ORIGINAL ARTICLE

Predictive Role of Skull Fracture Type and Location in Intracranial Hemorrhage Among Road Traffic Accident Victims: A CT-Based Observational Study

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ABSTRACT

Objective: To evaluate the predictive relationship between skull fracture types and the presence of Intra cranial Hemorrhage (ICH) in patients with head trauma due to Road Traffic Accidents (RTAs).

Study Design: Retrospective observational cross-sectional study

Place and Duration of Study: The study was carried out during the month of May 2025 at the Radiology Department of Lady Reading Hospital Peshawar

Materials and Methods: Following institutional review board approval, the retrospective study was carried out in May 2025 at the Radiology Department of Lady Reading Hospital Peshawar using data gathered in the Radiology Department's Health Management Information System (HMIS) between January and December 2022. The study analyzed CT brain scans of 300 RTA patients. Data included age, gender, fracture type and site, and presence and type of Intracranial hemorrhage (ICH). Chi-square and logistic regression were used to assess associations.

Results: Out of 300 RTA patients, 246 (82%) were male, with the majority aged 11–30 years. ICH was observed in 126 patients (42%), most commonly extradural hematoma (58.7%). Skull fractures were seen in 154 patients (51%), with parietal bone being the most frequently affected (30.7%). A significant association was found between skull fractures and ICH ($p < 0.001$). Logistic regression confirmed that fracture type independently predicted ICH ($p < 0.001$), with linear fractures showing the highest odds (OR = 5.34), followed by depressed (OR = 4.51) and comminuted fractures (OR = 2.13). Fracture site was also significantly associated with hemorrhage type ($p < 0.001$).

Conclusion: Skull fracture type and location are significant predictors of ICH in RTA patients. Linear and depressed fractures, in particular, are strongly associated with ICH. These findings highlight the importance of detailed CT evaluation for early identification and risk stratification in head trauma cases.

Key Words: *Brain, Computed Tomography; Craniocerebral Trauma, Intracranial Hemorrhage, Road Traffic Accidents, Skull Fracture.*

Introduction

One of the leading causes of mortality and disability worldwide is automobile accidents. RTAs, which cause over 85% of fatalities,[1] are disproportionately common in underdeveloped nations. As the eighth most common cause of mortality worldwide, traffic accidents (RTAs) have emerged as a significant public health concern. Globally, traumatic brain injury (TBI) is a significant health and socioeconomic issue. Out of all trauma-related injuries worldwide, it contributes the most to disability and mortality. In low- and middle-income countries like Pakistan, the burden is exacerbated by limited trauma care infrastructure and poor adherence to safety measures such as helmet or seatbelt use. According to the World Health Organization, approximately 1.3 million deaths occur each year due to RTAs, with many more individuals suffering non-fatal injuries, including head trauma.[2]

Among the spectrum of head trauma, intracranial hemorrhage (ICH) — including extradural hematoma (EDH), subdural hematoma (SDH), subarachnoid hemorrhage (SAH), and intracerebral hemorrhage (ICH) — is particularly critical due to its potential for rapid deterioration. Skull fractures, often resulting from high-velocity impacts, are a key predictor of such hemorrhages.[3-6] Another crucial finding in head injuries linked to RTAs is skull fractures, which

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frequently accompany or increase the risk of ICH. Linear, depressed, diastatic, and basilar fractures are all possible. While depressed and basilar fractures are associated with a higher risk of neurological deterioration and serious intracranial disease, linear fractures are the most common.[7-8] However, not all skull fractures carry the same risk. Fracture characteristics — including type (linear, depressed and comminuted) and location (parietal, frontal, occipital, facial and basal) — may influence the likelihood and severity of ICH. According to studies, the prevalence of different types of ICH varies; epidural hematomas are more common in auto accidents, although subdural and subarachnoid hemorrhages are common.[9-10] Age and gender play significant roles in the severity of outcomes, with the elderly experiencing more severe effects due to bone fragility, and males more frequently involved in RTAs.[9] Although early diagnosis has been enhanced by developments in diagnostic technologies such as computed tomography (CT), the incidence of TBI is still high.[11] While previous studies have established that skull fractures increase the risk of ICH, limited research focuses on how specific fracture types and anatomical sites predict hemorrhagic outcomes. This study investigates these associations in a Pakistani tertiary care setting, aiming to identify fracture characteristics most predictive of ICH and improve early triage and management.

Understanding the predictive value of skull fracture types and locations can refine risk stratification in emergency trauma care. By identifying which fracture characteristics are most strongly associated with ICH, clinicians can prioritize neuroimaging and intervention, especially in resource-limited settings. This study contributes context-specific data to guide trauma management in the local population.

Materials and Methods

This study was conducted following approval from the Institutional Ethical and Research Committee of Lady Reading Hospital, Peshawar (Approval Reference No. 184/LRH/MTI, dated 09.05.2025). As a retrospective observational cross-sectional study using anonymized patient data extracted from the Hospital Management Information System (HMIS) and Radiology PACS, informed consent was not required. All data were handled confidentially, and patient identifiers were removed to ensure privacy. A simple convenient sampling technique was used, including all CT brain scans of RTA patients available in PACS during January –December 2022, ensuring feasibility while capturing consecutive eligible cases. Total 300 patients having history of Road traffic accident in CT Brain report from January, 2022 to December 2022 were included in the study where CT brain was performed using the machine Optima GE 16 slice and reported on PACS system by consultant radiologist (a fellow of CPSP). For reliability, 10% of randomly selected reports were re-reviewed by another senior radiologist; any discrepancies were resolved by consensus. Owing to the large dataset, it was not feasible to re-check all scans; therefore a random sample was used as a quality assurance measure. Repeat/follow-up or post-operative scans from the same episode, known pre-existing intracranial pathology and non-diagnostic image quality scans were excluded.

Using OpenEpi calculator (version 3.01) with 95% confidence level, 19% expected frequency of intracranial hemorrhage among RTA head-injury patients[12], and 5% margin of error, the required sample size was 237. Patients' data was explored from HMIS and entered on a pre-designed proforma having age, gender, type and site of skull bone fracture, any intracranial hemorrhage, its type and site and contusions. Patients were divided into eight age groups based on decades from 0 to +70 years. Data was analyzed using SPSS V 26. Descriptive statistics summarized frequencies. Chi-square test was used to assess categorical associations. Binary logistic regression evaluated fracture type as a predictor of ICH ($p<0.05$ considered significant).

Results

A total of 300 patients involved in road traffic accidents (RTAs) were included in the study. The majority of patients were in the 11–21 years age group (n = 93; 31.4%), followed by the 21–30 years group (n = 68; 22.7%), with a pronounced male predominance (n = 246; 82%). The distribution of age groups and gender is presented in Figure 1A & B.

Intracranial hemorrhages (ICH) were observed in 126 patients (42%). The most common type was extradural hematoma (74 patients; 58.7% of all ICH-positive cases, 95% CI: 50.1–67.3), followed by subdural hematoma (25 patients; 19.8% 95% CI: 12.8–26.8 and other hemorrhages including SAH and intraparenchymal bleed (27 patients; 21.4%, 95% CI: 14.2–28.6). Age-wise distribution of hemorrhage types is shown in Table I.

Skull fractures were found in 154 patients (51.3%). The parietal bone was the most frequently involved (n = 48; 31.2%, 95%CI: 23.9–38.5; a depiction of linear fracture of parietal bone and associated EDH is presented in Figure 1C & D), followed by the frontal bone (n = 39; 25.3%, 95% CI: 18.5–32.1) and facial bones (n = 34; 22.1%, 95% CI: 15.6–28.6). Multiple skull bone fractures were present in 79 patients (51.3%; 95% CI: 43.4–59.2). The most common fracture type was linear (n = 84; 54.6%, 95% CI: 46.7–62.5), followed by comminuted (n = 57; 37.0%, CI: 29.4–44.6) and depressed fractures (n = 13; 8.4%, 95% CI: 4.0–12.8). The proportion of patients with associated intracranial hemorrhage (ICH) was highest in those with linear fractures (55/84; 65.5%), followed by depressed fractures (8/13; 61.5%) and comminuted fractures (25/57; 43.9%) Table II.

Among the 154 patients with skull fractures, 88 (57.5%) also had ICH, while 42.9% had no hemorrhage. Conversely, isolated ICH (without fracture) was seen in 38 patients (30.2% of ICH-positive cases; data not shown). A statistically significant association was found between skull fractures and ICH ($\chi^2 = 29.8$, df = 1, $p < 0.001$). Patients with skull fractures had nearly four times higher odds of developing ICH compared to those without fractures (OR = 3.79; 95% CI: 2.33–6.18). Hemorrhagic contusions were observed in 34 patients with skull fractures (22.2% of those with fractures) and in 15 patients without fractures. This difference was not statistically significant ($p = 0.4$).

Logistic regression demonstrated that the presence and type of skull fracture were significant predictors of intracranial hemorrhage ($\chi^2 = 36.5$, $p < 0.001$). Compared with patients without fractures, those with comminuted fractures had over two-fold increased odds of ICH (OR 2.13, 95% CI: 1.13–4.04, $p = 0.020$), while depressed fractures were associated with a more than four-fold increase (OR 4.51, 95% CI: 1.39–14.62, $p = 0.012$). Linear fractures conferred the greatest risk, with more than five-fold higher odds of ICH (OR 5.34, 95% CI: 2.98–9.56, $p < 0.001$) Table III.

A significant association was found between the site of skull fracture and the type of intracranial hemorrhage ($\chi^2 = 107.365$, df = 25, $p < 0.001$). Parietal fractures were most commonly associated with extradural hematoma (54.2% of parietal fracture cases; 35.1% of all EDH cases). Frontal and temporal fractures also frequently resulted in EDH (41% and 45.8% respectively), while subdural and subarachnoid hemorrhages were less common overall but occurred across multiple fracture sites. A majority of patients with facial fractures had no ICH (82.4%), while those with no fractures also occasionally demonstrated various types of hemorrhage, especially subdural and subarachnoid types.

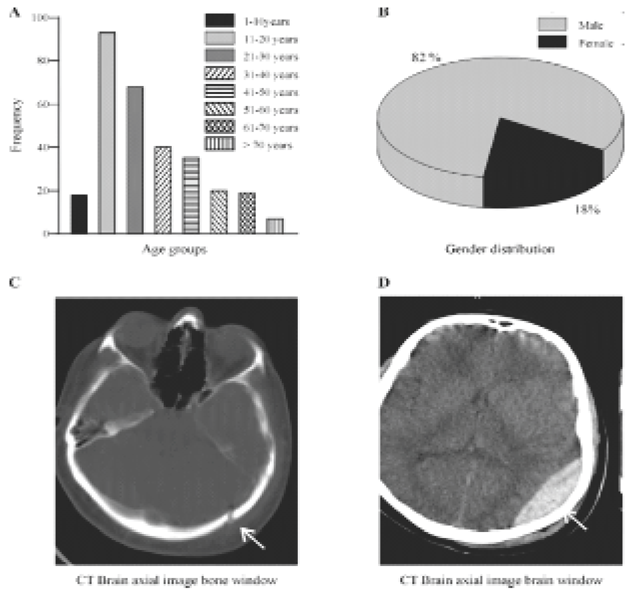

Figure 1. Age (A) and Gender (B) Wise Distribution of The Patients. CT-Brain Axial Image Bone Window (C) And Brain Window (D) Showing Linear Fracture of Left Parietal Bone and Associated Extradural Hematoma.

Table I: Age-Wise Distribution of Hemorrhage Types (n=300)

			Type of Hge					
			Extradural	Mixed	Parenchymal	SubArchnoid Hge	Subdural	Total
Age	1-10 yrs	Count	4	1	0	1	1	7
		% within Age	57.1%	14.3%	0.0%	14.3%	14.3%	100%
	11-20 yrs	Count	29	0	1	0	5	35
		% within Age	82.9%	0.0%	2.9%	0.0%	14.3%	100%
	21-30 yrs	Count	19	2	1	5	9	36
		% within Age	52.8%	5.6%	2.8%	13.9%	25.0%	100%
	31-40 yrs	Count	9	1	2	3	1	16
		% within Age	56.3%	6.3%	12.5%	18.8%	6.3%	100%
	41-50 yrs	Count	8	1	2	0	2	13
		% within Age	61.5%	7.7%	15.4%	0.0%	15.4%	100%
	51-60 yrs	Count	2	2	3	1	1	9
		% within Age	22.2%	22.2%	33.3%	11.1%	11.1%	100%
	61-70 yrs	Count	1	0	0	1	3	5
		% within Age	40.0%	0.0%	0.0%	20.0%	60.0%	100%
	+70 yrs	Count	2	0	0	0	3	5
		% within Age	40.0%	0.0%	0.0%	0.0%	60.0%	100%
Total		Count	74	7	9	11	25	126
		% within Age	58.7%	5.6%	7.1%	8.7%	19.8%	100%

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Table II: Correlation of Intracranial Hemorrhage and Skull Fracture (n=300)

			Skull fracture		Total
			No	Yes	
Intracranial hemorrhage	No	Count	108	66	174
		% within Intracranial hemorrhage	62.1%	37.9%	100.0%
		% within Skull fracture	74.0%	42.9%	58.0%
		% of Total	36.0%	22.0%	58.0%
	Yes	Count	38	88	126
		% within Intracranial hemorrhage	30.2%	69.8%	100.0%
		% within Skull fracture	26.0%	57.1%	42.0%
		% of Total	12.7%	29.3%	42.0%
Total		Count	146	154	300
		% within Intracranial hemorrhage	48.7%	51.3%	100.0%
		% within Skull fracture	100.0%	100.0%	100.0%
		% of Total	48.7%	51.3%	100.0%

Table III: Univariate and Multivariate Logistic Regression Analysis of Skull Fracture Type as a Predictor of Intracranial Hemorrhage

Fracture Type	Univariate OR (95% CI)	p-value	Multivariate OR (95% CI)	p-value
No Fracture	1.00 (reference)	--	1.00 (reference)	--
Comminuted	2.35 (1.31-4.21)	0.004	2.13 (1.13 – 4.04)	0.02
Depressed	4.90 (1.65-14.6)	0.004	4.51 (1.39-14.62)	0.012
Linear	5.62 (3.27-9.64)	<0.001	5.34 (2.98-9.56)	<0.001

Note: OR = odds ratio; CI = confidence interval; Ref = reference category. Univariate ORs were derived from crosstabulated frequencies; multivariate ORs from binary logistic regression including all fracture types simultaneously. Multivariate Model Fit: $\chi^2(3) = 33.77$, $p < 0.001$; Nagelkerke $R^2 = 0.154$; Overall Accuracy = 67.7% (Sensitivity = 50.0%, Specificity = 80.5%).

Discussion

This study aimed to evaluate whether the type and location of skull fractures in road traffic accident (RTA) victims with head trauma are predictive of intracranial hemorrhage (ICH). Our findings demonstrate a clear and statistically significant association between fracture patterns and the occurrence and type of ICH, with important clinical implications for trauma assessment and radiological triage.

In line with global and regional epidemiological trends[13], young adult males were most frequently affected, with the 11–30 years age group comprising over half of the study population. This reflects higher road exposure and risk-taking behavior, consistent with reports from similar LMIC contexts such as Pakistan and Nigeria.[2] Overall, ICH was observed in 42% of patients, with extradural hematoma (EDH) being the most prevalent type (58.7%), followed by subdural hematoma (SDH) (19.8%). These findings differ somewhat from Western literature, where SDH and SAH often predominate, especially in elderly patients.[14] Our younger cohort and high rate of skull fractures may explain the predominance of EDH, which is typically associated with high-impact trauma and arterial injury from fracture lines.

A key focus of this study was the predictive value of fracture types for ICH. Linear fractures were the most frequent (52.9%), followed by comminuted (38.6%) and depressed fractures (8.5%). This finding is similar to other studies where linear fracture was found in 93% of RTA patients.[15-16] Importantly, logistic regression analysis confirmed that fracture type is a statistically significant and independent predictor of ICH ($\chi^2 = 33.77$, $p < 0.001$). Patients with linear fractures had more than five-fold higher odds of ICH (OR = 5.34, 95% CI 2.98-9.56), those with depressed fracture had four-fold increased odds (OR = 4.51, 95% CI: 1.39-14.62) and comminuted fractures carried a two-fold risk (OR = 2.13, 95% CI: 1.13-4.04). These findings emphasize that linear fractures—often regarded as less severe—carry substantial risk of hemorrhagic injury, particularly in the temporoparietal region where the middle meningeal artery is vulnerable. Similar associations have been reported in prior studies, reinforcing the need to avoid underestimating the clinical significance of linear fractures.[17]

Analysis of the anatomical site of fractures revealed strong anatomical correlations with hemorrhage patterns. Parietal bone fractures were the most frequent and most strongly associated with EDH (54.2% of parietal fracture cases; 35.1% of all EDHs). Frontal and temporal fractures also frequently resulted in EDH, consistent with the anatomical course of meningeal vessels. By contrast, facial and occipital fractures were less frequently associated with hemorrhage. This is similar to another study by Hohlrieder et. al.,[18] which showed 14 folds increase in risk of ICH with cranial trauma as compared to facial fractures. A highly significant association between fracture site and hemorrhage type ($\chi^2 = 107.4$, $p < 0.001$) supports the role of fracture location in guiding clinical suspicion and imaging prioritization.

Interestingly, 30.2% of ICH-positive patients had no radiologically detectable skull fracture, a finding consistent with previous studies[19] that highlight the role of acceleration-deceleration forces in producing coup-contrecoup injuries, diffuse axonal injury, and vascular shearing. These cases reinforce that absence of fracture does not exclude serious intracranial pathology, emphasizing the role of clinical vigilance and liberal CT usage in high-risk trauma scenarios.

The study's findings have direct clinical relevance:

- Skull fracture type and location should be considered early indicators of potential ICH, particularly in resource-constrained settings where rapid triage is essential.
- Linear and depressed fractures, although sometimes underappreciated, demand careful evaluation due to their strong association with hemorrhagic injury.
- CT imaging remains indispensable in all moderate-to-severe head injury cases, regardless of external signs, given the significant number of hemorrhages observed without skull fracture.

Limitations and Future Directions

This single-center retrospective design limits generalizability, and important variables such as trauma mechanism, impact velocity, and protective device use were not assessed. Clinical outcomes (neurological status, surgery, mortality) were also not evaluated, and reliance on CT may have missed subtle MRI-detectable injuries like diffuse axonal injury. Future multicenter prospective studies incorporating trauma mechanisms, protective measures, and clinical outcomes, along with comparative CT–MRI assessments, are needed to refine risk models and enhance prognostic relevance.

Conclusion

Skull fracture type and location are strong predictors of intracranial hemorrhage in patients with RTA-related head trauma. These findings highlight the importance of fracture characterization on CT and support its role in risk stratification, triage, and management decisions in emergency settings.

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Conflict of Interest: Authors declare that they have not any conflict of scientific or financial interest with any person or institution.

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CONFLICT OF INTEREST
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DATA SHARING STATEMENT
The data that support the findings of this study are available from the corresponding author upon request.