An Autopsy-Based Study of the Pattern of Fatal Head Injuries in Road Traffic Accidents

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Abstract

Background: Head injury is one of the most significant causes of mortality after road traffic accidents (RTAs), especially in vulnerable road users and young adults. Post-mortem examination can give a full picture of any injuries to the skull and brain and can allow for the comparison of the pattern of external injuries to the internal injuries that are likely to be fatal.

Objective: To report the demographic characteristics, distribution of road users, pattern of skull fracture, intracranial lesions and selected associations of fatal road traffic accident (RTA) patients with head injury as the main cause of death.

Method: Retrospective autopsy-based observational study was designed using 148 fatal cases of RTA which were examined in a tertiary medicolegal centre.Design: Retrospective autopsy-based observational study was designed using 148 fatal cases of RTA examined during January-December 2016 in a tertiary medicolegal centre. A structured proforma was used to record the following demographic variables, road user category, survival interval, skull fractures, intracranial haemorrhages, cerebral injuries, and associated injuries.

Results: The mean age was 34.7 ± 14.6 years; 122 victims (82.4%) were male. The largest group were motorized two-wheelers (45.3%) and pedestrians (31.1%). Skull fractures were seen in 114 cases (77.0%) including 73 cases of basilar fracture (49.3%). The commonest intracranial haemorrhage (ICH) was subarachnoid haemorrhage (68.2%) followed by subdural haemorrhage (60.1%) and extradural haemorrhage (20.9%). Cerebral oedema was found in 70.3%, contusions in 56.8% and diffuse axonal injury was confirmed by histopathology in 16.9%. Skull fracture was significantly associated with extradural haemorrhage and cerebral contusion, and was more common in victims with no skull fracture than in those with a skull fracture ($p<0.001$).

Conclusions: The majority of fatal RTA head injuries were suffered by young males, particularly by two-wheelers and pedestrians. Skull base fractures, subarachnoid/subdural haemorrhage, cerebral

oedema and contusions were common causes of death, and severe intracranial injury was also possible without skull fracture.

Keywords: forensic autopsy; head injury; road traffic accident; skull fracture; intracranial haemorrhage; traumatic brain injury Introduction

Road traffic injury is a leading cause of early death and disability, and disproportionately affects economically active age groups. Indian data on mortality have revealed that a significant proportion of road traffic deaths are reported to be among men aged 15-59 years and that the majority of deaths involve head injury [1]. The medicolegal significance of these deaths is not just in establishing the medical cause of death, but also in reconstructing the mechanism, assessing the compatibility of the injuries and the circumstances, and documenting alcohol, disease or atypical patterns of injury [2].

Autopsy studies conducted in India consistently show that motorized two wheelers and pedestrians constitute significant proportion of the fatalities in RTA and head injury is one of the most common cause of death [3,4]. The male predominance and the age clustering of TBIs are also observed in hospital-based series, which also reveal that road traffic crashes account for a high proportion of cases of severe TBI [5,6]. Prehospital transport delays, multiple referrals, and lack of organized trauma systems may further impact outcome following severe head injury [7].

Pathological spectrum of fatal head injury consists of scalp trauma, skull vault and base fracture, extradural, subdural and subarachnoid haemorrhage, cerebral contusions and lacerations, brain swelling, herniation, vascular injury and diffuse axonal injury. The presence of a skull fracture does not necessarily reflect high impact energy; however, fracture and intracranial lesions are not necessarily correlated. Yavuz et al. showed that there is a possibility of intracranial lesion even in the absence of skull fracture following traffic related head injury [8]. The distinction is significant from a medicolegal point of view, as failure to detect a fracture does not preclude a serious or fatal brain injury.

Although computed tomography is a key part of the acute management, autopsy is the gold standard for full postmortem characterization particularly for subtle basal fractures, small haemorrhages and injuries that are hidden by treatment or decomposition. Research evaluating CT in medicolegal head injury has focused on the fact that fractures that are not identified or are inadequately described on imaging can also be of forensic importance [9]. Autopsy may also reveal injuries that were not clinically apparent such as occulta head and cervical injuries [10].

Diffuse axonal injury is noteworthy, as it can cause immediate and lasting coma without a large mass lesion or even a skull fracture. Systematic examination of predictable brain sites and histological techniques were classically shown to be necessary for diagnosis [11,12]. Acute subdural haematoma and diffuse axonal injury can occur together in fatal road traffic trauma and can contribute to poor

neurological outcome [13] and diffuse vascular injury has been associated with severe acceleration-deceleration mechanisms [14].

Although there is a large amount of clinical literature on traumatic brain injury, institution-specific autopsy data are still useful because of the geographic variation in road user characteristics, helmet use, vehicle mix, referral delays, and trauma systems. The present study was therefore undertaken to describe the distribution of fatal head injuries in RTA victims who underwent medicolegal autopsy, with particular focus on the demographics, road user category, survival time, skull fractures, intracranial haemorrhage, and the association between skull fracture and major intracranial lesions.

Materials and Methods

Study design and setting: This was a retrospective observational study carried out in the department of Forensic Medicine and Toxicology of a tertiary teaching hospital and medicolegal centre. All cases that underwent medicolegal autopsy.

Study population: Fatal road traffic accident victims included those with a complete cranial autopsy and whose head injury was the primary or predominant cause of death. All cases were included regardless of whether they died at the scene, in transport, in the emergency department or following hospital treatment. Decomposed bodies where it was impossible to make a reliable assessment of the cranial findings, cases with incomplete inquest/autopsy records, deaths caused primarily by burns or drowning following a traffic incident, and cases where large sections of the cranium had been removed due to major neurosurgical procedures were excluded.

Data collection: A structured proforma was used to gather data on age, sex, road-user category, alleged type of collision, time between injury and death, external head injury, skull fracture pattern, meningeal haemorrhage, parenchymal brain injury and major associated injury. Road users were defined as occupants of two-wheelers with motor power, pedestrians, four-wheelers, bicyclists or occupants of three-wheelers with motor power. Survival interval was categorized as death at the scene/within 1 hour, 1-24 hours, >24 hours to 7 days, and >7 days.

Routine external examination followed by autopsy examination where the scalp was reflected in layers to record subscalp haemorrhage and impact sites. A standard circular saw cut was used to open the calvarium, with special attention to maintaining fracture margins. Skull fractures were classified as vault fracture, base fracture, or both vault and base fracture, with depressed and comminuted fractures being reported separately. The dura was studied prior to removal. The distribution and site of each type of haemorrhage were recorded: extradural, subdural, subarachnoid, intraventricular and intracerebral. Brain was removed, weighed, and examined for contusions, lacerations, swelling and herniation, and serially sectioned after fixation if indicated. Representative sections of the corpus callosum, parasagittal white matter, basal ganglia and upper brainstem were examined histologically in cases in which diffuse axonal injury was clinically or grossly suspected.

Primary descriptive outcomes and statistical analysis: Frequencies of skull fractures and intracranial lesions were the primary descriptive outcomes and analyzed statistically. The chi-square test or Fisher's exact test was used to determine associations between skull fracture and selected intracranial findings. For continuous variables, the data were summarized as mean ± standard deviation if the data were approximately normally distributed. A two-sided p value <0.05 was considered statistically significant. The data were analysed by using the standard statistical software.

Results

A total of 148 fatal RTA cases fulfilled the inclusion criteria. The victims were predominantly male (82.4%), giving a male-to-female ratio of 4.7:1. Age ranged from 6 to 78 years, with a mean of 34.7 ± 14.6 years. The 21-40-year age group accounted for 72 cases (48.6%). Motorized two-wheeler users were the largest category (45.3%), followed by pedestrians (31.1%). Fifty-seven victims (38.5%) died at the scene or within the first hour, while 46 (31.1%) survived for 1-24 hours.

Table 1. Demographic and accident-related characteristics of fatal RTA head injury cases

Variable	Category	n	%
Sex	Male	122	82.4
	Female	26	17.6
Age group (years)	≤20	23	15.5
	21-40	72	48.6
	41-60	41	27.7
	>60	12	8.1
Road-user category	Motorized two-wheeler	67	45.3
	Pedestrian	46	31.1
	Four-wheeler occupant	21	14.2
	Bicyclist	9	6.1
	Motorized three-wheeler	5	3.4
Survival interval	Scene/≤1 h	57	38.5
	>1-24 h	46	31.1
	>24 h-7 d	33	22.3

Variable	Category	n	%
	>7 d	12	8.1

Skull fractures were identified in 114 cases (77.0%). Basilar fractures were present in 73 (49.3%), vault fractures in 58 (39.2%), and combined vault-and-base involvement in 17 (11.5%); categories overlapped because a combined fracture contributed to both anatomical regions. Linear fractures were the commonest morphology, although 22 victims had comminuted fractures and 11 had a depressed component. Among intracranial lesions, subarachnoid haemorrhage was most frequent (68.2%), followed by subdural haemorrhage (60.1%). Extradural haemorrhage occurred in 20.9%. Cerebral oedema was seen in 104 cases (70.3%), contusions in 84 (56.8%), lacerations in 50 (33.8%), and histologically supported diffuse axonal injury in 25 (16.9%).

Table 2. Distribution of skull and intracranial injuries

Autopsy finding	n	%
Any skull fracture	114	77.0
Basilar skull fracture	73	49.3
Vault fracture	58	39.2
Comminuted fracture	22	14.9
Depressed fracture component	11	7.4
Subarachnoid haemorrhage	101	68.2
Subdural haemorrhage	89	60.1
Extradural haemorrhage	31	20.9
Intraventricular haemorrhage	19	12.8
Intracerebral haemorrhage	28	18.9
Cerebral oedema	104	70.3
Cerebral contusion	84	56.8
Brain laceration	50	33.8
Diffuse axonal injury	25	16.9

When cases were stratified by the presence of skull fracture, extradural haemorrhage, subarachnoid haemorrhage, cerebral contusion, and brain laceration were significantly more frequent in the fracture group. In contrast, diffuse axonal injury was proportionately more frequent among the 34 victims without demonstrable skull fracture (38.2% versus 10.5%, $p<0.001$). Subdural haemorrhage occurred commonly in both groups and did not show a statistically significant difference. These findings demonstrate that severe and fatal brain injury can occur without fracture and that the lesion profile differs according to impact mechanics.

Table 3. Association between skull fracture and selected intracranial lesions

Intracranial lesion	Skull fracture present n=114	No skull fracture n=34	p value
Extradural haemorrhage	29 (25.4%)	2 (5.9%)	0.012
Subdural haemorrhage	72 (63.2%)	17 (50.0%)	0.168
Subarachnoid haemorrhage	83 (72.8%)	18 (52.9%)	0.029
Cerebral contusion	73 (64.0%)	11 (32.4%)	0.001
Brain laceration	45 (39.5%)	5 (14.7%)	0.008
Diffuse axonal injury	12 (10.5%)	13 (38.2%)	<0.001

Discussion

This autopsy-based study shows that head injury caused by RTA is more likely to be fatal in younger and middle aged males, and that over 3/4 of fatalities are attributed to motorized two wheeler and pedestrian crashes. This trend is similar to the Indian road traffic mortality data where vulnerable road users account for disproportionately high number of fatal injuries [1]. Previous forensic analysis in India also indicated high male predomination and high proportion of occupants of two wheelers and pedestrians [2,3]. The age group 21-40 is particularly significant because deaths in this age group have significant social and economic implications.

In the current series, 45.3% of the users were two-wheelers. Motorized two-wheelers were the most common victim group in a study of autopsies conducted by Kanchan et al. in South India, and head injuries accounted for almost three-fourths of the fatalities [3]. A similar study by the autopsy department of Chandigarh over the past 25 years also revealed that road traffic accidents were a

major cause of unnatural deaths [4]. The clinical TBI series from Maharashtra and Delhi have also shown that young men bear a heavy burden of clinical TBIs and motor vehicle crashes contribute significantly [5,6]. The converging findings justify the importance of targeted preventive measures, including the use of effective helmets, speed limits, making roads more visible, and making roads safer for vulnerable users.

In the current study, over two thirds of the victims died within 24 hours, of which 38.5% died at the scene or within one hour. This early mortality is indicative of the severity of cranio-cerebral trauma and also the possible impact of prehospital care. In a regional trauma centre, Radjou et al. found that head injury was the leading cause of death and that there were long transfer times and multiple referrals [7]. Urban prehospital factors have also been associated with death following traffic crashes in India [15]. Unfortunately, the autopsy alone is not sufficient to determine preventability, but a correlation of injury severity and survival interval can identify patterns that require review of the trauma system.

77.0% had skull fracture and around half had skull base involvement. High energy trauma often involves force being transmitted through the cranial vault and base, and severe intracranial trauma can be associated with complex fractures of the base. Yavuz et al. noted that skull fracture and intracranial lesions are correlated but not synonymous [8]. Our results confirm that conclusion. When a skull fracture was present, the incidence of extradural haemorrhage, subarachnoid haemorrhage, contusion and laceration were higher, but clinically and forensically significant lesions were also seen in the non-fractured skull.

The association between extradural haemorrhage and skull fracture was strong and the mechanism of this is plausible as the most common cause of epidural bleed is vascular injury close to the fracture line. On the other hand, subdural haemorrhage was prevalent in both fractured and non-fractured patients. This is clinically relevant in the interpretation of postmortem imaging or clinical radiology. Chawla et al. reported that some skull fractures of medicolegal significance may be missed by CT [9] and Moharamzad et al. reported that some injuries may be lethal that were not detected during initial clinical assessment [10]. Therefore, full autopsy is still useful even if antemortem imaging is done.

In this series, subarachnoid haemorrhage was the most frequent type of intracranial haemorrhage. Contusion, laceration and high-energy acceleration-deceleration injury are common with traumatic subarachnoid bleeding. The next most common lesion was subdural haemorrhage. In fatal RTA cases, Gusmão and Pittella reported that there was a close pathological association between acute subdural haematoma and diffuse axonal injury, especially when the victims were comatose from the beginning [13]. Focal mass lesions and diffuse microscopic injury is an important reason for unexpected severe neurological deterioration.

The 16.9% of cases with diffuse axonal injury was supported by histology, and was significantly more common in victims without skull fracture. The lack of fracture in DAI is well documented as

rotational and angular acceleration can cause damage to the axons without causing a focal bony failure. Simpson et al. emphasized the need to investigate predictable brain regions at autopsy to detect diffuse axonal injury [11] and Yamaki et al. showed that diffuse axonal injury can occur even in victims who die shortly after impact [12]. The negative association between DAI and skull fracture is not protective in our material, but rather another biomechanical pathway to death.

DVIN is also seen in fatal RTA cases and is reported to be related to severe DAI [14]. These lesions emphasize the need to consider gross haemorrhage or fracture alone as an inadequate criterion for the evaluation of fatal head trauma. A systematic neuropathological approach is especially critical in patients who are comatose immediately, have only gross brain injury, or have survival patterns that cannot be accounted for by a single mass lesion.

The study has some limitations. It is one medicolegal centre and only fatal cases where head injury was the main cause of death are included; therefore, the results are not representative of all RTA victims. Some records lacked detailed information on helmet use, vehicle speed, alcohol concentration, and precise collision geometry and were not used in inferential analysis. Histological testing for DAI was not done on all birds, so the actual prevalence could have been higher. However, the complete autopsy examination and consistent definition of lesions gives a good forensic picture of fatal cranio-cerebral trauma.

The forensic medicine aspect of the implications is that the distribution of lethal head injury should be viewed as a mix of external impact evidence, fracture distribution, intracranial haemorrhage, parenchymal injury, neuropathology, treatment history and scene circumstances. There is no single lesion that can reconstruct the accident. Thorough documentation also helps clarify issues with the court and investigating agencies if they have concerns about impact site, survivability, treatment, or injuries being compatible with the event.

Conclusion

In this series of autopsies, the majority of fatal head injuries were suffered by young adult males, motorized two-wheeler users and pedestrians. In over three-fourths of cases, there was a fracture of the skull, and a skull-base fracture was common. The most common intracranial findings were subarachnoid and subdural haemorrhage, cerebral oedema, and contusions. Skull fracture was significantly associated with extradural haemorrhage, contusion and laceration, whereas diffuse axonal injury occurred more commonly in those who did not have a fracture. The findings highlight the importance of not ruling out fatal brain injury in the absence of a skull fracture and the need for a complete medicolegal autopsy with histology if appropriate for proper characterization of road traffic head trauma.

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