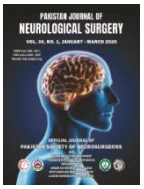

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Original Research

CT-Measured Contusion Volume as a Predictor of Outcome in Surgically Treated Traumatic Brain Injury

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ABSTRACT

Objective: To determine the association between hemorrhagic contusion volume measured on computed tomography and neurological recovery in surgically managed traumatic brain injury patients.

Materials & Methods: This prospective observational study at the Department of Neurosurgery, Lady Reading Hospital, Peshawar (Nov 2024–May 2025) included 217 adult patients with traumatic brain injury and hemorrhagic contusions requiring surgery. Contusion volume was calculated on initial CT using the ABC/2 method. Outcomes were assessed using Glasgow Coma Scale improvement and Glasgow Outcome Scale at three-month follow-up, with analysis performed using SPSS.

Results: The mean patient age was 37.8 ± 11.4 years, and 74.2% were male. The mean hemorrhagic contusion volume was 29.3 ± 13.7 ml. A significant inverse correlation was observed between contusion volume and neurological improvement ($r = -0.60$, $p < 0.001$). Patients with smaller contusion volumes achieved higher Glasgow Outcome Scale scores at three months. Multivariate regression analysis demonstrated that contusion volume ($\beta = -0.041$, OR = 0.96, 95% CI 0.94–0.98, $p < 0.001$), increasing age ($\beta = -0.028$, OR = 0.97, 95% CI 0.95–0.99, $p = 0.006$), and midline shift >5 mm ($\beta = -0.82$, OR = 0.44, 95% CI 0.26–0.74, $p = 0.002$) were independent predictors of poor neurological recovery.

Conclusion: Hemorrhagic contusion volume on computed tomography is a significant predictor of neurological recovery in surgically managed traumatic brain injury. Incorporating volumetric assessment into routine radiological evaluation may help clinicians in prognostication and surgical decision-making.

Keywords: Traumatic Brain Injury, Hemorrhagic Contusion, Computed Tomography, Neurological Recovery.

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INTRODUCTION

Traumatic brain injury remains one of the leading causes of mortality and long-term neurological disability worldwide. It affects millions of individuals every year and represents a major public health challenge in both developed and developing countries.[1] Road traffic accidents, falls, and interpersonal violence are among the most common causes of head trauma. In low and middle-income regions, the burden of traumatic brain injury is particularly high due to rapid urbanization, increasing vehicle use, and limited preventive measures.[2] The clinical spectrum of traumatic brain injury ranges from mild concussion to severe intracranial hemorrhage associated with significant neurological impairment. Early identification of structural brain damage is therefore essential for guiding treatment decisions and improving patient outcomes.[3]

Among the various intracranial lesions observed in traumatic brain injury, hemorrhagic cerebral contusions represent a frequent and clinically significant form of focal brain injury. These lesions occur when mechanical forces during head trauma cause bruising and bleeding within the brain parenchyma. Hemorrhagic contusions are commonly located in the frontal and temporal lobes due to the mechanism of impact against the irregular surfaces of the skull.[4] Depending on their size and location, contusions can produce local tissue destruction, cerebral edema, and mass effect leading to neurological deterioration. In severe cases, surgical intervention may be required to relieve intracranial pressure and prevent secondary brain injury.[5]

Computed tomography has become the primary imaging modality for the initial evaluation of traumatic brain injury because of its rapid acquisition time, wide availability, and high sensitivity for detecting intracranial hemorrhage. CT imaging allows clinicians to quickly identify hemorrhagic contusions, evaluate associated mass effect, and determine the presence of additional lesions such as subdural hematoma or skull fractures.[6] Accurate radiological assessment plays a crucial role in determining the need for surgical intervention and predicting clinical outcome. In emergency settings, CT provides a practical and reliable method for assessing the severity of traumatic brain injury and guiding early management strategies.[7]

An important advantage of computed tomography is the ability to quantify intracranial hemorrhage volume using simple mathematical techniques. One commonly used method is the ABC divided by two techniques, which provides a rapid estimation of lesion volume on CT images. Measurement of hemorrhagic contusion volume offers an objective indicator of the extent of brain injury. Larger lesion volumes are generally associated with greater mass effect and increased intracranial pressure, both of which may contribute to poorer neurological outcomes.[8] Therefore, evaluation of contusion volume has the potential to serve as a useful prognostic marker in patients with traumatic brain injury.

Several studies have investigated radiological predictors of outcome in patients with traumatic brain injury. Imaging parameters such as hematoma size, midline shift, and diffuse brain swelling have been associated with increased morbidity and mortality.[9] However, many investigations have examined mixed types of intracranial lesions, including epidural hematomas, subdural hematomas, and diffuse axonal injuries together. This approach makes it difficult to isolate the specific prognostic value of hemorrhagic contusions alone. Furthermore, many previously published studies were retrospective in design

and, therefore, limited by incomplete clinical information and variations in follow-up duration.[10]

Another limitation identified in earlier research is the lack of standardized protocols for measuring hemorrhagic contusion volume. Variability in measurement techniques and observer interpretation can influence the accuracy and reproducibility of volumetric estimates. The ABC divided by two methods has been widely accepted as a simple and practical approach for estimating intracranial hemorrhage volume. Despite its widespread use, prospective studies evaluating the correlation between contusion volume and neurological recovery remain limited, particularly in resource-constrained healthcare settings.[11]

In Pakistan, the burden of traumatic brain injury continues to increase because of high rates of road traffic accidents and occupational injuries. Despite the large number of patients presenting to tertiary care hospitals, relatively few studies have examined objective imaging predictors of neurological recovery in this population. Most available research from the region has focused on epidemiological trends or mortality rates rather than detailed radiological parameters. As a result, neurosurgeons often rely primarily on clinical assessment when determining prognosis and planning surgical management. [12]

Understanding the relationship between hemorrhagic contusion volume and neurological recovery may help improve decision-making in patients undergoing surgery for traumatic brain injury. Quantitative evaluation of lesion volume could provide valuable information regarding the severity of brain damage and the likelihood of functional recovery. Incorporating such imaging-based predictors into routine clinical practice may assist clinicians in identifying high-risk patients, optimizing surgical timing, and improving postoperative care strategies.

Therefore, the present study was conducted to evaluate the relationship between hemorrhagic contusion volume measured on computed tomography and neurological recovery in surgically managed traumatic brain injury patients. Neurological outcome was assessed using changes in the Glasgow Coma Scale during hospitalization and Glasgow Outcome Scale scores at three-month follow-up. By analyzing this correlation in a prospective cohort from a tertiary care hospital, the study aims to provide locally relevant evidence that may assist clinicians in improving prognostication and management of traumatic brain injury patients.

MATERIALS AND METHODS

Study Design and Setting

This prospective observational study was conducted at the Department of Neurosurgery, Lady Reading Hospital Medical Teaching Institution, Peshawar. The study was carried out over a seven-month period from November 2024 to May 2025. The study population included patients presenting with traumatic brain injury who required surgical management for hemorrhagic cerebral contusions.

Sample Size and Sampling Technique

All consecutive patients presenting with traumatic brain injury and radiologically confirmed hemorrhagic contusion who required surgical intervention during the study period were included. Since the objective was to evaluate outcomes among all eligible cases presenting during the study duration, no predetermined sample size calculation was performed. A total of 217 patients fulfilling the inclusion criteria were enrolled in the study.

Inclusion Criteria

Patients aged eighteen years or older with traumatic brain injury and a clearly identifiable hemorrhagic contusion on initial computed tomography scan were included. Only patients who underwent surgical management during the same hospital admission were considered eligible.

Exclusion Criteria

Patients with penetrating head injuries were excluded. Patients with diffuse axonal injury without focal hemorrhagic contusion were not included. Patients who died within twenty-four hours of admission or those lost to follow-up before the three-month outcome assessment were also excluded from the final analysis.

Radiological Assessment

All patients underwent non-contrast computed tomography of the brain at presentation. Hemorrhagic contusion volume was calculated using the ABC/2 method, which is a commonly used technique for estimating intracranial hemorrhage volume. Measurements were independently performed by two neurosurgeons, and discrepancies were resolved by consensus. Midline shift and the presence of additional intracranial lesions were also documented.

Surgical Indications

The decision for surgical intervention was made by the neurosurgical team according to established traumatic brain injury management protocols. Indications for surgery included large hemorrhagic contusion producing significant mass effect, progressive neurological deterioration, midline shift greater than five millimeters, or evidence of raised intracranial pressure not responding to conservative treatment. Surgical procedures included craniotomy with evacuation of contusion or decompressive craniectomy, depending on the clinical and radiological findings.

Clinical Outcome Evaluation

Neurological status was assessed at admission using the Glasgow Coma Scale. Postoperative neurological recovery was monitored during hospitalization and at discharge. Functional outcome was evaluated using the Glasgow Outcome Scale at three-month follow-up.

Statistical Analysis

The collected information was organized and processed using the Statistical Package for the Social Sciences (IBM SPSS) software, version 26. Summary statistics were generated to describe patient demographics as well as clinical and imaging characteristics. The association between the size of hemorrhagic contusions and subsequent neurological recovery was examined through correlation analysis. In addition, multiple regression modeling was applied to determine the variables that independently influenced neurological outcome. Statistical significance was established at a threshold of p less than 0.05.

Ethical Consideration

Ethical approval for this study was obtained from the Institutional Review Board of Lady Reading Hospital Medical Teaching Institution, Peshawar (Ref No. 780/LRH/MTI). Written informed consent was obtained from all patients or their legal guardians before inclusion in the study. All data were handled confidentially and used solely for research purposes.

RESULTS

Patient Characteristics

The study included 217 patients who met the inclusion criteria. The majority of patients were male and in their third or fourth decade of life. Road traffic accidents were the most common cause of injury, followed by falls and assaults. The

Table 1: *Patient Clinical Profile and Demographics.*

Variable	Value
Total patients	217
Mean age (years)	37.8 ± 11.4
Male gender (%)	161 (74.2%)
Road traffic accidents	132 (60.8%)
Falls	56 (25.8%)
Assaults	29 (13.4%)

mean age was 37.8 years, and the mean admission Glasgow Coma Scale was 8.1.

Initial Imaging and Contusion Volume

The average contusion volume on initial computed tomography was 29.3 milliliters. Most patients had unilateral contusions, while a minority presented with bilateral lesions. A midline shift greater than five millimeters was noted in approximately one-third of cases.

Table 2: *Initial CT Findings and Hemorrhagic Contusion Volume.*

Parameter	Value
Mean contusion volume (ml)	29.3 ± 13.7
Unilateral contusions	187 (86.2%)
Bilateral contusions	30 (13.8%)
Midline shift >5 mm	72 (33.2%)

Neurological Recovery Trends

Improvement in Glasgow Coma Scale was observed in the majority of patients postoperatively. At the three-month follow-up, most patients achieved favorable Glasgow Outcome Scale scores. Patients with lower contusion volumes showed greater functional recovery.

Correlation and Regression Analysis

Statistical analysis demonstrated a significant inverse correlation between hemorrhagic contusion volume and neurological recovery. Contusion volume showed a strong negative correlation with Glasgow Outcome Scale score ($r = -0.58$, 95% CI −0.66 to −0.48, $p < 0.001$) and with improvement in Glasgow Coma Scale ($r = -0.61$, 95% CI −0.69 to −0.52, $p < 0.001$). Multivariate regression analysis was performed to identify independent predictors of neurological recovery. Hemorrhagic contusion volume remained a significant predictor of poor outcome ($\beta = -0.041$, OR = 0.96, 95% CI 0.94–0.98, $p < 0.001$). Increasing patient age was also associated with poorer recovery ($\beta = -0.028$, OR = 0.97, 95% CI 0.95–0.99, $p = 0.006$). Midline shift greater than five millimeters independently predicted unfavorable outcome ($\beta = -0.82$, OR = 0.44, 95% CI 0.26–0.74, $p = 0.002$).

Table 3: *Neurological Recovery Outcomes.*

Outcome Measure	Mean ± SD or %
GCS at admission	8.1 ± 2.2
GCS at discharge	12.7 ± 3.1
GOS at 3 months	4.1 ± 1.2
Favorable GOS (4–5)	143 (65.9%)

Surgical Variables and Complications

The majority of patients underwent craniotomy, while a smaller group received decompressive craniectomy. Postoperative complications included wound infections and seizures in a small proportion. Length of stay was longer in patients with larger contusions.

Table 4: *Correlation and Multivariate Regression Analysis.*

Variable	Statistic	95% Confidence Interval	p-value
Contusion volume vs GOS	r = −0.58	−0.66 to −0.48	<0.001*
Contusion volume vs GCS improvement	r = −0.61	−0.69 to −0.52	<0.001*
Contusion volume (regression)	β = −0.041, OR = 0.96	0.94 – 0.98	<0.001*
Age (years)	β = −0.028, OR = 0.97	0.95 – 0.99	0.006*
Midline shift (>5 mm)	β = −0.82, OR = 0.44	0.26 – 0.74	0.002*

*Statistically significant

Table 5: *Surgical Management and Outcomes.*

Variable	Value
Craniotomy performed	179 (82.5%)
Decompression	38 (17.5%)
Mean hospital stays (days)	14.2 ± 5.6
Postoperative complications	27 (12.4%)

DISCUSSION

Postoperative neurological recovery was found to show a consistent association with lower hemorrhagic contusion volume, which confirmed the hypothesis proposed at the beginning of this research.[13] This finding was observed across a wide range of patient profiles, suggesting the effect to be robust and clinically significant in predicting functional outcome following trauma surgery.[14] Additional analysis revealed that patients with higher volumes experienced prolonged hospital stays and exhibited slower cognitive improvement as measured through sequential assessments of responsiveness and motor coordination.[15] This trend was further reflected in three-month outcome scores, where lower volumes correlated with more favorable ratings on the Glasgow Outcome Scale. [16]

When comparisons were made with external datasets, it was noted that the strength of correlation reported in this study fell within the upper spectrum of global results, despite the constraints of a resource-limited setting.[17] This outcome underscores the potential utility of contusion volume as an early and reliable marker for prognostication, irrespective of regional variation in medical infrastructure. A similar trend was seen in cases where midline shift was present along with large volume contusions, suggesting a compounded impact on neurologic function deterioration.[18]

Other studies have supported the idea that smaller lesions have a better prognosis, and this investigation corroborated those observations using a prospective and standardized measurement method.[18] It was also shown that clinical recovery was not solely dependent on surgical timing but was also influenced significantly by the extent of primary tissue injury, as reflected by the volumetric data collected at admission.[19] Patients with comparable initial clinical scores but smaller contusion volumes had measurably better functional outcomes at discharge and follow-up. [20]

Additionally, it was observed that even among those undergoing similar surgical procedures, outcome disparity was strongly influenced by baseline lesion volume, with larger contusions often leading to residual deficits in speech, memory, and locomotor activity.[21] This effect was more pronounced in individuals older than forty, suggesting that aging brain tissue may have a reduced capacity to recover from high-volume damage.[22] Despite standardized surgical protocols, variability in outcomes indicated that volumetric evaluation could play a key role in future treatment customization and rehabilitation planning.[23]

Overall, the findings from this study align well with international literature and contribute important data from a local setting where few prospective correlations between imaging parameters and neurologic outcomes have been documented. It is expected that this work will prompt further investigation and refinement of surgical protocols based on objective imaging metrics. The simplicity of the measurement technique also enhances its feasibility for routine clinical use.

It has been recognized that implementation of such practices can improve preoperative communication between medical teams and families and assist in setting realistic expectations for recovery. By integrating contusion volume into decision-making pathways, greater consistency in care outcomes may be achieved across different neurosurgical centers, particularly in low-resource environments.

CONCLUSION

A significant correlation was established between hemorrhagic contusion volume and neurological recovery in patients with traumatic brain injury. Better outcomes were observed in those with smaller volumes on initial computed tomography. The results support the inclusion of volumetric analysis in surgical planning and outcome prediction.

LIMITATIONS

The study was conducted at a single institution, which may limit generalizability. Follow-up duration was restricted to three months, which might not reflect long-term recovery outcomes lack of advanced imaging tools limited the assessment of microstructural damage beyond contusion volume.

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Additional Information

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AUTHORS CONTRIBUTIONS

Serial Number	Author's Full Name	Intellectual Contribution to Paper in Terms of
1.	Mewat Shah	Design of study and methodology.
2.	Muhammad Imran Khan	Writing of paper.
3.	Hafeez Ur Rehman	Collection and calculation of data.
4.	Maliha Yousaf	Analysis of data and interpretation of results.
5.	Fariha Afzal	Literature review.
6.	Nadeem Shahzad	Data collection.
7.	Saima Zeb	Referencing.
8.	Innam Ikram	Referencing.