

Medicolegal Patterns of Fatal Head Injuries in Road Traffic Crashes in Jaipur: An Autopsy Based Observational Study

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ABSTRACT

Background: Fatal head injuries remain an important forensic and road safety concern in India. We examined demographic characteristics, crash circumstances, and cranial injury patterns among traffic fatalities in Jaipur. **Methods:** This observational cross-sectional study included 150 consecutively selected eligible medicolegal autopsies at SMS Medical College during 2024–2025. Police documents, clinical records, attendant histories, and systematic autopsy examinations provided study data. **Results:** 117 victims were male. Two-wheeler users accounted for 88 deaths, pedestrians for 34, and four-wheeler occupants for 28. Helmet non-use was recorded in 66 two-wheeler victims. Evening crashes accounted for 65 cases. Fifty-two victims were brought dead, and another 38 survived for up to six hours. Scalp contusion occurred in 92 cases, linear skull fracture in 93, and combined subdural and subarachnoid haemorrhage in 66. Brain contusion was recorded in 74 cases. Injury-category distributions showed no statistically significant association with road-user type in exploratory comparisons. **Conclusions:** Young men and two-wheeler users predominated. Frequent early deaths and extensive cranial injuries support coordinated prevention, timely trauma care, and systematic forensic documentation. These descriptive findings cannot establish risk or protective-device effectiveness.

Keywords: Road traffic crashes; fatal head injury; medicolegal autopsy; skull fracture; intracranial haemorrhage; road safety

INTRODUCTION

Road traffic injuries impose a substantial burden on individuals, families, and health systems. The World Health Organization's 2023 report estimated approximately 1.19 million annual road traffic deaths and identified road injury as the leading cause of death among people aged 5–29 years.¹ Pedestrians, cyclists, and motorcyclists remain particularly exposed. Beyond mortality, crashes cause disability and financial hardship, highlighting the need for coordinated prevention and trauma care.

Traumatic brain injury can cause rapid death or persistent neurological impairment. Global studies demonstrate its substantial contribution to morbidity and disability, although estimates vary with definitions

and ascertainment methods.^{2,3} The Lancet Neurology commissions emphasise an integrated response encompassing prevention, emergency care, treatment, rehabilitation, and research.^{4,5} Fatal head injuries therefore require assessment of both anatomical damage and the circumstances surrounding the crash. India recorded 461,312 road accidents and 168,491 deaths in 2022.⁶ Gururaj identified road traffic injury as a major contributor to traumatic brain injury and highlighted deficiencies in prevention and prehospital services.⁷ Massenburg and colleagues reported a predominance of young men, road traffic crashes as the leading injury mechanism, and weaknesses in research reporting.⁸ Local forensic studies can

supplement these findings with detailed injury patterns.

Two-wheeler users and pedestrians are particularly vulnerable to cranial trauma. Fitzharris and colleagues documented head injuries among two-wheeler users in urban India⁹, while Pruthi and colleagues demonstrated the clinical and mortuary burden of pedestrian head injuries in Bangalore.¹⁰ Comparing these groups may identify differences in fatal injury patterns.

A Cochrane review found that motorcycle helmets reduce death and head injury among crash victims.¹¹ Evidence from African and American studies and a review of universal helmet laws supports their protective role.¹²⁻¹⁴ However, fatality-only autopsy studies cannot establish helmet effectiveness without suitable comparison groups.

Autopsy provides detailed assessment of scalp, skull, meningeal, and brain injuries, as demonstrated by Menon and colleagues.¹⁵ Correlation with clinical and circumstantial information remains essential given the heterogeneity of traumatic brain injury.¹⁶ We therefore studied 150 eligible traffic fatalities at SMS Medical College, Jaipur, to describe demographic characteristics, crash circumstances, survival categories, and autopsy findings, and explore injury-pattern variation across road-user groups.

METHODS

This hospital-based cross-sectional observational study included 150 consecutively enrolled medicolegal road traffic fatalities with fatal head injuries at the Department of Forensic Medicine and Toxicology, SMS Medical College and Attached Group of Hospitals, Jaipur, during 2024–2025. Institutional Research Review Board and Institutional Ethics Committee approval was obtained. Written informed consent for research participation was obtained from an attendant or legal heir. Cases with independently fatal extracranial injuries or previous surgery for head injury were excluded.

Sample size was calculated using an assumed linear skull fracture proportion of 62%, based on the seed article by Sreekanth S. Nair et al.¹⁷, with 95% confidence and an absolute allowable error of eight percentage points. The formula $n = Z^2p(1 - p)/d^2$,

using $Z = 1.96$, $p = 0.62$, and $d = 0.08$, yielded 141.42; the planned sample was increased to 150.

A predesigned, pretested proforma captured demographic characteristics, crash location and timing, road-user category, victim role, offending vehicle, survival category, and protective-device use. Sources included police inquest papers, clinical records, death summaries, and attendant histories. Unknown helmet or seatbelt status was retained separately; these devices were considered inapplicable to pedestrians. Suspected alcohol use was recorded when available, without quantitative analysis.

Complete medicolegal autopsy documented external injuries and their characteristics, followed by examination of the reflected scalp, skull vault and base, meninges, and brain. Scalp injuries were classified as contusions, lacerations, abrasions, mixed injuries, or absent; skull fractures as linear, basal, depressed, comminuted or multiple, or absent. Intracranial haemorrhage was categorised as combined subdural–subarachnoid, isolated subdural, isolated subarachnoid, other or mixed, or absent. Injury locations, bleeding extent, brain contusions, lacerations, oedema, and associated injuries were recorded. Cause of death was determined through pathological, clinical, and circumstantial correlation; overlapping diagnostic labels were retained as recorded.

De-identified data were checked for completeness and consistency and entered into Microsoft Excel. Age was summarised using mean, standard deviation, and range; categorical variables using counts and percentages. Denominators were 150 unless otherwise specified. Brought-dead status remained separate from timed survival categories, and unaccounted anatomical counts were identified without assigning diagnoses.

Associations between road-user group and scalp injury, skull fracture, and intracranial haemorrhage were explored using Pearson chi-square tests on aggregate counts, with $p < 0.05$. Sparse expected counts warranted exploratory interpretation. Protective-device categories were not compared across road-user groups because applicability differed. No multivariable or causal analysis was performed.

RESULTS

We examined 150 eligible fatalities. Mean age was 34.61 ± 14.07 years (range 7–67). The 21–30-year group comprised 49 cases (32.67%); 117 victims (78.00%) were male. Urban residents accounted for 88 cases (58.67%). Table 1 combines the demographic distributions.

Table 1 Demographic characteristics of the 150 victims

Characteristic	Category	n	%
Age in years	0-10	2	1.33
	11-20	20	13.33
	21-30	49	32.67
	31-40	29	19.33
	41-50	28	18.67
	51-60	16	10.67

	61-70	6	4.00
Sex	Male	117	78.00
	Female	33	22.00
Residence	Urban	88	58.67
	Rural	62	41.33
Education	Illiterate	10	6.67
	Primary	34	22.67
	Secondary	64	42.67
	Graduate	34	22.67
	Postgraduate and above	8	5.33
Occupation	Unemployed	18	12.00
	Self-employed	36	24.00
	Student	32	21.33
	Housewife	10	6.67
	Employed	43	28.67
	Pensioner	3	2.00
	Others	8	5.33

Age is additionally summarised as mean $\pm$ SD: 34.61 $\pm$ 14.07 years. Percentages use N = 150.

Two-wheeler users formed the largest road-user group (88; 58.67%), followed by pedestrians (34; 22.67%) and four-wheeler occupants (28; 18.67%). Heavy motor vehicles were the most frequently recorded offending-vehicle category (48; 32.00%). Evening crashes comprised 65 cases (43.33%). Fifty-two victims (34.67%) were brought dead, and 38 (25.33%) were recorded in the first six-hour survival category (Table 2 and Figure 1).

Table 2 Road user crash environment and survival characteristics

Characteristic	Category	n	%
Road user	Two-wheeler	88	58.67
	Pedestrian	34	22.67
	Four-wheeler	28	18.67
Offending vehicle	Heavy motor vehicle	48	32.00
	Car/jeep	33	22.00
	Bus	25	16.67
	Two wheeler	16	10.67
	Stationary object	12	8.00
	Unknown	16	10.67
Crash time	00:01-06:00 (Night)	18	12.00
	06:01-12:00 (Morning)	30	20.00
	12:01-18:00 (Day)	37	24.67
	18:01-24:00 (Evening)	65	43.33
Road type	National highway	35	23.33
	State highway	36	24.00
	City road	39	26.00
	Intersection	31	20.67
	Bypass/ring road	4	2.67
	Service lane	3	2.00
	Rural road	2	1.33
Survival category	Brought dead	52	34.67
	0-6 h	38	25.33
	6-12 h	20	13.33
	12-24 h	15	10.00
	24-48 h	11	7.33
	48-72 h	6	4.00
	3 days-7 days	6	4.00
	7 days-1 month	2	1.33
	More than 1 month	0	0.00

Percentages use N = 150. Brought-dead status is separate from timed survival. The recorded survival intervals have boundary labels that overlap; these labels are reproduced without reallocating cases.

Helmet non-use was recorded in 66 of 88 two-wheeler victims (75.00%); status was unknown for eight (9.09%). Seatbelt non-use was recorded in 18 of 28 four-wheeler occupants (64.29%), with unknown status in two (7.14%). Table 3 presents each device within its applicable road-user group.

Table 3 Protective device status within applicable road user groups

Road user	Device status	n	Within group %
Two-wheeler (n = 88)	Helmet used	14	15.91
	Helmet not used	66	75.00
	Unknown	8	9.09
Four-wheeler (n = 28)	Seatbelt used	8	28.57
	Seatbelt not used	18	64.29
	Unknown	2	7.14
Pedestrian (n = 34)	Not applicable	34	100.00

Device-specific percentages use the indicated road-user denominator. No causal device-effect comparison was made.

Scalp contusion was recorded in 92 cases (61.33%), and linear skull fracture in 93 (62.00%). Intracranial haemorrhage occurred in 123 cases (82.00%), including 66 (44.00%) with combined subdural and subarachnoid haemorrhage. Multiple haemorrhage regions were recorded in 104 cases (69.33%). Brain contusion was the most frequent recorded brain finding (74; 49.33%). The cause-of-death entries were cranio-cerebral damage in 97 cases (64.67%), traumatic brain injury in 50 (33.33%), and intracranial haemorrhage in three (2.00%). These entries reflect the recorded terminology (Table 4 and Figure 2).

Table 4 Combined autopsy findings and recorded cause of death

Domain	Finding	n	%
Scalp injury	Contusion	92	61.33
	Laceration	16	10.67
	Abrasion	5	3.33
	Mixed scalp injury	17	11.33
	Absent	20	13.33
Scalp location	Frontal	26	17.33
	Temporal	15	10.00
	Parietal	3	2.00
	Occipital	6	4.00
	Multiple regions	79	52.67
	Absent	20	13.33
Skull fracture	Unaccounted for in location summary	1	0.67
	Linear fracture	93	62.00
	Basal skull fracture	9	6.00
	Depressed fracture	8	5.33
	Comminuted/multiple fracture	20	13.33
Intracranial bleeding	Absent	20	13.33
	SDH + SAH	66	44.00
	SDH	24	16.00
	SAH	23	15.33
	Other/mixed hemorrhage	10	6.67
Bleeding location	Absent	27	18.00
	Frontal	9	6.00
	Temporal	4	2.67
	Parietal	1	0.67
	Occipital	5	3.33
	Multiple regions	104	69.33
Brain finding	Absent	27	18.00
	Brain contusion	74	49.33
	Cerebral edema	48	32.00
	Brain laceration	17	11.33
	Diffuse axonal injury	7	4.67
Cause of death	Unaccounted for in brain summary	4	2.67
	Traumatic brain injury	50	33.33

Associated injury	Intracranial haemorrhage	3	2.00
	Cranio-cerebral damage	97	64.67
	Limb abrasions/contusions	45	30.00
	None recorded	40	26.67
	Limb fracture	29	19.33
	Multiple superficial injuries	16	10.67
	Facial injuries	11	7.33
	Chest wall contusion	9	6.00

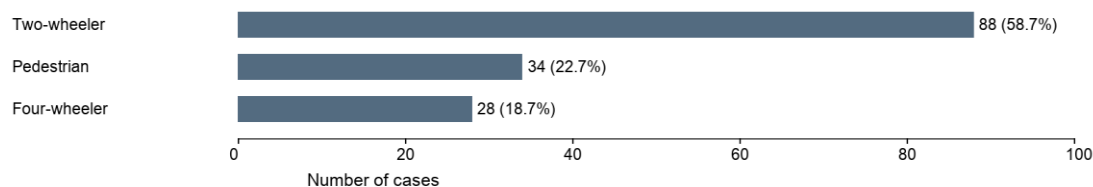
Percentages use N = 150. Scalp-location counts total 149 and listed brain-finding counts total 146; the remainder is unaccounted for, not an inferred diagnosis. SDH = subdural haemorrhage; SAH = subarachnoid haemorrhage. Linear fractures and combined subdural and subarachnoid haemorrhage were the most frequent categories in all three road-user groups. Recalculation from the aggregate counts gave $\chi^2 = 6.31$, $p = 0.612$ for scalp injury; $\chi^2 = 12.44$, $p = 0.133$ for skull fracture; and $\chi^2 = 3.49$, $p = 0.900$ for intracranial haemorrhage (all $df = 8$). None met the prespecified significance threshold. Small expected cell counts require caution; these results do not establish equivalence between groups (Table 5).

Table 5 Head injury categories according to road user group

Finding	Two-wheeler n = 88	Pedestrian n = 34	4-wheeler n = 28
Scalp injury: Contusion	51 (57.95)	23 (67.65)	18 (64.29)
Scalp injury: Laceration	11 (12.50)	2 (5.88)	3 (10.71)
Scalp injury: Abrasion	2 (2.27)	2 (5.88)	1 (3.57)
Scalp injury: Mixed scalp injury	11 (12.50)	5 (14.71)	1 (3.57)
Scalp injury: Absent	13 (14.77)	2 (5.88)	5 (17.86)
Skull fracture: Linear fracture	55 (62.50)	18 (52.94)	20 (71.43)
Skull fracture: Basal skull fracture	5 (5.68)	2 (5.88)	2 (7.14)
Skull fracture: Depressed fracture	1 (1.14)	5 (14.71)	2 (7.14)
Skull fracture: Comminuted/multiple fracture	14 (15.91)	5 (14.71)	1 (3.57)
Skull fracture: Absent	13 (14.77)	4 (11.76)	3 (10.71)
Intracranial bleeding: SDH + SAH	37 (42.05)	15 (44.12)	14 (50.00)
Intracranial bleeding: SDH	14 (15.91)	5 (14.71)	5 (17.86)
Intracranial bleeding: SAH	14 (15.91)	4 (11.76)	5 (17.86)
Intracranial bleeding: Other/mixed hemorrhage	7 (7.95)	3 (8.82)	0 (0.00)
Intracranial bleeding: Absent	16 (18.18)	7 (20.59)	4 (14.29)

Values are n (within-group %). Pearson chi-square comparisons are exploratory; expected counts below five occurred in 9/15 scalp cells, 9/15 fracture cells, and 4/15 haemorrhage cells.

A Road-user distribution



B Time of crash

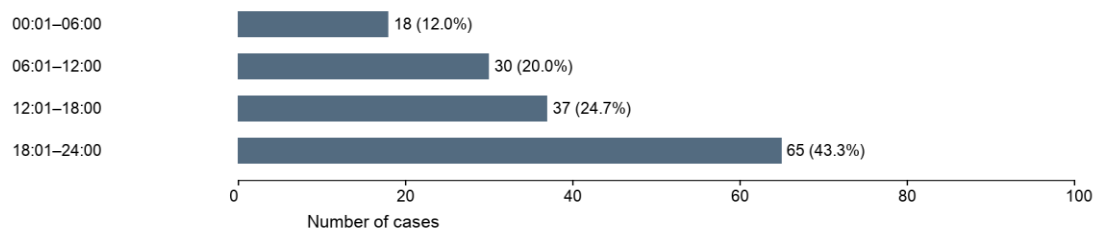


Figure 1 Road user distribution and crash timing

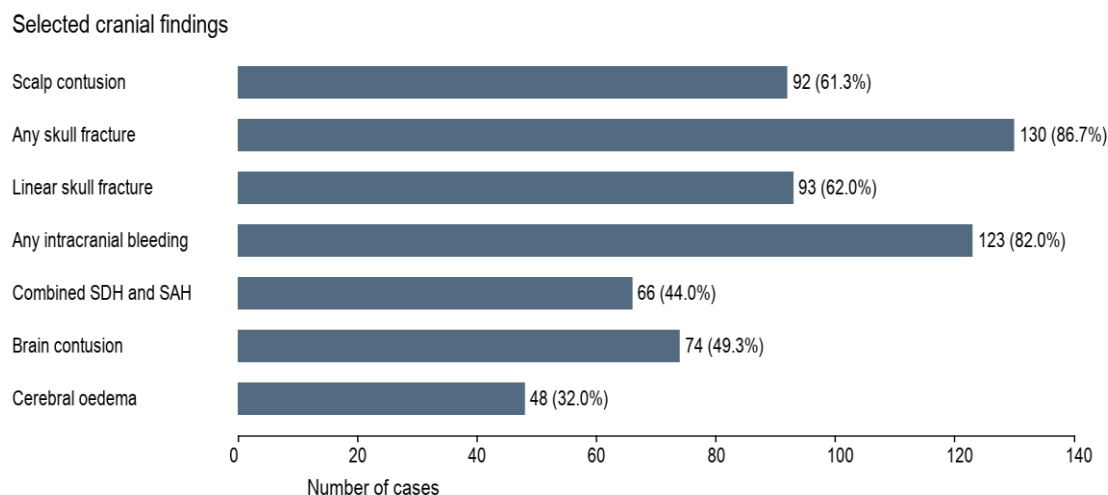


Figure 2 Selected cranial injury findings

DISCUSSION

Our study describes a selected series of 150 fatal road traffic head injuries in Jaipur, with a predominance of young men and two-wheeler users. The largest age group was 21–30 years, and 78.00% of victims were male. This profile resembles the young male predominance reported in Indian brain injury research and in Menon and colleagues' autopsy study.^{8,15} Greater traffic exposure and occupational mobility are plausible explanations, but our data do not measure either. The proportions therefore identify the composition of this mortuary series; they cannot establish age-specific or sex-specific risks within the underlying road-user population.

Two-wheeler users comprised 58.67% of cases, while pedestrians contributed 22.67%. These findings are consistent with the importance of exposed road users in the urban Indian studies of Fitzharris and Pruthi.^{9,10} Differences between centres should be expected because vehicle ownership, travel behaviour, referral patterns, and inclusion criteria vary. Our exclusion of independently fatal extracranial injuries and previous cranial surgery further narrows the case mix. The observed predominance of two-wheelers is consequently useful for directing local surveillance and prevention attention but does not quantify their relative danger compared with other transport modes. Reported helmet non-use affected 66 of 88 two-wheeler victims, and seatbelt non-use affected 18 of 28 four-wheeler occupants. These observations reinforce the practical importance of recording protective-device use. Independent evidence supports helmets: the Cochrane review, African meta-analysis, and American linked-record study consistently indicate protection against serious head outcomes.^{11–13} Evidence on universal helmet laws also supports sustained enforcement.¹⁴ However, fatality-only sampling selects on the outcome being studied. We cannot infer that non-use caused a particular death, compare mortality

between device users and non-users, or evaluate helmet quality, fastening, coverage, or crash energy.

Evening incidents accounted for 43.33% of fatalities. Menon and colleagues also observed substantial afternoon and evening involvement, and Pruthi's pedestrian series identified an evening concentration.^{10,15} Traffic volume, visibility, and fatigue could contribute, but none was measured adequately here. City roads, state highways, national highways, and intersections all contributed appreciable numbers, suggesting that prevention should address several environments. Our location counts lack traffic-volume denominators and cannot rank road-specific risk. They offer starting points for linkage with geocoded police records and engineering assessments rather than proof that any particular road category is intrinsically more hazardous.

Scalp contusions were the most frequent external finding, and linear fractures predominated among skull injuries. Nevertheless, scalp injury and skull fracture were each absent in 20 cases. This is important medicolegally because the absence of an obvious external or skeletal lesion does not exclude fatal intracranial trauma. Menon's study similarly demonstrates the value of examining several cranial compartments¹⁵. Interpretation should consider the full injury distribution and available scene evidence. A fracture category alone cannot establish collision speed, reconstruct a unique sequence, or determine legal responsibility. Our findings support systematic documentation, with anatomical observations distinguished from mechanistic inference.

Combined subdural and subarachnoid haemorrhage was the largest bleeding category, and haemorrhage commonly involved multiple regions. Brain contusion and cerebral oedema were the leading recorded brain findings. These lesions illustrate the heterogeneous structural consequences of traumatic brain injury discussed by Maas and colleagues.¹⁶ Seven cases were labelled diffuse axonal injury, but the available

methods do not establish a uniform microscopic confirmation protocol. Adams and colleagues showed that reliable identification and grading can require histological examination.¹⁸ That count should therefore be interpreted as the recorded classification. Four cases were also unaccounted for in the brain-injury summary, limiting interpretation of its complete distribution.

Fifty-two victims were brought dead, while 38 were assigned to the first six-hour survival category. This concentration of deaths around presentation and early survival draws attention to emergency response, although brought-dead status does not itself establish the interval from injury to death. Evidence from prehospital trauma-system research supports organised early care¹⁹, while severe brain injury guidelines provide an evidence-based foundation for hospital protocols.²⁰ Our study cannot identify preventable deaths or assess treatment quality because physiological severity, transport delays, and detailed interventions were unavailable. A structured audit linking these variables to autopsy findings would provide stronger evidence for service improvements. Exploratory comparisons did not show statistically significant differences in major injury categories across road users. Sparse cells and modest subgroup sizes, particularly among four-wheeler occupants, limit the strength of this finding. Absence of statistical significance should not be interpreted as anatomical equivalence. Taken together, our results support integrated attention to protective devices, road design, speed management, and post-crash care, consistent with the WHO technical package.²¹ Their principal contribution is a local anatomical and circumstantial profile that can inform surveillance and generate testable questions, provided future studies use clearer classification, complete records, and appropriate comparison populations. Regular reconciliation of anatomical totals with original case records would also improve reproducibility and ensure that future comparisons reflect genuine differences rather than inconsistent coding or incomplete documentation.

Limitations

This single-centre study included a selected consecutive series of fatalities and cannot estimate population incidence, exposure-adjusted risk, or protective-device effectiveness. Exclusion of independently fatal extracranial injuries and previous head injury surgery limits generalisability to the wider spectrum of traffic deaths. Crash and safety-device histories depended partly on secondary records and attendant accounts; speed, helmet quality, toxicological alcohol measurements, physiological severity, transport delays, and detailed treatment were not available for adjusted analysis. Sparse contingency-table cells weaken exploratory chi-square comparisons. Scalp-location counts accounted for 149 cases, and brain-injury counts accounted for 146; these

discrepancies were retained transparently. The reported diffuse axonal injury classification also lacked a documented uniform histological confirmation protocol, and the cause-of-death labels overlapped conceptually.

Strengths of the Study

1. **Consecutive autopsy-based sample:** The study included 150 consecutively selected eligible medicolegal fatalities, reducing the likelihood of selective case inclusion within the study setting.
2. **Systematic forensic examination:** A structured autopsy assessment documented scalp injuries, skull fractures, intracranial haemorrhage, brain injuries, and associated injuries, providing a detailed anatomical profile of fatal head trauma.
3. **Integration of multiple data sources:** Demographic, crash-related, survival, and protective-device information was obtained from police records, clinical documents, death summaries, attendant histories, and autopsy findings.
4. **Road-user-specific assessment:** Head injury patterns were described separately among two-wheeler users, pedestrians, and four-wheeler occupants, allowing exploratory comparison between major road-user categories.
5. **Transparent handling of missing and inconsistent data:** Unaccounted anatomical counts and uncertain protective-device information were retained and reported rather than being assigned or inferred, improving transparency of the findings.
6. **Appropriate interpretation of statistical findings:** The exploratory chi-square analyses were interpreted cautiously in view of sparse expected cell counts, and the study avoided making causal claims from a fatality-only design.

CONCLUSIONS

Among 150 eligible fatal traffic-related head injuries examined at SMS Medical College, Jaipur, young men and two-wheeler users predominated. Evening crashes were frequent, and many victims were brought dead or assigned to an early survival category. Scalp contusion, linear skull fracture, and combined subdural and subarachnoid haemorrhage were the leading recorded patterns, although fatal head injury also occurred without scalp injury or skull fracture. Exploratory road-user comparisons did not demonstrate significant differences in injury-category distributions. These findings underline the value of comprehensive autopsy examination and provide a local basis for prevention and trauma-service assessment, while remaining descriptive rather than

establishing causal or population-level risk relationships.

Recommendations

We recommend coordinated enforcement of correctly fastened certified helmets for riders and pillion passengers and seatbelts for vehicle occupants, combined with speed management, safer pedestrian crossings, improved intersection design, and adequate lighting. Emergency services should strengthen rapid notification, trained first response, appropriate triage, and timely access to trauma and neurosurgical care. A linked regional registry should integrate police, ambulance, hospital, and autopsy information using standard definitions and explicit missing-data fields. Future multicentre studies should include surviving crash victims, verify protective-device and alcohol exposure, document transport and treatment intervals, and use standard neuropathological confirmation where indicated, allowing prevention measures and potentially avoidable deaths to be evaluated more rigorously.

DECLARATIONS

Ethics Approval and Consent to Participate

Institutional Research Review Board and Institutional Ethics Committee approval was obtained before commencement of the study. Written informed consent for research participation was obtained from an attendant or legal heir, as applicable.

Consent for Publication

Not applicable. The study used de-identified medicolegal and autopsy data, and no individually identifiable information is presented.

Competing Interests

The authors declare that they have no competing interests.

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Authors' Contributions

Anurag Khichar contributed to study conception, data collection, autopsy-based assessment, data analysis, interpretation of findings, and manuscript preparation. Chandra Shekhar Sharma contributed to study supervision, interpretation of forensic findings, and critical revision of the manuscript. Sumanta Dutta contributed to study supervision, methodological guidance, interpretation of results, and critical revision of the manuscript. All authors reviewed and approved the final manuscript and agree to be accountable for all aspects of the work.

Data Availability

The datasets generated and/or analysed during the current study are not publicly available because they contain medicolegal and autopsy-related information but may be available from the corresponding author on reasonable request, subject to institutional and ethical restrictions.

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AI Use Disclosure

The authors declare that no generative artificial intelligence tools were used to generate or substantially modify the scientific content of this manuscript.

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