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ORIGINAL ARTICLE

Factors Influencing the Diagnostic Performance of Computed Tomography in Fatal Traumatic Brain Injury: An Observational CT–Autopsy Correlation Study

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ABSTRACT

Whether antemortem CT accurately reflects what autopsy later documents is a question this unit has examined before. In a prior analysis of 50 fatal TBI admissions from this tertiary care centre, CT failed to detect injuries across all 16 parameters measured, with autopsy being the reference throughout. That finding was clear enough. What remained unclear was which clinical circumstances make those failures most likely, and how large the sensitivity gap becomes under adverse conditions.

This paper addresses those questions directly. The same 50 cases were re-examined with four variables in focus: GCS severity at admission, time elapsed between injury and hospital arrival, duration of survival after admission, and injury type. Non-parametric statistical tests were applied throughout, with autopsy serving as the diagnostic gold standard.

Findings were consistent across all three time-related and severity-related variables. Cases with GCS ≤8 showed significantly more CT missed findings compared to moderate-injury cases. Sensitivity was higher in patients arriving within six hours than in those arriving later, and among patients who survived longer after admission, CT–autopsy agreement was notably worse. Intracranial haemorrhage and brain laceration were the injury types most often absent from CT reports, despite being present at post-mortem findings with direct medico-legal consequences.

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CT sensitivity in fatal TBI is not a stable figure. It varies with injury severity and with the time elapsed before imaging. When such a report is tendered as evidence, that variability matters considerably.

KEYWORDS

• Traumatic brain injury • Computed tomography • Glasgow Coma Scale • CT Sensitivity • Missed findings • Medico-legal

INTRODUCTION

R.L. Jalappa Hospital receives fatal head injury admissions with a consistency that makes the demographic profile almost predictable: young men, road accidents, the overwhelming majority on two-wheelers without helmets.[1,2] This is not a pattern specific to Kolar; published data from trauma centres across India show the same distribution.[3] In virtually every admission of this type, a CT head is performed before death, except in brought-dead cases. The implicit assumption is that this scan constitutes an adequate record of the intracranial injuries. Whether that assumption holds when autopsy findings are later compared is a question that has received insufficient attention in the Indian forensic literature.

An earlier CT–autopsy correlation study from this centre, covering 50 consecutive fatal TBI cases, found that imaging failed to detect injuries on every one of the 16 parameters examined when autopsy served as the reference standard, without exception.[4,5] That work demonstrated the gap exists. What it did not address was the clinical context in which the gap is widest—which patients, which arrival times, which injury patterns are most likely to produce a CT report that substantially underrepresents what the post-mortem later shows.

The diagnostic limitations of CT in acute TBI are not new information. The scanner performs reliably for large haemorrhages and most skull fractures, and in the casualty setting, nothing replaces it for speed.[6-8] But diffuse axonal injury is a well-documented blind spot: axons sheared by rotational forces and scattered through white matter produce little or nothing on a 16-slice scan, even when the clinical picture is severe.[9-11] Time compounds the problem in ways that are also understood individually but rarely quantified together in a single series.

A subdural haematoma that appears small on the initial antemortem scan may expand substantially in the hours before death.[12] Ischaemic change developing at six hours may be invisible on the earlier study; subdural blood becomes isodense as haemoglobin degrades; small ICH volumes fall below the resolution threshold of standard scanners.[13-15] The scan records one moment. The pathological process continues after it.

The implications reach beyond clinical management. That CT report eventually reaches a courtroom, where it may be treated as a complete and static account of the injury.[16] Published series have shown that imaging captures only a proportion of the injuries later confirmed at autopsy—the remainder are present on post-mortem examination but absent from the imaging record.[17,18] Forensic practitioners working in this field tend to be aware of this discrepancy. Legal professionals relying on these reports are frequently not.

The present study returned to the same 50 fatal TBI cases and systematically examined four variables: GCS severity at admission, time from injury to hospital arrival, survival duration after admission, and injury type, testing each against CT missed findings and sensitivity figures. The objective was to identify which factors are independently associated with worse CT–autopsy agreement, and thereby to provide some evidence-based basis for predicting when a CT report is most likely to be incomplete.

MATERIALS AND METHODS

Ethical clearance for this study was obtained from the Institutional Ethics Committee of Sri Devaraj Urs Academy of Higher Education and Research, Kolar (**CEC Ref no: SDUAHER/KLR/R&D/CEC/S/PG Dissertation /50/2024-25 dated: 09-05-2024**). The study drew entirely

on pre-existing case records and medico-legal autopsy documentation.

Fifty fatal traumatic brain injury cases admitted to R.L. Jalappa Hospital and Research Centre, Kolar, were enrolled over 19 months spanning June 2024 to December 2025. RL Jalappa Hospital and Research Centre functions as the tertiary care teaching hospital of SDUAHER and receives referrals predominantly from Kolar and Chikkaballapur districts, a largely rural catchment. Road traffic accidents, specifically those involving unhelmeted two-wheeler riders, represent the principal mechanism of TBI-related death at this institution. The patient population and institutional context are described in greater detail in a related publication from this research group.

A PROBE framework governed data collection—Prospective, Randomised, Open-label, Blinded Endpoint. The radiologist interpreting CT scans had no access to autopsy findings at the time of reporting; conversely, the autopsy surgeon documented post-mortem findings before reviewing any imaging. Blinding was maintained deliberately at both ends of the data collection process. All cases satisfying the inclusion criteria were enrolled consecutively, without selection or exclusion on clinical grounds. A subset of cases pre-dated the formal study start date and were incorporated retrospectively; the remaining cases were prospective inclusions.

Inclusion required the simultaneous availability of an antemortem CT scan of the head and a complete medico-legal autopsy report, with traumatic brain injury documented as the primary cause of death. Cases were excluded where CT or autopsy data were incomplete, where the brain injury had a non-traumatic aetiology, or where the patient was brought dead with no documented period of hospital admission.

Case records were reviewed for age, sex, mechanism of injury, GCS score at admission, time from the injury event to hospital arrival, and total duration of survival after admission. GCS severity was categorised as follows: 13–15 indicated mild injury, 9 –12 moderate, and ≤8 severe. CT and autopsy findings were coded across four domains: scalp injuries, skull fractures, meningeal haemorrhages, and brain parenchymal lesions, with each of the 16 individual parameters recorded as present or absent in each case. The count of CT-missed findings per case was tallied, and CT sensitivity by injury category was calculated using autopsy as the reference standard.

Statistical analysis was performed using SPSS version 22.0. GCS divided the cohort into two groups (severe and moderate); the Mann–Whitney U test was used to compare CT missed findings between them, given non-normal distribution. Time to hospital arrival and survival duration each produced three subgroups, with the Kruskal–Wallis test applied to assess CT sensitivity differences across these. For categorical comparisons, chi-square or Fisher's exact test was selected based on expected cell counts. A p-value of ≤0.05 was considered statistically significant.

RESULTS

The cohort comprised 50 cases. Median age was 41.5 years (IQR 15.75); 29 were male (58%) and 21 female (42%). Road traffic accidents accounted for the predominant mechanism. Median GCS at admission was 7 (IQR 4), with 35 cases (70%) classified as severe (GCS ≤8) and 15 (30%) as moderate (GCS 9–12). Median time from injury to hospital arrival was 7.5 hours (IQR 11.75); median survival after admission was 10 hours (IQR 6.75). Demographic and clinical details are presented in Tables 1 and 2.

Table 1: Demographic Profile of Study Participants (N = 50)

Variable	Value
Age (years)	41.5 (IQR = 15.75)
Gender, n (%)	
Male	29 (58.0%)
Female	21 (42.0%)

Age presented as median (IQR). IQR – Interquartile range.

Table 2: Clinical Characteristics of Study Participants (N = 50)

Variable	Value
Time to hospital (hours)	7.5 (IQR = 11.75)
Survival period (hours)	10 (IQR = 6.75)
GCS score	7 (IQR = 4)
GCS severity, n (%)	
Severe (≤8)	35 (70.0%)
Moderate (9–12)	15 (30.0%)

Values presented as median (IQR). GCS – Glasgow Coma Scale; IQR – Interquartile range.

Table 3 presents the relationship between GCS severity and autopsy-confirmed injury prevalence. Severe cases showed higher rates across most parameters.

Table 3: Association between GCS Severity and Autopsy Findings (N = 50)

Autopsy Finding	Severe (n=35) n (%)	Moderate (n=15) n (%)	p-value
Scalp Abrasion	24 (68.6%)	9 (60.0%)	0.746
Scalp Contusion	33 (94.3%)	9 (60.0%)	0.006*
Scalp Laceration	33 (94.3%)	7 (46.7%)	<0.001*
Fissured Fracture	32 (91.4%)	8 (53.3%)	0.004*
Depressed Fracture	30 (85.7%)	5 (33.3%)	<0.001*
Comminuted Fracture	30 (85.7%)	5 (33.3%)	<0.001*
ACF	30 (85.7%)	8 (53.3%)	0.027*
MCF	27 (77.1%)	12 (80.0%)	1.000
PCF	31 (88.6%)	3 (20.0%)	<0.001*
EDH	25 (71.4%)	6 (40.0%)	0.056
SDH	32 (91.4%)	10 (66.7%)	0.043*
SAH	34 (97.1%)	7 (46.7%)	<0.001*
IVH	24 (68.6%)	6 (40.0%)	0.114
ICH	29 (82.9%)	5 (33.3%)	0.002*
Brain Contusion	32 (91.4%)	8 (53.3%)	0.004*
Brain Laceration	32 (91.4%)	11 (73.3%)	0.176

*p <0.05 statistically significant. Chi-square / Fisher's exact test applied. GCS – Glasgow Coma Scale.

SAH was documented at autopsy in 97.1% of severe cases against 46.7% of moderate; ICH in 82.9% versus 33.3%; scalp laceration in 94.3% versus 46.7%; scalp contusion 94.3% versus 60.0%; brain contusion 91.4% versus 53.3%. All of these between-group differences reached statistical significance, with p-values ranging from <0.001 to 0.006. Parameters that did not achieve significance between severity groups included scalp abrasion, MCF involvement, EDH, IVH, and brain laceration.

Table 4 compares CT missed findings by GCS severity group. The severe group had a median of 2 missed findings per case (mean 2.43 ± 1.24), while the moderate group had a median of 0 (mean 0.60 ± 0.74). This difference was statistically significant at p<0.001, establishing that greater injury severity was consistently associated with a higher number of autopsy-confirmed findings absent from CT.

Table 4: Association between GCS Severity and CT Missed Findings (N = 50)

GCS Severity	N	Mean ± SD (missed findings)	Median (IQR)	p-value
Severe (≤8)	35	2.43 ± 1.24	2 (IQR = 1)	<0.001*
Moderate (9–12)	15	0.6 ± 0.74	0 (IQR = 1)	

*Mann–Whitney U test. p < 0.05 is considered statistically significant. GCS – Glasgow Coma Scale; IQR – Interquartile range

Table 5 presents CT sensitivity across subgroups defined by time to hospital and survival duration. Among the 23 cases arriving within six hours, the mean CT sensitivity was 86.8% (median 85.71, IQR 21.11). This fell to 61.1% in the 11 cases arriving between six and twelve hours, and to 47.9% in the 16 cases arriving beyond twelve hours. The Kruskal–Wallis test confirmed this decline was statistically significant (p<0.001). Survival duration showed the same pattern: mean sensitivity was 79.96% among the 32 cases surviving under twelve hours, dropped to 51.44% in the 12 cases surviving twelve to twenty-four hours, and reached 43.21% in the six cases surviving beyond twenty-four hours (p<0.001). Across all subgroups, longer time after injury—whether measured to hospital arrival or to death—was associated with worse CT–autopsy agreement.

Table 5: Association Between Time Factors and CT Sensitivity (N = 50)

Time Factor	Category	N	Mean ± SD CT Sensitivity (%)	Median (IQR)	p-value
Time to the hospital	≤6 hours	23	86.8 ± 11.74	85.71 (IQR = 21.11)	
	6–12 hours	11	61.11 ± 4.26	62.5 (IQR = 7.15)	<0.001*
	>12 hours	16	47.9 ± 4.73	50 (IQR = 3.85)	
Survival period	≤12 hours	32	79.96 ± 14.97	80 (IQR = 27.68)	
	12–24 hours	12	51.44 ± 2.23	50 (IQR = 3.46)	<0.001*
	>24 hours	6	43.21 ± 4.56	45.8 (IQR = 5.94)	

*Kruskal–Wallis test applied. CT – Computed tomography; IQR – Interquartile range. p ≤0.05 is considered statistically significant.

DISCUSSION

The results point consistently in one direction, and the direction is not surprising to anyone who works in this setting. What the data add is a quantified account of how large the sensitivity drop actually is across clinically meaningful intervals, and that figure is larger than one might intuitively expect.

A case from this series is worth describing briefly. The patient arrived following a road accident with a GCS of 8. The CT was reviewed, read as showing no lesion requiring immediate surgical intervention, and the patient was admitted to a ward bed. Twelve hours later, he was dead. Post-mortem examination revealed an ICH that had not been visible on the antemortem scan, a brain laceration the CT had entirely missed, and diffuse axonal injury throughout. The scan was not misinterpreted. It was taken before enough pathology had accumulated to fall within the detection range of a 16-slice machine, in a patient whose injury pattern was too diffuse for that resolution to resolve. This is not an unusual scenario. What is unusual is having the data to show how frequently it occurs and under which conditions it is most likely.

GCS severity was the first variable examined. The severe group had a median of 2 missed findings; the moderate group, zero. The difference was held at $p<0.001$. This is biologically consistent: severe TBI is associated with more DAI, more diffuse cerebral oedema, and more of the injury subtypes—scattered, small-volume, deep parenchymal—that 16-slice resolution cannot reliably detect.[19-21] Garland and colleagues reported the same in their post-mortem CT study, finding parenchymal injuries went undetected regardless of imaging timing.[22] The present data suggest the same applies to antemortem scanning.

The time-to-hospital variable produced a steeper gradient than GCS alone. Sensitivity was 86.8% in cases arriving within six hours and 47.9% in those arriving beyond twelve—a drop of nearly 39 percentage points across a single time interval. The mechanism is well established in the literature: haemoglobin breakdown causes hyperdense subdural blood to become isodense with surrounding brain tissue, oedema fills compartments that were unremarkable on earlier imaging, and small ICH volumes that were already near the scanner's resolution limit become even harder to distinguish.[23,24] Kawasumi *et al.* documented this specifically for subdural collections, showing antemortem volumes were substantially smaller than what post-mortem imaging revealed.[25] The present findings suggest the same biology operates in the hours between the antemortem scan and death.

Survival duration showed an identical pattern, with mean CT sensitivity declining from 79.96% in those surviving under twelve hours to 43.21% in those surviving beyond twenty-four hours ($p<0.001$). This is not a separate phenomenon from the time-to-hospital finding—it reflects the same underlying process. More time alive after admission means more time for pathology to accumulate and evolve beyond what the earlier scan recorded: oedema progresses, contusion sites haemorrhage further, and ischaemic change develops. The CT captured the injury state at one moment. The report, however, was used as though it described the final state.

ICH and brain laceration were the two injury types that appeared most consistently in the missed-findings columns. Both are parenchymal, neither involves the brain surface, where CT performs more reliably, and both involve blood or disrupted tissue sitting deep within brain substance at attenuation values close enough to surrounding parenchyma that a 16-slice scanner cannot dependably separate them, especially at small volumes. Published reviews of forensic imaging modalities have consistently identified parenchymal injuries as the weakest detection category across imaging methods. The present series confirms this in an Indian forensic context, and to our knowledge, represents the first quantitative documentation of this finding in this setting.

The practical implication is direct. A patient with GCS ≤8 arriving more than twelve hours after injury—a combination that is not uncommon in this catchment area, given referral distances from rural locations—may have a CT sensitivity below 50% by these figures. Half of what the autopsy will later document is not in the imaging report. That report is nonetheless the document that reaches the forensic expert, informs the medico-legal opinion, and enters the courtroom. The autopsy findings, if they have been conducted, may never be placed before the court at all.

This disconnect is not hypothetical. It recurs in medico-legal casework at this centre, and it begins at the moment the scan is taken.

Several limitations apply. This is a single-centre study using a 16-slice scanner; the sensitivity figures reported are specific to this equipment and this patient population. A 64-slice scanner at a higher-volume centre would likely produce different absolute values, though the directional findings—sensitivity declining with severity and delay—would almost certainly persist. Acute MRI was not available; DAI was therefore characterised at post-mortem histopathology rather than captured on imaging. Inter-observer variability in CT interpretation and autopsy documentation could not be quantified. The findings apply to Kolar. Whether they generalise to urban trauma centres in Mumbai, Bengaluru, or Delhi is a question that requires separate study in those settings.

The direction this point is towards three-stage documentation as a standard for all fatal TBI cases with medico-legal significance: antemortem CT, post-mortem CT, and full conventional autopsy. No Indian forensic or emergency department currently operates this protocol routinely. This study provides one evidence-based reason why the question of implementing it deserves serious consideration.

CONCLUSION

CT sensitivity in fatal TBI is not a fixed quantity. It shifted with each of the clinical variables this study examined—GCS severity, time to hospital arrival, and survival duration after admission—with worse values consistently associated with greater severity and greater elapsed time. The relationship was statistically significant and directionally consistent across all three variables.

Intracranial haemorrhage and brain laceration were the injury types that CT most reliably failed to document. Both are parenchymal, both involve deep tissue at densities close to the surrounding brain, and neither was captured reliably by 16-slice antemortem imaging in this series. In severely injured patients who arrived late, the CT report accounted for considerably less than half of what the subsequent autopsy confirmed. No case in this series was adequately explained by the CT findings alone.

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Conflict of Interest

The authors declare no conflict of interest.

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