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Original Research Article

Brainstem Injuries in Fatal Road Traffic Accidents: A Medico-Legal Autopsy Analysis of Pontine and Medullary Lesions from Southern India.

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Abstract: ***Background:*** Brainstem injuries are among the most devastating consequences of road traffic accidents (RTAs) because they involve vital respiratory, cardiovascular, and neurological centers. Traumatic lesions involving the pons and medulla are frequently associated with instantaneous death or rapid clinical deterioration. Despite their considerable medico-legal significance, these injuries are often overlooked during routine autopsy unless meticulous brainstem examination is performed. ***Materials and Methods:*** A cross-sectional autopsy-based study was conducted on 155 fatal road traffic accident victims examined in the Department of Forensic Medicine and Toxicology, Shimoga Institute of Medical Sciences, Karnataka, India, between January and December 2013. During medico-legal autopsy, the brain was removed along with the intact brainstem and upper cervical spinal cord. Serial gross sections of the pons and medulla were examined for traumatic lesions including hemorrhage, contusion, laceration, and transection. Demographic characteristics, road-user category, and brainstem injury patterns were analyzed using descriptive statistics. ***Results:*** Among 155 fatal RTA victims, pontine injuries were identified in 17 (10.96%) cases and medullary injuries in 5 (3.2%) cases. Pontine hemorrhage was the commonest lesion (7.1%), followed by transection (3.2%) and laceration (0.6%). Medullary injuries comprised transection (1.9%), contusion (0.6%), and laceration (0.6%). Riders and pedestrians constituted the majority of victims with brainstem injuries. Most victims sustaining medullary or pontine transection died at the scene of the accident. ***Conclusion:*** Brainstem injuries represent an important cause of mortality in fatal road traffic accidents. Pontine hemorrhage is the predominant brainstem lesion, whereas medullary transection is strongly associated with instantaneous death. Routine systematic examination of the brainstem during medico-legal autopsy is essential for accurate determination of the mechanism and cause of death.

Keywords: Brainstem injury; Road traffic accident; Pons; Medulla oblongata; Autopsy; Forensic pathology.

INTRODUCTION

Road traffic accidents (RTAs) continue to be a major global public health problem and remain one of the leading causes of trauma-related mortality. According to recent global estimates, approximately 1.2 million individuals die annually because of road traffic injuries, while millions more sustain permanent disabilities. Low- and middle-income countries contribute disproportionately to this burden owing to rapid urbanization, increasing motorization, inadequate road infrastructure, and limited trauma care facilities.[1]

Traumatic brain injury (TBI) remains the principal cause of death among victims of fatal road traffic accidents. Although cerebral hemispheric injuries have been extensively investigated, traumatic lesions involving the brainstem remain comparatively underreported despite their critical contribution to mortality.[2,3]

The brainstem, comprising the midbrain, pons, and medulla oblongata, serves as the anatomical and physiological bridge between the cerebrum and spinal cord. It contains ascending and descending neural pathways together with nuclei responsible for consciousness, respiration, cardiovascular regulation, cranial nerve function, and autonomic control. Even relatively small traumatic lesions involving these structures may produce catastrophic physiological disturbances leading to immediate death.[4,5]

Brainstem injuries usually occur following high-energy trauma resulting from motorcycle collisions, pedestrian impacts, high-speed vehicular crashes, falls from height, and acceleration-deceleration mechanisms. Rotational forces generated during these events produce diffuse axonal injury, vascular disruption, and craniovertebral junction instability, which frequently involve the pons and medulla. Hyperflexion and hyperextension injuries may additionally result in traumatic brainstem transection, particularly when associated with atlanto-occipital or atlanto-axial dislocation.[6–8]

Among brainstem lesions, traumatic pontine hemorrhage represents one of the commonest pathological findings encountered during forensic autopsy. Shearing forces acting upon perforating branches of the basilar artery produce focal or diffuse hemorrhage within the pontine parenchyma. Such lesions frequently coexist with diffuse axonal injury and severe cerebral edema, reflecting extremely high-impact trauma.[9,10]

Traumatic injuries involving the medulla oblongata are relatively uncommon but carry profound clinical and forensic significance. The medulla contains the cardiac, respiratory, and vasomotor centers essential for maintenance of life. Consequently, medullary contusions, lacerations, or complete transection often result in immediate respiratory arrest, neurogenic cardiovascular collapse, and death at the scene of the accident.[11,12]

Modern neuroimaging techniques have improved the diagnosis of traumatic brain injury in living patients; however, several brainstem lesions remain undetected clinically because victims frequently succumb before hospital evaluation or because imaging is limited by extensive associated injuries. Consequently, medico-legal autopsy remains the gold standard for identifying traumatic brainstem lesions and establishing the precise mechanism of death.[13]

Forensic examination of the brainstem requires careful removal of the brain together with the cervical spinal cord and meticulous serial sectioning of the pons and medulla. Failure to perform systematic examination may result in underdiagnosis of fatal lesions, thereby compromising determination of the exact cause of death and reconstruction of injury mechanisms. Recent forensic pathology recommendations advocate routine evaluation of the brainstem in all fatal road traffic accidents involving severe head injury or cervical spine trauma.[14–16]

Although several studies have evaluated intracranial injuries following road traffic accidents, dedicated autopsy-based analyses focusing specifically on pontine and medullary injuries remain limited, particularly from southern India. Regional epidemiological data are essential because the increasing use of motorcycles and changing traffic patterns may influence the incidence and characteristics of fatal brainstem trauma. Furthermore, understanding the distribution of pontine and medullary lesions has important implications for trauma prevention, emergency medical services, and medico-legal interpretation.

The present study was therefore undertaken to determine the prevalence, pattern, and forensic significance of traumatic pontine and medullary lesions among fatal road traffic accident victims subjected to medico-legal autopsy at a tertiary care teaching hospital in southern India.

AIM

To evaluate the prevalence, pattern, and medico-legal significance of brainstem injuries among fatal road traffic accident victims undergoing medico-legal autopsy.

MATERIALS AND METHODS

This was one year descriptive cross-sectional, 155 autopsy-based observational study conducted to evaluate the prevalence and pattern of brainstem injuries among fatal road traffic accident (RTA) victims. All medico-legal autopsies were performed at the McGann Hospital Mortuary attached to the Shimoga Institute of Medical Sciences. The study complied with the ethical principles of biomedical research involving human participants and adhered to institutional guidelines for research using medico-legal autopsy material.[17]

All autopsies were performed according to standard forensic autopsy techniques. After reflection of the scalp and removal of the calvarium, the dura mater was examined for extradural and subdural hemorrhages. The brain was carefully removed together with the intact brainstem and upper cervical spinal cord to preserve the craniovertebral junction. Following fixation in 10% buffered formalin for approximately two weeks, detailed examination of the brain was undertaken. The cerebral hemispheres, cerebellum, and brainstem were inspected for evidence of traumatic lesions. Particular attention was paid to the pons and medulla oblongata because of their critical physiological functions and their susceptibility to acceleration-deceleration injuries.[18]

Whenever cervical spine injuries were suspected, the atlanto-occipital and atlanto-axial articulations were examined carefully for instability, fractures, ligamentous disruption, and dislocation. Particular attention was also given to injuries involving the upper cervical spinal cord because of their close association with traumatic brainstem damage.[19]

Statistical Analysis: Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics (Version 25.0).
Possible ssociations between categorical variables were assessed using the Chi-square test or Fisher's exact test where appropriate. A p-value <0.05 was considered statistically significant.[20].

RESULTS

Table 1. Distribution of Cases According to Sex

Sex	Number (n=155)	Percentage (%)
Male	133	85.8
Female	22	14.2
Total	155	100

Male victims predominated, accounting for more than four-fifths of all fatal road traffic accident deaths, yielding a male-to-female ratio of approximately 6:1.

Table 2. Distribution According to Age

Age Group (Years)	Cases	Percentage (%)
1–10	9	5.8
11–20	19	12.3
21–30	40	25.8
31–40	23	14.8
41–50	17	11.0
51–60	28	18.1
>60	19	12.3
Total	155	100

Young adults aged 21–30 years constituted the largest proportion of victims, followed by those aged 51–60 years.
Brainstem Injuries

Table 3. Distribution of Pontine Lesions

Lesion	Cases	Percentage (%)
Hemorrhage	11	7.1
Laceration	1	0.6
Transection	5	3.2
Intact	138	89.0
Total	155	100

Overall, 17 (10.96%) victims demonstrated traumatic pontine injuries. Pontine hemorrhage represented the commonest lesion, accounting for approximately two-thirds of all pontine injuries.

Table 4. Distribution of Medullary Lesions

Lesion	Cases	Percentage (%)
Contusion	1	0.6
Laceration	1	0.6
Transection	3	1.9
Intact	150	96.8
Total	155	100

Five victims (3.2%) sustained traumatic medullary injuries. Medullary transection constituted the predominant lesion.

Table 5. Distribution of Pontine Injuries According to Road-User Category

Road User	Cases

Rider	7
Pedestrian	6
Driver	1
Pillion Rider	1
Occupant (Co-passenger)	1
Others	1
Total	17

Motorcycle riders and pedestrians together accounted for 76.5% of all pontine injuries observed.

Table 6. Distribution of Medullary Injuries According to Road-User Category

Road User	Cases
Rider	2
Pedestrian	2
Driver	1
Total	5

Traumatic medullary injuries were most frequently encountered among riders and pedestrians, reflecting exposure to high-energy impact mechanisms.

Table 7. Overall Brainstem Injury Pattern

Brainstem Injury	Cases	Percentage (%)
Pontine injury only	17	10.96
Medullary injury only	5	3.2
No gross brainstem injury	133	85.8
Total	155	100

Brainstem injuries were identified in 22 (14.2%) of the fatal RTA victims examined. Pontine lesions were more than three times as common as medullary lesions.

The results indicate that traumatic brainstem injuries constitute a significant proportion of fatal road traffic accident deaths. Pontine haemorrhage emerged as the predominant lesion, whereas medullary transection, though less frequent, was consistently associated with catastrophic injury. Motorcycle riders and pedestrians represented the most vulnerable road-user groups sustaining brainstem trauma.

DISCUSSION

The present autopsy-based study evaluated the prevalence and pattern of traumatic brainstem injuries among 155 fatal road traffic accident (RTA) victims. Brainstem injuries were identified in 22 (14.2%) cases, with pontine lesions accounting for 10.96% and medullary lesions for 3.2% of the study population. These findings emphasize the importance of meticulous examination of the brainstem during medico-legal autopsy, as such lesions frequently explain sudden death in victims of high-energy trauma.[21]

The majority of victims were males (85.8%), with a male-to-female ratio of approximately 6:1. This finding is consistent with recent epidemiological studies from India and other low- and middle-income countries, which have reported that young adult males constitute the highest-risk population for fatal road traffic injuries because of greater exposure to motorized travel, occupational mobility, risk-taking behaviour, speeding, and lower compliance with road safety measures.[22,23]

The highest incidence of fatalities occurred in the 21–30-year age group (25.8%). Individuals in this economically productive age group are more likely to use motorcycles and travel long distances, thereby increasing their exposure to high-velocity collisions. Similar age distributions have been reported in contemporary Indian forensic autopsy studies and global road safety reports.[24,25]

Brainstem injuries were identified in 14.2% of the present series. Although the overall incidence appears relatively low compared with diffuse cerebral injuries, their clinical and forensic significance is disproportionately high because of the concentration of vital autonomic centres within the pons and medulla. Modern neuropathological studies have demonstrated that many fatal brainstem injuries occur in conjunction with diffuse axonal injury, craniovertebral junction disruption, or severe cervical spine trauma, resulting in immediate cardiorespiratory failure.[26,27]

The prevalence observed in this study is comparable with previously published autopsy series, although reported frequencies vary depending on study design, mechanism of injury, and the extent of brainstem dissection performed during postmortem examination. Differences among studies may also reflect variations in traffic patterns, helmet usage, emergency medical services, and referral practices.[28]

Pontine lesions were identified in 17 victims (10.96%), with traumatic pontine hemorrhage representing the most frequent pathological finding. Hemorrhage accounted for nearly two-thirds of all pontine injuries, followed by complete transection and laceration.

Traumatic pontine hemorrhage is generally attributed to rupture of perforating branches of the basilar artery during sudden acceleration-deceleration or rotational forces. Shearing stresses generated during high-speed collisions produce tearing of small intraparenchymal vessels, resulting in focal or diffuse hemorrhage. In severe trauma, these lesions frequently coexist with diffuse axonal injury and marked cerebral edema, both of which contribute to rapid neurological deterioration.[29,30]

Pontine transection, observed in five cases, represents one of the most severe forms of traumatic brainstem injury. Such injuries are usually associated with violent hyperextension or hyperflexion of the head and neck, atlanto-occipital dislocation, or fractures involving the craniovertebral junction. Complete disruption of pontine pathways interrupts essential ascending reticular activating systems and descending motor tracts, rendering survival virtually impossible.[31]

Medullary injuries were identified in five victims (3.2%), including three cases of complete transection, one contusion, and one laceration. Although less common than pontine lesions, medullary injuries are considered among the most lethal forms of neurotrauma because the medulla contains respiratory, cardiovascular, and vasomotor centres indispensable for life.[32]

Victims sustaining medullary transection generally die instantaneously or within a few minutes due to respiratory arrest, cardiac dysrhythmias, or neurogenic shock. Similar observations have been reported in recent forensic neuropathology studies evaluating fatal craniovertebral injuries following motorcycle crashes and pedestrian impacts.[33]

Motorcycle riders constituted the largest proportion of victims sustaining both pontine and medullary injuries, followed closely by pedestrians. This distribution reflects the biomechanics of high-energy trauma. Riders frequently experience direct impact against the road surface or fixed objects after ejection from the motorcycle, while pedestrians are exposed to secondary impacts involving the bonnet, windshield, and ground. These mechanisms generate substantial rotational and translanar forces that predispose to diffuse axonal injury and traumatic brainstem lesions.[34]

The increasing use of motorcycles in India has contributed significantly to the burden of fatal head injuries. Inadequate helmet use, excessive speed, alcohol consumption, and poor adherence to traffic regulations remain important determinants of mortality.[35]

Brainstem injuries possess considerable medico-legal importance because they frequently explain sudden death in individuals who may show relatively limited external injuries. Identification of pontine or medullary lesions assists forensic pathologists in reconstructing the mechanism of injury, determining the severity of trauma, and correlating associated cervical spine injuries with the cause of death.

Routine examination of the brainstem also has important legal implications in cases involving alleged medical negligence, delayed treatment, or disputed mechanisms of injury. Failure to identify traumatic brainstem lesions may lead to inaccurate certification of the cause of death and incomplete medico-legal opinions. Consequently, dedicated dissection of the brainstem should form an integral component of every medico-legal autopsy involving fatal head injury.

CONCLUSION

Traumatic brainstem injuries are important contributors to mortality in fatal road traffic accidents and represent one of the most devastating forms of neurotrauma encountered during medico-legal autopsy. In the present study, gross brainstem lesions were identified in 14.2% of fatal RTA victims, with pontine injuries occurring more frequently than medullary injuries. Traumatic pontine haemorrhage emerged as the commonest brainstem lesion, whereas medullary transection, although less common, was invariably associated with rapidly fatal outcomes.

Young adult males constituted the majority of victims, reflecting the demographic profile of road traffic fatalities observed in developing countries. Motorcycle riders and pedestrians were the most vulnerable road-user categories sustaining brainstem injuries, highlighting the need for targeted preventive strategies, including strict enforcement of helmet use, speed regulation, pedestrian safety measures, and improvement of trauma systems.

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