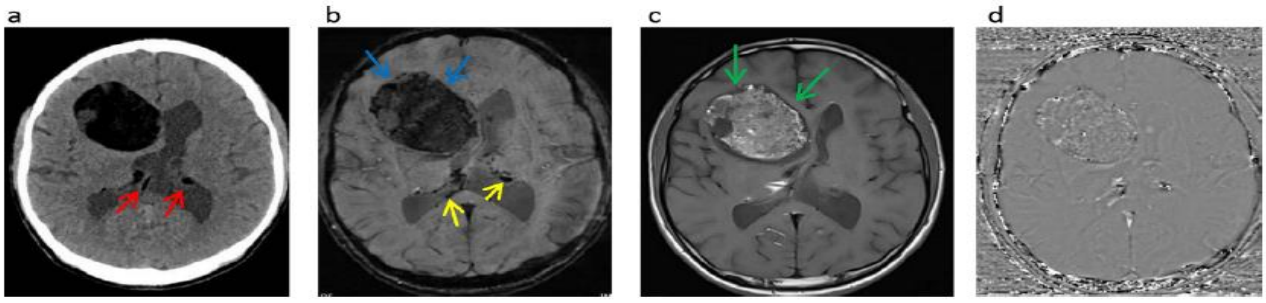

Figure 4: A 31-year-old female with an underlying history of loss of consciousness. Unenhanced head CT scan (A) Indicates a well-defined huge fat-containing lesion in the right frontal lobe, leading to mass effect, with Multiple fat-

containing droplets noted in the lateral ventricles (red arrows), interhemispheric fissure, and subarachnoid space (not shown). The SWI image (B) Reveals a blooming thin rim around the right-sided lesion (blue arrows), and the intraventricular fat droplets appear hypointense with blooming artifacts (yellow arrows). In T1- weighted image (C), the image reveals a bright signal intensity lesion. Left-handed phase image (D) Reveals a ruptured Intracranial dermoid cyst [3].

4.0 Conclusion

SWI is an exceptional MRI technique that offers valuable information on neurological disorders as well as cerebral diamagnetic and paramagnetic substances. The advent of SWI has enormously improved numerous applications in research and clinical neuroradiology such as the detection and assessment of hemorrhage, TBI, and neurodegenerative disease. It is worth noting that SWI is very useful as an alternative imaging tool in the management of stroke patients, via the facilitation and differentiation of calcium from a brain hemorrhage.

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