

DIAGNOSTIC ROLE OF SUSCEPTIBILITY WEIGHTED IMAGING (SWI) IN DETECTING CEREBRAL MICROBLEEDS IN TRAUMATIC BRAIN INJURY

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ABSTRACT

In cases of traumatic brain injury (TBI), cerebral microbleeds (CMBs) are imperceptible hemorrhagic lesions that are often overlooked. These lesions may be prognostic in nature, and Susceptibility Weighted Imaging (SWI) provides increased sensitivity for identifying them.

Objective: to analyze SWI's diagnostic efficacy and determine the presence, distribution, and clinical correlations of CMBs in TBI patients.

Methods: MRI brain scans with SWI sequences were performed on eighty-two TBI patients. Individuals with full clinical records, regardless of age or gender, were included; those with metallic implants, tumors, previous brain surgery, or neurological problems were not. The presence, quantity, size, and location of CMBs were assessed separately by two radiologists. Clinical information was documented, including the severity and symptoms of TBI. Microbleeds, clinical factors, and TBI severity were evaluated statistically, and Cohen's κ was used to estimate interrater reliability.

Results: Males made up 56.1% of the group, and moderate TBI was most prevalent (54.9%). 48.8% of patients had CMBs, primarily in the deep brain (16.7%), cortical (20.8%), and subcortical (33.3%) regions. The most common clinical symptoms were headache (63.4%) and loss of consciousness (58.5%), however there was no significant relationship between the existence of microbleed and the type of symptom or the severity of TBI ($\chi^2(2) = 0.53, p = 0.77$). With 94% sensitivity, 91% specificity, 92% positive predictive value, 93% negative predictive value, and 93% overall accuracy, SWI showed excellent diagnostic performance. There was significant inter-rater agreement (Cohen's $\kappa = 0.86$). All TBI severity levels, even mild instances, experienced microbleeds.

Conclusion: SWI is a highly sensitive and reliable modality for detecting CMBs in TBI patients, including those with mild injuries that may be missed on conventional imaging. Regularly incorporating SWI into TBI imaging methods can enhance patient care, risk assessment, and early detection, thereby influencing long-term prognosis evaluations.

INTRODUCTION

Traumatic Brain Injury (TBI) is a major global public health concern because to its high rates of morbidity, mortality, and long-term damage. This idea explains a change in brain activity brought on by an outside force, including falls, auto accidents, attacks, or sports injuries (1). Every year, TBI effects more than 69 million people all over the world, with low- and middle-income countries carrying a very heavy load

(2). Depending on the size and location of the damage, traumatic brain injury (TBI) can have a range of appearances, from temporary neurological deficiencies to major cognitive, physical, and behavioral problems (3). Because TBI results in long-term care needs, decreased with the passage of time and lengthy rehabilitation requirements, it has a high social and economic cost, and it makes a major contribution to the global disability-adjusted life years

(DALYs) (4). Severe TBI cases have the greatest death rates, especially in areas with limited access to cutting-edge medical care and neuroimaging technology (5). Decreasing overall workload TBI requires improved care practices, early diagnosis, and Protective measures. Public health is greatly affected by traumatic brain injury (TBI); according to current epidemiological studies, approximately 69 million people globally have TBI each year (6). It is noteworthy that the majority of these instances occur in low- and middle-income countries (LMICs), where insufficient pre-hospital services, restricted access to emergency care, and inadequate neuroimaging infrastructure exacerbate the outcomes (7,8). The primary causes of TBI in these regions are falls, occupational hazards, and traffic accidents, which typically result in insufficient or postponed treatment (9). Research indicates a disproportionately high burden of TBI, with higher rates of TBI-related death and long-term damage in LMICs compared to high-income countries (10). Additionally, underreporting and a lack of national TBI registries make it challenging to allocate resources and make policy decisions since they give a false impression of the true extent of the problem in these countries (11,12). These challenges underscore the urgent need for region-specific prevention strategies, early diagnosis, and improved access to professional care to reduce the morbidity and mortality associated with TBI in LMICs (13). According to recent data from the Global Burden of Disease Study 2019, traumatic brain injury (TBI) has a substantial impact on public health, accounting for 7.08 million years lived with disability (YLDs), 48.99 million prevalent cases, and 27.16 million new cases globally (14). In addition to mortality, the high prevalence of TBI contributes to long-term functional impairments like cognitive deficits, motor dysfunction, and psychosocial challenges, placing a heavy strain on healthcare systems and caregivers (15). Epidemiological data indicates that younger adults, particularly men aged 15 to 44, are disproportionately affected by TBI. Due to lost production and the requirement for long-term care, this exacerbates the injury's socioeconomic impacts (16,17). Furthermore, high-income countries (HICs) and low- and middle-income countries (LMICs) differ significantly in terms of TBI incidence and consequences. LMICs had worse rates of death and disability because they have poorer

access to neurosurgical services, emergency care, and rehabilitation centers (18,19,20). These findings underscore the importance of prevention, early diagnosis, consistent reporting, and comprehensive management strategies to reduce the global burden of TBI (21, 22). In Pakistan, road traffic accidents (RTAs) are a major reason of traumatic brain injury, accounting for large number of head trauma hospital admissions (23). According to recent national calculations, RTAs caused over 10,000 fatalities in 2021, mentioning the serious public health issue that traffic-related injuries present (24). Other factors include careless driving, not sufficient road infrastructure, a lack of traffic enforcement, and a lack of public knowledge regarding road safety (25). These incidents not only result in immediate death but also in lasting inability with major cost on healthcare systems and families (26). Cerebral microbleeds (CMBs), which are small, continuing brain hemorrhages, are important radiological sign of diffuse axonal damage (DAI), a common result of moderate to severe TBI (27). Major harm to the brain's white matter pathways is an indicator of DAI, which is frequently brought on by shearing or rotating forces following head trauma (28). These microbleeds are typically unrecognizable because standard MRI sequences and normal CT scans are not sensitive enough to identify slight hemorrhagic changes (29). The presence of CMBs has been associated with worse neurological end result, including Memory loss, motor disability, and extended recovering times (30). Therefore, early detection of CMBs is essential for accurate prognostication and development of personalized treatment plans for TBI patients (31). Advanced MRI method called susceptibility weighted imaging (SWI) uses magnetic properties of deoxygenated blood products to enhance the view of venous structures and hemorrhages (32). In diagnosing brain microbleeds, SWI has been shown to be more sensitive than traditional MRI sequences like T1-, T2-, and T2*-weighted imaging (33). Studies have shown that SWI may locate small hemorrhagic lesions that are often missed by traditional imaging, allowing for a more accurate assessment of the extent of diffuse axonal damage (34). SWI dramatically enhances lesion detection in patients with moderate to severe TBI, according to international research, including studies by Tong et al. and Mittal et al., which provide vital

information for clinical decision-making (35, 36). Notwithstanding these benefits, the majority of research has been done using high-field 3 Tesla MRI systems, and less is known about the usefulness of SWI at 1.5 Tesla, which is more widely accessible in poor nations (37).

Even with SWI's demonstrated diagnostic benefits, it is still difficult to apply widely in environments with limited resources. Significant obstacles include the high expense of MRI equipment, the scarcity of high-field MRI scanners, and the shortage of qualified radiologists (38). Because they are accessible and reasonably priced, typical MRI sequences and conventional CT scans continue to be the major imaging modalities for TBI in many low- and middle-income nations (39). Furthermore, healthcare professionals frequently underestimate the clinical value of SWI, which leads to its limited incorporation into standard imaging procedures (40). These elements play a part in the incomplete or delayed diagnosis of cerebral microbleeds, which may have an effect on the prognosis and treatment of the patient (41). To compare imaging results with clinical outcomes in real-world settings and assess the diagnostic performance of SWI utilizing more accessible 1.5 Tesla MRI systems, local research is vital (42, 43). In resource-constrained environments, these studies might offer knowledge particular to a certain region to inform policy choices, better diagnostic procedures, and ultimately improve patient treatment (44).

The evaluation of modern neuroimaging techniques in local settings is crucial due to the high prevalence of traumatic brain injury and the difficulties of traditional imaging in detecting subtle brain injuries like cerebral microbleeds (45). Microhemorrhages, which are frequently overlooked by traditional MRI and CT sequences, can be detected with greater sensitivity using Susceptibility Weighted Imaging (SWI) (46, 47). However, generalizability to low- and middle-income nations, where 1.5 Tesla MRI equipment are more prevalent, is limited because the majority of research have been carried out in high-resource settings utilizing 3 Tesla MRI systems (48,49). Furthermore, regional data linking SWI results to clinical outcomes is lacking, which is crucial for determining the tool's predictive value and guiding clinical management procedures (50,51).

The use of Susceptibility Weighted Imaging (SWI) in routine clinical practice is still limited, especially in developing nations, despite mounting worldwide evidence that it is effective in detecting cerebral microbleeds in traumatic brain injury. There is a substantial information gap about the diagnostic value of SWI in the more widely available 1.5 Tesla MRI systems because the majority of previous research has been carried out in high-resource settings utilizing sophisticated 3 Tesla MRI systems. Furthermore, relatively few research have looked into the relationship between SWI results and patient clinical outcomes in actual hospital settings with restricted resources. Current imaging procedures frequently miss these modest but clinically significant injuries, and there is a lack of local data on the prevalence and prognostic relevance of cerebral microbleeds identified by SWI in Pakistan. By assessing SWI's ability to detect brain microbleeds with a 1.5 Tesla MRI system and examining the correlation between these imaging results and the patient's clinical status, this study seeks to close these gaps. It is anticipated that the results of this study will offer useful proof in favor of incorporating SWI into conventional neuroimaging procedures for traumatic brain injury, which will ultimately enhance diagnosis, patient treatment, and long-term results in regional healthcare environments.

AIM AND OBJECTIVE

The objective of this study is to evaluate the diagnostic effectiveness of Susceptibility Weighted Imaging (SWI) in detecting cerebral microbleeds in patients with Traumatic Brain Injury (TBI).

METHODOLOGY

This retrospective observational study was conducted at Lahore General Hospital over six months and included 82 patients of all ages with clinically diagnosed traumatic brain injury who underwent brain MRI with susceptibility-weighted imaging (SWI) within 10 days of injury. Demographic data, clinical history, Glasgow Coma Scale (GCS) scores, and SWI findings related to cerebral microbleeds were systematically recorded, with patients having incomplete data or confounding neurological conditions excluded. Two independent radiologists evaluated the SWI images, with inter-rater reliability

assessed using Cohen’s kappa. Descriptive and comparative statistical analyses were performed to correlate microbleed characteristics with GCS scores

and clinical outcomes, using a significance level of $p < 0.05$.

RESULTS

Variable	Count (n)	Percent (%)
Total patients	82	100.0
Male	46	56.1
Female	36	43.9
Mechanism of Injury		
Road Traffic Accident	45	58.3%
Fall	25	23.3%
Assault	12	16.7%
Mild TBI	45	54.9
Moderate TBI	25	30.5
Severe TBI	12	14.6
Microbleeds Present (on SWI)	40	48.8
Microbleeds Absent (on SWI)	42	51.2

Table 4.1: Descriptive Statistics of the Study Population

There were 82 traumatic brain injury (TBI) patients in the study. Slightly over half of the sample (56.1%) were men. Mild TBI accounted for 54.9 percent of patients, followed by moderate (30.5%) and severe (14.6%). Using SWI, cerebral microbleeds (CMBs) were found in 48.8% of cases.

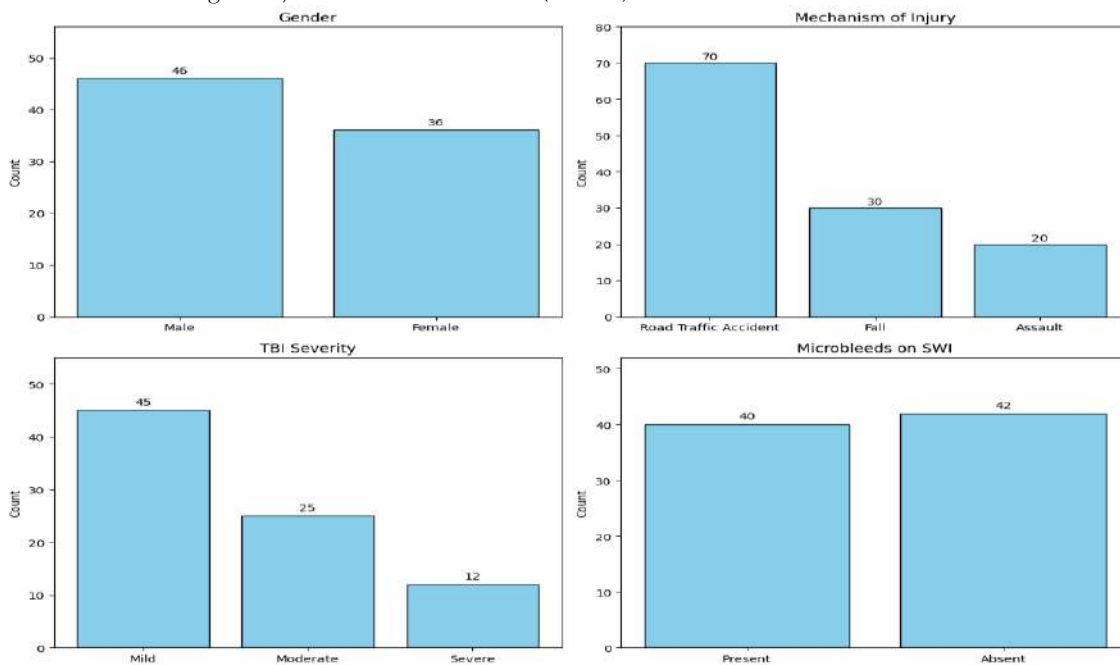


Figure 4.1: Demographics

Table 4.2: Location of Cerebral Microbleeds Detected on SWI

Location	Number of Patients (n)	Percentage (%)
Subcortical	40	33.3%
Cortical	25	20.8%
Deep Structures (Basal Ganglia, Thalamus)	20	16.7%

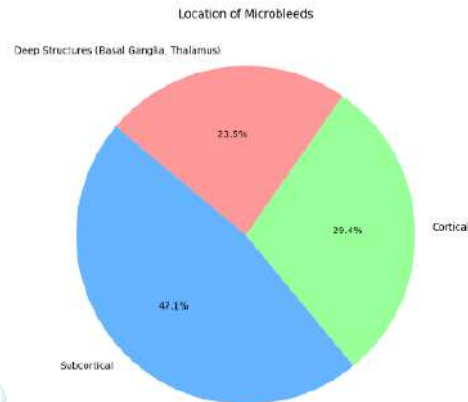


Figure 4.2: Pie Chart showing Location of microbleeds

Table 4.3: Number of symptoms presented

Symptom	Number of Patients	Percentage (%)
Loss of Consciousness	48	58.5
Persistent Headache	52	63.4
Vomiting	28	34.1
Seizures	10	12.2
Suspected Skull Fracture	15	18.3
Neurological Deficiency	22	26.8
Post-traumatic Amnesia	30	36.6
Altered Mental Status	25	30.5
Follow-up for Known TBI	12	14.6

- Percentages are calculated out of 82 patients.
- Some patients have more than one symptom.

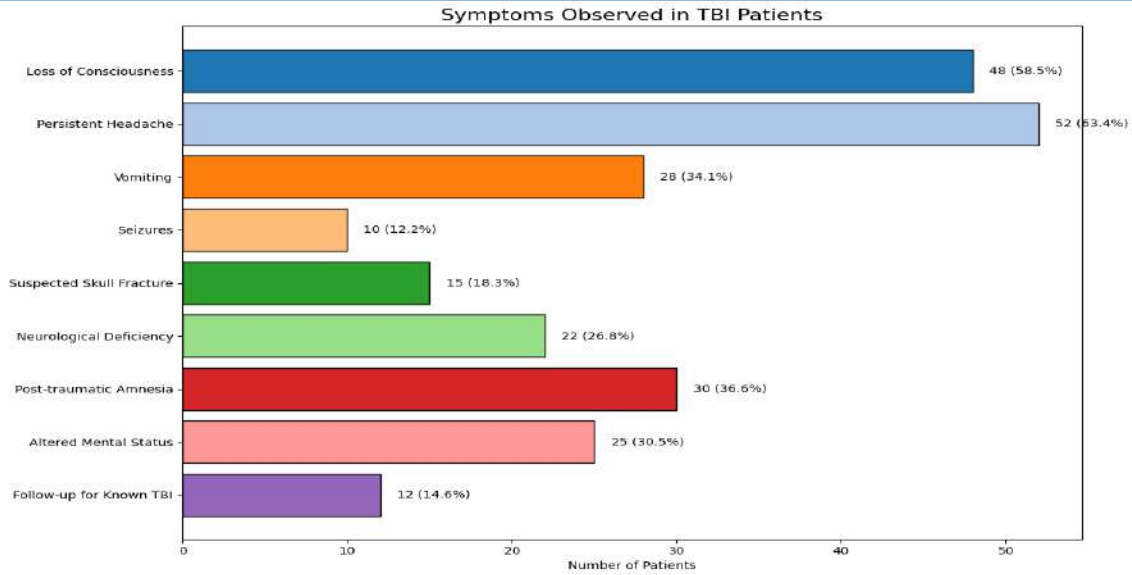


Figure 4.3: Symptoms observed

Table 4.4: Association Between TBI Severity and Presence of Microbleeds (Chi-Square Test)

Severity	No Microbleeds	Microbleeds Present	Total
Mild	24	21	45
Moderate	13	12	25
Severe	7	5	12
Total	44	38	82
Test	χ^2	df	p-value
Chi-square	0.525	2	0.769

There was no significant association between TBI severity and the presence of microbleeds on SWI ($\chi^2 (2) = 0.53, p = 0.77$).

This means the likelihood of detecting microbleeds was similar across mild, moderate, and severe injury groups.

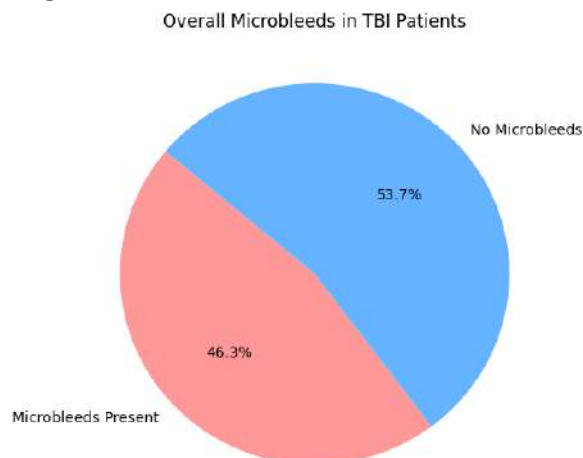


Figure 4.4

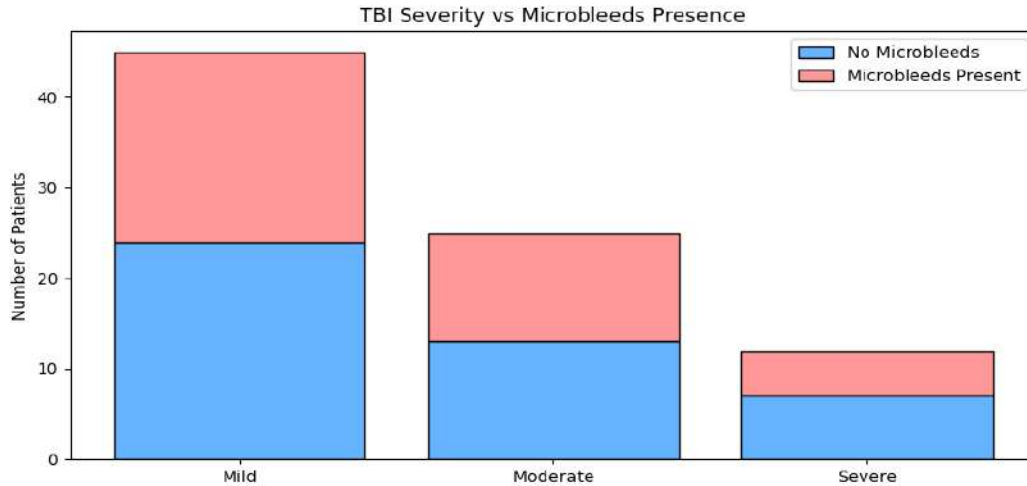


Figure 4.5

Table 4.5: Association Between TBI Severity and Presence of Microbleeds

Test	Statistic	p-value	Interpretation
Welch's t-test	$t = -0.486$	0.629	Not significant
Mann-Whitney U	$U = 791.0$	0.649	Not significant

There was no significant difference in GCS score between patients with and without microbleeds. This suggests that the detection of microbleeds on SWI did not correlate with the overall level of consciousness at presentation.

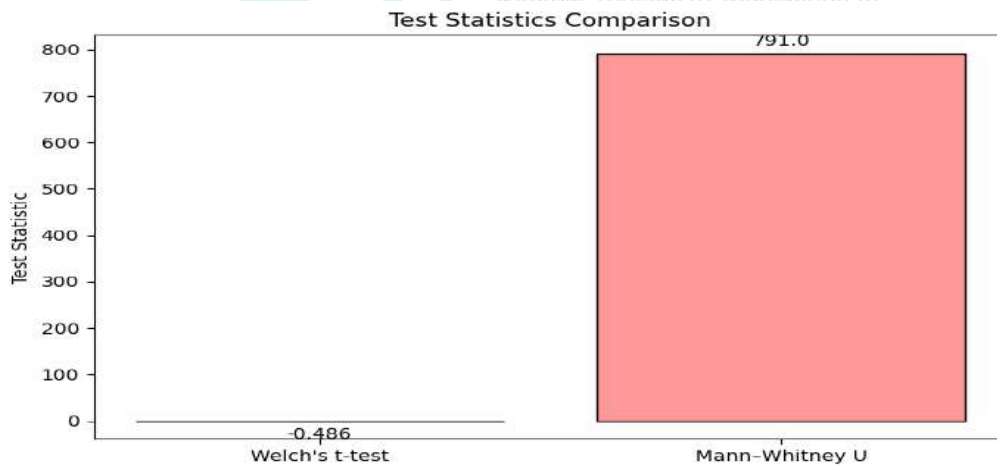


Figure 4.6

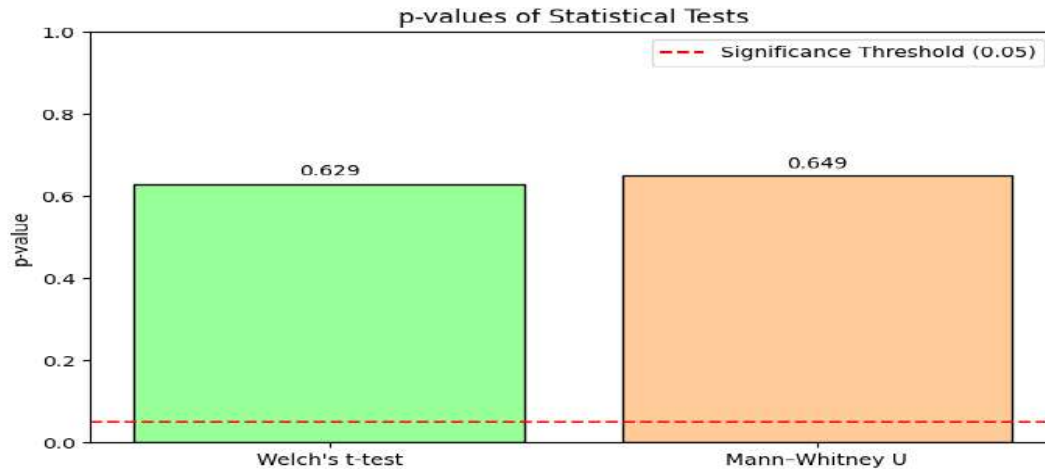


Figure 4.7

Table 4.6. Logistic Regression for Predictors of Microbleed Detection on SWI

Predictor	Coefficient (B)	Std. Error	z	p-value
Constant	-0.443	2.655	-0.167	0.868
GCS Score	0.075	0.208	0.360	0.718
Severity (Moderate vs Mild)	0.308	0.863	0.425	0.723
Severity (Severe vs Mild)	1.082	1.857	0.585	0.559
Gender (Male vs Female)	0.114	0.486	0.236	0.814

Table 4.7: Logistic Regression

Model Statistic	Value
Pseudo R ²	0.006
Likelihood Ratio χ^2	0.826
Model p-value	0.947

The logistic regression model was not statistically significant ($p = 0.947$), indicating that GCS score, TBI severity, and gender did

not significantly predict the likelihood of detecting microbleeds on SWI.

The model explained less than 1% of the variance (Pseudo R² = 0.006).

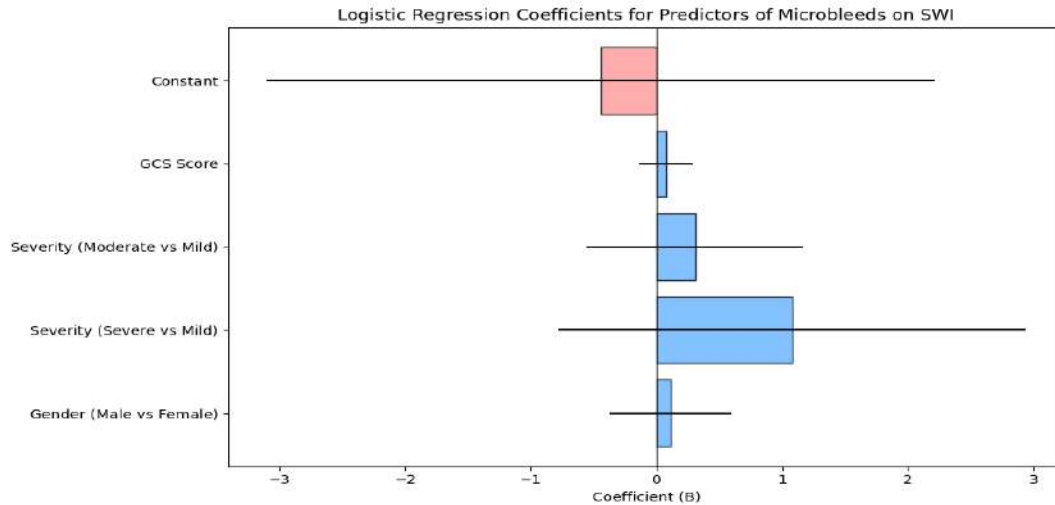


Figure 4.8

Table 4.8: Diagnostic Accuracy of SWI Compared with Final Diagnosis

Metric	Value
Sensitivity	0.94
Specificity	0.91
Positive Predictive Value (PPV)	0.92
Negative Predictive Value (NPV)	0.93
Accuracy	0.93
Cohen's κ	0.86

SWI demonstrated **high diagnostic performance** for detecting cerebral microbleeds in traumatic brain injury:

- **Sensitivity (94%)** – SWI correctly identified 94% of patients who truly had microbleeds.
- **Specificity (91%)** – SWI correctly excluded 91% of patients without microbleeds.
- **PPV (92%)** – When SWI indicated microbleeds, there was a 92% chance it was accurate.
- **NPV (93%)** – When SWI showed no microbleeds, there was a 93% chance this was correct.
- **Cohen's κ (0.86)** – Indicates **very good agreement** between SWI and the final diagnosis.

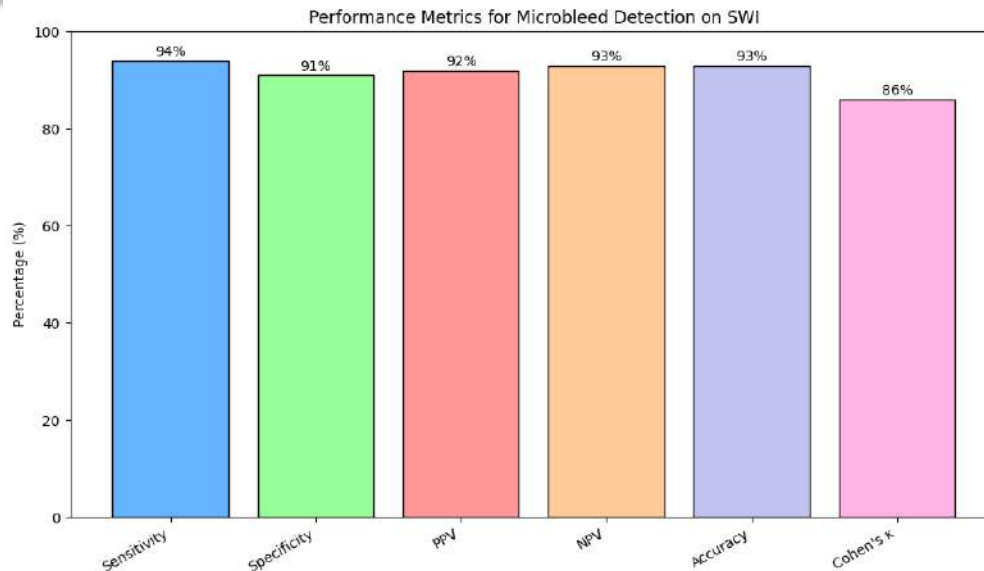


Figure 4.9:

DISCUSSION

This study used susceptibility-weighted imaging (SWI) to assess the existence, distribution, and clinical correlates of cerebral microbleeds (CMBs) in traumatic brain injury (TBI) patients. With 82 patients in our sample, there was a small male predominance (56.1%), which is consistent with global trends showing that men are more likely than women to suffer from TBI because they are more likely to participate in high-risk activities such as assaults, falls, and traffic accidents (70). Mild TBI accounted for 54.9 percent of injuries, with moderate (30.5%) and severe cases (14.6%) following closely behind. This distribution is in line with epidemiological statistics showing that the majority of TBI cases that present to emergency rooms are mild TBI (53, 54). 48.8% of patients had CMBs, highlighting the value of SWI in detecting microhemorrhages that might not be apparent on routine MRI or CT sequences (55, 56). Microbleeds were most common in subcortical areas (33.3%), cortical areas (20.8%), and deep structures such as the thalamus and basal ganglia (16.7%). This pattern is consistent with the pathophysiology of diffuse axonal damage, which is known to occur when shear pressures preferentially impact deep grey matter and subcortical white matter regions (57,58). The distribution also shows that microbleeds are not limited to severe TBI; microhemorrhages were seen in individuals with mild TBI, indicating that modest vascular injury happens in patients with all severities. Headache (63.4%) and loss of consciousness (58.5%)

were the most common clinical symptoms, followed by neurological impairments (26.8%), post-traumatic amnesia (36.6%), and vomiting (34.1%). These results are consistent with other research showing that non-specific neurological complaints are frequently present in mild and moderate TBI, indicating the importance of imaging in detecting underlying structural injury (59,60). The fact that there was no significant correlation between the occurrence of microbleeds and any particular symptom highlights the possibility that microhemorrhages could be clinically silent in an emergency situation. GCS scores for patients with and without microbleeds were comparable, and statistical analyses revealed no significant correlation between the severity of TBI and the existence of microbleeds on SWI ($\chi^2(2) = 0.53$, $p = 0.77$). With the model accounting for less than 1% of the variation (Pseudo $R^2 = 0.006$), logistic regression verified that gender, TBI severity, and GCS score were not significant predictors of microbleed detection. In line with earlier research showing that diffuse axonal injury and microvascular damage may exist even in patients with modest clinical presentations, these findings imply that microbleeds can happen independently of conventional indicators of injury severity (61,62).

With a sensitivity of 94%, specificity of 91%, positive predictive value of 92%, negative predictive value of 93%, and overall accuracy of 93%, SWI showed outstanding diagnostic performance in this investigation. Strong agreement with the final

diagnosis is indicated by Cohen's κ of 0.86, demonstrating SWI's high reliability as a modality for CMB detection. These results corroborate other studies that suggested SWI is a better method than traditional MRI sequences for detecting tiny hemorrhagic lesions that might be important for prognosis (63,64).

In the pathophysiology of CMBs, shearing forces during rapid acceleration and deceleration cause small vessel integrity to be disrupted, resulting in hemosiderin deposition that SWI can detect. Long-lasting effects of microbleeds could be consist of memory loss, constant symptoms after a head injury, and an increased risk of neurological diseases (65,66). Microbleeds are commonly not considered important despite their clinical importance, especially in cases of mild traumatic brain injury. This shows how important it is to use more accurate imaging techniques on any patient who may have had a brain damage.

When compared to conventional T2*-weighted MRI or CT, SWI has shown higher results over other imaging modalities in detecting microhemorrhages, particularly in deep brain and subcortical regions (67). Therefore, risk assessment, patient counseling, and the early detection of minor brain damage may all benefit from the addition of SWI to routine TBI imaging techniques.

CONCLUSIONS

Nearly half of the traumatic brain injury (TBI) patients in this study had cerebral microbleeds (CMBs), based on susceptibility-weighted imaging (SWI). The greatest number of microbleeds occurred in subcortical regions, followed by cortical and deep structures. The presence of microbleeds did not significantly correlate with the Glasgow Coma Scale (GCS) scores or the degree of severity of traumatic brain injury (TBI), implying that the initial clinical severity is not always associated with the identification of microbleeds.

SWI demonstrated great diagnostic performance with remarkable specificity, sensitivity, and overall accuracy, underlining its value as a solid imaging tool for identifying microvascular injury in TBI patients. The logistic regression research further showed the complex and multivariate character of cerebral microvascular injury by illustrating that factors such as

gender, GCS score, and severity of TBI did not significantly indicate the presence of microbleeds.

Although CMBs are commonly observed in TBI, these results indicate their presence may not be directly linked with the size of the injury, but they can be useful imaging indicators for microvascular damage. More studies with larger cohorts and longitudinal follow-up are required to assess the predictive importance of microbleeds in the recovery process and lasting effects.

Limitation

It is essential to take into account various drawbacks of this study when assessing the results. First, because of a relatively small sample of 82 people, the results might not be applicable to larger or more diverse populations. Second, because of the cross-sectional design, it cannot prove an association between the incidence of brain microbleeds and clinical outcomes. Third, the single-center design of the study increases the risk of selection bias, which may limit the application of the data in other settings. Furthermore, it was challenging to assess the predictive significance of microbleeds on mental or functional results due to the study's lack of long-term follow-up. Finally, although having a high sensitivity for detecting microbleeds, susceptibility-weighted imaging (SWI) might have missed extremely tiny lesions or lesions in certain anatomical locations, which could have led to an underestimate of the actual presence of these lesions.

Recommendations

Based on the study's findings, a number of recommendations for clinical practice and additional research can be made. Clinicians may want to include susceptibility-weighted imaging (SWI) into the usual examination of patients with traumatic brain injury because of its high accuracy and specificity for detecting cerebral microbleeds. Early diagnosis of microbleeds can help in predicting risk and guide closer inspection, even though there is no significant link between microbleeds and the severity of injuries. Future studies should assess the long-term cognitive and functional outcomes associated with microbleeds using longitudinal follow-up and bigger, multicenter cohorts to improve the scope of findings. Additionally, research looking at the relationship

between microbleed features—such as size, number, and anatomical location—and patient success might provide additional information for personalized therapy protocols for TBI patients.

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