Original Research Article

Diffusion MRI of the Brain and Susceptibility Weighted Imaging (SWI) in Evaluation of Patients with Acute Stroke

Abstract

Background: Magnetic resonance imaging (MRI) is useful not only in identifying ischemic lesions. Susceptibility-weighted imaging (SWI) is a new magnetic resonance procedure that utilizes the magnetic susceptibility variances of various tissues, such as iron, blood and calcification. The aim of this work was to highlight the role of addition of susceptibility weighted MR images to diffusion weighted images of the brain in diagnosis of cases with acute stroke.

Methods: This prospective study included 30 subjects with clinical manifestations of acute stroke. All the subjects underwent history taking, routine laboratory tests, cardiologic assessment by echocardiogram and imaging modalities including non-contrast CT study and MRI of the brain.

Results: PVS on SWI was found in 23 (76.7%) cases, 6 (20%) cases had macro-hemorrhage (low signals) on SWI, and 1 (3.3%) patient had no SWI findings. DWI showed a sensitivity of (100%) and SWI showed a sensitivity of (96.7%) for detection of infarct All of the 30 (100 %) cases showed hyperintense signals on T2WIs, FLAIR sequences and on DWI and hypointense signals on ADC map.

Conclusions: SWI is a potential adjunct in those patients for detecting an asymmetric prominent hypointense vessels, positive DWI-SWI mismatch is considered as a marker of infarct expansion and an indicator of the ischemic penumbra.

Keywords: Diffusion MRI, Susceptibility Weighted Imaging, Acute Stroke, Brain

Introduction:

Stroke is a sudden onset of a focal neurological deficit caused by avascular event that lasts more than 24 hours. Acute stroke refers to a stroke that occurs within the first 24 hours. Stroke is categorized as either ischemic (caused by thrombosis or embolism) or hemorrhagic (caused mainly by rupture of blood vessel or aneurysm). Acute ischemic stroke occurs when a blood vessel ruptures or a thrombus obstructs it., resulting in diminished blood supply to the brain and so decreased O_2 supply and nutrients causing brain tissue damage [1, 2].

Acute ischemic stroke is categorised according to trial of org 10127 in acute stroke treatment (TOAST) into five subtypes: strokes due to large artery atherosclerosis, cardio-embolic strokes, small artery occlusion (lacunar infarctions), stroke of undetermined cause (cryptogenic), and stroke of other determined cause [3, 4].

Magnetic resonance imaging (MRI) is valuable not only for detecting ischemia lesions, but also for determining the link between lesions, structural, and functional changes in the brain [5, 6].

Diffusion weighted sequences (DWI) can help with therapeutic decisions by providing information on the pathophysiology of ischemia. In the early detection of acute cerebral ischemia in small strokes, it is more sensitive than T2 and FLAIR[7, 8].

Susceptibility-weighted imaging (SWI) is a new magnetic resonance procedure that utilizes the magnetic susceptibility variances of various tissues, such as iron, blood and calcification. It entails by both phase pictures and magnitude from a three-dimensional (3D) completely velocity-compensated gradient echo sequence with excellent resolution. By multiplying the phase mask with the magnitude images, which are shown using minimum intensity projection (MIP), the visibility of tiny veins and other sources of susceptibility effects is enhanced. [9].

Acute hemorrhage and intravascular clots can be detected with SWI. SWI sequences can also be used to determine tissue viability [10, 11].

Higher O_2 extraction fraction and flow reduction in the ischemic brain led to larger levels of vein dilatation and deoxy hemoglobin, which makes vessels more visible on SWI. This prominent vessel sign (PVS) on SWI has been reported to reveal enhanced O_2 extraction and correlates well with venous and capillary deoxy-hemoglobin levels [12]. The goal of this research was to highlight the role of addition of susceptibility weighted MRI to diffusion weighted images of the brain in diagnosis of subjects with acute stroke.

Meterials and Methods:

This prospective study included 30 subjects with clinical manifestations of acute stroke who aged from 36 to 88 years old. The study took place at Radio-diagnosis & Medical Imaging department.

Exclusion criteria were cases with heart pacemaker, metallic aneurysmal clip in the brain, claustrophobia and vitally unstable.

All subjects underwent history taking, routine laboratory tests, cardiologic assessment by echocardiogram and imaging modalities (non-contrast CT study and MRI of the brain).

MRI of the brain:

Prior to entering the magnetic region, detachable metallic implants in the case's body or clothing, such as keys and teeth prosthesis, were removed. With the utilization of a circular polarised head-array coil and ultra-gradients, the cases were put in a supine position with the head in the neutral position. All MRI scans were achieved by MRI 1.5 Tesla unit closed magnet right-handed system (GE Signa Explorer) in Radiodiagnosis and Medical Imaging department, Tanta University Hospitals. The following sequences were used to image the selected patients using an MRI stroke protocol: T1WIs (Tr =120, Te =21), T2WIs (Tr =5288, Te =120), FLAIR sequences (Tr =1100/2800, Te =130), DWIs and ADC maps (Tr =3580, Te =112) and high-resolution susceptibility weighted images (SWI) were then added with the following parameters: TR/TE 24/34, flip angle 10. During the exam, post-processing was

done, and MIP images were created. The entire scan time was less than 30 minutes for all protocols. All of the original MRI were analysed. The description of an infarct area was hypersignal on T2WI, FLAIR sequence, DWI, hyposignal on ADC and hyposignals on SWI (either due to macro-hemorrhage or microbleed in the form of small dark signal dots with their maximum diameter < 10mm and increased size and/or number of regional veins which will appear as low signals as well).

The Alberta Stroke Program Early CT Score (ASPECTS) method was utilized to score infarct extent on individual DWI and SWI in 23 subjects with blockage of the middle cerebral artery. This topographic method assigns 1 point to each of 10 zones of the MCA territory. A score of 10 is normal whereas 0 suggests diffuse infarction. In this 10-point semi-quantitative CT scoring system,1 point was substracted from 10 zones for each area of acute infarction in DWI. Also 1 point was substracted from 10 for each location demonstrating asymmetric hypointense conspicuous vessels on SWI with either raised diameter or vessel number in the target area (MCA territory) in comparison with the normal contralateral side. SWI-DWI positive mismatches were determined if DWI ASPECTS was greater than SWI ASPECTS value, WI-DWI negative mismatches were defined if DWI ASPECTS was fewer than SWI ASPECTS value and no mismatches were determined if ASPECTS on both DWI and SWI was equal.

Statistical analysis:

The statistical package for social sciences IBM SPSS software package version 20.0 was used for data entry, processing, and statistical analysis. (IBM Corporation, Armonk, NY). Number and percent were used to describe qualitative data. The Shapiro-Wilk test was done to ensure that the distribution was normal. Range (minimum and maximum), mean, and standard deviation were used to characterise quantitative data. The significance of the acquired results was assessed at a 5% level. Sensitivity: A test's ability to correctly detect ill people in a

population of "True positives." Divide true positives (TP) by true positives + false negatives (TP+FN) to get the answer.

Results:

Table 1 shows age, sex, risk factors, laboratory results in the studied subjects.

Table 1: Age, sex, risk factors, laboratory results in the studied patients (n = 30)

		Number of patients (%)
Age (years)	**≤60**	11 (36.7%)
	>60	19 (63.3%)
	Mean ± S.D.	63.47±12.221
Sex	**Male**	18 (60.0%)
	Female	12 (40.0%)
Hypertension		17 (56.7%)
Diabetes Mellitus		16 (53.3%)
Smoking		5 (16.7%)
Hypercholesterolemia		4 (13.3%)
Hb		11.28±1.413
WBCs		11.81±2.630
Platelets		160.10±48.325
INR		2.17±0.655
PT		10.61±0.456
PTT		58.83±5.826

Data are presented as mean ± SD or frequency (%). Hb: Hemoglobin, WBCs: White blood cells, INR: International normalized ratio, PT: Prothrombin time, PTT: Partial thromboplastin time.

Table 2 shows distribution according to type of stroke, side of lesion and SWI findings in the studied cases.

Table 2: Distribution according to type of stroke, side of lesion and SWI findings in the studied patients (n = 30)

Type of stroke	**Ischemic stroke**	24 (80 %)
	Hemorrhagic stroke	6 (20 %)
Side of lesion	**Left-sided**	20 (66.7%)
	Right sided	7 (23.3%)
	Bilateral	3 (10%)
SWI findings	**Prominent vessels sign**	23 (76.7%)

	Macro-hemorrhage (low signals)	6 (20 .0%)
	No findings	1 (3.3%)

Data are presented as frequency (%). SWI: Susceptibility weighted imaging.

Table 3 shows the site of occluded artery in the studied 24 cases with ischemic stroke.

Table 3: The site of occluded artery in the studied 24 patients with ischemic stroke (n = 24)

Occluded Artery	Number of patients (%)
Middle cerebral artery	23 (95.8%)
Anterior cerebral artery	1 (4.2%)

Data are presented as frequency (%).

Table 4 shows conventional MRI, DWI and ADC map findings in the studied 30 cases

Table 4: Conventional MRI, DWI and ADC map findings in the studied 30 patients (n = 30)

Findings	T2WIs	FLAIR	DWIs	ADC map
Hyperintense signals	30 (100%)	30 (100%)	30 (100%)	0 (0%)
Hypointense signals	0 (0%)	0 (0%)	0 (0%)	30 (100%)

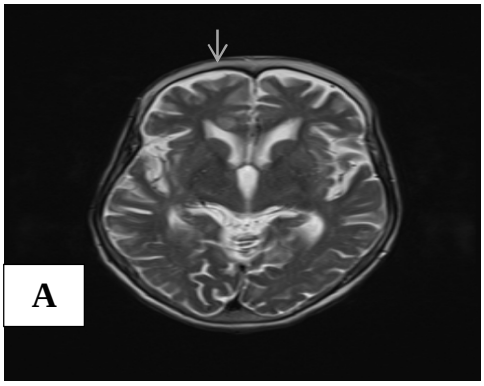
Data are presented as frequency (%). T2WIs: T2-weighted images, FLAIR: Fluid attenuated inversion recovery, DWI: Diffusion weighted imaging, ADC map: Apparent diffusion coefficient map.

Table 5 shows Diffusion weighted imaging (DWI) score and susceptibility weighted imaging (SWI) score and DWI/SWI mismatch in the studied 23 cases with manifestations of acute ischemic stroke due to middle cerebral artery occlusion.

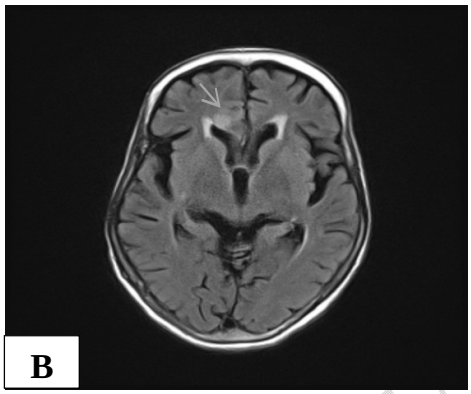
Table 5: Diffusion weighted imaging (DWI) score and susceptibility weighted imaging (SWI) score and DWI/SWI mismatch in the studied 23 patients with manifestations of acute ischemic stroke due to middle cerebral artery occlusion (n = 23)

	Mean ± S.D. (Number of patients (%))
DWI score	6.70 ± 1.52
SWI score	4.96 ± 2.50
DWI/SWI mismatch	
DWI > SWI	15 (65.2%)
DWI = SWI	6 (26.1%)
DWI < SWI	2 (8.7%)
Total	23 (100%)

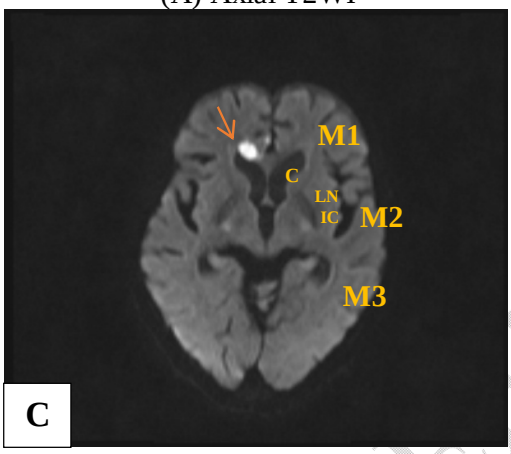
Data are presented as mean ± SD or frequency (%). DWI: Diffusion weighted imaging, SWI: Susceptibility weighted imaging.



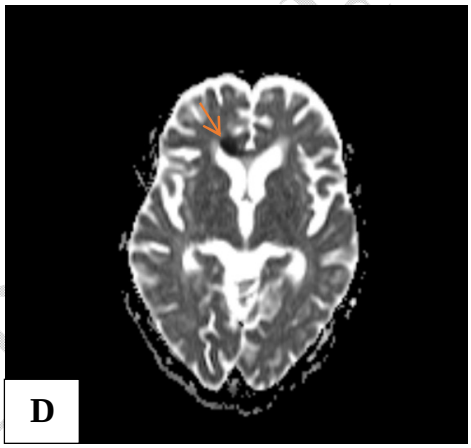
(A) Axial T2WI



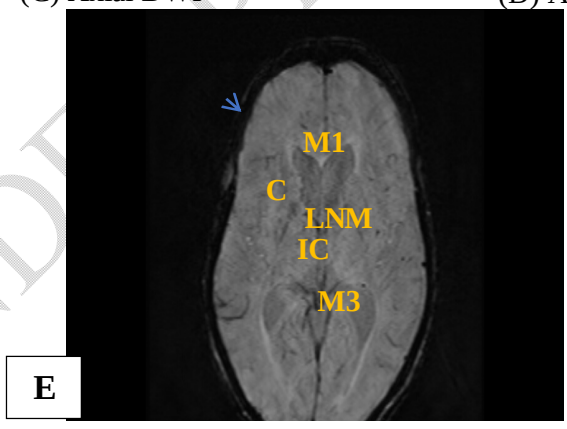
(B) Axial FLAIR



(C) Axial DWI

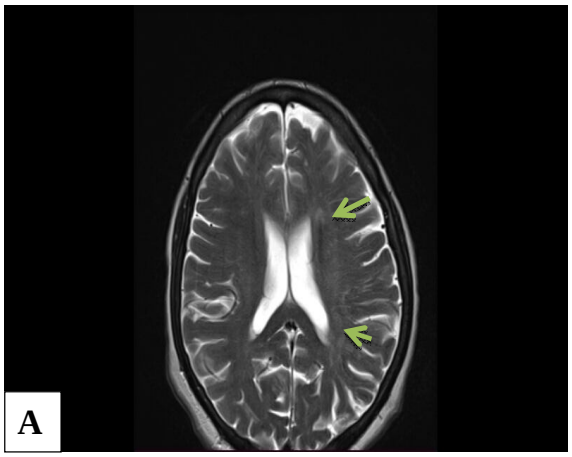


(D) Axial ADC map

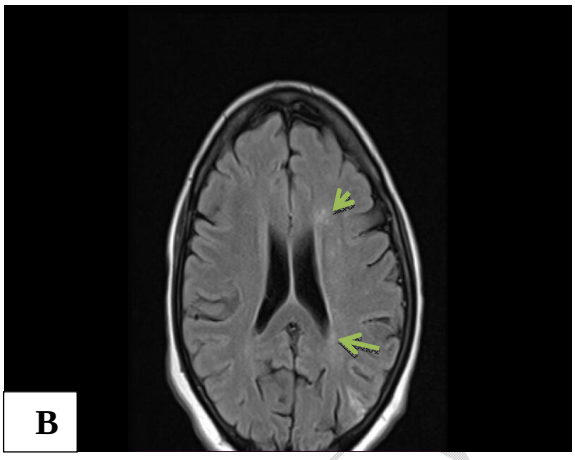


(E) Axial SWI

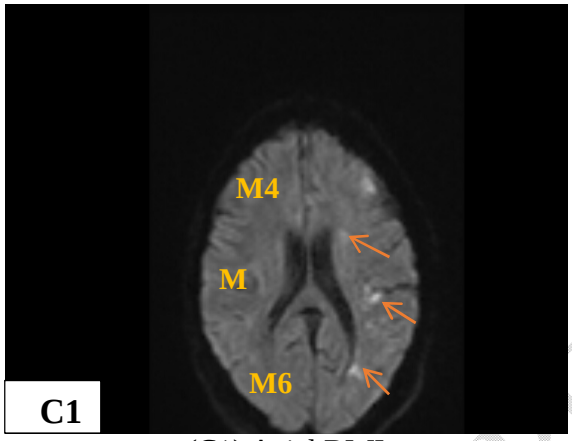
Figure 1: shows a tiny focus of high signals in the right frontal lobe (short arrows in A & B), with true restricted diffusion (short arrows in C& D) and prominent vessel sign (PVS) on SWI (arrowhead in E)



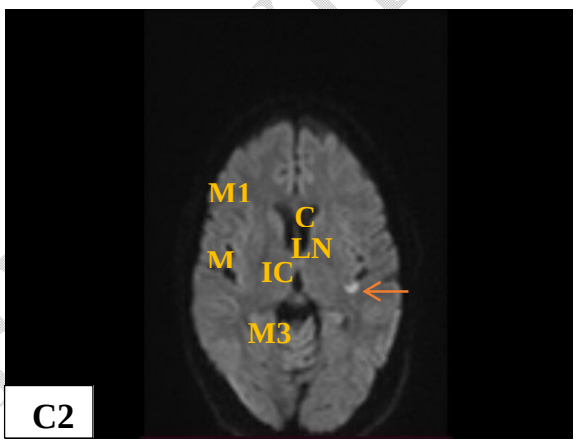
(A) Axial T2WI



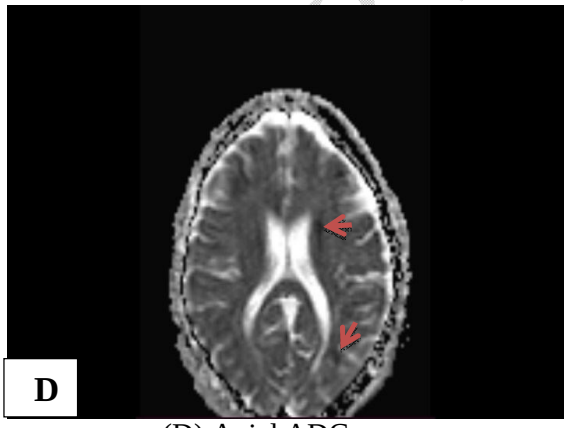
(B) Axial FLAIR



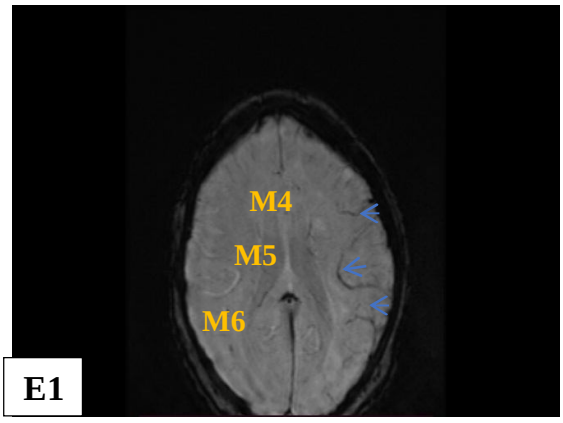
(C1) Axial DWI



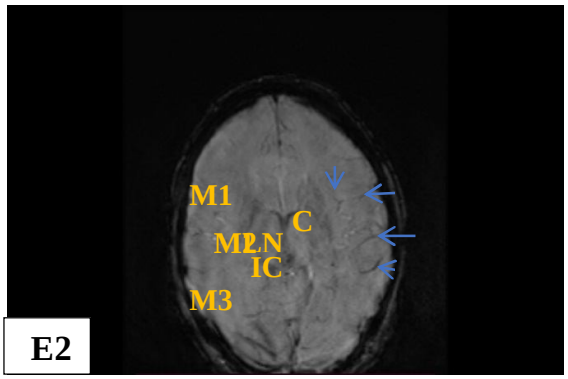
(C2) Axial DWI



(D) Axial ADC map



(E1) Axial SWI



(E2) Axial SWI

Figure 2: shows foci of high signals in the left parietal, frontal and occipital lobes (arrows in A & B) with additional focus also noted in the left lentiform nucleus and all show true restricted diffusion (marks in C1 , C2 & D) and prominent vessel sign (PVS) on SWI (marks in E1 & E2). DWIs reveal the presence of acute infarcts in M4-M6 regions and LN with a resultant ASPECT score of (6), meanwhile SWIs (E &G) reveal prominent vessel sign (PVS) in M4-M6, M1 and M2 regions with a resultant ASPECT score of (5)

Discussion

SWI is a relatively new imaging procedure that focuses on the susceptibility effects within veins [13].

As regard the laboratory investigations of the studied cases , hemoglobin (Hb) was ranged between 9-13.5 g/dl ,white blood cells (WBCs) was ranged between 7.2-16.3 x103 /mm 3, platelets were ranged between 103-247 x103 /mm 3 , international normalized ratio (INR) was ranged between 1.2-3.3, prothrombin time (PT) was ranged between 10-11.4 sec and partial thromboplastin time (PTT) was ranged between 51-70 sec .This agreed with the research of Merbach et al. [14] in which The mean INR at admission for the whole group was 1.6.

The most common presenting symptoms in the research were headache in 26 (86.7%) cases followed by unilateral weakness in 14 (46.7%) cases, 6 (20%) cases with disturbed conscious level, drowsiness in 5 (16.7%) cases, convulsion in 4 (13.3%) cases and the least group was 3

(10%) cases that were presented with slurred speech. This agreed with the research of Harriott et al. [15], in which headache happened in 6% to 44% of the ischemic stroke cases.

In the current research, ischemic stroke was discovered in 24 (80%) cases and hemorrhagic stroke was detected in 6 (20%) cases. Our findings were backed by the research of Joseph et al. [16]as they reported that of 757 cases included, 85.1% have ischemic and 41.9% have hemorrhagic stroke.

As regard distribution of the different location of lesions among brain parenchyma in the studied cases, most of our cases had lesions in subcortical regions in 14 (46.7%) ,10 (33.3%) cases had lesions in cortical regions and 6 (20%) cases had both cortical and subcortical lesions. This matched with the research of Ma et al. [17] as it showed that 56 (83.6%) cases have infarction in the subcortical regions.

Most of our cases had lesions on the left side of the brain as shown in 20 (66.7%) cases, 7 (23.3%) cases had lesion on the right side of the brain and 3 (10%) cases had lesion on either side of the brain. Our research agreed with Mubarak et al. [18] who stated that 13 cases have left sided, and 9 cases have right sided MCA territory infarct. In contrary to our research and according to Liang et al. [19], 19 cases had infarction on the right side and 18 had infarction on the left side.

Because of its direct flow and huge size, the of blood from the ICA into the MCA, the MCA territory was the greatest common vascular territory to be included in an ischemic stroke. This provided a direct conduit for thromboembolism [20].

In our research, middle cerebral artery involvement was detected in 23 (95.8%) cases and the remaining 1 (4.2%) patient had anterior cerebral artery involvement. Our findings were backed up by the research of Chen et al. [12] as they reported that the middle cerebral artery territory infarct is on the left side in 13 cases and on the right side in 9 cases. Arterial occlusion was found in 19 cases, intra-arterial blood clots in 9 cases, and microbleed in 6

cases. On the other hand, Darwish et al. [21] found that 11 cases (55%) and 9 cases (45%) have infarctions of the right and left MCA territories respectively. Our research agreed with Naik et al. [22] showed that the infarcts with hemorrhage are distributed as follows: 11-middle cerebral artery, 1-anterior cerebral artery, 5-posterior cerebral artery, 1-anterior inferior cerebellar artery, 3-superior cerebellar artery, and 1-posterior inferior cerebellar artery.

All of the studied cases showed hyperintense signals on T2WIs, FLAIR sequences and on DWIs and hypointense signals on the ADC map images. Stefan et al. [23] mentioned that blood brain barrier will break in acute stroke and results in a vasogenic edema.

Mullins et al. [24] reported a 97% sensitivity and 100% specificity with using DWIs compared to 100% sensitivity in the current research in assessment of cases with early period of stroke.

In the recent research, PVS on SWI was found in 23 (76.7%) cases,6 (20%) cases had macro-hemorrhage (low signals) on SWI, and 1 (3.3%) patient had no SWI findings. Stefan et al. [23] mentioned that In hypoperfused tissue, the uncoupling of O_2 supply and demand result in a relative raise in deoxy-hemoglobin levels and a reduction in oxy-hemoglobin in the tissue capillaries and draining veins, resulting in a low SWI signal within the draining vein. Also, Kesavadas et al. [25] discovered significant veins in hypoperfused brain areas using SWI. Bosemani et al. [26] indicated that SWI can also indicate hyperintense signals in the draining areas of the vein of hyper-perfusion or luxury perfusion indicating a greater risk of developing post ischemic malignant edema. None of our cases had evidence of this sign.

In contrary to our research, the research of Naik et al. [22] found that of the 22 cases investigated with hemorrhage, 17 had petechial hemorrhage and 5 cases had macro-hemorrhage within the infarct bleeds. Also, they reported that SWI can provide vital information on haemorrhage and vascular thrombosis, which could be useful in determining the severity of an acute stroke. In our research, 20% of the cases showed evidence of macro-hemorrhage within the infarct bleeds and none of the cases had evidence of micro-

hemorrhage within the infarct bleeds. Hermier and Nighoghossian. [27] recorded that SWI has a sensitivity of 100% and accuracy of 100% in assessment of intra-cranial hemorrhage.

DWIs had a sensitivity of 100% and susceptibility weighted images SWIs had a sensitivity of 96.7% in assessment of infarct of our cases. Lingegowda et al. [28] stated that The susceptibility sign's total sensitivity and specificity for all acute major cerebral artery obstructions were 82% and 100%, respectively.

According to the semi-quantitative ASPECT scoring system, The MCA territory has ten zones.: caudate nucleus, lentiform nucleus, internal capsule, insula, M1, M2, and M3 (anterior, middle, and posterior third of the lower MCA territory, respectively), and M4, M5, and M6 (anterior, middle, and posterior third of the higher MCA territory, respectively). The following is the link between DWI ASPECTS and SWI ASPECTS: A positive mismatch was found when the DWI ASPECT was higher than SWI ASPECTS (SWI revealed a greater number of damaged vascular regions than DWI). A negative mismatch was found when the DWI ASPECT was fewer than the SWI ASPECTS (DWI revealed a greater number of damaged vascular regions than SWI.). No mismatch was found when the DWI and SWI ASPECTS scores were identical [21].

DWI ASPECT score in the present research was ranged between 4.0 – 9.0 with a mean value of 6.70 ± 1.52 while SWI ASPECT score was ranged between 0.0 – 9.0 with a mean value of 4.96 ± 2.50 in 23 cases with evidence of middle cerebral artery occlusion. Positive mismatch (DWI>SWI) in 15 (65.2%) cases, 6 (26.1%) cases have no mismatch (DWI = SWI), and 2(8.7%) cases have a negative mismatch (DWI < SWI). In the research of Darwish et al. [21], A positive DWI/ SWI mismatch had a sensitivity, specificity, positive predictive value, negative predictive value, and efficacy of 100 %, 71.43 %, 60 %, 100 %, and 80 % in predicting infarction growth, respectively.. Kao et al. [29] and Mittal et al. [30] also observed that the DWI-SWI mismatch is useful in detecting of penumbra. Also, SWI/DWI mismatch is

beneficial in detecting penumbra in MCA infarct, therefore predicting progression of infarction on follow-up pictures, according to research on pediatric arterial ischemic stroke [31].

Limitations: The major limitation faced during this research is the small sample size, which may have influenced its results, apart from obvious MR contraindications such as cardiac pacemakers, a decreased level of consciousness, vomiting, agitation, and hemodynamic compromise are the most common reasons for an MRI exclusion, and no follow-up research was conducted to examine the disease's course.

Conclusions:

Conventional and DWI MR images are the mainstays for assessment of cases with acute stroke, SWI is a potential adjunct in those cases for detecting an asymmetric prominent hypointense vessels, positive DWI-SWI mismatch is considered as a marker of infarct expansion and an indicator of the ischemic penumbra and SWI is particularly sensitive for detecting haemorrhage in acute stroke cases that no other MRI sequences could detect.

Ethical Approval and Consent:

A written informed consent was taken from every case before contributing to this research. The study was done after approval from the Ethical Committee Tanta University Hospitals.

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