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Original Research Article

PATTERN, DISTRIBUTION, AND MECHANISM OF SKULL BONE FRACTURES IN FATAL HEAD INJURIES: AN AUTOPSY-BASED STUDY AT SSIMS & RC, DAVANGERE, KARNATAKA

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ABSTRACT

Background: Fatal traumatic head injuries are a major cause of mortality, particularly in developing countries. Skull fractures reflect the severity and mechanism of trauma, and their evaluation through radiology and autopsy is essential for accurate diagnosis and medico-legal interpretation. The aim is to evaluate and correlate radiological and autopsy findings in skull fractures associated with fatal traumatic head injuries, and to assess the pattern and distribution of skull fractures along with the diagnostic accuracy of imaging modalities. **Materials and Methods:** A prospective cross-sectional study was conducted over 18 months (October 2018–March 2020) at SSIMS & RC, Davangere, including 60 fatal head injury cases. Detailed medicolegal autopsies were performed, and skull fractures were analyzed for type, pattern, and distribution. Radiological findings (CT scan) were obtained and compared with autopsy findings. Statistical analysis was performed to assess associations and diagnostic accuracy. **Result:** Road traffic accidents accounted for the majority of cases (78.3%). Linear fractures were the most common type (66.7%). A significant association was observed between mechanism of injury and fracture pattern ($p = 0.041$). Helmet use significantly reduced the severity of fractures ($p = 0.008$). Temporal bone (91.7%) and middle cranial fossa (78.3%) were most frequently involved. CT scan showed sensitivity of 78.3%, specificity of 100%, and overall accuracy of 80%, with limitations in detecting sutural and mixed fractures. **Conclusion:** There is a strong correlation between radiological and autopsy findings; however, autopsy remains the gold standard. Preventive strategies such as helmet use and improved road safety measures are crucial in reducing fatal head injuries.

INTRODUCTION

Traumatic head injury remains one of the leading causes of mortality and morbidity worldwide, particularly in low- and middle-income countries where rapid urbanization and increasing motorization have contributed to a surge in road traffic accidents. Skull fractures are a critical component of fatal head injuries, serving as both markers of the severity of trauma and indicators of the mechanism of impact. The pattern and distribution of skull fractures provide valuable insights into the biomechanics of injury, aiding not only in clinical management but also in forensic interpretation. Autopsy-based studies, in particular, offer a definitive evaluation of fracture morphology and associated intracranial damage, making them indispensable for understanding the true burden and nature of fatal head trauma.[1,2]

The skull, being a rigid yet anatomically complex structure, responds to external forces in predictable yet varied ways depending on the magnitude, direction, and nature of the applied force. Linear fractures are commonly associated with low- to moderate-energy impacts, whereas comminuted, depressed, and hinge fractures are typically indicative of high-velocity trauma such as that seen in road traffic accidents. The base of the skull, comprising the anterior, middle, and posterior cranial fossae, is particularly vulnerable to indirect

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forces and may sustain fractures even in the absence of obvious vault involvement. Understanding these fracture patterns is crucial in reconstructing the sequence of events leading to injury and in determining the cause and manner of death in medico-legal cases.[3,4]

In the Indian context, road traffic accidents account for the majority of fatal head injuries, followed by falls and assaults. The increasing incidence of high-speed collisions, poor compliance with safety measures such as helmet use, and inadequate enforcement of traffic regulations have further exacerbated the problem. Several studies have demonstrated that helmet use significantly reduces the severity of head injuries and the likelihood of skull fractures, underscoring the importance of preventive strategies. However, despite advancements in imaging modalities such as computed tomography (CT), certain fracture types—particularly sutural and subtle linear fractures—may still be missed, highlighting the continued relevance of autopsy as the gold standard for diagnosis.[5-7]

The distribution of skull fractures across different cranial bones and fossae also reflects the dynamics of injury. The temporal bone, due to its relative thinness and anatomical position, is frequently involved, especially in lateral impacts. Similarly, the middle cranial fossa is often affected in high-energy trauma, given its structural vulnerability and proximity to vital neurovascular structures. These anatomical considerations are essential for correlating clinical findings with autopsy results and for improving the accuracy of radiological interpretations.[8,9]

Despite numerous studies on head injury, there remains a need for region-specific data that correlates fracture patterns with mechanisms of injury in fatal cases. Such information is particularly valuable in tertiary care centers like SSIMS & RC, Davangere, which cater to a diverse patient population and a high volume of medico-legal autopsies. The present study aims to analyze the pattern, distribution, and mechanism of skull bone fractures in fatal head injuries through detailed autopsy evaluation. By correlating these findings with the mechanism of trauma, this study seeks to contribute to a better understanding of injury biomechanics, enhance diagnostic accuracy, and support both clinical and forensic decision-making.[10]

In fatal head injuries, the pattern and distribution of skull bone fractures commonly reflect the mechanism of trauma, with high-velocity impacts producing extensive craniofacial involvement. The incidence of facial bone fractures on CT ranges from approximately 40–70%, frequently involving the nasal, maxillary, zygomatic, and orbital bones, while paranasal sinus fractures—most often affecting the maxillary and frontal sinuses—are observed in about 30–60% of cases. CT effectively demonstrates fracture patterns, displacement, and associated sinus air-fluid levels; however, autopsy studies consistently report a slightly lower incidence due to poor detection of fine, non-displaced, and complex fractures, especially within sinus walls and deep facial structures. Thus, while autopsy provides reliable visualization of fracture distribution and mechanism, CT remains superior for identifying subtle fractures, making both modalities complementary in accurately assessing facial and sinus fracture incidence in fatal head injuries.

To evaluate and correlate radiological and autopsy findings of skull fractures in fatal traumatic head injury cases, with special emphasis on the pattern and distribution of skull fractures, mechanism of injury, demographic profile of affected individuals, diagnostic accuracy and limitations of imaging modalities, and to suggest preventive strategies for reducing head injuries, particularly among road users and construction workers.

MATERIALS AND METHODS

Study Design: Prospective cross-sectional study.
Study Setting: SSIMS & RC, Karnataka.
Study Duration: October 2018 to March 2020 (18 months).
Sample Size: 60 cases of fatal traumatic head injury fulfilling inclusion criteria.
Source of Data: Deceased individuals (male and female) with severe head injury who underwent radiological investigation followed by medicolegal autopsy.
Ethical Considerations: Institutional Ethics Committee approval obtained. Written informed consent taken from next of kin or police authorities (in unidentified cases).
Method of Data Collection:

- Detailed medicolegal autopsy performed.
- Scalp reflected and skull vault opened using electric saw.
- External and internal skull examined for fracture type, site, and pattern.
- Radiological findings collected from Department of Radiodiagnosis.
- Radiological findings compared with autopsy findings.

Inclusion Criteria:

- Age >15 years.
- Fatal head injury cases with prior radiological evaluation.
- Cases autopsied at SSIMS & RC.

Exclusion Criteria:

- Age ≤15 years.
- Cases without prior radiological investigation.
- Presence of generalized skeletal disorders (e.g., Paget's disease, osteomalacia, fibrous dysplasia).
- Cases with only superficial external injuries without skull fractures.

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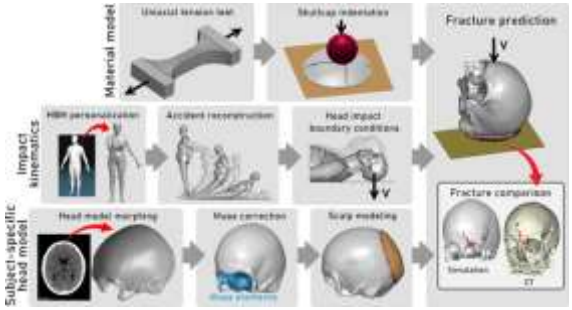

Statistical Analysis: Statistical analysis was performed by entering data into Microsoft Excel and subsequently analyzing it using SPSS version 27.0 (SPSS Inc., Chicago, IL, USA) and GraphPad Prism version 5. Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. The unpaired t-test was used to compare continuous variables between independent groups, whereas the paired t-test was applied for within-group comparisons. Categorical variables were analyzed using the Chi-square test or Fisher's exact test as appropriate. A p-value of <0.05 was considered statistically significant.

RESULTS

Table 1: Association between Mechanism of Injury and Type of Skull Fracture

Mechanism of Injury	Linear n (%)	Comminuted n (%)	Hinge n (%)	Mixed n (%)	Total	P-value
RTA (n=47)	32 (68.1)	21 (44.7)	8 (17.0)	14 (29.8)	47	0.041
Fall (n=11)	7 (63.6)	4 (36.4)	1 (9.1)	3 (27.3)	11	
Assault (n=2)	1 (50.0)	1 (50.0)	0 (0)	0 (0)	2	
Total	40	26	9	17	60	

Table 2: Correlation between Helmet Use and Severity of Skull Fractures

Helmet Use	Vault + Base n (%)	Isolated Vault n (%)	Isolated Base n (%)	Total	P-value
No (n=53)	44 (83.0)	4 (7.5)	5 (9.4)	53	0.008
Yes (n=7)	3 (42.9)	1 (14.3)	3 (42.9)	7	
Total	47	5	8	60	

Table 3: Association between Survival Period and Extent of Skull Fractures

Survival Period	Combined Fractures n (%)	Single Site n (%)	Total	P-value
<24 hrs (n=19)	16 (84.2)	3 (15.8)	19	0.62
1–7 days (n=33)	25 (75.8)	8 (24.2)	33	
>7 days (n=8)	6 (75.0)	2 (25.0)	8	
Total	47	13	60	

Table 4: Diagnostic Accuracy of CT scan Compared to Autopsy in Skull Fracture Detection

Parameter	Value (%)
Sensitivity	78.3
Specificity	100
Positive Predictive Value (PPV)	100
Negative Predictive Value (NPV)	33.3
Overall Accuracy	80
P-value	<0.001

Table 5: Distribution of Cranial Fossae Involvement According to Mechanism of Injury

Cranial Fossae	RTA n (%)	Fall n (%)	Assault n (%)	Total	P-value
Anterior Cranial Fossa (ACF)	23 (48.9)	2 (18.2)	2 (100)	27	0.036
Middle Cranial Fossa (MCF)	39 (83.0)	6 (54.5)	2 (100)	47	
Posterior Cranial Fossa (PCF)	12 (25.5)	3 (27.3)	0 (0)	15	
Total Cases	47	11	2	60	

Table 6: Association between Anatomical Bone Involvement and Mechanism of Injury

Bone Involved	RTA n (%)	Fall n (%)	Assault n (%)	Total	P-value
Temporal Bone	44 (93.6)	9 (81.8)	2 (100)	55	0.048
Parietal Bone	28 (59.6)	8 (72.7)	2 (100)	38	
Occipital Bone	20 (42.6)	4 (36.4)	1 (50.0)	25	
Sphenoid Bone	31 (66.0)	6 (54.5)	2 (100)	39	
Total Cases	47	11	2	60	

Table 7: CT Miss Rate According to Fracture Type

Fracture Type	Detected by CT n	Missed by CT n	Miss Rate (%)	P-value
Linear	32	8	20	<0.001
Comminuted	13	0	0	
Sutural	0	13	100	
Mixed	5	12	70.6	
Total	50	33	—	

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Table 8: Comparison of Facial Bone Fracture Detection between Autopsy and CT scan

Facial Bone Fracture Detection	Autopsy Frequency n (%)	CT Scan Frequency n (%)	Missed Frequency at Autopsy n (%)
Negative for Fracture	23 (74.2)	0 (0)	23 (50.0)
Positive for Fracture	8 (25.8)	31 (100)	23 (50.0)
Total	31 (100)	31 (100)	46 (100)

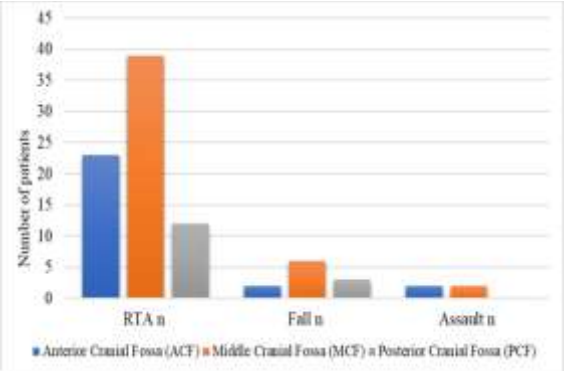

Figure: 1. Distribution of Cranial Fossae Involvement According to Mechanism of Injury

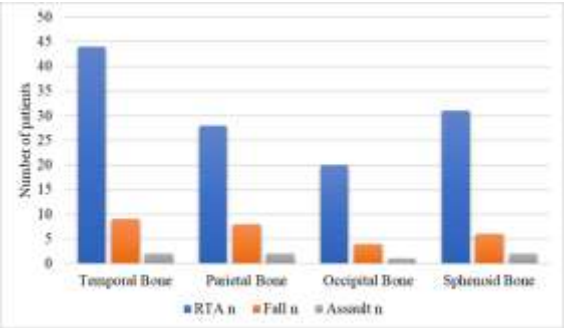

Figure 2: Association between Anatomical Bone Involvement and Mechanism of Injury

[Table 1] demonstrates the association between mechanism of injury and type of skull fracture. Road traffic accidents (RTA) constituted the most common mechanism of injury, involving 47 cases. Among these, linear fractures were the most frequent, observed in 32 cases (68.1%), followed by comminuted fractures in 21 cases (44.7%), mixed fractures in 14 cases (29.8%), and hinge fractures in 8 cases (17.0%). In fall-related injuries (11 cases), linear fractures were also predominant, occurring in 7 cases (63.6%), while comminuted fractures were seen in 4 cases (36.4%), mixed fractures in 3 cases (27.3%), and hinge fractures in 1 case (9.1%). Among assault cases (2 cases), both linear and comminuted fractures were noted in 1 case each (50.0%), while no hinge or mixed fractures were observed. The association between mechanism of injury and fracture type was found to be statistically significant (p=0.041).

[Table 2] depicts the correlation between helmet use and severity of skull fractures. Among patients who were not wearing helmets (53 cases), combined vault and base fractures were the most common pattern, seen in 44 cases (83.0%), whereas isolated vault fractures and isolated base fractures were observed in 4 cases (7.5%) and 5 cases (9.4%), respectively. In contrast, among helmet users (7 cases), combined vault and base fractures were identified in only 3 cases (42.9%), while isolated vault fractures and isolated base fractures were each seen in 1 case (14.3%) and 3 cases (42.9%), respectively. The association between helmet use and fracture severity was statistically significant (p=0.008).

[Table 3] shows the association between survival period and extent of skull fractures. Among patients who survived for less than 24 hours (19 cases), combined fractures were observed in 16 cases (84.2%), while single-site fractures were seen in 3 cases (15.8%). In patients surviving for 1–7 days (33 cases), combined fractures were present in 25 cases (75.8%) and single-site fractures in 8 cases (24.2%). Among those surviving for more than 7 days (8 cases), combined fractures were noted in 6 cases (75.0%), whereas single-site fractures occurred in 2 cases (25.0%). However, the association between survival period and extent of skull fractures was not statistically significant (p=0.62).

[Table 4] presents the diagnostic accuracy of CT scan compared to autopsy in detecting skull fractures. CT scan demonstrated a sensitivity of 78.3%, specificity of 100%, positive predictive value (PPV) of 100%, negative predictive value (NPV) of 33.3%, and an overall diagnostic accuracy of 80%. The findings were statistically highly significant ($p<0.001$), indicating excellent specificity and good overall diagnostic performance of CT scan in skull fracture detection.

[Table 5] illustrates the distribution of cranial fossae involvement according to mechanism of injury. In RTA cases (47 cases), middle cranial fossa (MCF) involvement was most common, occurring in 39 cases (83.0%), followed by anterior cranial fossa (ACF) involvement in 23 cases (48.9%) and posterior cranial fossa (PCF) involvement in 12 cases (25.5%). Among fall-related injuries (11 cases), MCF involvement was noted in 6 cases (54.5%), ACF involvement in 2 cases (18.2%), and PCF involvement in 3 cases (27.3%). In assault cases (2 cases), both ACF and MCF involvement were present in all cases (100%), while no PCF involvement was detected. The association between cranial fossae involvement and mechanism of injury was statistically significant (p=0.036).

[Table 6] demonstrates the association between anatomical bone involvement and mechanism of injury. Temporal bone fractures were the most frequently involved fractures, observed in 44 RTA cases (93.6%), 9 fall cases (81.8%), and both assault

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cases (100%), giving a total of 55 cases. Parietal bone involvement was seen in 28 RTA cases (59.6%), 8 fall cases (72.7%), and 2 assault cases (100%). Occipital bone fractures were identified in 20 RTA cases (42.6%), 4 fall cases (36.4%), and 1 assault case (50.0%). Sphenoid bone involvement was present in 31 RTA cases (66.0%), 6 fall cases (54.5%), and 2 assault cases (100%). The association between anatomical bone involvement and mechanism of injury was statistically significant (p=0.048).

[Table 7] shows the CT miss rate according to fracture type. Linear fractures had a CT detection rate of 32 cases, while 8 cases were missed, resulting in a miss rate of 20%. Comminuted fractures were detected in all 13 cases with no missed cases, yielding a miss rate of 0%. Sutural fractures were not detected by CT in any case, with all 13 cases missed, corresponding to a miss rate of 100%. Mixed fractures were detected in 5 cases, whereas 12 cases were missed, giving a miss rate of 70.6%. The association between fracture type and CT miss rate was statistically highly significant (p<0.001).

[Table 8] compares facial bone fracture detection between autopsy and CT scan. Autopsy identified facial bone fractures in 8 cases (25.8%) and was negative for fractures in 23 cases (74.2%). In contrast, CT scan detected facial bone fractures in all 31 cases (100%). Additionally, autopsy missed facial bone fractures in 23 cases (50.0%). These findings indicate that CT scan demonstrated superior detection capability for facial bone fractures compared to autopsy.

DISCUSSION

The present study demonstrated a statistically significant association between mechanism of injury and type of skull fracture (p=0.041), with road traffic accidents (RTAs) accounting for the majority of cases and linear fractures being the most common fracture pattern. RTAs are typically associated with high-velocity impacts that transmit substantial kinetic energy to the cranial vault, resulting in extensive fracture propagation. Similar findings were reported by Ravindra Kumar et al., who observed that RTAs were the predominant cause of fatal head injury and that linear fractures represented the most frequent fracture morphology due to diffuse impact forces.[11] Likewise, Agarwal et al. documented a higher incidence of comminuted and mixed fractures in severe vehicular trauma, emphasizing the role of acceleration–deceleration mechanisms in producing complex skull fractures.[12] The relatively lower occurrence of hinge fractures in the present study may be attributed to fewer cases of extreme basilar trauma compared to studies involving high-speed collisions.

The present study found a significant association between helmet use and severity of skull fractures (p=0.008). Non-helmeted individuals predominantly sustained combined vault and base fractures, whereas helmet users demonstrated a comparatively lower frequency of severe fracture patterns. Helmets are known to dissipate impact energy, thereby reducing transmission of force to the skull and cranial base. Comparable observations were made by Servadei et al., who reported that helmet use significantly reduced the incidence of severe craniofacial and basilar skull fractures among motorcyclists.[13] Similarly, Kraus et al. demonstrated that helmeted riders had lower rates of intracranial injuries and compound skull fractures compared with non-users.[14] The findings of the current study further reinforce the protective role of helmets in minimizing the severity of traumatic cranial injuries.

In the present study, combined skull fractures were more common among patients with survival periods of less than 24 hours, although the association between survival duration and fracture extent was not statistically significant (p=0.62). This suggests that extensive skull fractures may contribute to rapid deterioration and early mortality, but survival is also influenced by associated intracranial injuries and timely medical intervention. Similar results were reported by Menezes et al., who observed that patients with extensive cranial fractures often had shorter survival periods due to severe brain injury and hemorrhage.[15] However, Sharma et al. noted no consistent statistical relationship between survival time and fracture extent, highlighting that prognosis is multifactorial and depends on factors such as age, associated organ injury, and quality of emergency care.[16]

The present study showed that CT scan had a sensitivity of 78.3%, specificity of 100%, and overall accuracy of 80% in detecting skull fractures compared to autopsy findings. The excellent specificity indicates that fractures identified on CT were highly reliable, whereas the lower sensitivity suggests that certain fracture types, particularly fine linear or sutural fractures, may be overlooked radiologically. Similar findings were reported by Ringl et al., who demonstrated high specificity but moderate sensitivity of multidetector CT in identifying skull fractures, especially in complex cranial regions.[17] Likewise, Jackowski et al. found that postmortem CT was highly effective for major fracture detection but less accurate for subtle fractures compared with autopsy examination.[18] These findings support the complementary role of autopsy in forensic assessment despite advances in imaging technology.

The present study revealed that the middle cranial fossa (MCF) was the most commonly involved cranial fossa, particularly in RTA cases, and the association between cranial fossae involvement and mechanism of injury was statistically significant (p=0.036). The high frequency of MCF involvement may be attributed to the anatomical vulnerability of the temporal and sphenoid bones during lateral

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cranial impact. Similar findings were reported by Arunkumar et al., who identified the middle cranial fossa as the most frequently fractured region in fatal head injury cases associated with vehicular accidents.[19] In another study, Rao et al. observed increased incidence of anterior and middle cranial fossa fractures following high-energy blunt trauma and emphasized their association with severe intracranial complications.[20] The present findings therefore correlate well with previously published forensic and radiological literature.

The present study demonstrated a statistically significant association between anatomical bone involvement and mechanism of injury ($p=0.048$), with the temporal bone being the most commonly affected bone. Temporal bone fractures are frequently encountered in high-impact trauma because of their relatively thin structure and proximity to the middle cranial fossa. Similar observations were made by Kumar et al., who reported temporal bone involvement in the majority of fatal RTA-related head injuries.[11] Agarwal et al. also documented frequent sphenoid and parietal bone fractures in severe craniofacial trauma, attributing this to transmission of impact forces across the cranial base.[12] The predominance of temporal and sphenoid bone fractures in the current study further supports the vulnerability of the skull base in high-velocity trauma.

The present study identified significant variation in CT miss rates according to fracture type ($p<0.001$). CT scan detected all comminuted fractures accurately but demonstrated high miss rates for sutural and mixed fractures. This may be due to the difficulty in differentiating sutural fractures from normal cranial sutures and the subtle appearance of certain fracture lines on routine imaging. Similar findings were reported by Ringl et al., who observed that multidetector CT had excellent performance in detecting displaced and comminuted fractures but was less sensitive for fine linear and sutural fractures.[17] Jackowski et al. also reported limitations of postmortem CT in detecting subtle skull base and non-displaced fractures compared to autopsy.[18] These observations highlight the need for careful radiological interpretation and possible adjunctive imaging reconstruction techniques in equivocal cases.

The present study demonstrated that CT scan was superior to autopsy in detecting facial bone fractures, identifying fractures in all cases, whereas autopsy missed fractures in 50% of cases. Facial fractures may remain undetected during routine autopsy because of limited dissection and difficulty in visualizing deep facial structures. Comparable findings were reported by Jackowski et al., who concluded that postmortem CT was more sensitive than conventional autopsy for detecting facial skeletal injuries and complex craniofacial fractures.[18] Similarly, Rao et al. noted that multidetector CT provided superior visualization of facial bones, orbital walls, and maxillofacial structures compared to traditional forensic examination.[20] The present study therefore supports the increasing utility of CT imaging as an adjunct to forensic autopsy in the evaluation of craniofacial trauma.

CONCLUSION

The present study highlights the significant role of road traffic accidents as the predominant cause of fatal skull fractures, with linear fractures being the most common pattern observed. Temporal bone and middle cranial fossa involvement were frequently associated with high-velocity trauma. Helmet use showed a protective effect by reducing the severity and extent of skull fractures. Combined vault and base fractures were more commonly associated with shorter survival periods, although the association was not statistically significant. Computed tomography (CT) scan demonstrated excellent specificity and good overall diagnostic accuracy in detecting skull fractures; however, it showed limitations in identifying sutural and subtle mixed fractures when compared with autopsy findings. CT scan was superior to autopsy in detecting facial bone fractures and provided better visualization of craniofacial injuries. However, autopsy remains the gold standard for accurate identification of skull vault and skull base fractures, especially subtle and complex fracture patterns. The study emphasizes the complementary role of radiological imaging and autopsy in forensic evaluation and underscores the importance of preventive strategies, particularly helmet use and road safety measures, in reducing traumatic head injuries.

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