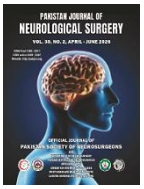

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Original Research

Accuracy of T2WI, DWI, & SWI MRI Sequences in The Diagnosis of Diffuse Axonal Injury: A Cross-Sectional Study

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ABSTRACT

Objective: To determine the diagnostic performance of T2WI, DWI, and SWI in the diagnosis of DAI in patients with traumatic head injury.

Materials & Methods: The study was a cross-sectional study that involved 116 suspected DAI adults. Each of the participants received CT and MRI (T2WI, DWI, & SWI). The results were recorded on demographic data, clinical parameters, and imaging. Chi-square tests were used to determine diagnostic utility.

Results: The average age was 32.6 years with a standard deviation of 10.2, and 67.2% were males. Sixty- three percent of injuries were a result of road traffic accidents. DAI was established in 70.7 per cent of patients. SWI micro bleeds were detected in 55.2 per cent, and they showed a statistically significant relationship with DAI ($p < 0.03$). In 34.5% of the cases, there was DWI restriction in the corpus callosum, which was significantly related to DAI ($p = 0.02$). T2WI hyperintensities were common (67.2%), but they did not demonstrate any significant diagnostic association ($p = 0.312$). CT defects were not predictive of DAI.

Conclusion: SWI and DWI- especially corpus callosum involvement- have the best diagnostic value for the diagnosis of DAI when compared to CT and T2WI. SWI and DWI should be part of the regular imaging of moderate-to-severe TBI, as it significantly improves early diagnosis and clinical decision-making.

Keywords: Diffuse Axonal Injury, Susceptibility-Weighted Imaging (SWI), Diffusion-Weighted Imaging (DWI), T2-Weighted Imaging (T2WI), Traumatic Brain Injury (TBI), MRI, Corpus Callosum.

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INTRODUCTION

The diffuse axonal injury (DAI) is one of the most devastating consequences of traumatic brain injury (TBI), whereby the axons in the grey-white matter junction, along with the deep midline structures, are sheared. DAI is a leading cause of long-term coma, neurological disability, and death due to high-velocity trauma across the globe.[1] Road traffic injuries, falls, and interpersonal violence are the main pathways that

lead to rotational acceleration-deceleration injuries that predispose an individual to DAI.[2]

Neuropathology of DAI is motivated by axonal stretching, cytoskeletal dysregulation, and disruption of axoplasmic flow that cause cytotoxic edema and delayed axonal disconnection.[3] These histologic alterations are often not evident in CT, providing a diagnostic uncertainty in the acute situation. The sensitivity of CT with non-hemorrhagic or small hemorrhagic axonal lesions is significantly low sensitivity although it is still essential in rapidly ruling out mass lesions.[4]

MRI has emerged as the new gold-standard technique in suspected DAI because it has better soft-tissue resolution and can identify both hemorrhagic and non-hemorrhagic axonal injuries. T2-weighted imaging can identify white matter edema and gliotic changes, but may underestimate the burden of acute axonal injury.[5]

Diffusion-weighted imaging (DWI) can identify areas of restricted diffusion that are typical of cytotoxic edema, much better than T2-weighted imaging, and micro hemorrhages, the hallmark lesions of hemorrhagic DAI.[6-7] The diagnostic merits of T2WI, DWI, and SWI in comparison to CT and conventional MRI sequences, especially the ability to detect lesions of the corpus callosum and brainstem, have strong prognostic implications but remain under-characterized in relation to their overall comparative performance in routine clinical practice, especially in low-resource settings. [8-9]

The current research evaluates the diagnostic performance of T2WI, DWI, and SWI in the diagnosis of DAI in patients with head injuries and determines the relationship between imaging results and actual diagnosis. Diffuse axonal injury (DAI) is a catastrophic sequela of traumatic brain injury (TBI) and is usually unseen on computed tomography (CT). Specialized magnetic resonance imaging (MRI) protocols, such as T2-weighted imaging (T2WI), diffusion-weighted imaging (DWI), and susceptibility-weighted imaging (SWI), increasingly serve the purpose of identifying microstructural axonal damage.

MATERIALS AND METHODS

Study Design and Setting

It was a cross-sectional study conducted at the Department of Neurosurgery, Liaquat University of Medical and Health Sciences (LUMHS), Hyderabad/Jamshoro, in six months (October 2024 to March 2025). STARD guideline (Standards for Reporting Diagnostic Accuracy Studies).

Sample and Population of the Study

The necessary sample size was calculated with a confidence interval of 95 percent and a margin of error of 5 percent, amounting to 116. The non-probability consecutive sampling method was used.[10]

Inclusion Criteria

Inclusion criteria were Age 1850 years, both sexes, sustained traumatic / acceleration TBI, GCS 12, Loss of consciousness above 6 hours, MRI within 30 days, and no hemorrhagic contusion on the initial CT scan of the brain.

Exclusion Criteria

Brain surgery, stroke, or neurodegenerative disease that occurred previously, systemic complications of CNS functioning, combined circulatory failure, or incomplete imaging sequences.

Data Collection Procedures

Neurological examination, vital signs examination, the first CT scan, and MRI sequences (T2WI, DWI, SWI) were performed for all patients as standardized procedures. The structured proformas were used to extract radiological findings. SWI lesions were classified according to

the location (corpus callosum, brainstem, subcortical white matter). DWI restriction and T2 hyperintensities were also stratified.

Ethical Approval

The ethical approval was taken from Liaquat University of Medical and Health Sciences, Jamshoro, LUMHS/REC/-1377.

Statistical Analysis

SPSS 25.0 was used for analysis. Frequencies and percentages were used to represent categorical variables, whereas the continuous ones were presented as a mean with the SD. Chi-square tests were used to compare the diagnostic relationships of MRI results with known DAI. The p-value of less than 0.05 was regarded as statistically significant.

RESULTS

Demographics and Clinical Characteristics

Table 1 presents the baseline demographic characteristics, mechanisms of injury, and clinical features of the study participants. The majority of patients were young adult males, with road traffic accidents being the most frequent cause of injury. Clinical parameters, including vital signs and Glasgow Coma Scale (GCS) scores at presentation, are also summarized.

Radiographic Finding

Table 2 summarizes the radiological findings on MRI and CT imaging among study participants. MRI sequences, including susceptibility-weighted imaging (SWI), diffusion-weighted imaging (DWI), and T2-weighted imaging (T2WI), demonstrated

Table 1: *Baseline Demographic and Clinical Characteristics (n = 116).*

Variable	Frequency (%) / Mean ± SD
Age (years)	32.6 ± 10.2
Male	78 (67.2%)
Female	38 (32.8%)
Mean age (Male)	35.9 ± 8.9
Mean age (Female)	30.0 ± 9.2
Mechanism of Injury	
Road traffic accident	70 (60.3%)
Fall from height	25 (21.6%)
Assault	14 (12.1%)
Others	7 (6.0%)
Clinical Features	
Loss of consciousness >6 hours	68 (58.6%)
Sedation/Intubation history	45 (38.8%)
Pulse rate (beats/min)	88.3 ± 12.1
Blood pressure (mmHg)	124.5 ± 15.2
Temperature (°F)	98.6 ± 1.2
Respiratory rate (breaths/min)	19.7 ± 3.4
SpO_2 (%)	96.4 ± 2.8
GCS score	10.2 ± 2.4

Table 2: *Radiological Findings on MRI and CT Imaging (n = 116).*

Variable	Frequency (%)
Timing of MRI	
≤24 hours	38 (32.8%)
24–72 hours	52 (44.8%)
>72 hours	26 (22.4%)
SWI Findings	
Microbleeds	64 (55.2%)
Hemosiderin deposits	22 (19.0%)
Normal SWI	30 (25.9%)
Corpus callosum involvement	48 (41.4%)
Brainstem involvement	38 (32.8%)
DWI Findings	
Diffusion restriction (any)	72 (62.1%)
Corpus callosum involvement	40 (34.5%)
Internal capsule involvement	30 (25.9%)
T2WI Findings	
Hyperintensities present	78 (67.2%)
Frontal lobe involvement	25 (21.6%)
Temporal lobe involvement	20 (17.2%)
CT Findings	
Midline shift	34 (29.3%)
Skull fracture	40 (34.5%)

various abnormalities suggestive of diffuse axonal injury. CT scan findings, including midline shift and skull fractures, are also presented.

Association of Diffuse Axonal Injury And Imaging

Table 3 shows the final diagnosis of diffuse axonal injury (DAI) and its association with different MRI findings. Susceptibility-weighted imaging (SWI) microbleeds and diffusion-weighted imaging (DWI) corpus callosum involvement showed statistically significant associations with DAI, whereas T2 hyperintensities and overall DWI abnormalities were not significantly associated.

Table 3: *Final Diagnosis and MRI Associations with Diffuse Axonal Injury (n = 116).*

Variable	Frequency (%) / p-value	Interpretation
Final Diagnosis		
DAI confirmed	82 (70.7%)	—
DAI not confirmed	34 (29.3%)	—
MRI Associations with DAI		
SWI microbleeds	<0.03	Significant
DWI corpus callosum involvement	0.02	Significant
T2 hyperintensities	0.312	Not significant
DWI abnormalities (any)	0.42	Not significant

Table 4: *Final Diagnosis and MRI Associations with Diffuse Axonal Injury (n = 116).*

Variable	Frequency (%) / p-value	Interpretation
Final Diagnosis		
DAI confirmed	82 (70.7%)	The majority of patients were diagnosed with DAI
DAI not confirmed	34 (29.3%)	—
MRI Associations with DAI		
SWI microbleeds	p = 0.03	Statistically significant association with DAI
DWI corpus callosum involvement	p = 0.02	Statistically significant association with DAI
T2 hyperintensities	p = 0.312	No statistically significant association
DWI abnormalities (any location)	p = 0.42	No statistically significant association

Final Diagnosis and MRI Associations with Diffuse Axonal Injury (n = 116)

Diffuse axonal injury was confirmed in 70.7% of cases. The presence of SWI microbleeds and DWI corpus callosum involvement demonstrated statistically significant associations with DAI ($p < 0.05$); however, T2 hyperintensities and overall DWI abnormalities did not show statistically significant correlations with confirmed DAI (Table 4).

DISCUSSION

This paper has shown that SWI and DWI, especially the involvement of the corpus callosum, are greatly associated with confirmed diffuse axonal injury, which has given great importance to the diagnostic mechanism of traumatic brain injury. SWI restriction (55.2%), DWI restriction (62.1%), and a high rate of microbleeds on the images are compatible with recent findings that the MRI sequences are better than CT and traditional MRI in identifying hemorrhagic and non-hemorrhagic axonal injuries.

SWI Superiority in the detection of hemorrhagic DAI

The paramagnetic sensitivity of SWI to blood products allows it to be the only imaging system to detect micro hemorrhages that are frequently

overlooked using T1, T2, or CT. Various studies show that SWI identifies one to three to six times more hemorrhagic foci than gradient-echo imaging or CT [10]. Our cohort results ($p < 0.03$) of a significant correlation between SWI microbleeds and DAI are consistent with our findings as well as those of Tao et al, who have shown that SWI considerably increases the capability of detecting splenial and brainstem microbleeds--lesions highly associated with worse neurological outcomes.[11]

DWI as an Indicator of Focal Axonal Damage

DWI in the corpus callosum (34.5) was found to be a significant predictor of DAI ($p = 0.02$). DWI abnormalities are probably cytotoxic edema due to axonal stretch damage. The literature from Moritani et al, and Starkey et al, argues in favor of the fact that DWI hyperintensity in midline structures is a predictor of early, frequently irreversible axonal pathology, explaining the clinical relevance of this imaging technique in early prognostication.[12,13]

Poor Diagnostic Value of T2WI

Although the T2WI hyperintensities were prevalent (67.2%), they were not significantly associated with diagnosis ($p = 0.312$). The T2 signal alterations can indicate the presence of edema, gliosis, or non-specific white matter damage, which is why they are less specific. Previous research has also found inconsistent associations between T2 hyperintensities and DAI severity and concluded that T2WI in isolation is not an effective diagnostic measure.[14] CT is still not suitable for the detection of DAI. CT was not predictive of DAI, as was consistent with the larger body of literature suggesting that up to 70% of DAI lesions can be missed on CT.[15] CT is, however, still vital in initial trauma evaluation to eliminate surgically amenable lesions. The clinical and Prognostic Implications, the corpus callosum and brainstem lesions preponderance, agree with the biomechanical models that have shown that the corpus callosum and brainstem are the most affected areas under the rotational shearing forces. These lesions have been closely associated with adverse outcomes, extended coma, and neurocognitive deficits in the long-term.[16]

SWI and DWI have been used together to give a combined picture of hemorrhagic and cytotoxic parts of axonal injury. According to studies by Haacke et al, and Shenton et al, these modalities should be used in regular MRI procedures to diagnose TBI, where significant changes in diagnostic accuracy and outcome forecasting have been found.[17,18]

Comparison of Global Literature

Our results support an individual consensus that is becoming increasingly universal: SWI and DWI are demonstrably much more efficient in diagnosing DAI than CT and standard MRI. Most recent meta-analyses indicate that MRI abnormalities, especially in DWI and SWI abnormalities, are associated with post-traumatic cognitive and behavioral impairments, indicating that they could be helpful in the planning of early rehabilitation.[19,20]

STUDY LIMITATIONS

This was a single-center design that restricts generalizability. We did not have No follow up to compare MRI with functional outcomes in the long-term. MRI timing variability can have an effect on lesion visibility. Although these are limitations, the study presents solid local evidence to adopt the SWI and DWI in regular TBI imaging.

CONCLUSION

SWI and DWI are helpful in the detection of diffuse axonal injury to a great extent as compared with CT and T2WI. DAI can be

diagnosed positively by microbleeds on SWI and diffusion restriction in the corpus callosum. It is highly advised to incorporate these high-level MRI sequences into the standard TBI imaging protocols to enhance the early diagnosis, dictate treatment, and shape prognosis.

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Additional Information

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AUTHORS CONTRIBUTIONS

Sr.#	Author's Full Name	Intellectual Contribution to Paper in Terms of:
1.	Abdul Rauf Menon	1. Study design and methodology
2.	Aurangzeb Kalhoro	2. Paper writing, editing, and quality insurer
3.	Haseebullah Qazi	3. Data collection and calculations
4.	Laeebah Chaudhary	4. Analysis of data and interpretation of results, and Literature review and referencing