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The burden of head trauma in rural and remote North Queensland, Australia

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ABSTRACT

Background: Head trauma is a leading cause of death and disability worldwide. Young males, Indigenous people, and rural/remote residents have been identified as high-risk populations for head trauma, however, Australian research is limited. Our aim was to define and describe the incidence, demographics, causes, prehospital interventions, and outcomes of head trauma patients transported by aeromedical services within North Queensland, Australia. We hypothesized that young, Indigenous males living remotely would be disproportionately affected by head trauma.

Methods: We conducted a retrospective study of all head trauma patients transferred by air to or between Townsville, Cairns, Mount Isa and Mackay Hospitals between January 1, 2016 and December 31, 2018. Patients were identified from the Trauma Care in the Tropics data registry and followed for a median 30-months post-injury. Primary endpoints were patient and injury characteristics. Secondary outcome measures were hospital stay and mortality.

Results: A total of 981 patients were included and 31.1 % were Indigenous. Sixty-seven percent of injuries occurred remotely and the median time from injury to hospital was 5.8-hours (range 67–3780 min). Eighty percent of severe head injuries occurred in males ($p = 0.007$). Indigenous and remote patients were more likely to sustain mild injuries. The most common mechanism of injury overall was vehicle accident (37.5 %), compared to assault in the Indigenous subgroup (46.6 %, $p<0.001$). The overall mortality rate was 4.9 %, with older age and lower initial Glasgow Coma Score significant predictors of in-hospital mortality. Prehospital intubation was associated with a 7-fold increased risk of mortality ($p = 0.056$), while patients that received tranexamic acid (TXA) were almost 5-times more likely to die.

Conclusions: In North Queensland, young Indigenous males are at highest risk of traumatic head injuries. Vehicle accidents are an important preventable cause of head injury in the region. TXA administration is an important consideration for remote head trauma retrievals, in which time to emergency care is prolonged. Appropriate treatment and risk stratification strategies considering time to definitive care, severity of injury, and other prehospital patient factors require further investigation.

Introduction

Head trauma, defined as penetrating or non-penetrating injury to the brain, skull, or scalp, is a leading cause of preventable death and disability worldwide [1–3]. Patients with traumatic head injuries face the risk of permanent disability, cognitive impairment, and psychiatric disturbance, all of which incur significant impact on quality of life, family support and health care systems [4–7]. Young males and Indigenous people have previously been identified as higher-risk populations [1,8]. In Australia, the reported incidence of head trauma among Aboriginal and/or Torres Strait Islander peoples is nearly double that of non-Indigenous people, and similar findings have been recorded in other Indigenous populations in Asia/Pacific and North America, however thorough investigation as to why, is lacking [1,8-10].

The burden of traumatic head injury is also disproportionately higher in rural and remote areas, with poorer outcomes linked to longer

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prehospital times and inefficiencies during the continuum-of-care [11]. A recent systematic review and meta-analysis of 36 studies comprising approximately 2.5 million global head trauma patients identified that both the incidence and severity of head trauma was significantly higher in rural settings, with rural patients being 28 % more likely to suffer severe injury, and have worse outcomes [8]. This review also identified a number of variables including prehospital and follow-up patient data, that are often overlooked but necessary to fully understand the burden of head trauma within any given population [8].

Unfortunately, population-based head trauma in Australia research is fairly limited, despite head injuries being the most common injury requiring medical transfer [12,13]. The North Queensland region of Australia covers an area of 881,274 km^2 (340,295 square miles) with a predominantly rural and remote geography. The Indigenous population comprises more than 10 % of the dispersed population of >730,000 residents (compared to 3.3 % overall in Australia) [14]. Understanding the burden of head trauma in this region is vital to optimise prehospital care and improve head trauma outcomes. The major aim of this multi-centre retrospective descriptive study was to define and describe the incidence, demographics, causes and outcomes of head trauma transported by aeromedical emergency services within North Queensland. We hypothesized that young, Indigenous males living remotely would be disproportionately affected by head trauma. Secondary aims of the study were to (i) determine the nature and frequency of clinical interventions in the prehospital environment; (ii) compare patient characteristics and outcomes between remote and non-remote areas of North Queensland; and (iii) determine factors associated with morbidity and mortality, which may be implemented in future care pathways.

Materials and methods

Ethical considerations

The study was approved by the Townsville Hospital and Health Service (THHS) Human Research Ethics Committee (HREC) (HREC/2018/QTHS/43810) and James Cook University HREC (H7614). A waiver of consent was granted in accordance with Australia's National Statement on Ethical Conduct in Human Research (NHMRC, 2018) Section 2.3.10 that the study was retrospectively analysing previously collected data and constituted negligible risk to participants who had already received standard-of-care. The study was also reviewed and supported by THHS Aboriginal and Torres Strait Islander Health Leadership Advisory Council (ATSIHLAC), and complied with Australia's National Statement on Ethical Conduct in Research with Aboriginal and Torres Strait Islander Peoples and Communities (NHMRC, 2018).

Study population, service area and hospitals

The study included head trauma patients (including polytrauma patients with concomitant injuries in other body regions) of all ages transferred by air to or between Townsville University Hospital, Cairns Hospital, Mount Isa Hospital and Mackay Base Hospital by LifeFlight Retrieval Medicine or Royal Flying Doctor Service (RFDS) between January 1, 2016 and December 31, 2018. Patients transferred for other traumatic injuries not involving the head were excluded from the study.

Townsville University Hospital (TUH) (791-bed) is the only tertiary referral centre in North Queensland, and importantly, the only hospital with neurosurgical capability, to service an area of 881,274 km^2 (340,295 square miles) with a geographically-dispersed population of >730,000 residents. The North Queensland population is also supported by Cairns Hospital (721-bed), Mount Isa Hospital (80-bed) and Mackay Base Hospital (251-bed) which provide moderate-risk ambulatory care clinical services. Depending on injury location, head trauma patients may be transferred initially by road to one of ten small district hospitals, five rural hospitals, or ten rural multipurpose health services providing low-risk ambulatory care clinical services, or one of 34 community clinics (primary health care centres) prior to aeromedical retrieval. The Queensland Ambulance Service (QAS) provides the prehospital road ambulance service from 302 locations in Queensland, with approximately 75 of those based in North Queensland. These ambulances are predominantly staffed by qualified paramedics, with rural and remote locations also utilising volunteer first responders. The vast size of Queensland necessitates the use of aeromedical services for both rural and remote prehospital care and longer distance interfacility transfers. Coordinated and governed by Retrieval Services Queensland (RSQ), a dedicated and specialised network of 13 helicopter- and 7 aeroplane-bases across Queensland seeks to provide timely access to critical care services. This fleet is staffed 24/7 with a combination of critical care-trained doctors, nurses and/or paramedics.

Data collection

The Trauma Care in the Tropics de-identified dataset was used in this study. This dataset includes all trauma patients transferred by air between North Queensland hospitals from January 1, 2016 and December 31, 2018, and was compiled from multiple sources including the Retrieval Services Queensland (RSQ) patient database, clinical coordination and patient assessment forms; Queensland Health (QH) Clinical Coordination Retrieval Information System (CCRIS) database; Queensland Neonatal, paediatric and high risk obstetric Emergency Transfer Service (QNETS) database; Queensland Ambulance Service (QAS) Case Reports; Royal Flying Doctor Service (RFDS) Aeromedical Transfer records (ATR), Telehealth Consultation Records (TCR), observation sheets, and Aviation Flight Records (AFR); and LifeFlight Retrieval Medicine Air Maestro electronic database and patient records.

The Trauma Care in the Tropics patient cohort was identified using both ICD-10 classifications, and searches of free text fields for multiple terms including: head; brain; trauma; injury; injuries; accident; MVC; MBA; ATV; assault; and fall. The patient cohort and prehospital aeromedical data was linked by QH Data Linkage Group (DLG) to the Queensland Health Admitted Patient Data Collection (QHAPDC) and Emergency Data Collection (EDC) for hospital data, and Queensland Registry of Births, Deaths and Marriages for mortality data. The median follow-up time was 886 days (29.5 months), with a range of 367 to 1663 days.

Data variables

The following de-identified data variables were collected for each patient: Patient demographics (age, gender, Aboriginal and/or Torres Strait Islander status, home residence, Socioeconomic Indexes for Areas [SEIFA]) [15]; medical history (previous trauma, comorbidities); date and time of injury and retrieval; location of injury and retrieval point; mechanism of injury (MOI); head injury severity (see definition below); clinical notes (including injury description, details of helmet, protective gear and seatbelt use, and alcohol/substance use); prehospital and in-hospital physiological parameters; clinical interventions (fluid and blood product administration, intubation and oxygen delivery); and outcomes (mortality, duration of cardiovascular support [CVS; mechanical ventilation], Intensive Care Unit [ICU] admission, and ICU and hospital length of stay [LOS]).

Home residence, and injury and retrieval locations were categorized as inner regional, outer regional, remote, or very remote, using Area of Remoteness Index of Australia (ARIA+) codes [16]. Remoteness and population size were also measured using the Modified Monash Model (MMM) on a scale of MM1 (major city) to MM7 (very remote) [17]. The relative level of socio-economic status of each area was determined from the SEIFA score which assesses income, education, employment, occupation, housing and family structure [15]. Head injury severity was classified as mild, moderate, or severe using the following definitions: mild, Glasgow Coma Scale (GCS)>13 and/or post-traumatic amnesia (PTA) duration <24 h, and/or loss of consciousness (LOC) <30 min;

moderate, GCS 8–13, and/or PTA >24hr-<14d, and/or LOC 30min-24 h; and severe, GCS<8, and/or PTA >14d, and/or LOC >24 h [18,19]. PTA is defined as acute cognitive impairment including confusion, disorientation, behavioural disturbance, and memory deficits, assessed using the Westmead Post-Traumatic Amnesia Scale (WPTAS) [20,21].

Statistical analysis

SPSS Statistics 27.0 software package was used for all data analysis (IBM, Armonk, NY), with $p<0.05$ considered statistically significant. Categorical variables have been presented as frequency and percentages. The central tendency and dispersion of continuous variables are presented as mean and standard deviation for normal (parametric) data or median and interquartile range (IQR) for non-parametric data. Data normality was assessed using Shapiro-Wilks test. Subgroup analyses were performed of paediatric (<16 years) versus adult patients; isolated head injury versus polytrauma patients; Indigenous versus non-Indigenous patients; remote (ARIA+ remote or very remote or MM6–7) and non-remote (ARIA+ inner regional or outer regional or MM1–5) patients; and mild, moderate, and severe head trauma. Categorical variables were compared using the Chi-square test, with Mann-Whitney U or Kruskal Wallis test for nonparametric variables, and one-way ANOVA for parametric variables. Mortality (30-day, all-cause, and primary injury mortality) were assessed by Kaplan Meier survival analysis with a log rank (Mantel-Cox) test for between-group differences. Cox regression analysis was used to determine predictors of mortality, adjusted for age and head injury severity, and presented as hazard ratios (HR) with 95 % confidence intervals (CI). Multinomial logistic regression analysis was used to determine odds ratios (OR) and 95 % CI of hospital separation mode (discharge destination), also adjusted for head injury severity.

Results

Demographics and medical history

The mean age for head trauma was 35.4 years, with the youngest patient being 1 month and the eldest, 93 years old (Table 1). Males, Indigenous Australians, and those residing in very remote regions, were overrepresented compared to their population size (69.4 %, 31.1 %, and 42.6 %, respectively) (Table 1). Nearly half of the paediatric patient cohort were Indigenous, compared to 29.4 % of adults ($p<0.001$) (**Supplementary Table 1**). Approximately 14 % of patients had a previous traumatic injury, with 4.1 % having a previous head injury (Table 1).

Injury characteristics

More than three quarters of traumatic head injuries were mild, which is consistent with a median first recorded GCS of 13.14, whereas ~18 % were severe (Table 1). Almost 80 % of severe head injuries occurred in males ($p = 0.007$) (**Supplementary Table 2**). Two thirds of traumatic head injuries occurred in the setting of polytrauma (Table 1). Isolated head trauma was more likely in males and paediatric patients ($p = 0.029$ and $p<0.0001$, respectively), as well as those with a previous head injury ($p = 0.004$) (**Supplementary Table 1, Supplementary Table 3**).

Mechanisms of injury and injury location

The most common mechanism of injury, particularly severe injury and polytrauma, was vehicle accident (37.5 %), half of which involved cars, and almost a quarter, motorbikes (Fig. 1**AB, Supplementary Table 2, Supplementary Table 3**). Twenty-two percent of patients were not wearing a helmet, and 23 % were unrestrained at the time of their injury (Table 1, Fig. 1A). Falls were responsible for a quarter of head traumas, the majority of which were mechanical falls, i.e., slips and

Table 1
Demographics, medical history, injury and clinical characteristics for whole cohort.

Data Category	Parameter	Frequency (%) / Median (IQR)	p value *
Demographics	Sex	Male: 681 (69.4%) Female: 300 (30.6%)	<0.001
	Age (years)^	35.40 (19.95); Range: 0.11-93	
	Age Group	Paediatric: 121 (12.8%) Adult: 851 (86.2%) (Geriatric: 94 (9.7%))	<0.001
	Indigenous Status	Indigenous: 305 (31.1%) Non-Indigenous: 657 (67.0%) Unknown: 19 (1.9%)	<0.001
	Home ARIA Score	7.58 (8.13)	
	Home ARIA Category		<0.001
	• Major City	30 (3.5%)	
	• Inner Regional	48 (5.6%)	
	• Outer Regional	279 (32.6%)	
	• Remote	134 (15.7%)	
	• Very Remote	365 (42.6%)	
	SEIFA		<0.001
	• 1	369 (42.5%)	
	• 2	146 (16.8%)	
	• 3	148 (17.1%)	
	• 4	85 (9.8%)	
	• 5	44 (5.1%)	
	• 6	20 (2.3%)	
	• 7	9 (1.0%)	
	• 8	29 (3.3%)	
	• 9	9 (1.0%)	
	• 10	9 (1.0%)	
Medical History	Diabetes	48 (4.9%)	<0.001
	Hyperlipidaemia	41 (4.2%)	<0.001
	Hypertension	109 (11.1%)	<0.001
	Heart Disease	71 (7.2%)	<0.001
	Renal Disease	17 (1.7%)	<0.001
	Epilepsy/Seizure	22 (2.2%)	<0.001
	Neurological Disease	9 (0.9%)	<0.001
	Smoking	83 (8.5%)	<0.001
	Alcohol Abuse	93 (9.5%)	<0.001
	Substance Use	37 (3.8%)	<0.001
	Mental/Behavioural	84 (8.6%)	<0.001
	• Depression	46 (4.7%)	<0.001
	• Anxiety	11 (1.1%)	<0.001
	• Bipolar Disease	6 (0.6%)	<0.001
	• Dementia	4 (0.4%)	<0.001
	• Schizophrenia	5 (0.5%)	<0.001
	• PTSD	2 (0.2%)	<0.001
	• Psychosis	5 (0.5%)	<0.001
	• Self-Harm	5 (0.5%)	<0.001
	• Behavioural Disorder	6 (0.6%)	<0.001
	• Suicidal Ideation	11 (1.1%)	<0.001
	Previous Injury	132 (13.5%)	<0.001
	Previous Head Trauma	40 (4.1%)	<0.001
Injury Characteristics	Remote	652 (66.7%)	<0.001
	Injury ARIA Score	9.17 (7.44)	
	Injury ARIA Category		
	• Major City	2 (0.2%)	
	• Inner regional	29 (3.0%)	
	• Outer Regional	293 (30.0%)	
	• Remote	190 (19.4%)	
	• Very Remote	463 (47.4%)	
	Injury MMM		<0.001
	• 1	2 (0.2%)	
	• 2	62 (6.3%)	
	• 3	1 (0.1%)	
	• 4	148 (15.1%)	
	• 5	113 (11.6%)	
	• 6	133 (13.6%)	
	• 7	518 (53.0%)	

(*continued on next page*)

Table 1 (*continued*)

Data Category	Parameter	Frequency (%) / Median (IQR)	p value *
	Alcohol or Drug Involvement	252 (25.7%)	<0.001
	Self-Harm	19 (1.9%)	<0.001
	Home Accident	136 (15.5%)	<0.001
	Work Accident	124 (16.5%)	<0.001
	Farm Accident	140 (17.5%)	<0.001
	Mining Accident	19 (1.9%)	<0.001
	Sports Accident	35 (3.6%)	<0.001
	Recreational Accident	56 (5.7%)	<0.001
	Helmet use#	No: 42 (21.8%) Yes: 11 (5.7%) NR: 140 (72.5%)	<0.001
Clinical Measures	HI Severity		
	• Mild	746 (76.1%)	
	• Moderate	60 (6.1%)	
	• Severe	174 (17.8%)	
	Polytrauma	651 (66.4%)	<0.001
	Initial GCS^	13.14 (3.53)	
	Consciousness Score		<0.001
	• Alert	866 (73.4%)	
	• New Confusion/ Agitation	61 (6.5%)	
	• Responds to Voice	59 (6.3%)	
	• Responds to Pain	33 (3.5%)	
	• Unresponsive	96 (10.2%)	
	LOC	507 (54.2%)	0.010
	• LOC Duration		<0.001
	• Brief (<30min)	179 (36.6%)	
	• Moderate (30min-24h)	20 (4.1%)	
	• Prolonged (>24h), with return	4 (0.8%)	
	• Prolonged (>24h), no return	8 (1.6%)	
	Hypotension	76 (8.0%)	<0.001
	Tachycardia	264 (27.1%)	<0.001
	Headache	90 (10.1%)	<0.001
	Dizziness	26 (2.9%)	<0.001
	Confusion	63 (6.4%)	<0.001
	Drowsiness	21 (2.1%)	<0.001
	Agitation	49 (5.0%)	<0.001
	Nausea/Vomiting	171 (19.3%)	<0.001
	Amnesia	192 (21.5%)	<0.001
	• Amnesia Time		<0.001
	• <24h	10 (5.6%)	
	• >24h-<14d	55 (30.7%)	
	• >14d	21 (11.7%)	
	• Unknown	92 (51.4%)	
	ICH	127 (14.6%)	<0.001
	• SAH	74 (8.5%)	<0.001
	• SDH	92 (10.6%)	<0.001
	• EDH	18 (2.1%)	<0.001
	Cerebral Oedema	26 (3.0%)	<0.001
	Skull/Facial Bone Fracture	192 (22.1%)	<0.001
	• BOS	95 (10.9%)	<0.001
	• Vault of Skull	45 (5.2%)	<0.001
	• Nasal Bones	52 (6.0%)	<0.001
	• Orbital Floor	37 (4.3%	<0.001
	• Malar/Maxillary	65 (7.5%)	<0.001

Data presented as frequency (%) or median (IQR) except where indicated.

^ mean (standard deviation).

* Chi-square test assessing difference between presence and absence of categorical variable.

\# Applies to motorbike and horse-riding accidents. IQR, Interquartile Range; ARIA, Accessibility and Remoteness Index of Australia; SEIFA, Socio-Economic Indexes for Areas; PTSD, Post-Traumatic Stress Disorder; MMM, Modified Monash Model; HI, Head Injury; GCS, Glasgow Coma Scale; LOC, Loss of Consciousness; ICH, Intracranial Haemorrhage; SAH, Subarachnoid Haemorrhage; SDH, Subdural Haemorrhage; EDH, Epidural Haemorrhage; BOS, Base of Skull.

trips. Horse falls were another common mechanism of injury in adult patients (23.6 %), and also significantly more likely to cause polytrauma (31 %, $p<0.05$) (Fig. 1**C, Supplementary Table 1, Supplementary Table 3**).

After vehicle accidents and falls, assaults were another significant cause of head trauma, comprising 21 % of all injuries. Of these, 28 % were due to domestic violence (DV) (Fig. 1**A**). Assaults were more likely to result in mild isolated head trauma (**Supplementary Table 2, Supplementary Table 3**). Assault-related head trauma was significantly higher in the adult cohort (22.9 % vs 6.6 %, $p<0.001$), however, alarmingly, the rate of paediatric head trauma from DV assaults was more double that of adults (62.5 % vs 27.2 %, $p = 0.044$) (**Supplementary Table 1**). A quarter of all head traumas involved alcohol or drug use, and ~2 % resulted from self-harm (Table 1).

Approximately two-thirds of traumatic head injuries in North Queensland requiring aeromedical retrieval occurred in a remote or very remote area (Table 1). The median time from injury to hospital was 349 min and ranged from 67 to 3780 min (Table 2). Eighteen percent of injuries occurred on farms, and 2 % were mining accidents.

Clinical characteristics

Approximately half of head trauma patients experienced a period of loss of consciousness (LOC), however a majority were alert on first responder arrival, with only 10.2 % unresponsive (Table 1). After LOC, the most common prehospital observation was tachycardia (27.1 %), followed by nausea and vomiting (19.3 %), headache (10.1 %), and hypotension (8.0 %) (Table 1). Hypotension and tachycardia were significantly more likely in severely injured patients ($p<0.001$) (**Supplementary Table 2**). Post-traumatic amnesia (PTA) was reported in 21.5 % patients, with approximately one-third experiencing PTA lasting longer than one day, and 11.7 % more than 14 days. There was a positive correlation between head injury severity and PTA, with 28.2 % of severely injured patients experiencing PTA (Table 1, **Supplementary Table 2**).

Intracranial haemorrhage (ICH) occurred in 14.6 % of all head injuries, with subdural haemorrhage the most common (10.6 %), and more severe injury increasing the likelihood of haemorrhage (Table 1, **Supplementary Table 2**). Approximately one in five traumatic head injuries involved a skull and/or facial fracture (Table 1), and these were significantly more likely in severely injured and adult patients (39.0 % and 23.3 %, respectively) (**Supplementary Table 1, Supplementary Table 2**).

Prehospital interventions

Fifteen percent of patients were intubated prior to hospital arrival, and almost one-half received supplemental oxygen, most commonly delivered via nasal prongs (Table 2). Hypertonic saline was administered in the prehospital environment to 2.8 % of patients, while tranexamic acid (TXA) and blood products were given to 3.9 % and 4.1 % of patients, respectively (Table 2). Isotonic fluids (median volume 1 L) were administered to almost 40 % of all patients, more commonly in adults than paediatric patients (42.0 % vs 16.5 %, $p<0.001$) (**Supplementary Table 1**).

Mortality and other outcomes

The all-cause mortality rate for this traumatic head injury cohort was 4.9 %, with a median time to mortality of 19 days (Table 2). Twenty-seven patients were deceased on arrival of aeromedical services and not included in further analysis due to missing information on patient and injury characteristics. Of the 48 analysed deaths, 27 (56.3 %) were due to the primary injury, with 93 % occurring within 30 days of injury (Table 2). Compared to mild (2.5 %) and moderate (3.3 %) head injuries, severe head trauma had a significantly higher mortality rate (15.5 %,

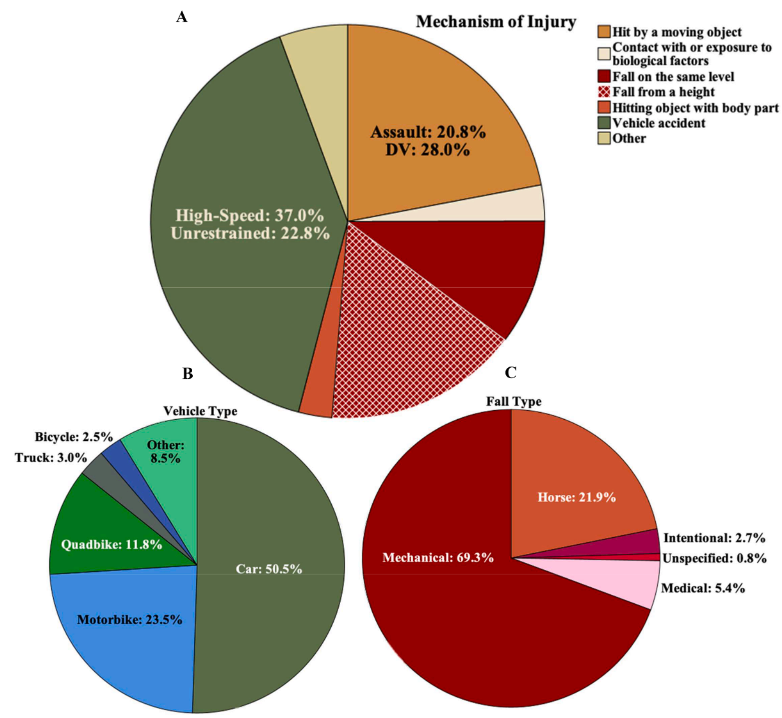

Fig. 1. (A) Mechanism of injury for whole patient cohort ($p<0.001$). Other mechanisms of injury include contact with or exposure to heat or cold, exposure to variations in pressure, other muscular stress, repetitive movement with low muscle loading, single contact with chemical or substance, stabbing or gunshot, submersion injuries, and multiple and unknown mechanisms of injury. DV, Domestic Violence. (B) Vehicle types involved in head trauma-related vehicle accidents (Chi-square test of frequency distribution: $p<0.001$). Other vehicle types include armoured vehicle, boat, train, plane, helicopter, bus, scooter, buggy, go-kart, tractor, bobcat and forklift. (C) Fall type (Chi-square test of frequency distribution: $p<0.001$).

$p<0.001$) (**Supplementary Table 2**), and significantly shorter median survival time (5 days; $p = 0.004$) (Fig 2**A**). There were no paediatric mortalities, and no difference in mortality between polytraumatized and isolated head injury patients (**Supplementary Table 1, Supplementary Table 3**). Patients that were intubated prior to hospital admission were over 7-fold more likely to die than those who were not intubated ($p = 0.056$), while those that received TXA were almost 5 times more likely to die (Table 3).

The mean length of stay (LOS) in hospital was 6.4 days. Eighteen percent of all head trauma patients were admitted to ICU, with a median LOS of ~92 h (Table 2). A significant majority of patients were discharged to their home or usual residence, with 4.9 % transferred to another hospital or care facility. With every increased year of age, head trauma patients were 2.8 % more likely to die in hospital than to be discharged home or to their usual residence ($p = 0.020$), while for every unit decrease in initial GCS score, the odds of in-hospital mortality were 22.7 % higher than home discharge ($p = 0.038$) (Table 4).

Remote vs non-remote patients

Remote traumatic head injury patients were significantly more likely to be younger and Indigenous males (Table 5; Fig. 3**A**). Remote patients were also more likely to have had a previous traumatic injury, including previous head trauma ($p<0.001$) (Table 5). Over half of non-remote head injuries occurred due to a vehicle accident, compared to 35 % of remote injuries ($p<0.001$) (Table 5). However, almost half of remote vehicle accidents were high-speed, compared to 23.8 % in non-remote areas ($p<0.001$). Compared to their non-remote counterparts, the incidence of remote assault-related head trauma, including domestic violence assaults, was significantly higher ($p<0.01$) (Table 5). Overall, patients from remote areas were more likely to have milder injuries, and therefore higher initial GCS scores, as well as fewer episodes of LOC, hypotension, and tachycardia.

The median time to hospital was 6.65 h for remote patients compared to 4.25 h for non-remote patients ($p<0.001$). Remote patients had a shorter hospital stay (4 vs 11 days, $p<0.001$), and were 11 % less likely to die in hospital ($p<0.05$) (Table 5). As demonstrated in Fig. 2**B**, for 30-day mortality, the median survival time was 9 days for remote patients compared to 4 days for non-remote patients ($p = 0.038$).

Indigenous vs non-Indigenous patients

Indigenous patients were approximately 10 years younger than non-Indigenous patients at the time of injury ($p<0.001$) (Table 6). The incidence of head trauma was significantly higher in Indigenous children aged 10–14 years and adults 30–34 years (Fig. 3**B**). Although males were overrepresented in both Indigenous and non-Indigenous populations, significantly more Indigenous females suffered head trauma (36.7 % vs 28.2 %, $p = 0.007$) (Table 6). The rate of behavioural disorders was eight times higher and suicidal ideation four times higher in the Indigenous cohort, and they were also significantly more likely to have been previously injured and have acquired a previous head injury than non-Indigenous patients ($p<0.001$) (Table 6).

Indigenous patients had different mechanisms of head injury compared to non-Indigenous patients (Table 6). The commonest cause of injury in Indigenous patients was being hit by a moving object (43.6 %, $p<0.05$), followed by vehicle accidents (23.3 %, $p<0.05$). Conversely, for non-Indigenous patients, the commonest cause of injury was vehicle accidents (48.4 %), with being hit by a moving object accounting for only 12.0 % of all injuries (Table 6). Assault was a significant cause of head trauma in the Indigenous population, accounting for 46.6 % of head injuries, 36.9 % of which were reported as domestic violence (DV) ($p<0.001$ vs non-Indigenous cohort) (Table 6). Mild head injuries were more common in Indigenous patients (82.0 % vs 73.2 % in non-Indigenous patients; $p<0.05$). Consistent with more mild injuries, Indigenous patients had shorter hospital stays (4 vs 8 days; $p<0.001$), and were more likely to be discharged home (95.2 % vs 90.7 %, $p<0.005$). In-hospital deaths and all-cause mortality were significantly

Table 2
Prehospital interventions and outcomes for all head trauma patients.

Data Category	Parameter	Frequency (%) / Median (IQR)	p value*
Pre-Hospital Interventions	Intubation	151 (15.4%)	<0.001
	Oxygen Delivery		<0.001
	• Room Air	418 (51.2%)	
	• Nasal Prongs	206 (25.2%)	
	• Hudson Mask	37 (4.5%)	
	• Non-Rebreather	5 (0.6%)	
	• Intubated + Ventilated	151 (18.5%)	
	Isotonic Fluids	381 (38.8%)	
	• Fluid Volume (mL)	1000 (1150), Range: 50-6500	
	Hypertonic Saline <0.001	27 (2.8%)	
	• Volume (mL)	250 (250), Range: 100-1500	
	Mannitol	5 (0.5%)	<0.001
	• Volume (mL)^	538 (350)	
	Blood Products	40 (4.1%)	40 (4.1%)
	• Total Blood Units^	0.7 (4.8), Range: 0-73	0.7 (4.8), Range: 0-73
	• PRBC	38 (3.9%)	38 (3.9%)
	○ Units^	2.4 (4.0)	2.4 (4.0)
	• FFP	2 (0.2%)	2 (0.2%)
	○ Units^	9 (8.5)	9 (8.5)
	• Platelets	2 (0.2%)	2 (0.2%)
	○ Units^	3.5 (3.5)	3.5 (3.5)
	• Cryoprecipitate	4 (0.4%)	4 (0.4%)
	○ Units^	14.5 (10.9)	
	Fibrinogen	4 (0.4%)	<0.001
	○ Dose (g)^	4.3 (2.6)	
	TXA	38 (3.9%)	<0.001
	○ Dose (g)^	1.1 (3.0)	
	Time to Hospital (min)	349 (306), Range: 67-3780	
Hospital Outcomes	Hospital LOS (days)^	6.4 (15.3), Range: 0-376	
	ICU Admission	171 (18.0%)	<0.001
	ICU LOS (min)	5547 (9062)	
	Mechanical Ventilation	152 (15.9%)	<0.001
	Ventilation Time (min)	4320 (8271)	
	Separation Mode		<0.001
	• Home/Usual Residence	871 (92.2%)	
	• Transferred to Another Hospital	40 (4.2%)	
	• Care Type Change	7 (0.7%)	
	• Died in Hospital	25 (2.6%)	
	• Other	2 (0.2%)	
Mortality	All-Cause Mortality	48 (4.9%)	<0.001
	• Time (days)	19 (551), Range: 0-1197	
	Mortality due to Primary Injury	27 (56.3%)	0.386
	Time (days)	5 (6), Range: 0-281	
	30-Day Mortality	25 (52.1%)	0.773
	• Time (days)	4 (6), Range: 0-24	

Data presented as frequency (%) or median (IQR) except where indicated.
^ mean (standard deviation).
* Chi-square test assessing difference between presence and absence of categorical variable. IQR, Interquartile Range; PRBC, Packed Red Blood Cells; FFP, Fresh Frozen Plasma; TXA, Tranexamic Acid; LOS Length of Stay; ICU, Intensive Care Unit.

lower (0.7 % vs 3.6 %, $p<0.05$ and 3.0 % vs 5.9 %, $p = 0.031$, respectively) (Table 6).

Discussion

Head trauma is associated with significant risk of mortality and morbidity [1–3], and a rapid response time with evidence-based, prehospital care is paramount for survival and good recovery. Compared to urban communities, rural and remote regions of Australia offer a significant challenge to healthcare systems because of the vast distances and high incidences of trauma [11]. However, little is known on the burden of head trauma in North Queensland. The present multicentre retrospective descriptive study addresses this knowledge gap by describing the incidence, demographics, causes and outcomes of head trauma patients transported by aeromedical retrieval services in this region. The key findings were the following: (i) head trauma was significantly more likely in young Indigenous males from remote areas; (ii) a majority of the remote traumatic head injuries were mild; (iii) vehicle accidents were the commonest cause of head injury; (iv) higher rates of assault-related head trauma were identified in remote, paediatric and Indigenous patients; (v) predictors of in-hospital mortality were older age and lower initial GCS; and (vi) TXA administration in the prehospital environment was significantly associated with all-cause mortality. These findings will now be discussed.

Head trauma was significantly more likely in young indigenous males from remote areas

The present study found that young males (15–29 years) have the highest rates of head trauma in North Queensland (Table 1). Furthermore, young males in remote regions had higher rates of head injury than those from non-remote regions (Table 5, Fig 3). Young males have been previously identified as a high-risk group in various studies globally [8]. Our finding is also consistent with other studies in other Australian districts [5,22,23], and typically attributed to risk-taking behaviours, such as males being more likely to engage in occupations and recreational activities that predispose them to trauma [24,25]. Similar to other studies, we also found that Indigenous patients were overrepresented compared to their population size (Table 1) [18,22,26,27]. This will be discussed in greater detail below under the heading, *"Higher rates of assault-related head trauma in remote, paediatric and Indigenous patients"*.

Mild head injuries account for the majority of aeromedical retrievals from remote areas

An interesting finding of the study was that most remote traumatic head injuries requiring aeromedical transfer were of mild severity. Mild injury appears to be related to remote patients being more likely to suffer head trauma from assault (**Supplementary Table 1**) compared to more serious head injuries associated with vehicle accidents [28]. A higher incidence of mild head trauma in remote areas is contrary to a recent systematic review and meta-analysis that included 36 studies across multiple countries [8]. In this review we reported a higher incidence of severe head trauma in rural compared to urban patients [8]. Possible reasons for the discrepancy include an underestimation of mild head trauma in the systematic review studies we examined, and the requirement in North Queensland for aeromedical transfer of even mildly injured patients from remote areas to larger facilities for diagnostic imaging and further management. In contrast, mild head injuries occurring in regional, non-remote, areas are unlikely to require aeromedical transfer, and would be transferred by road or self-present, and therefore not included in the current study.

Vehicle accidents are a common cause of severe head injury

Vehicle accidents were the most common overall cause of head injury overall in North Queensland, and this trend persisted regardless of age or remoteness (Fig. 1**A, Supplementary Table 1**, Table 5). Importantly, vehicle accidents accounted for approximately half of all severe head injuries (**Supplementary Table 2**). Other studies in Australia, South America and Africa have shown similar correlations between

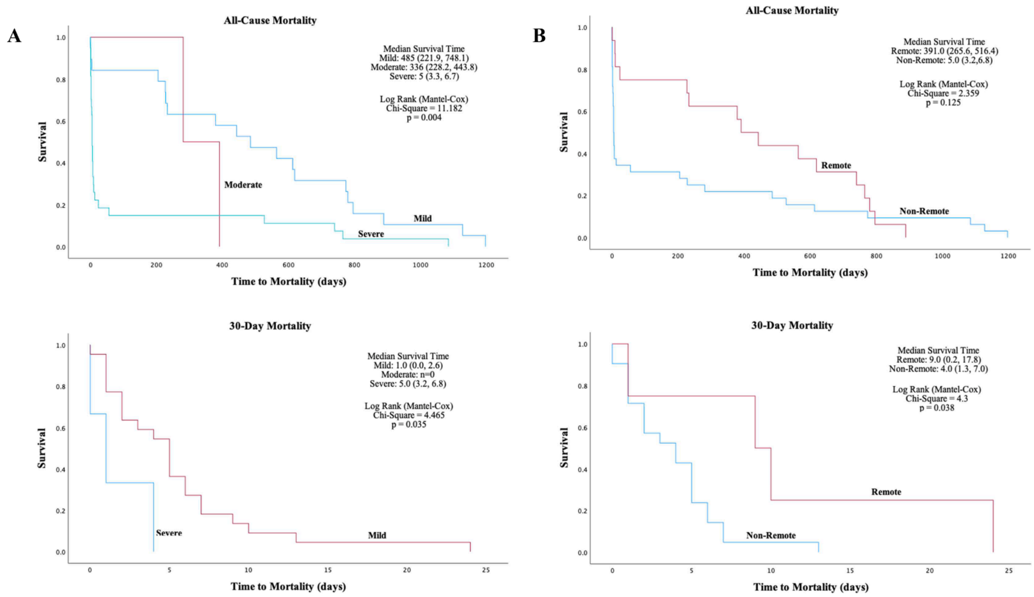

Fig. 2. Kaplan-Meier survival curves for all-cause mortality and 30-day mortality by (A) head injury severity and (B) remoteness.

Table 3
Cox regression analysis of head trauma mortality.

Parameter	HR	95% CI	p value
Female Sex	0.649	0.220, 1.909	0.432
Age*	0.992	0.943,1.001	0.404
Initial GCS*	0.930	0.828, 1.046	0.229
Hypotension*	1.799	0.799, 4.050	0.156
Intubation	7.397	0.954, 54.372	0.056
Blood Products	1.680	0.747, 3.779	0.210
TXA*	4.876	1.779, 13.363	0.002
ICU Admission	3.054	0.670, 13.917	0.149
ICU LOS*	0.999	0.999, 1.000	<0.001
Ventilation time*	0.999	0.998, 0.999	<0.001

Data presented as Hazard Ratio (HR) and adjusted for head injury severity and age.
[*] Variables included in multivariate Cox regression analysis (overall model Chi-square = 22.124, df = 7, p=0.002). GCS, Glasgow Coma Scale; TXA, Tranexamic Acid; ICU, Intensive Care Unit; LOS, Length of Stay.

vehicle accidents and increasing head injury severity, attributed to the high-impact nature of the mechanism [18,29-31]. There are multiple factors that may contribute to the high incidence of vehicle accident-related head injuries, including behavioural factors such as increased risk-taking, as well as environmental factors such as poorer road quality, unpredictable weather conditions and the presence of livestock and wildlife [8,32,33]. As a major contributor to severe head trauma, which has poorer prognosis, identifying and addressing these potentially modifiable factors is essential to minimising the incidence and improving patient outcomes.

Higher rates of assault-related head trauma in remote, paediatric and indigenous patients

Our retrospective study supports and extends previous reports, with assault being a common mechanism of injury in remote areas, affecting a significantly higher percentage of female and paediatric Indigenous patients (Table 5). As a point of clarification, earlier we discussed that young males have the highest rates of head injury in remote communities, and these were likely due to their higher risk-taking activities. However, when head trauma due to assault was specifically examined, the patient distribution shifted to a higher percentage of female and paediatric Indigenous patients compared to young males, or any other group. This is a key clinical finding of our study. It is widely known that Indigenous people experience severe health inequities which are compounded by remote living [34]. For example, poverty and alcohol-misuse, factors that are more prevalent in the Indigenous population, which was indicated in this study by lower SEIFA scores and 2.6-fold higher incidence of alcohol abuse (Table 6), are strongly linked

Table 4
Multinomial logistic regression analysis for predictors of hospital separation mode (discharge destination).

Parameter	Separation Mode (Discharge Destination)	OR	95% CI	p-value
Age (years)	Home/Usual Residence	1.000		
	Transferred to Another Hospital	0.983	0.965, 1.000	0.055
	Care Type Change	1.012	0.969, 1.057	0.592
	Died in Hospital	1.028	1.004, 1.053	**0.020**
	Other	1.022	0.953, 1.095	0.540
Injury ARIA Score	Home/Usual Residence	1.000		
	Transferred to Another Hospital	0.957	0.882, 1.039	0.291
	Care Type Change	0.178	0.072, 0.443	**<0.001**
	Died in Hospital	0.839	0.711, 0.991	**0.038**
	Other	1.242	0.802, 1.923	0.331
Initial GCS	Home/Usual Residence	1.000		
	Transferred to Another Hospital	1.013	0.779, 1.319	0.922
	Care Type Change	0.857	0.588, 1.249	0.421
	Died in Hospital	0.773	0.605, 0.986	**0.038**
	Other	0.280	0.055, 1.426	0.126

Data presented as Odds Ratio (OR) with 95% confidence interval (CI), and adjusted for head injury severity. Overall model Chi-square = 138.863, df = 20, p=0.001. Age, injury ARIA Score, and initial GCS account for 27.7% of variance in separation mode/discharge destination (Nagelkerke = 0.277). ARIA, Accessibility and Remoteness Index of Australia; GCS, Glasgow Coma Scale.

Table 5
Demographics, injury and clinical characteristics, interventions and outcomes for remote vs non-remote patients.

Data Category	Parameter	Remote	Non-Remote	p value
Demographics	Male Sex	66.9%	74.5%	**0.015**
	Age (years)^	33.40 (18.83) Range: 0.11-93	39.66 (21.51) Range: 0.40-87	**<0.001**
	Paediatric	12.2%	12.9%	0.763
	Geriatric	7.1%	15.1%	**<0.001**
	Indigenous	41.9%	11.8%	**<0.001**
Medical History	Diabetes	5.4%	4.0%	0.351
	Hyperlipidaemia	3.1%	6.5%	**0.013**
	Hypertension	9.5%	14.5%	**0.021**
	Heart Disease	6.6%	8.6%	0.252
	Renal Disease	2.0%	1.2%	0.390
	Epilepsy/Seizure	1.4%	4.0%	**0.009**
	Neurological Disease	1.1%	0.6%	0.480
	Smoking	9.5%	6.5%	0.107
	Alcohol Abuse	9.4%	9.8%	0.806
	Substance Use	2.5%	6.5%	**0.002**
	Mental/Behavioural	7.2%	11.4%	**0.028**
	Previous Injury	17.0%	6.5%	**<0.001**
	Previous Head Trauma	5.7%	0.9%	**<0.001**
Injury Characteristics	Mechanism of Injury			**<0.001**
	• Vehicle Accident	35.0%	51.4%	**<0.05**
	• Vehicle Type			**<0.05**
	• Car	49.8%	51.8%	
	• Motorbike	26.0%	20.2%	
	• Quadbike	12.1%	11.3%	
	• Truck	3.9%	1.8%	
	• Bicycle	2.2%	3.0%	
	• Others	6.1%	11.9%	**<0.05**
	• High-speed	48.0%	23.8%	**<0.001**
	• Unrestrained	21.6%	24.7%	**<0.001**
	• Hit by a moving object	28.4%	9.5%	**<0.05**
	• Biological factors	3.7%	1.2%	**<0.05**
	• Fall (same level)	8.1%	14.5%	**<0.05**
	• Fall from a height	16.0%	16.0%	
	• Hitting object with body part	3.5%	1.2%	
	• Other†	5.3%	6.2%	
	Assault	26.2%	10.2%	**<0.001**
	• Domestic Violence	32.9%	8.8%	**0.005**
	Alcohol/Drug Involvement	27.0%	23.4%	0.224
	Self-Harm	1.4%	3.1%	0.070
	Home Accident	16.0%	14.5%	0.565
	Work Accident	19.0%	11.0%	**0.006**
	Farm Accident	20.3%	11.1%	**0.001**
	Mining Accident	1.8%	2.2%	0.738
	Sports Accident	4.1%	2.5%	0.183
	Recreational Accident	5.2%	6.5%	0.426
	No Helmet#	22.4%	19.3%	0.062
Clinical Measures	HI Severity			**<0.001**
	• Mild	85.6%	57.2%	**<0.05**
	• Moderate	4.5%	9.5%	**<0.05**
	• Severe	10.0%	33.2%	**<0.05**
	Polytrauma	66.7%	65.5%	0.713
	Initial GCS^	13.93 (2.69)	11.51 (4.41)	**<0.001**
	LOC	48.1%	66.0%	**<0.001**
	Hypotension	4.6%	14.6%	**<0.001**
	Tachycardia	24.0%	33.4%	**0.002**
	Headache	11.6%	7.4%	**0.049**
	Dizziness	3.7%	1.6%	0.080
	Confusion	6.4%	6.5%	0.991
	Drowsiness	1.5%	3.4%	0.060
	Agitation	3.7%	7.7%	**0.007**
	Nausea/Vomiting	21.0%	16.4%	0.100
	Amnesia	20.2%	23.8%	0.214
	ICH	5.5%	31.3%	**<0.001**
	• SAH	3.9%	17.0%	**<0.001**
	• SDH	3.2%	24.3%	**<0.001**
	• EDH	0.7%	4.6%	**<0.001**
	Cerebral Oedema	0.9%	6.9%	**<0.001**
	Skull/Facial Fracture	14.8%	35.9%	**<0.001**
Pre-Hospital Interventions	Intubation	5.5%	34.8%	**<0.001**
	Isotonic Fluids	38.3%	40.0%	0.617
	Hypertonic Saline	0.9%	6.5%	**<0.001**
	Mannitol	0.5%	0.6%	0.749
	Blood Products	1.2%	9.8%	**<0.001**
	• Total Blood Units^	0.1 (0.3)	7.5 (14.8)	**<0.001**
	TXA	2.0%	7.7%	**<0.001**
	Time to Hospital (min)	399 (347) Range: 67-3780	255 (223) Range: 73-1657	**<0.001**
Hospital Outcomes	Hospital LOS (days)^	4.3 (7.7)	10.6 (23.7)	**<0.001**
	ICU Admission	7.4%	39.6%	**<0.001**
	ICU LOS (min)	7150 (10652)	5523 (8613)	0.823
	Mechanical Ventilation	6.6%	34.8%	**<0.001**
	Ventilation Time (min)	4434 (11399)	4350 (7927)	0.987
	Separation Mode			**<0.001**
	• Home/Usual Residence	94.6%	87.2%	**<0.05**
	• Transferred to Another Hospital	4.5%	3.8%	
	• Care Type Change	0.0%	2.2%	**<0.05**
	• Died in Hospital	0.6%	6.7%	**<0.05**
	• Other	0.3%	0.0%	

Data presented as percentage or median (IQR) except where indicated.
^ mean (standard deviation).
# Applies to motorbike and horse-riding accidents.
† Includes contact with or exposure to heat or cold, exposure to variations in pressure, other muscular stress, repetitive movement with low muscle loading, single contact with chemical or substance, stabbing or gunshot, submersion injuries, and multiple and unknown mechanisms of injury. IQR, Interquartile Range; DV, Domestic Violence; GCS, Glasgow Coma Scale; LOC, Loss of Consciousness; ICH, Intracranial Haemorrhage; SAH, Subarachnoid Haemorrhage; SDH, Subdural Haemorrhage; EDH, Epidural Haemorrhage; TXA, Tranexamic Acid; LOS Length of Stay; ICU, Intensive Care Unit.

to all forms of violence, especially domestic violence (DV) [18,35,36]. Given limited access to healthcare opportunities, ongoing financial hardship and alcohol-misuse in both Indigenous communities and remote living, it is not surprising that assault is a leading cause of head injury in remote North Queensland. This is a social health issue that needs urgent attention from local, state and multiple federal government agencies. Supply reduction through Alcohol Management Plans or prohibition has been linked with significantly lower rates of injury in both Australian and Alaskan Indigenous communities [37,38], and may be a key public health intervention to address high head trauma rates in these populations.

Identifying predictors of in-hospital mortality following head injury: older age and lower initial GCS

Identifying the different risk factors responsible for mortality following head injury may be clinically useful for triaging patients, and adjusting thresholds for more intensive or invasive interventions [1–3]. In this study, patient age, as well as a lower initial GCS was predictive of in-hospital mortality (Table 4), and may serve as useful prognostic tools to guide prehospital care. Low GCS has been identified as an independent risk factor for mortality in other head trauma cohorts [39,40], with

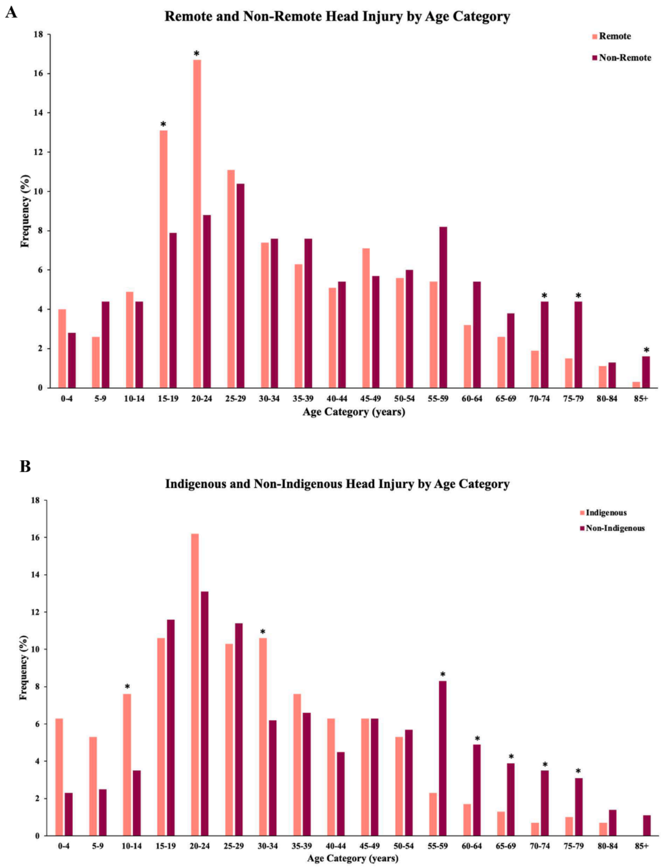

Fig. 3. Head trauma by age category in (A) remote and non-remote patients, and (B) Indigenous and non-Indigenous patients. * $p<0.05$.

discriminative capacity comparable to complex trauma scores including the Revised Trauma Score (RTS), and mechanism, GCS, age, systolic blood pressure (MGAP) score [41]. However, it should be noted that the GCS has several known limitations due to its 'single-score' conversion, which has been shown to be unreliable and inaccurate in certain populations including children, those with disabilities and cognitive impairment [42,43]. Additionally, it is subject to the confounding effects of alcohol, drugs, sedatives, and other medications commonly used in trauma care [42–44]. There is evidence that some of these limitations can be overcome by the use of the motor component of the GCS score alone (GCS-m) [45,46]. Unfortunately, a breakdown of the prehospital GCS score into motor (m), eye (e), and verbal (v) components, was not available to assess this. Finally, although the limited fatality rate in this study prevented the identification of additional significant predictors of mortality, other studies support patient-guided prehospital care, such as the use of less invasive ventilation and restriction of intravenous fluids in stable patients [47–49]. This is an important area of future investigation.

Prehospital TXA administration is significantly associated with all-cause mortality

In addition to identifying risk factors of mortality following head injury, another important area is to examine treatment modalities from point-of-injury to hospital care. In our study, we found all-cause mortality was associated with the prehospital administration of TXA (Table 3). TXA is a common therapeutic agent in trauma management to treat hyperfibrinolysis, however, the benefits of its use in the prehospital management of traumatic head injury are still debated [50,51]. In this study, consistent with the clinical guidelines at the time, TXA administration was rare in isolated head injury (1.5 %), and significantly associated with polytrauma (**Supplementary Table 3**). The mortality rate in patients with severe, isolated head trauma administered TXA prior to hospital arrival was 67 %, which is consistent with "The Prehospital TXA for TBI" trial that found TXA administration was associated with significantly increased odds of mortality in patients with severe, isolated, head injury [51]. Other factors may also have contributed to TXA-related mortality, and our results provide a good example that correlation of TXA with mortality may not be causal, and further investigation is required.

Modifiable factors to prevent and/or reduce the impact of head trauma

Overall, the most alarming findings of our retrospective study were the high rates of preventable behaviours associated with traumatic head injuries. Specifically, in remote communities, one-quarter of all injuries involved alcohol or drug use, helmets were not worn in one-in-five motorcycle and horse-riding accidents, and seatbelts were not in use in ~23 % of all vehicle accidents (Table 1, Fig. 1). There is a substantial amount of evidence to support the implementation of population-based health promotion strategies aiming to minimise risk-taking behaviours in rural communities [29,52,53]. Unfortunately, the present study indicates that previous public health messaging around these personal behaviours is not having the required impact.

On a larger scale, creation of public policy enforcing safer driving practices and conditions on remote roads may assist in minimising the environmental factors contributing to vehicle accident-related head trauma. The Australian National Road Safety Strategy states that speed enforcement in rural communities may be optimised by the implementation of credible and appropriate speed limits and public education regarding the dangers of speeding and strengthening community support for speed enforcement [54–56]. In addition, given the high incidence of rural and remote head trauma occurring in farms and workplaces, revision of workplace health and safety regulations, such as safe handling of quadbikes and helmet use, may also be relevant.

It is clear from our study that enhancing access to culturally safe services addressing alcohol and other drug use, DV and mental health, particularly for remote Aboriginal and/or Torres Strait Islander communities, is critical for reducing the burden of assault-related head trauma in North Queensland. This may involve increasing funding for rural outreach services, increasing the scope of practice for Aboriginal Health Workers and providing education for primary health providers on opportunistic alcohol/drug use and DV screening [57,58].

Strengths and limitations of the study

This retrospective descriptive study of traumatic head injuries in North Queensland has several key strengths. First is the inclusion of both prehospital and in-hospital data, and a prolonged follow-up of ~30 months for mortality data. Studies excluding prehospital and sufficient follow-up data run the risk of missing crucial morbidity and mortality data and consequently, underreporting outcome results for head trauma patients [8]. Secondly, as head trauma represents a leading cause of morbidity, we have analysed outcomes other than mortality, including duration of mechanical ventilation, hospital and ICU length of stay, and discharge destination, which provides valuable information for patient prognosis and healthcare system burdens. Lastly, we have addressed the unmet need for subgroup analyses of Indigenous peoples, a population that has known health inequities, but is seldom investigated in head trauma research [8].

A potential limitation of the present study is its retrospective design. Retrospective studies incur the risk of missing data, which we have mitigated through linkage of multiple of data sources for each individual patient, a method validated for trauma registries like the Trauma Care in the Tropics dataset. In this study, we encountered a statistically insignificant percentage of missing data for key variables including patient demographics, mortality, injury severity and mechanism of injury

Table 6
Demographics, injury characteristics, clinical measures, pre-hospital interventions and outcomes for Indigenous and Non-Indigenous head trauma patients.

Data Category	Parameter	Indigenous	Non-Indigenous	p value
Demographics	Male Sex	63.3%	71.8%	**0.007**
	Age (years)^	28.98 (16.78)	38.37 (20.64)	**<0.001**
		Range: 0.1-84	Range: 0.4-93	
	Paediatric	19.1%	9.4%	**<0.001**
	Geriatric	3.0%	13.0%	**<0.001**
	Home ARIA Score	12 (3.74)	4.97 (8.77)	**<0.001**
	Home ARIA Category			**<0.001**
	Major City	1.0%	4.9%	**<0.05**
	Inner regional	0.0%	8.4%	**<0.05**
	Outer Regional	10.7%	44.0%	**<0.05**
	Remote	18.0%	14.5%	
	Very Remote	70.2%	28.2%	**<0.05**
	Home MMM			**<0.001**
	• 1	1.0%	4.9%	**<0.05**
	• 2	3.1%	16.3%	**<0.05**
	• 3	0.0%	1.3%	**<0.05**
	• 4	2.1%	16.5%	**<0.05**
	• 5	5.5%	17.2%	**<0.05**
	• 6	10.0%	14.2%	
	• 7	78.2%	29.6%	**<0.05**
	SEIFA			**<0.001**
	• 1	78.1%	24.6%	**<0.05**
	• 2	2.4%	24.1%	**<0.05**
	• 3	10.7%	20.7%	**<0.05**
	• 4	3.8%	12.7%	**<0.05**
	• 5	1.0%	7.0%	**<0.05**
	• 6	0.3%	3.0%	**<0.05**
	• 7	0.3%	1.4%	
	• 8	2.8%	3.6%	
	• 9	0.0%	1.6%	**<0.05**
	• 10	0.3%	1.4%	
Medical History	Diabetes	8.2%	3.3%	**0.001**
	Hyperlipidaemia	2.6%	4.9%	0.104
	Hypertension	10.5%	11.6%	0.623
	Heart Disease	6.9%	7.6%	0.689
	Renal Disease	3.6%	0.9%	**0.003**
	Epilepsy/Seizure	4.3%	1.4%	**0.005**
	Neurological Disease	0.7%	1.1%	0.539
	Smoking	8.2%	8.7%	0.804
	Alcohol Abuse	16.7%	6.4%	**<0.001**
	Substance Use	4.3%	3.7%	0.647
	Mental/Behavioural	7.9%	9.1%	0.518
	• Depression	3.0%	5.6%	0.070
	• Anxiety	0.3%	1.5%	0.189
	• Bipolar Disease	0.3%	0.8%	0.671
	• Dementia	0.3%	0.5%	1.000
	• Schizophrenia	0.3%	0.6%	1.000
	• Post-Traumatic Stress Disorder	0.0%	0.3%	1.000
	• Psychosis	1.0%	0.3%	0.334
	• Self-Harm	1.0%	0.3%	0.334
	• Behavioural Disorder	1.6%	0.2%	**0.014**
	• Suicidal Ideation	2.3%	0.6%	**0.043**
	Previous Injury	21.3%	9.9%	**<0.001**
	Previous Head Trauma	7.2%	2.6%	**<0.001**
Injury Characteristics	Remote	87.5%	56.7%	**<0.001**
	Injury ARIA Score	12 (3.4)	6.69 (7.8)	**<0.001**
	Mechanism of Injury			**<0.001**
	• Vehicle Accident	23.3%	48.4%	**<0.05**
	• Hit by a moving object	43.6%	12.0%	**<0.05**
	• Biological factors	2.0%	3.3%	
	• Fall on the same level	10.2%	10.4%	
	• Fall from a height	10.5%	18.7%	**<0.05**
	• Hitting object with body part	3.9%	2.1%	
	• Other†	6.6%	5.0%	
	Assault	46.6%	9.1%	**<0.001**
	• Domestic Violence	36.9%	11.5%	**<0.001**
	Alcohol or Drug Involvement	44.6%	17.4%	**<0.001**
	Self-Harm	2.6%	1.7%	0.325
	Home Accident	27.8%	10.1%	**<0.001**
	Work Accident	14.2%	85.8%	**<0.001**
	Farm Accident	6.1%	22.9%	**<0.001**
	Mining Accident	0.7%	2.4%	0.054
	Sports Accident	3.0%	4.0%	0.438

(*continued on next page*)

Table 6 (*continued*)

Data Category	Parameter	Indigenous	Non-Indigenous	p value
	Recreational Accident	3.3%	6.7%	**0.032**
	No Helmet[#]	27.9%	18.5%	0.117
Clinical Measures	HI Severity			**0.004**
	• Mild	82.0%	73.2%	**<0.05**
	• Moderate	6.2%	6.3%	
	• Severe	11.8%	20.6%	**<0.05**
	Polytrauma	52.1%	72.9%	**<0.002**
	Initial GCS[^]	13.53 (3.16)	12.94 (3.68)	**0.018**
	Loss of Consciousness	46.6%	57.5%	**0.002**
	Hypotension	4.5%	9.8%	**0.006**
	Tachycardia	28.1%	26.7%	0.668
	Headache	10.6%	9.4%	0.570
	Dizziness	4.0%	2.5%	0.208
	Confusion	2.0%	8.7%	**<0.001**
	Drowsiness	2.6%	2.0%	0.525
	Agitation	5.2%	5.0%	0.884
	Nausea/Vomiting	23.2%	17.2%	**0.039**
	Amnesia	12.5%	25.0%	**<0.001**
	Intracranial Haemorrhage	4.8%	19.1%	**<0.001**
	Cerebral Oedema	1.5%	3.7%	0.078
	Skull/Facial Fracture	5.1%	17.1%	**0.005**
Hospital Outcomes	Hospital LOS (days)[^]	4.0 (7.6)	7.6 (17.1)	**<0.001**
	ICU Admission	7.8%	23.1%	**<0.001**
	• ICU LOS (min)	2889 (6176)	5755 (9707)	0.087
	Mechanical Ventilation	7.8%	19.9%	**<0.001**
	• Ventilation Time (min)	2460 (6704)	5083(8696)	**0.023**
	Separation Mode			**0.032**
	• Home/Usual Residence	95.2%	90.7%	**<0.005**
	• Transferred to Another Hospital	3.8%	4.4%	
	• Care Type Change	0.0%	1.1%	
	• Died in Hospital	0.7%	3.6%	**<0.005**
	• Other	0.3%	0.2%	
Mortality	All-Cause Mortality	3.0%	5.9%	**0.048**
	Time (days)	391 (601)	7 (524)	0.077
	Mortality due to Primary Injury	22.2%	64.1%	**0.031**
	Time (days)	5.5 (5.0)	24.9 (69.7)	0.821

Data presented as percentage or median (IQR) except where indicated.

^ mean (standard deviation).

Applies to motorbike and horse-riding accidents.

† Includes contact with or exposure to heat or cold, exposure to variations in pressure, other muscular stress or repetitive movement, contact with chemical or substance, stabbing or gunshot, submersion injuries, multiple and unknown mechanisms of injury. IQR, Interquartile Range; ARIA, Accessibility and Remoteness Index of Australia; SEIFA, Socio-Economic Indexes for Areas; PTSD, MMM, Modified Monash Model; HI, Head Injury; GSC, Glasgow Coma Scale; LOS Length of Stay; ICU, Intensive Care Unit.

(maximum missing data for any one variable was 6.8 %). The mortality rate was low (<5 %) which limited significant findings from regression analyses and thereby the determination of specific risk factors. The heterogeneity of injury, which is a challenge in all trauma studies, may have also contributed to this. Another important limitation is the sole inclusion of patients transferred by air at some point during the continuum-of-care, which excludes those self-presenting to hospital and road transfers without onward aeromedical transfer. It should be noted though, that there is a heavy reliance on aeromedical transfer in the North Queensland region due to its geographical nature covering >880,000 km^2 (or >340,000 square miles) and limited resources outside of the only tertiary hospital located in the regional city of Townsville. Therefore, road transfer of head injury patients is either by short distances to definitive care, or to smaller regional hospital and remote health centres with onward aeromedical transfer, as was the case for 78 % of the cases analysed in this study.

Conclusions

Young, Indigenous males from North Queensland are disproportionately affected by head trauma. Motor vehicle accidents are the most common cause of head injury, except in the Indigenous population, where assaults predominate affecting a higher percentage of female and paediatric Indigenous patients. Predictors of in-hospital mortality include older age and lower initial GCS, and prehospital TXA administration is correlated with all-cause mortality. These findings highlight the importance of targeted health promotion strategies to reduce the incidence and severity of head trauma in North Queensland. Future, larger, prospective multicentre studies are required to identify significant patient and prehospital risk factors for mortality and morbidity that should be considered when planning aeromedical retrieval and prehospital care, especially for rural and remote patients living in North Queesnland.

Declaration of Competing Interest

None.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.injury.2023.111181.

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