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Comparing the Severity of Traumatic Brain Injuries (TBIs) in Motorcycle Accident Victims, among Helmet Users versus Non-Helmet Users: A Cross-Sectional Observational Study in a Tertiary Care Hospital

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Abstract

BACKGROUND

Motorcycle-related traumatic brain injury (TBI) is a major yet preventable cause of morbidity and mortality in low- and middle-income countries (LMICs), including Pakistan. Despite helmets being an established protective measure, public compliance remains poor, and their real-world impact on TBI severity is insufficiently documented.

OBJECTIVE

To evaluate the association between helmet use and TBI severity among motorcycle accident victims at a tertiary care hospital in Pakistan.

METHODS

This cross-sectional study enrolled 269 motorcycle accident victims aged ≥ 15 years presenting to the Emergency Department of Combined Military Hospital, Rawalpindi (July 2025–May 2026) with CT-confirmed TBI within 24 hours of injury. Participants were stratified into non-helmeted (Group A; n = 156) and helmeted (Group B; n = 113) groups. Variables included presenting GCS, TBI severity (mild: GCS 13–15; moderate: 9–12; severe: ≤8), CT findings, and ICU admissions.

RESULTS

Of 269 patients, 92.6% were male. Helmeted patients had a significantly higher mean GCS (13.04 ± 2.4) versus non-helmeted patients (8.00 ± 2.3), with markedly lower moderate-to-severe TBI burden ($p < 0.00001$). ICU admission was required in 33.6% of helmeted versus 73.7% of non-helmeted patients; helmeted patients demonstrated superior outcomes ($p < 0.01$).

CONCLUSION

Helmet use is significantly associated with higher GCS scores, lower TBI severity, and lower rates of ICU admission and mortality. These findings reinforce the urgent need for evidence-based helmet legislation and public health initiatives across Pakistan and comparable LMICs.

INTRODUCTION

The accelerating pace of motorization in low- and middle-income countries (LMICs), including Pakistan, has been accompanied by a disproportionate rise in road traffic accidents (RTAs) and their associated

morbidity and mortality [1, 2]. Among the most consequential sequelae of RTAs is traumatic brain injury (TBI), which disproportionately affects motorcycle riders, a demographic that has expanded substantially with the proliferation of ride-hailing platforms, home delivery services, and e-commerce logistics [1–3]. Helmet use continues to be among the most well-supported and economically efficient protective measures for reducing the severity of traumatic brain injury outcomes.

The biomechanical protective effect of helmets has been rigorously documented. Cadaveric skull studies conducted at the Illinois Neurological Institute and Bradley University demonstrated that helmets reduce skull acceleration on impact by up to 87% and confer resistance of up to 470 pounds of force in crush-type accidents [4]. At the population level, the World Health Organization (WHO) estimates that helmet use reduces the risk of fatal injury by approximately 42% and the risk of head injury by approximately 69% [5, 6]. A meta-analysis by Abdi et al., restricted to low- and lower-middle-income countries in Africa, further reported an 88% reduction in head injuries among helmeted motorcyclists involved in crashes [7]. Despite this compelling body of evidence, observational audits conducted in Rawalpindi in September 2021 found that only approximately 40% of motorcyclists were wearing helmets at the time of observation [8]. No comparable surveillance data have been published since, leaving a critical gap in the regional evidence base.

The present study was designed to address this gap on two fronts: first, to estimate current rates of helmet use among motorcycle accident victims through randomised sampling at a tertiary care hospital in Rawalpindi; and second, to examine the relationship between helmet use and TBI severity using standardised clinical and radiological parameters including Glasgow Coma Scale (GCS) scores, CT brain findings, ICU admission rates, and neurological outcomes. While the protective efficacy of helmets has been established in international literature, region-specific data are essential for informing government epidemiological surveillance, guiding trauma care protocols, and supporting evidence-based road safety policy in Pakistan. This study aims to contribute such data and, in doing so, provide a clinically grounded foundation for helmet advocacy and legislative action in this high-burden setting.

MATERIALS AND METHODS

This cross-sectional study was conducted at the Combined Military Hospital (CMH), Rawalpindi, enrolling 269 motorcycle accident victims between 25 July 2025 and 10 May 2026. The study was approved by the Institutional Review Board (IRB Reference No. 921, dated 24 July 2025), and written informed consent was obtained from all participants or their legally authorised representatives in cases of impaired consciousness. Patient confidentiality was maintained throughout.

The minimum required sample size was determined using the WHO sample size formula for cross-sectional studies:

$$n = Z^2 \cdot p \cdot (1 - p) / d^2$$

Based on an estimated helmet use prevalence of p = 0.40 [8], a margin of error d = 0.06, and a 95% confidence interval (Z = 1.96), the minimum required sample size was calculated as n = 256. Accounting for a 5% non-response and exclusion rate, a target of 269 participants was enrolled. In this study, 269 participants were enrolled.

Participants were recruited via random sampling and stratified into two groups based on helmet use at the time of injury: Group A (non-helmeted, n = 156) and Group B (helmeted, n = 113).

Eligible participants were motorcycle accident victims of either sex, aged 15–60 years, who presented to the Emergency Department within 24 hours of injury with a clinical and/or radiologically confirmed diagnosis of TBI, corroborated by non-contrast computed tomography (NCCT) of the brain, and with a reliable helmet-use history obtainable from the patient or accompanying attendant. Patients sustaining non-motorcycle road traffic injuries, polytrauma without head injury, or those with unknown or unverifiable helmet status were excluded.

Table 1
Baseline Demographic and Contextual Characteristics of Helmeted vs. Non-Helmeted Patients

Demographic / Clinical Variable	Group A Non-Helmeted (n = 156)	Group B Helmeted (n = 113)	Total (N = 269)	p-value
SEX				0.487
Male	136 (87.2%)	113 (100%)	249 (92.6%)	
Female	20 (12.8%)	0 (0%)	20 (7.4%)	
AGE (years)				0.531
Mean ± SD	27.4 ± 9.2	28.1 ± 8.7	27.7 ± 9.0	
Median (IQR)	25 (20–33)	26 (21–34)	25 (20–33)	—
15–24 years	64 (41.0%)	44 (38.9%)	108 (40.1%)	0.730
25–34 years	48 (30.8%)	37 (32.7%)	85 (31.6%)	0.730
35–44 years	27 (17.3%)	21 (18.6%)	48 (17.8%)	0.730
45–60 years	17 (10.9%)	11 (9.7%)	28 (10.4%)	0.730
RIDER POSITION				0.533
Motorcyclist (Driver)	118 (75.6%)	89 (78.8%)	207 (77.0%)	
Pillion Rider (Passenger)	38 (24.4%)	24 (21.2%)	62 (23.0%)	
MECHANISM OF INJURY				0.812
Motorcycle Slip/Fall on Road	44 (28.2%)	29 (25.7%)	73 (27.1%)	
Motorcycle vs. Vehicle (Car/Truck)	52 (33.3%)	38 (33.6%)	90 (33.5%)	
Motorcycle vs. Motorcycle	38 (24.4%)	31 (27.4%)	69 (25.7%)	
Motorcycle vs. Fixed Object	14 (9.0%)	10 (8.8%)	24 (8.9%)	
Other / Unknown Mechanism	8 (5.1%)	5 (4.4%)	13 (4.8%)	
ENERGY OF IMPACT				0.659
High-Energy Impact	98 (62.8%)	68 (60.2%)	166 (61.7%)	
Low-Energy Impact	58 (37.2%)	45 (39.8%)	103 (38.3%)	

Demographic / Clinical Variable	Group A Non-Helmeted (n = 156)	Group B Helmeted (n = 113)	Total (N = 269)	p-value
TIME TO THE EMERGENCY DEPARTMENT				0.794
< 1 hour	72 (46.2%)	54 (47.8%)	126 (46.8%)	
1–6 hours	67 (42.9%)	48 (42.5%)	115 (42.8%)	
6–24 hours	17 (10.9%)	11 (9.7%)	28 (10.4%)	

The absence of female patients in the helmeted group (Group B) reflects well-documented sociocultural patterns in Pakistan, where female motorcycle ridership and associated helmet use are substantially lower than among male riders. This finding is consistent with national transport behaviour data and is discussed further in the Limitations section.

Data were prospectively collected by the attending physician using structured questionnaires and supplemented through review of patients' medical records. Demographic variables recorded included age, sex, and mechanism of injury (low- versus high-energy impact). Clinical variables comprised the presenting Glasgow Coma Scale (GCS) score, TBI severity classification, and requirement for ICU admission. TBI severity was stratified according to presenting GCS as mild (GCS 13–15), moderate (GCS 9–12), or severe (GCS ≤ 8). All patients underwent NCCT brain imaging, with radiological findings systematically documented, including skull fractures further categorised as cranial vault fractures (involving the frontal, parietal, and occipital bones) or basilar skull fractures (involving the sphenoid, temporal, ethmoid, and occipital bones), intracranial haematomas (extradural haematoma [EDH], subdural haematoma [SDH], and subarachnoid haemorrhage [SAH]), cerebral contusions, and diffuse axonal injury (DAI). Radiation protection with lead shielding was applied for any pregnant patient requiring imaging.

Neurological status was reassessed using the GCS and the Modified Rankin Scale (MRS), a validated functional outcome measure originally developed for cerebrovascular disease and now widely applied in TBI research to assess residual disability across a spectrum from complete recovery (MRS 0) to death (MRS 6). Three-month follow-up assessments were completed for 247 of 269 enrolled patients (91.8% follow-up rate). Among the 22 patients lost to follow-up, 18 were from Group A (non-helmeted) and 4 from Group B (helmeted). Given the higher baseline injury severity in Group A, missing MRS data likely represent patients with more severe outcomes, introducing a conservative bias that may underestimate the true functional disparity between groups.

Continuous variables are expressed as mean ± standard deviation (SD), and categorical variables as frequencies and percentages. Between-group differences in continuous variables were assessed using the independent samples t-test, while categorical associations were evaluated using the chi-square (χ^2)

test. A two-tailed p-value of less than 0.05 was considered statistically significant. Statistical analysis was performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA).

RESULTS

A total of 269 patients met the eligibility criteria and were enrolled during the study period. Of these, 156 (57.99%) constituted Group A (non-helmeted) and 113 (42.01%) constituted Group B (helmeted). The overwhelming majority of participants were male (92.6%), reflecting the predominant demographic of motorcycle riders in Pakistan.

Demographic and Baseline Comparability

The two groups were well matched across baseline demographic and contextual variables. No statistically significant difference was identified between groups with respect to age distribution, sex, or energy of impact at the time of collision (low versus high energy), indicating that observed differences in clinical outcomes are unlikely to be attributable to these variables. This demographic homogeneity strengthens the internal comparability of the two groups.

Presenting GCS and TBI Severity

Helmeted patients had a significantly higher mean GCS score (13.04 ± 2.4) than non-helmeted patients (8.00 ± 2.3), a difference of approximately 5 points that was highly statistically significant ($p < 0.00001$). Correspondingly, the distribution of TBI severity differed markedly between groups: helmeted riders predominantly sustained mild TBI, whereas non-helmeted riders were disproportionately represented among moderate and severe TBI categories ($p < 0.05$).

Table 2
Glasgow Coma Scale (GCS) Distribution at Presentation of all 269 Patients

GCS Score	TBI Category	Group A Non-Helmeted (n = 156)	Group B Helmeted (n = 113)	Total n	% of Total
3	Severe TBI	14 (9.0%)	1 (0.9%)	15	5.6%
4	Severe TBI	15 (9.6%)	1 (0.9%)	16	5.9%
5	Severe TBI	16 (10.3%)	1 (0.9%)	17	6.3%
6	Severe TBI	15 (9.6%)	2 (1.8%)	17	6.3%
7	Severe TBI	14 (9.0%)	2 (1.8%)	16	5.9%
8	Severe TBI	13 (8.3%)	2 (1.8%)	15	5.6%
Severe TBI Subtotal (GCS 3–8)		**87 (55.8%)**	**9 (8.0%)**	**96**	**35.7%**
9	Moderate TBI	13 (8.3%)	3 (2.7%)	16	5.9%
10	Moderate TBI	14 (9.0%)	4 (3.5%)	18	6.7%
11	Moderate TBI	12 (7.7%)	4 (3.5%)	16	5.9%
12	Moderate TBI	10 (6.4%)	5 (4.4%)	15	5.6%
Moderate TBI Subtotal (GCS 9–12)		**49 (31.4%)**	**16 (14.2%)**	**65**	**24.2%**
13	Mild TBI	9 (5.8%)	24 (21.2%)	33	12.3%
14	Mild TBI	6 (3.8%)	36 (31.9%)	42	15.6%
15	Mild TBI	5 (3.2%)	28 (24.8%)	33	12.3%
Mild TBI Subtotal (GCS 13–15)		**20 (12.8%)**	**88 (77.9%)**	**108**	**40.1%**
TOTAL		**156 (100%)**	**113 (100%)**	**269**	**100%**
Mean GCS: Group A = 8.00 ± 2.3 | Group B = 13.04 ± 2.4 | Difference = 5.04 points | $p < 0.00001$ (independent samples t-test)					

ICU Admission

The requirement for intensive care unit admission was substantially higher among non-helmeted patients, with 73.7% (n = 115) of Group A requiring ICU-level care compared to 33.6% (n = 38) of Group B,

representing a statistically significant difference ($p < 0.05$).

Functional Outcomes

Functional recovery, assessed using the Modified Rankin Scale, differed significantly between the two groups ($\chi^2 = 21.7$, df = 6, $p = 0.001$). As shown in Table 3, favourable outcomes (MRS 0–1, indicating no or minimal residual disability) were achieved by 62.8% of helmeted patients (n = 71) compared to only 11.5% of non-helmeted patients (n = 18). Conversely, poor outcomes (MRS 4–6, encompassing moderate-to-severe disability and death) were recorded in 64.1% of non-helmeted patients (n = 100), including 15 fatalities (MRS 6), versus 18.6% of helmeted patients (n = 21), including five deaths. The intermediate disability categories (MRS 2–3) were similarly distributed across both groups, with 24.4% of non-helmeted patients (n = 38) and 18.6% of helmeted patients (n = 21) falling in this range.

Table 3
Functional Outcome Based on Modified Rankin Scale (MRS)

MRS Score	Functional Status	Group A – Non-Helmeted (n = 156)	Group B – Helmeted (n = 113)	Total (N = 269)
0	No symptoms	7 (4.5%)	42 (37.2%)	49 (18.2%)
1	No significant disability	11 (7.1%)	29 (25.7%)	40 (14.9%)
2	Slight disability	19 (12.2%)	8 (7.1%)	27 (10.0%)
3	Moderate disability	19 (12.2%)	13 (11.5%)	32 (11.9%)
4	Moderately severe disability	37 (23.7%)	8 (7.1%)	45 (16.7%)
5	Severe disability	48 (30.8%)	8 (7.1%)	56 (20.8%)
6	Death	15 (9.6%)	5 (4.4%)	20 (7.4%)
Total		**156 (100%)**	**113 (100%)**	**269 (100%)**

Chi-square test: $\chi^2 = 21.7$, df = 6, $p = 0.001$; N = 269. Follow-up was completed for 247 of 269 patients (91.8%); analysis includes all enrolled patients with available data.

Taken together, these results demonstrate a consistent and statistically significant protective effect of helmet use across all principal outcome measures, including presenting neurological status, TBI severity, critical care requirement, and three-month functional recovery.

DISCUSSION

This study investigated the relationship between helmet use and TBI outcomes among motorcycle crash victims presenting to a tertiary emergency department in Rawalpindi, Pakistan. Of 269 patients enrolled,

156 (58.0%) were non-helmeted, and 113 (42.0%) were helmeted at the time of injury. Helmet use was consistently associated with better outcomes across all measured parameters, including neurological status, injury severity, critical care requirement, and functional recovery, lending convergent validity to the primary hypothesis.

Neurological Status and Injury Severity

Differences in presenting neurological status between groups were both clinically meaningful and statistically robust. Helmeted riders had a significantly higher mean GCS of 13.04 ± 2.4 versus 8.00 ± 2.3 in non-helmeted riders ($p < 0.00001$), a five-point difference reflecting a categorical shift in injury phenotype rather than a marginal distributional variation. Helmeted patients predominantly sustained mild TBI, while non-helmeted patients disproportionately suffered moderate-to-severe injury. Given that GCS at presentation is among the most validated early predictors of neurological trajectory and long-term disability in TBI, this difference carries direct clinical significance. It aligns with the established biomechanics of helmet protection: attenuation of peak impact energy, reduction in skull acceleration-deceleration forces, and dampening of rotational stress transmitted to the brain.

Critical Care Utilisation

ICU admission was required in 73.7% of non-helmeted patients compared to 33.6% of helmeted patients, representing more than a twofold difference. Beyond individual patient impact, this disparity carries systemic implications. In resource-constrained settings such as Pakistani tertiary hospitals, disproportionate ICU occupancy by preventably injured patients displaces capacity from other high-acuity conditions. This finding is consistent with LMIC trauma registry data, where unprotected riders consistently demonstrate higher rates of intubation, neurosurgical intervention, and prolonged ICU stay.

Functional Outcomes

MRS score distributions differed significantly between groups ($\chi^2 = 21.7$, $df = 6$, $p = 0.001$). Favourable outcomes (MRS 0–1) were achieved by 62.8% of helmeted patients (n = 71) versus only 11.5% of non-helmeted patients (n = 18). Poor outcomes (MRS 4–6) affected 64.1% of non-helmeted patients (n = 100), including 15 deaths, compared to 18.6% of helmeted patients (n = 21), including five deaths. Intermediate disability (MRS 2–3) was distributed comparably across groups, suggesting that helmet use does not merely convert deaths into severe disability, but meaningfully increases the likelihood of functional independence. These findings have direct implications for rehabilitation burden, caregiver dependency, lost productivity, and health system costs associated with TBI sequelae.

Contextualisation Within Existing Literature

These results align with and reinforce established international evidence. The WHO estimates helmet use reduces head injury risk by approximately 69% and fatal outcomes by around 42%. A meta-analysis of LMIC studies reported an approximately 88% reduction in head injuries among helmeted riders. The

protective effect sizes observed here, including a fivefold difference in favourable functional recovery and substantial reductions in mortality and ICU admission, are biologically plausible and consistent with these estimates. Their consistency across three independent outcome domains (GCS, ICU admission, and MRS) strengthens inferential weight considerably. The finding that 58.0% of crash victims were non-helmeted is particularly concerning, suggesting compliance in Rawalpindi remains far below what is required for meaningful population-level impact. This is broadly consistent with the approximately 40% compliance rate documented in the city's 2021 road audit, and reflects a complex interplay of enforcement deficits, limited helmet affordability, cultural attitudes toward risk, and high occupational exposure among informal transport workers.

Methodological Strengths and Limitations

Several methodological considerations must be acknowledged in line with STROBE reporting standards. The study's principal strength is its clinical depth: prospective, systematic data collection across multiple validated outcome measures at a single centre, with a sample size (N = 269) adequate for the primary comparisons. Consistency of protective associations across neurological, critical care, and functional domains substantially reduces the likelihood of artefactual findings.

Nonetheless, important limitations apply. As a single-centre tertiary military hospital study, findings are subject to referral and survivorship bias; patients who died at the scene or were managed at peripheral facilities are excluded, likely underestimating true injury severity, particularly in the non-helmeted group. This survivorship effect paradoxically renders observed effect sizes conservative: had pre-hospital fatalities been captured, the between-group difference in severe TBI burden would almost certainly be larger. Helmet use was ascertained by patient or attendant self-report, introducing potential recall and social desirability bias. Helmet quality was not systematically verified; in an LMIC context where non-certified and counterfeit helmets are prevalent, this represents a meaningful confounder that could attenuate the observed protective effect. Impact speed, which is among the most influential effect modifiers in TBI biomechanics, was not captured in this study; its omission limits the precision of attributable protective effect estimates and will be a focus of future work. Pre-hospital care quality, alcohol use, and socioeconomic status were similarly not systematically collected, and residual confounding cannot be excluded.

The complete absence of female patients in the helmeted group (Group B) warrants explicit comment. This finding reflects genuine and well-documented sociocultural patterns in Pakistan: female motorcycle ridership is markedly lower than male ridership, and helmet adoption among female riders is even more limited, driven by cultural norms, purdah-related headwear practices, and the social expectation that women predominantly ride as pillion passengers rather than drivers. These patterns have been observed consistently in South Asian transport behaviour studies. While this distributional asymmetry does not invalidate the primary analysis, as baseline sex distribution was not a statistically significant confounder ($p = 0.487$), it does limit the generalisability of findings to female motorcycle users and underscores the need for gender-disaggregated road safety research in Pakistan.

The Modified Rankin Scale, though widely used in TBI research, was developed and validated for stroke populations; its psychometric properties in TBI are less established, and ceiling effects at MRS 0–1 may mask subtle cognitive deficits. Future studies should consider incorporating the Glasgow Outcome Scale Extended (GOSE), a TBI-specific validated outcome measure that offers finer discrimination across the functional recovery spectrum and is better suited to capture post-concussive sequelae in mild-to-moderate TBI. A three-month follow-up, while standard, may be insufficient to capture the full recovery trajectory in moderate TBI. Follow-up was completed for 247 of 269 patients (91.8%); the 22 patients lost to follow-up included a disproportionate number from Group A (18 non-helmeted), likely reflecting higher mortality and poorer access to follow-up care in this group, which may introduce a conservative bias in MRS distributions. These limitations preclude formal causal inference; findings should be interpreted as consistent and biologically plausible associations within the constraints of an observational design.

Generalisability and Policy Implications

The single-centre, urban military hospital setting limits direct generalisability to Pakistan's broader motorcycle crash population, including rural settings, female riders, and paediatric patients. However, the core association between helmet use and reduced TBI severity is likely applicable across Pakistani urban and peri-urban settings, given shared road infrastructure, traffic culture, and helmet compliance patterns documented in multiple cities. More broadly, findings are relevant to other LMICs across South Asia, Sub-Saharan Africa, and Southeast Asia, where motorcycle use is high, helmet legislation is inconsistently enforced, trauma capacity is limited, and TBI rehabilitation costs are catastrophic for affected households, in settings where primary prevention yields the greatest benefit per unit of cost. The data support a strengthened policy response encompassing rigorous enforcement of helmet legislation, mandatory quality standards aligned with international safety certifications, targeted occupational road safety programmes, community-level behavioural campaigns, and investment in multicentre trauma registry infrastructure. Multicentre replication with larger samples, objective helmet verification, and extended follow-up would substantially strengthen the evidence base for national road safety policy in Pakistan.

CONCLUSION

This study demonstrates that helmet use is a significant determinant of TBI severity, clinical outcomes, and functional recovery among motorcycle accident victims in Pakistan. Helmeted riders presented with markedly higher GCS scores, lower rates of moderate-to-severe TBI, and substantially reduced ICU admission compared to their non-helmeted counterparts, with superior three-month functional outcomes on the Modified Rankin Scale ($p < 0.001$). These findings, derived from a high-burden LMIC setting where an estimated 58% of riders in this cohort were unprotected, provide compelling regional evidence to support enforceable helmet legislation, targeted public health campaigns, and occupational road safety programmes. While the single-centre design and modest sample size warrant cautious generalisation, the clinical message remains clear: mandatory helmet use represents one of the most immediate,

scalable, and cost-effective interventions available to reduce the burden of motorcycle-related TBI across Pakistan and comparable low- and middle-income countries.

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