

Epidemiology and delays in neurosurgical care among patients with traumatic brain injury in a regional referral hospital in Sri Lanka: a retrospective cohort study

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OBJECTIVE The objective of this study was to develop a pilot traumatic brain injury (TBI) registry through a retrospective review of medical records. This was done to investigate the epidemiology and the prevalence of delays to care, both before and after hospital admission, among patients with TBI in the Teaching Hospital Jaffna, a regional referral hospital in Sri Lanka.

METHODS This was a single-center retrospective cohort study, in which purposive sampling was used to select TBI cases treated between January and December 2021. Patients with TBI were initially identified via *International Classification of Diseases, Tenth Revision, Clinical Modification* codes and then stratified via mechanism of injury and length of stay; data collection was done through a review of physical medical records.

RESULTS Among the 99 patients with TBI who were identified, the majority (72%) were referred from peripheral facilities without neurosurgical support. Road traffic accidents were the leading cause of injury (68.7%) and death (75.9%). TBIs were classified as mild (50.5%), moderate (21.2%), and severe (28.3%). Eighty percent of patients with TBIs who were referred to neurosurgery received opinions within 2 hours, with no significant association with mortality rate. Compared to patients with mild/moderate TBI, those with severe TBI had shorter median times before receiving neurosurgical opinions and CT scan reports. Delays in CT scan reports resulted in prolonged times to receive neurosurgical management. Most patients were managed without neurosurgical operative intervention, with subsequent neurosurgical interventions linked to a higher mortality rate (HR 6.08, $p < 0.001$). The inpatient mortality rate was 29.3%, mainly from severe TBIs (69%). Patients needing intracranial pressure monitoring had higher inpatient mortality ($p < 0.001$). Deteriorating Glasgow Coma Scale scores prior to intervention, typically due to inadequate vital sign stabilization, predicted significantly lower survival rates (52% vs 82%, $p = 0.0019$).

CONCLUSIONS Patients with TBI in our cohort faced delays in three main areas: lengthy referral pathways, late stabilization of vital signs and intracranial pressure, and initial neurosurgical management. Developing strategies to mitigate these delays in care will be a crucial factor in reducing neurological morbidity and mortality for patients with TBI seeking treatment in resource-limited settings.

<https://thejns.org/doi/abs/10.3171/2024.12.FOCUS24785>

KEYWORDS traumatic brain injury; delays to care; neurosurgical management; lower-middle-income country

TRAUMATIC brain injury (TBI) is a significant cause of global morbidity and mortality, affecting an estimated 69 million individuals each year. According to the WHO, the burden of TBI is most pronounced in lower-middle-income countries (LMICs), with Africa and Southeast

Asia reporting the highest proportions. Although TBIs can result from various causes, road traffic accidents (RTAs) emerge as a leading contributor to these injuries in LMICs, attributed to factors such as rapid urbanization, substance abuse, and inadequate road safety infrastructure.^{1,2}

ABBREVIATIONS ED = emergency department; GCS = Glasgow Coma Scale; ICD-10-CM = *International Classification of Diseases, Tenth Revision, Clinical Modification*; ICP = intracranial pressure; LMIC = lower-middle-income country; RTA = road traffic accident; SAH = subarachnoid hemorrhage; SDH = subdural hemorrhage; TBI = traumatic brain injury; THJ = Teaching Hospital Jaffna.

SUBMITTED October 6, 2024. **ACCEPTED** December 20, 2024.

INCLUDE WHEN CITING DOI: 10.3171/2024.12.FOCUS24785.

Patients with TBI in LMICs experience higher levels of mild to moderate disability compared to high-income countries.³ Outcomes include worse 6-month mortality rate, lower Glasgow Outcome Scale scores, and higher postdischarge economic dependence.^{4,5} These disparities stem from delayed medical care, limited neurosurgical facilities, and socioeconomic challenges.⁵ Studies from sub-Saharan Africa highlight the need for improved infrastructure and capacity building to minimize delays and enhance neurosurgical care.⁶ Streamlining referral processes, improving healthcare provider communication, and enhancing healthcare systems are vital to provide timely and appropriate surgical care for patients with TBI who are referred to tertiary centers.⁷ The United Nations Decade of Action for Road Safety (2011–2020) aimed to reduce TBIs through prevention, better trauma care, and improved road safety policies.⁸

In LMICs, referral networks are crucial in ensuring timely surgical care, particularly for rural populations with limited access to specialist services. The Lancet Commission on Global Surgery established the so-called three delays framework, categorizing delays in accessing timely surgical care into the following groups: delays in seeking care (first delay), reaching care (second delay), and receiving care (third delay). Studies indicate that delays in interfacility referrals and emergency departments (EDs) are common in LMICs.^{9,10} Within traumatic injury cohorts, delays in hospital admissions, imaging investigations, and surgical management have been identified as predictors of increased complications, extended hospital length of stay, and higher 30-day mortality rates.^{3,11}

In Sri Lanka, TBIs are a significant public health concern, with an average of 38,000 RTAs annually, exacerbated by a 67% growth in vehicle ownership between 2011 and 2018.¹² A 2020 road traffic trauma registry highlighted RTAs as a key cause of trauma admissions and emphasized the severe lack of prehospital care, causing significant delays in hospital arrival and underlining the need for better emergency medical services.¹³ The economic impact of TBIs in LMICs is considerable, with RTAs incurring a median cost of US\$4200 per injury, encompassing direct medical and nonmedical expenses (medicolegal administrative costs, funeral costs, transportation) as well as indirect expenses (loss of income, cost of premature death, pain and suffering, and the cost of restricted activity) per injury.¹⁴

The healthcare system in the Jaffna district is vital in meeting northern Sri Lanka's medical needs—however, it has only one senior neurosurgeon serving the entire province. Trauma surgical referrals in Sri Lanka remain poorly explored, with limited data on TBI care delays and outcomes.^{13,15} This study aims to investigate the epidemiology and the prevalence of delays to care, both before and after hospital admission, among patients with TBI in a regional referral hospital in Sri Lanka.

Methods

Study Setting

This was a single-center study conducted at the Teaching Hospital Jaffna (THJ), a referral center in the Jaffna

district, which is one of the five districts in the Northern Province of Sri Lanka, with an estimated population of 1.2 million, including 0.6 million residents in the Jaffna district alone. The Jaffna district, one of only two in the province with access to CT scanners, serves as the largest immediate catchment area for patients with TBI. The other hospital with a CT scanner is located in the district of Vavuniya, which is 144 km away from the neurosurgical support of THJ and requires a 2.5-hour journey by car. The THJ has 1228 beds and admits 111,129 patients annually.¹³ Additionally, it is the only hospital in the Northern Province equipped with on-site neurosurgical support, including a dedicated neurosurgical intensive care unit and fully functional neurosurgical operating theaters.

Study Population

A retrospective review of medical records was conducted via purposive sampling of moderate to severe cases of TBI in patients admitted to the ED at THJ between January and December 2021. Given the higher mortality rates in cohorts with moderate to severe TBI, these cases were prioritized over mild TBI cases.¹⁶ Patients were identified using the *International Classification of Diseases, Tenth Revision, Clinical Modification* (ICD-10-CM) codes: S00 (Superficial injury of head), S01 (Open wound of head), S02 (Fracture of skull and facial bones), S03 (Dislocation and sprain of joints and ligaments of head), S05 (Injury of eye and orbit), S06 (Intracranial injury), S07 (Crushing injury of head), and S09 (Other and unspecified injuries of head). Codes S00, S03, S05, and S09, were excluded due to high volumes of superficial lacerations as the primary diagnosis. Further stratification focused on moderate to severe cases via mechanisms of injury (transport injuries, fall, struck by object, assault, cut/stab) and length of stay > 72 hours (following evidence of mild TBI in patients requiring further care¹⁷). Data were collected through retrospective review of physical medical records by on-site medically trained personnel. Non-TBI cases, unspecified head injuries without CT scans, pediatric patients (≤ 16 years old), and those transferred out on admission were excluded. The sampling frame is shown in Fig. 1.

Study Variables

The database included patient demographics (age, sex, substance-use history, comorbidities, baseline vital signs and laboratory investigations); presentation date and time at the ED; mechanism of injury; and presenting TBI severity based on the Glasgow Coma Scale (GCS) score. TBI severities were defined as mild (GCS 13–15), moderate (GCS 9–12), and severe (GCS 3–8). Following the three delays framework by the Lancet Commission on Global Surgery, the first delay involves delays in seeking care due to financial, systemic, or personal reasons.^{9,18} This delay was not assessed due to lack of available data. Second delays refer to delays in reaching care when surgical capacity is scarce and patients are impeded from seeking the appropriate neurosurgical care. Second delay variables included referral patterns (direct vs referred) and distance traveled from the referral institution. Third delays involve delays in receiving care due to hospital-based circumstances, in-

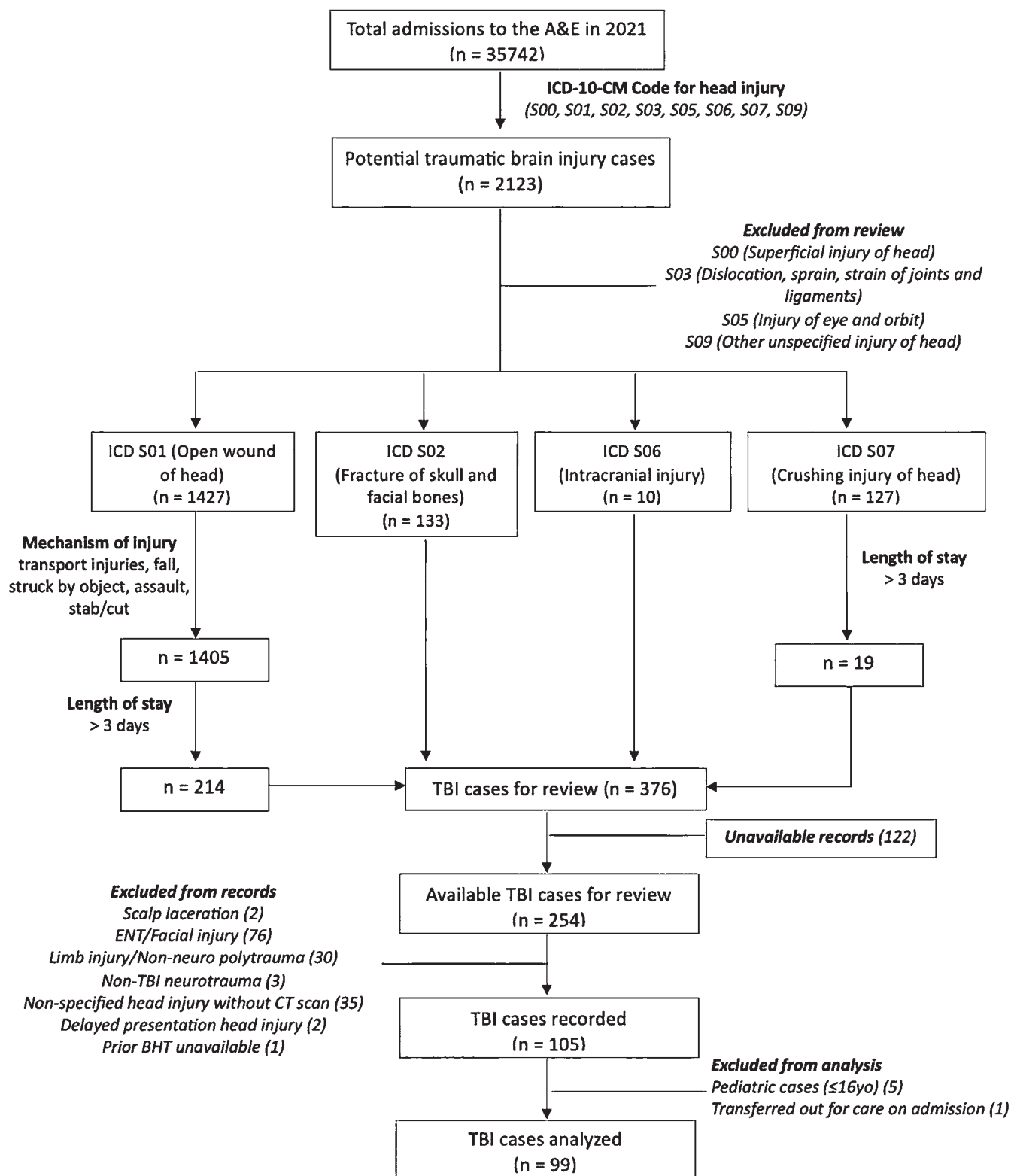


FIG. 1. Population sampling frame. A&E = accident and emergency; BHT = bed head ticket.

cluding stabilization management with tranexamic acid, antiepileptic and hyperosmolar therapy, hypoxia management, blood transfusion, and intracranial pressure (ICP) monitoring with external ventricular drains. Third delay

time-to-care variables included time from ED presentation to the following: 1) receiving neurosurgical opinion—taken as time of input by the neurosurgical team in medical records; 2) receiving CT brain scan assessment—taken

from time of CT brain results reported in medical records; and 3) receiving definitive management—taken from time of nonoperative management initiation at the intensive care unit/ward or operative intervention in the operating theater. Outcome variables included death, length of hospitalization, and discharge destination (home, return to primary institution, self-discharge).

Statistical Analysis

Variables with > 20% of observations missing were excluded from our final analysis, which included patient comorbidities and use of anticoagulants. Categorical variables were reported with frequencies and percentages, with chi-square tests (or Fisher exact tests where appropriate) used to compare categorical demographic and clinical variables on TBI severity. Continuous variables were reported with the mean $\pm$ standard deviation, and compared between TBI severities via two-sample t-test or Mann-Whitney U-test (depending on normality assumption). Univariate logistic regression was performed to investigate potential risk factors of mortality outcomes, adjusted for TBI severity by using multivariable logistic regression. Firth's penalized likelihood approach was applied to reduce the estimates bias, and Cox proportional hazards regression was conducted to assess the association between covariates and survival outcome. Kaplan-Meier survival curves compared survival times between groups, and log-rank p value was calculated. Odds ratio or hazard ratio and 95% confidence intervals are reported for the corresponding analysis. Goodness-of-fit of the logistic regression analysis was evaluated via Hosmer-Lemeshow test, whereas the proportional hazard ratio assumption was verified in Cox regression models. Statistical significance was set at $p < 0.05$. All analyses were performed in R version 3.5.1.¹⁹

Ethics

This study was approved by the University of Jaffna Ethics Review Committee, as well as the National University of Singapore Institutional Review Board (NUS-IRB).

Results

Demographic and Clinical Characteristics

Our sample included 99 patients treated within the study period of January to December 2021. Patients were predominantly male (81.8%) and had a mean age of 43.8 ± 18.6 years (Table 1). The most common mechanism of injury was RTAs, which contributed to 68.7% of reported TBI cases. RTAs were also the leading mechanism of injury among those who died (75.9%, $p = 0.018$). A total of 21/99 (21.2%) patients were also under the influence of alcohol on presentation at the ED. Most cases were classified as mild (50.5%), followed by severe (28.3%), and moderate (21.2%) TBI. A total of 22/99 (22.2%) patients were intubated on presentation to the ED. Presenting mean hemoglobin and hematocrit levels were also significantly lower in patients with worse mortality outcomes ($p = 0.037$ and $p = 0.012$, respectively). The mean baseline laboratory findings can be found in Table 1.

The inpatient mortality rate was 29/99 (29.3%), with a

significant majority of deaths occurring in patients with severe TBI (20/29, 69%, $p < 0.001$). The most common cause of death reported was craniocerebral injury (25/29, 86.2%) followed by polytrauma (2/29, 6.9%), and nontrauma-related causes (2/29, 6.9%). The mean time from presentation to death was 4.2 ± 2.6 days. Among patients who survived, the mean number of days hospitalized was 8.4 ± 10.4 days, with the majority (57/70, 81.4%) being discharged home and 12/70 (17.1%) being discharged back to the initial hospital they were referred from for continuity of care.

CT Findings

A total of 23/99 (23.2%) patients had a normal CT scan finding with 100% discharge rates (Table 2). By proportions, the most common pathological CT finding was a contusion (33/99, 33.3%), followed by skull fracture (25/99, 25.3%), and then by subdural hemorrhage (SDH) and subarachnoid hemorrhage (SAH) (17/99, 17.2% each). There was also a greater proportion of patients with TBI who had higher mortality outcomes in those with CT findings of subdural hemorrhage, midline shifts, and subarachnoid hemorrhages. Figure 2A shows the distribution of pathologies diagnosed on CT across mortality outcomes. Across TBI categories, patients with severe injury suffered from mainly contusions (14/58, 24.1%), SAHs (11/58, 19%), and SDHs (9/58, 15.5%) (Fig. 2B).

Stabilization of Patients With TBI

A total of 22/99 (22.2%) patients required intubation, and 42/99 (42.4%) patients were administered tranexamic acid on presentation (Tables 1 and 2). The majority of patients with ICP monitoring died while inpatients ($p < 0.001$). As expected, patients requiring stabilizing prophylactic pharmacotherapy (mannitol, phenytoin, tranexamic acid), oxygenation supplementation, and ICP monitoring experienced lower survival probabilities than their counterparts who did not require these stabilizing measures (Fig. 3B). In the multivariate Cox regression analysis, the need for stabilizing measures was significantly associated with an increased risk of inpatient death (prophylactic pharmacotherapy—HR 2.6, 95% CI 1.14–5.93, $p = 0.023$; oxygen supplementation—HR 3.1, 95% CI 1.48–6.38, $p = 0.003$; and ICP monitoring—HR 4.8, 95% CI 2.12–10.9, $p < 0.001$) (Table 3).

Prior to the initial intervention, 15/99 (15.2%) patients had a worsening in GCS scores (Table 2). A large proportion of patients with worsening GCS scores also died while inpatients ($p = 0.001$). Adjusting for TBI severity, a worsening GCS score prior to the initial intervention was found to be a significant predictor of mortality (adjusted OR 9.87, 95% CI 2.40–40.5, $p = 0.001$) (Table 3). In the multivariate Cox regression analysis, a deterioration in GCS score prior to the initial intervention was also associated with a 3-fold greater risk of inpatient mortality (HR 3.19, 95% CI 1.48–6.88, $p = 0.003$). The median survival time for patients with a worsened preintervention GCS score was 6 days (Fig. 3B). At 3 days of admission, the survival probability for patients with a worsened preintervention GCS score was significantly lower than that of

TABLE 1. Demographics of patients with TBI treated at THJ

	All Pts, n = 99 (%)	Discharged, n = 70 (%)	Died, n = 29 (%)	p Value*
Age in yrs	43.76 ± 18.6	38.8 ± 15.8	56.1 ± 19.5	<0.001
Male sex	81 (81.8)	58 (82.9)	23 (79.3)	0.776
Referral pattern				
Direct	28 (28.3)	20 (28.6)	8 (27.6)	>0.99
Referred	71 (71.7)	50 (71.4)	21 (72.4)	
Distance to hospital in km	51.7 ± 41	53.7 ± 42	46.9 ± 40	0.523
Substance abuse				
None	78 (78.8)	52 (74.3)	26 (89.7)	0.110
Alcohol	21 (21.2)	18 (25.7)	3 (10.3)	
Mechanism of injury				
Not recorded	1 (1)	0 (0)	1 (3.4)	0.018
RTAs	68 (68.7)	46 (65.7)	22 (75.9)	
Assault	22 (22.2)	20 (28.6)	2 (6.9)	
Fall	7 (7.1)	3 (4.3)	4 (13.8)	
Others	1 (1)	1 (1.4)	0	
TBI severity				
Mild	50 (50.5)	47 (67.1)	3 (10.3)	<0.001
Moderate	21 (21.2)	15 (21.4)	6 (20.7)	
Severe	28 (28.3)	8 (11.4)	20 (69)	
Received blood transfusion, pre-/intra-intervention	8 (8.1)	1 (1.4)	7 (24.1)	<0.001
Oxygen				
None	75 (75.8)	61 (87.1)	14 (48.3)	<0.001
Supplemental	2 (2)	1 (1.4)	1 (3.4)	
Intubated	22 (22.2)	8 (11.4)	14 (48.3)	
MAP in mm Hg	101 ± 16	99.1 ± 13	106 ± 23	0.116
Baseline laboratory, ref value				
Hemoglobin, 13–16	12.6 ± 2.2	12.9 ± 2.0	11.8 ± 2.4	0.037
Hematocrit, 39–48	37.3 ± 6.1	38.4 ± 5.8	34.9 ± 6.0	0.012
White blood cells, 4–10	14.6 ± 5.4	13.8 ± 4.7	16.2 ± 6.7	0.097
Platelets, 150–410	227 ± 78	230 ± 62	222 ± 105	0.699
Prothrombin time, 10–13	12.1 ± 2.3	11.7 ± 1.5	12.6 ± 3.1	0.147
INR, 0.8–1.2	1.02 ± 0.23	0.98 ± 0.13	1.08 ± 0.30	0.104

INR = international normalized ratio; MAP = mean arterial pressure; pts = patients.

Values are expressed as the mean ± SD or as the frequency (percent). Boldface type indicates statistical significance.

* Calculated using the t-test or Mann-Whitney U-test for continuous variables; the chi-square or Fisher exact test was used for categorical variables.

patients with stable/improved preintervention GCS scores (52% vs 82%, $p = 0.0019$).

Delays to Care

Of those referred to neurosurgery (91/99), 6 patients did not have their time of review recorded. The most common time to neurosurgical opinion from admission was within 2.0 hours (68/85, 80%) (Fig. 4A). Delays varied by TBI severity, with a higher proportion of patients with severe TBI (24/28, 85.7%) seen by the neurosurgical team within 2.0 hours of admission. The median time to a neurosurgical opinion was significantly shorter in the severe TBI group compared to the moderate/mild TBI groups (Fig.

4E; 1.7 vs 2.4/2.2 hours, $p = 0.04$). However, our multivariate regression model revealed no significant associations between delay to neurosurgical review and mortality outcomes (Table 3). At 1 week, the survival probability for patients initially seen by the neurosurgical team within 2 hours was lower than in those seen 2 hours after admission (62% vs 65%, $p > 0.99$) (Fig. 4C).

The most common time to receiving a CT scan report was within 4.0 hours (57/99, 57.6%). Most patients with severe TBI received their reports within 1.1–2.0 hours of admission (12/28, 42.9%), whereas the longest delays reached 6.1–7.0 hours (Fig. 4B). Conversely, the majority of patients who received their CT scan reports > 12.0 hours after admission (17/20, 85%) had mild TBI. The median

TABLE 2. Clinical characteristics and interventions in patients with TBI

	All Pts, n = 99 (%)	Discharged, n = 70 (%)	Died, n = 29 (%)	p Value
Prophylactic pharmacotherapy				
Tranexamic acid	42 (42.4)	22 (31.4)	20 (69)	<0.001
Mannitol	3 (3)	0 (0)	3 (10.3)	0.023
Phenytoin	1 (1)	0 (0)	1 (3.4)	0.293
CT findings	n = 96	n = 69	n = 27	
Not recorded*	3	1	2	
Normal	23 (24)	23 (33.3)	0 (0)	<0.001
Abnormal†	73 (76)	46 (66.7)	27 (100)	
ICP monitoring	9 (9.1)	1 (1.4)	8 (27.6)	<0.001
As first intervention	2 (22.2)	1 (100)	1 (12.5)	0.222
As subsequent intervention	7 (77.8)	0 (0)	7 (87.5)	
Worsening GCS score prior to initial intervention, Δ GCS –1 to –12	15 (15.2)	5 (7.1)	10 (34.5)	0.001
Initial intervention	n = 98	n = 70	n = 28	
Death before intervention*	1	0	1	
Neurosurgery	9 (9.2)	4 (5.7)	5 (17.9)	0.046
Nonneurosurgical management‡	89 (90.8)	66 (94.3)	23 (82.1)	
Neurosurgical intervention after nonneurosurgical management	n = 89	n = 66	n = 23	
Performed	8 (9)	1 (1.5)	7 (30.4)	0.002

Boldface type indicates statistical significance.

* Variable category not included in statistical analysis.

† Includes extradural hemorrhage, SDH, intraventricular hemorrhage, SAH, contusion, midline shift, skull fracture, pneumocephalus, suspected diffuse axonal injury.

‡ Nonneurosurgical management includes conservative management, wound management, and nonneurosurgical operative procedures.

time to receiving a CT scan report was significantly shorter in the severe TBI group in comparison to the moderate/mild TBI groups (2.1 vs 2.5/6.1 hours, $p = 0.003$) (Fig. 4E). Adjusting for TBI severity, abnormal CT findings were shown to predict death (adjusted OR 10.4, 95% CI 0.57 to > 100 , $p = 0.03$). However, no significant associations were found between the time to CT scan and in-hospital death in our regression models (Table 3). At 1 week, the survival probability for patients who received CT reports within 4 hours was actually lower than for those reported at > 4 hours (60% vs 65%, $p > 0.99$) (Fig. 3C).

Nearly all patients (89/99, 89.9%) received nonneurosurgical primary interventions at admission, including conservative management in high-acuity settings (ED, intensive care unit, high-dependency units, neurosurgical units), lower-acuity settings, and basic wound care (Table 2). Most initial neurosurgical interventions were for severe TBI (6/8, 75%), with a median delay of 2.83 hours (Fig. 4C, 4E). The median survival time was 6 days for those undergoing initial neurosurgical interventions and 9 days for nonneurosurgical interventions ($p = 0.19$) (Fig. 3C). Although time to neurosurgical intervention was not linked to in-hospital death, the need for subsequent neurosurgery following initial nonneurosurgical management predicted higher mortality rates (HR 6.08, 95% CI 2.45–15.1, $p < 0.001$). Eight of 89 patients requiring initial nonneurosurgical care later needed neurosurgery (7 ICP monitoring, 1 evacuation of SDH). The average time to subsequent neurosurgery was 1.13 ± 0.64 days, with a mortality rate of 87.5% in these patients compared to 19.8% in those who did not require additional neurosurgery ($p = 0.002$). At 1

week, survival probability was 12.5% for those needing additional neurosurgery, versus 72.1% for those who did not ($p < 0.001$) (Fig. 3C).

Subgroup Analyses of Referred Patients

Seventy-one of 99 (71.7%) patients were transferred to THJ from peripheral facilities: district general hospital (32/71), base hospital (28/71), or divisional hospital (11/71), with a mean transport distance of 51.7 ± 41 km (Table 1). Most referred patients with TBI had mild/moderate injury severity (49/71, 69%) (Table 4). Approximately 20% of referred patients with TBI were also found to have an unremarkable CT scan. Most (53/71, 74.7%) were treated conservatively initially, with 58.5% in high-acuity settings.

Discussion

This study is one of the first to investigate TBI epidemiology and care delays in northern Sri Lanka. We recorded 99 TBI cases across mild (50.5%), moderate (21.1%), and severe (28.3%) injury levels. Patients with severe TBI had lower survival rates, reflecting the prognostic significance of the GCS score.^{20,21} LMIC data reported similar patterns in severity distributions.^{22,23} In line with the literature,²⁴ RTAs were a major cause of TBI incidence and fatalities in our cohort, with alcohol intoxication being present in 20% of cases. This reflects broader challenges in developing countries where RTAs result in high mortality rates and disability-adjusted life years lost.^{11,25–27} Data from a northern Sri Lanka registry showed nearly half of motor vehicle collision victims were primary family income pro-

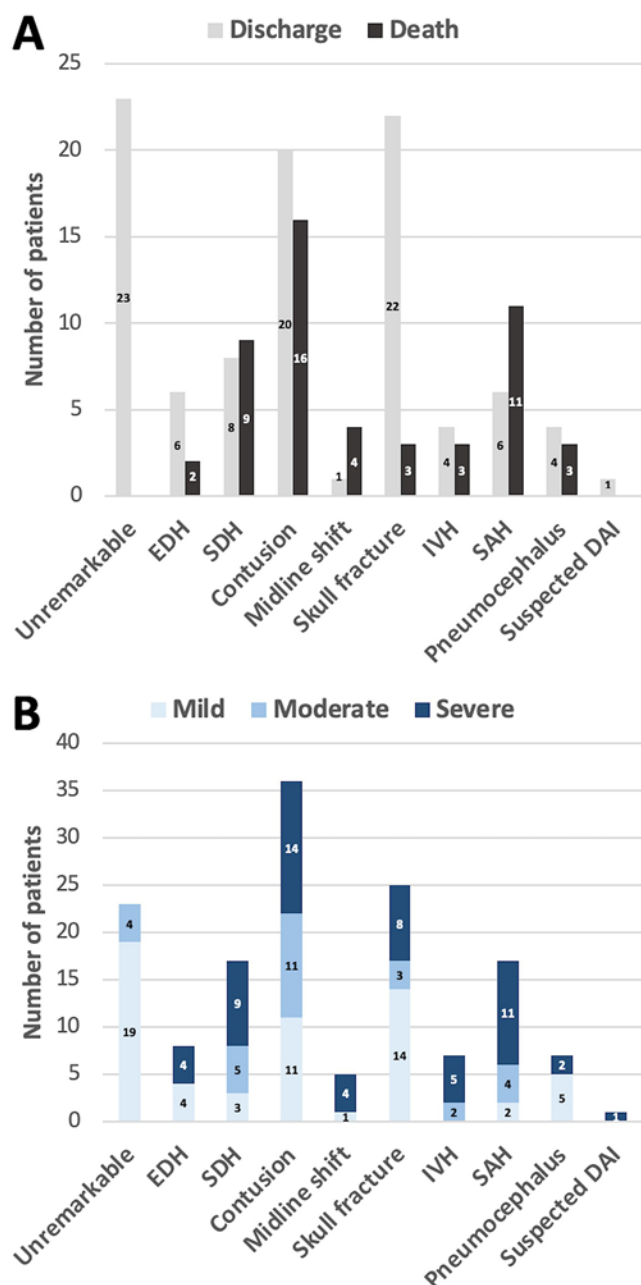


FIG. 2. CT findings in patients with TBI. **A:** Outcomes of patients with TBI across CT findings. **B:** CT findings across mild, moderate, and severe TBI. DAI = diffuse axonal injury; EDH = extradural hemorrhage; IVH = intraventricular hemorrhage.

viders.¹³ Given the economic and societal impact, stricter regulation enforcement is vital in LMICs.^{28,29}

Our dataset demonstrated significant associations between mean hemoglobin and hematocrit levels at presentation and higher mortality outcomes. This aligns with findings from Folweiler et al. in the Citicoline Brain Injury Treatment Trial (COBRIT), Transforming Research and Clinical Knowledge in Traumatic Brain Injury (TRACK-TBI) datasets, and with Griesdale et al. on predicting 6-month outcomes with hemoglobin levels.^{30,31} These re-

sults underscore the importance of baseline investigations to refine resuscitation protocols in LMICs, where access to blood transfusion may be limited.

Following the three delays framework by the Lancet Commission on Global Surgery, the second delay involves delays in reaching care, often due to regional shortages requiring patients to travel to facilities with surgical capacity. THJ is the only specialized neurosurgical care provider in the Northern Province, located in one of just two districts with CT scanners. The transfer process to THJ includes a phone consultation from a district hospital with the province's sole senior neurosurgical consultant, who receives patient status details verbally and via WhatsApp. This information is inconsistently documented and varies between referrals from senior and junior doctors. The senior neurosurgeon then determines whether a transfer is necessary. This delay is highlighted by the fact that 17% of referred patients with normal results on CT scans undergo conservative treatment in lower-acuity settings and are discharged after an average of 5 days, straining THJ resources that should focus on tertiary care. Delays in hospital arrival beyond 4 hours are associated with increased mortality rates in patients with TBI.³² Clavijo et al. emphasize that delays in transferring patients with TBI to specialized centers worsens outcomes.³³ Additionally, prehospital trauma care systems in LMICs remain underdeveloped and lack documentation.^{34,35} Analyzing referral data to THJ could optimize CT scanner placements, streamline referrals, reduce unnecessary transfers, and ensure timely access to care.³⁶

The third delay, characterized by delays in receiving care, occurs when in-hospital circumstances prevent immediate stabilization or treatment for the patient with TBI. Brain Trauma Foundation guidelines emphasize avoiding hypotension, hypoxia, managing raised ICP, and maintaining cerebral perfusion pressure.³⁷ Within our cohort, a worsening GCS score before initial intervention was a stronger mortality predictor than delays in receiving a neurosurgical opinion, CT scan report, or neurosurgical intervention. Despite administration of stabilization measures (ICP monitoring, prophylactic pharmacotherapy, supplemental oxygen), survival probability remained lower for these patients. Additionally, inadequate oxygen supplementation was identified in 7 patients with severe TBI, 3 of whom had a GCS score of 3. Limited resources led to ICP monitoring being the primary intervention for only 8 of 28 patients with severe TBI, with delays in 5 patients. Although these stabilizing factors significantly predict death in patients with severe TBI in LMICs,^{38,39} limited high-acuity-care resources, ICP monitoring, and specialized nursing capacities challenge adherence to these stabilization guidelines.³

Access to medical imaging for patients with TBI is limited by the availability of CT scanning facilities in the Northern Province, with scans showing severe TBI interpreted within 2 hours of admission, whereas mild TBI reports took > 12 hours. This demonstrates efficient triage prioritizing critically injured patients; however, a third delay occurs in neurosurgical intervention, with most surgeries happening > 2 hours postadmission, probably due to delayed CT scanning. Timely interventions within the

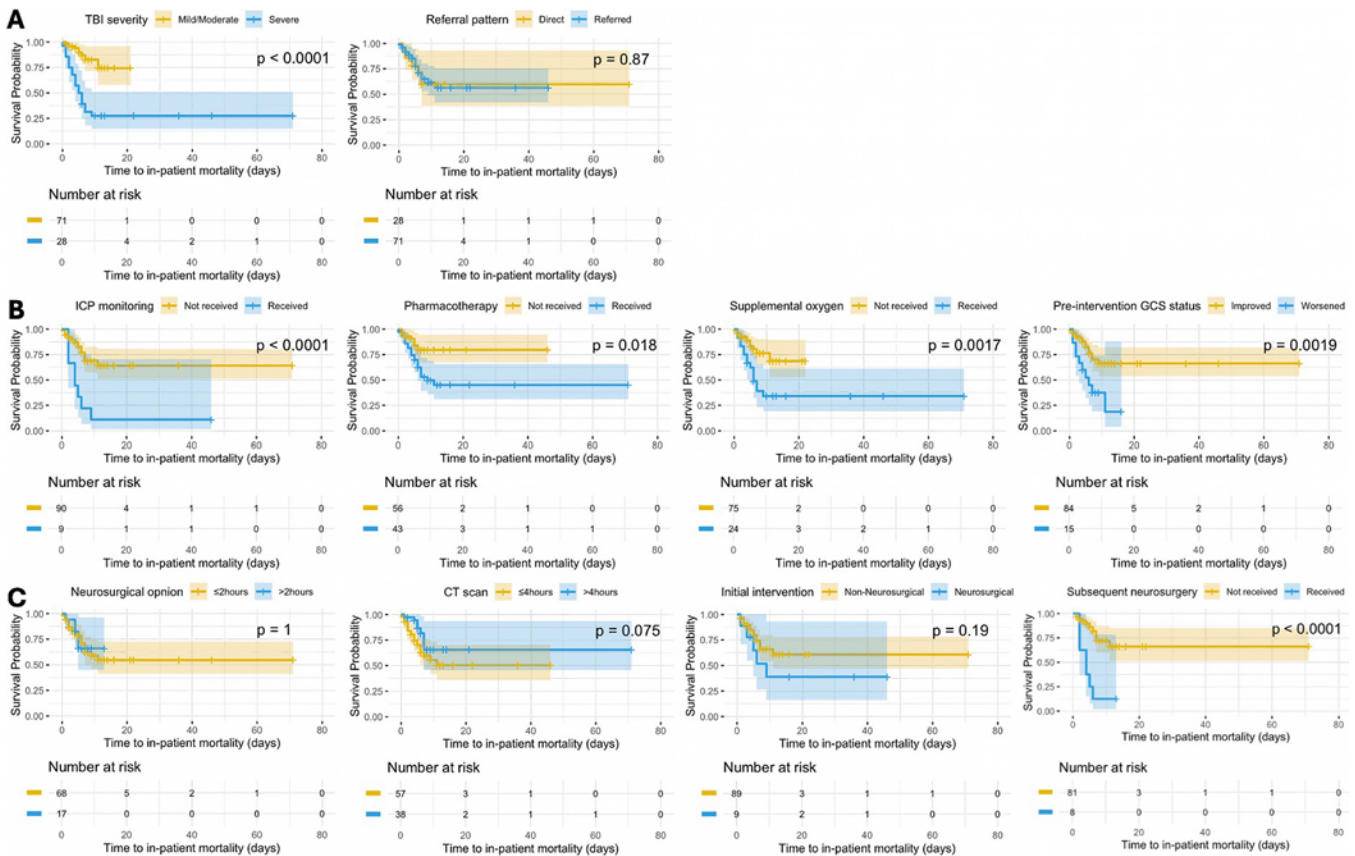


FIG. 3. Kaplan-Meier survival analysis of TBI cohorts. **A:** Survival analysis of patients with TBI across presenting TBI severities and referral patterns. **B:** Survival analysis of patients with TBI across presenting preintervention clinical characteristics. **C:** Survival analysis of patients with TBI across interventions and delays to care.

TABLE 3. Univariate and multivariate regression model for predictors of inpatient mortality outcomes

	Unadjusted OR (95% CI)	p Value	Adjusted OR (95% CI)*	p Value	HR (95% CI)	p Value
TBI severity; severe vs mild/moderate	17.2 (6.14 to 53.8)	<0.001	ND	ND	6.01 (2.73 to 13.2)	<0.001
Referral pattern; referred vs direct	1.05 (0.41 to 2.87)	0.921	0.71 (0.23 to 2.24)	0.564	0.93 (0.41 to 2.11)	0.900
Received prophylactic pharmacotherapy†	5.73 (2.27 to 15.7)	<0.001	1.84 (0.57 to 5.89)	0.317	2.60 (1.14 to 5.93)	0.023
Received oxygen supplementation	7.26 (2.71 to 20.7)	<0.001	0.5 (0.07 to 3.43)	0.465	3.07 (1.48 to 6.38)	0.003
Received ICP monitoring	26.3 (4.46 to >100)	0.003	10.0 (1.35 to 74.1)	0.016	4.80 (2.12 to 10.9)	<0.001
Deterioration in GCS score prior to initial intervention; Δ GCS ≥ 0 vs <0	6.84 (2.16 to 24.3)	0.002	9.87 (2.40 to 40.5)	0.001	3.19 (1.48 to 6.88)	0.003
Abnormal CT findings	29.2 (3.78 to >100)	<0.001	10.4 (0.57 to >100)	0.030	NE	>0.9
Initial neurosurgical intervention	3.46 (0.91 to 13.1)	0.069	0.82 (0.16 to 4.13)	0.814	1.88 (0.71 to 4.97)	0.200
Subsequent neurosurgical intervention following conservative management	28.44 (4.61 to >100)	0.002	21.6 (2.68 to >100)	0.011	6.08 (2.45 to 15.1)	<0.001
Neurosurgical opinion; >2 hrs	0.82 (0.24 to 2.49)	0.729	1.45 (0.39 to 5.35)	0.585	1.00 (0.38 to 2.65)	>0.9
CT scan; >4 hrs	0.36 (0.13 to 0.92)	0.040	0.60 (0.20 to 1.81)	0.362	0.47 (0.20 to 1.11)	0.085
Neurosurgical intervention; >2 hrs	3.00 (0.09 to 95.2)	0.511	1.67 (0.05 to 58.3)	0.773	0.82 (0.09 to 7.50)	0.900
Nonneurosurgical intervention; >4 hrs	0.34 (0.12 to 0.98)	0.049	0.58 (0.16 to 2.07)	0.417	0.38 (0.16 to 0.91)	0.029

ND = not done; NE = not evaluable.

Boldface type indicates statistical significance.

* Adjusted for TBI severity.

† Prophylactic pharmacotherapy includes administration of mannitol, phenytoin, and tranexamic acid.

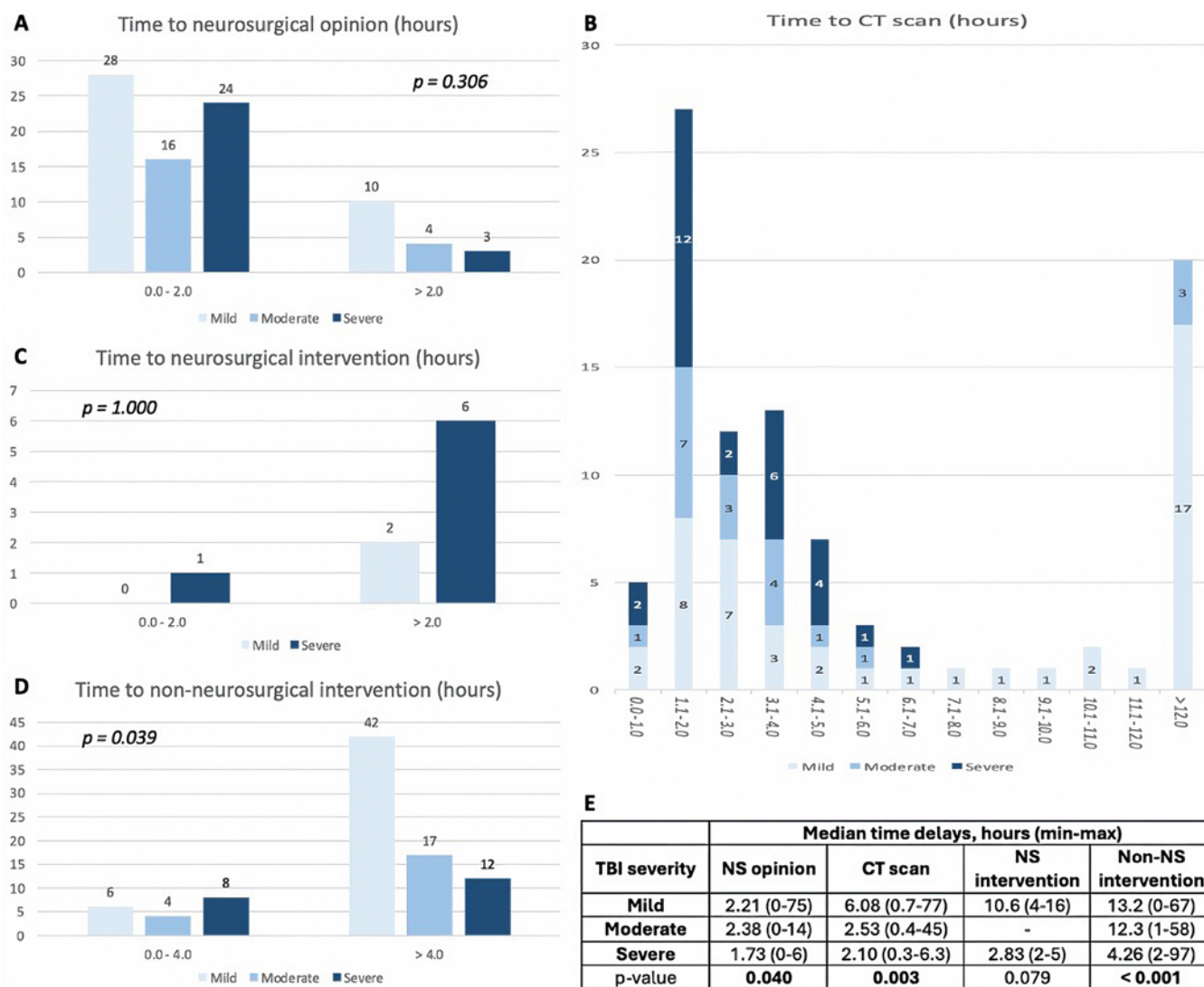


FIG. 4. Proportion of patients with mild, moderate, and severe TBI in each of the time delays to care. **A:** Time delay to neurosurgical opinion across TBI severities. **B:** Time delay to CT scan across TBI severities. **C:** Time delay to neurosurgical intervention across TBI severities. **D:** Time delay to nonneurosurgical intervention across TBI severities. **E:** Median time delays to care across TBI severities. NS = neurosurgical.

golden hour are essential in neurotrauma care to reduce death and long-term morbidity.^{11,40,41}

Appropriate monitoring is crucial in managing patients with TBI. Our study revealed that delays in neurosurgical interventions following initial medical management significantly predicted death. Aggressive monitoring of ICP and brain tissue oxygen tension in patients with severe TBI is associated with improved outcomes.^{42,43} Baseline investigations and advanced monitoring techniques facilitate early complication detection and inform personalized treatment, enhancing decision-making and patient care quality.^{44,45} Time-to-care data accessibility enables better resource allocation, including investments in standardized stabilization protocols and ICU resources, aiming to reduce third delays in resource-limited hospitals.^{5,46}

Prospective trauma registries are vital for developing guidelines suited to LMICs, facilitating quality im-

provement, severity scoring, injury prevention, resource allocation, and performance tracking of trauma care.⁴⁷ Predictive models from large cohorts forecast TBI outcomes, emphasizing the need for personalized strategies in LMICs.^{16,30,48} Current evidence-based treatment guidelines often lack applicable evidence for LMICs, because most research originates from high-income countries with fewer resource constraints.^{49,50} The compounded challenges of inadequate infrastructure, limited equipment, and shortages of skilled personnel in LMICs contribute to higher mortality rates.^{51,52} In low-resource settings, tools such as Research Electronic Data Capture (REDCap) improve data usability and integrate well with clinician workflow.^{32,53} In northern Sri Lanka, a pilot road traffic trauma registry demonstrated the effectiveness of a prospective electronic registry in identifying injury mechanisms and setting prevention priorities.¹³ Recognizing this

TABLE 4. Subgroup analysis of referred patients with TBI

	All Pts, n = 71 (%)	Discharged, n = 50 (%)	Died, n = 21 (%)	p Value
TBI severity				
Mild	33 (46.5)	32 (64)	1 (4.8)	<0.001
Moderate	16 (22.5)	11 (22)	5 (23.8)	
Severe	22 (31)	7 (14)	15 (71.4)	
CT findings	n = 70	n = 49	n = 21	
Not recorded*	1	1	0	
Abnormal†	57 (81.4)	36 (73.5)	21 (100)	0.007
Initial intervention	n = 70	n = 50	n = 21	
Death before intervention	1	0	1	
Nonneurosurgical management‡	61 (87.1)	46 (92)	15 (75)	0.107
Neurosurgery	9 (12.9)	4 (8)	5 (25)	
Conservative management	n = 53	n = 38	n = 15	
General surgery ward	22 (41.5)	19 (50)	3 (20)	0.065
High-acuity care (HDU, ICU, NSU)	31 (58.5)	19 (50)	12 (80)	
Subsequent neurosurgical intervention performed	5 (9.4)	1 (2.6)	4 (26.7)	

HDU = high-dependency unit; ICU = intensive care unit; NSU = neurosurgical unit.

Boldface type indicates statistical significance.

* Variable category not included in statistical analysis.

† Includes extradural hemorrhage, SDH, intraventricular hemorrhage, SAH, contusion, midline shift, skull fracture, pneumocephalus, and suspected diffuse axonal injury.

‡ Nonneurosurgical management includes conservative management, wound management, and nonneurosurgical operative procedures.

gap, findings from this study are being used to establish a prospective neurotrauma registry in the THJ to improve TBI care in the Northern Province.

Our retrospective study has several limitations. Prioritizing patients with moderate to severe TBI may underrepresent mild cases due to exclusions and potential prehospital fatalities among patients with severe TBI. The relatively low total TBI numbers may also reflect the reduced trauma load during the study period, coinciding with COVID-19 public health restrictions. The lack of a formal TBI registry and reliance on primary diagnoses, along with potential miscoding of ICD-10-CM codes, limit generalizability. Paper-based records lead to inconsistent documentation, affecting the completeness of patient findings, CT reports, and procedures. Additionally, the unavailability of records for 32% of patients reduces robustness, and the absence of standardized patient identification and follow-up data leaves postdischarge mortality rates unknown. Addressing these issues through our ongoing prospective TBI registry is crucial for generating more robust data to inform resource-directed local guidelines and optimize patient management.

Conclusions

Our study revealed the impact of second delays in underdeveloped referral pathways and third delays in the stabilization and initial management of patients with TBI. Establishing a prospective neurotrauma registry is crucial for collecting context-specific data on baseline investigations and delay factors, with the goal of refining transfer and resuscitation protocols, reducing neurologi-

cal morbidity, mortality, and the economic impact of TBI in resource-limited settings.

Acknowledgments

We extend special appreciation for the invaluable assistance of Dr. T. Sathiyamoorthy (Director of Teaching Hospital Jaffna) and the administrative team at the medical records office for their on-site expertise, guidance, and support in facilitating the necessary resources throughout various stages of the study. Funding was provided to Shereen X. Y. Soon by SingHealth Duke-NUS Global Health Institute and the SingHealth Foundation.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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