Hard hitting facts on childhood head trauma: An Epidemiological analysis.

By

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Declaration

I, Yolandi Ferreira hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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Abstract

Background

According to the World Health Organization (WHO), Traumatic Brain Injury (TBI) will become the third largest cause of global disease by the year 2020. Despite its astonishing numbers, TBI remains a silent or even forgotten epidemic with significant paucity in epidemiological data. TBI in developing countries represents a disproportionate burden of disease and data are lacking regarding the unique demographics in South Africa to design and implement focused prevention programmes.

A valuable tool to assess the severity of TBI is the use of Computer tomography (CT). CT also is the main imaging modality to provide rapid identification and information for the management of children with TBI. CT scanning utilises ionising radiation and as an imaging modality poses risk to the patient. In order to guide decision protocol/algorithm, various Clinical Decision Rules (CDRs) have been established in High Income Countries. These protocols, including the need for CT scan might differ in a Medium/Low Income setting.

Methodology

This is a prospective, single centre cohort study. Data were collected over an 18-month period (1 August 2015 – 31 January 2017). Children under the age of 13 years (n=3007) presenting to RCWCH after sustaining a head injury were included. Various epidemiological data were collected. A Road Safety Questionnaire was also used to evaluate safety knowledge of health care workers. Three different CDRs were compared to the standard of practice in RCWCH. A final analysis of demographics, mechanism of injury, radiology outcome, safety analysis and evaluation of a comparison of local protocol compared to the other CDRs was performed using descriptive statistics.

Results

The mean age of paediatric patients presenting after a head injury was 4.6 years. There was a significant male predominance (66%) and almost two thirds of all children were of pre-school age. Falls (53%; n=1601) represented the most common mechanism of injury across all age groups, followed by road traffic related injuries (RTI) (29%; n=864), struck by or against an object (9%; n=279) and injuries as a result of interpersonal violence (8%; n=230).

Within the subset of RTI (n=864) only 6 passengers were appropriately restrained, with 142 unrestrained and 56 passengers transported on the back of a goods vehicle. In the under 3-year-old age group, only 1 patient was appropriately transported in a car seat, with 51 unrestrained and 6 transported on the back of a goods vehicle. Pedestrian related injuries were by far the largest group of RTI (70%) with 50% of these under the age of 5 years.

Intentional injuries inflicted by an adult were most common (34%) in the pre-verbal (under 2 years old) group. Interpersonal violence among minors (assault with a brick or stone) constituted 52% of intentional injuries. Eight firearm related injuries were recorded. Appliances and iron gates that were not correctly installed were additional causes of injury.

CT scans were obtained according to the RCWCH protocol in 59% of cases and 34% showed an abnormal result. The sensitivity (98%) and specificity (93%) while using the standard of practice protocol was better than the 3 CDRs developed in High Income Countries.

Analysing our Road Safety Questionnaire there appears great room for improvement regarding awareness of road safety guidelines and legislation.

Conclusion

The performance of the current RCWCH CT scan protocol appears appropriate in our setting although there is some room for improvement using the strengths of the other CDRs.

Valuable insight regarding the epidemiology of TBI in our setting has been highlighted. Of specific importance is the large proportion of very young children at risk of injury by all mechanisms of injury, particularly pedestrian-related injuries, unrestrained passengers and interpersonal violence among minors.

Important gaps in knowledge about current recommendations for road safety were identified by the questionnaire. As long as these issues are not appropriately addressed through enhanced injury prevention programmes, children will continue to carry the heavy burden of TBI morbidity and mortality.

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Yolandi Ferreira

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Abbreviations

ALARA	as low as reasonably achievable
CAT	computer axial tomography
CATCH	Canadian Assessment of Tomography for Childhood Head Injury
CCS	Children's Coma Score
CDC	Centre for Disease Control
CDR	clinical decision rule
CHALICE	Children's Head Injury Algorithm for the prediction of Important Clinical Events
CI	confidence interval
ciTBI	clinically-important traumatic brain injury
CT	computerized tomography
ED	emergency department
EMI	Electrical Musical Industries, Ltd
GCS	Glasgow Coma Scale
HI	head injury
ICD	International Classification of Disease
LMIC	Low and Middle-Income Countries
MOI	mechanism of injury
MRI	magnetic resonance imaging
NAI	non-accidental injury
NICE	National Institute for Health and Clinical Excellence
NRTA	National Road Traffic Act
PECARN	Paediatric Emergency Care Applied Research Network
PI	primary investigator
PICU	paediatric intensive care unit
RTC	road traffic crash
RTI	road traffic related injuries
RCWCH	Red Cross War Memorial Children's Hospital
SA	South Africa
SDH	subdural haematoma
SD	standard deviation

SXR	skull x-ray
TV	television
TBI	traumatic brain injury
US	United States of America
UK	United Kingdom
WHO	World Health Organization

Chapter 1. Introduction

'Trauma kills. Trauma maims. Trauma is a disease; it is not an accident. Like heart disease and cancer, trauma has identifiable causes with established methods of treatment and defined methods of prevention.' [1]

The American Trauma Society

Traumatic Brain Injury (TBI) is often referred to as the silent or forgotten epidemic.[2,3,4]

It is a global health problem, but insufficiently recognised.[4,5] The magnitude is underestimated by current surveillance systems in the developed world. TBI is the leading cause of mortality in young adults. Across all ages and all countries TBI is a major cause of death and disability, with a disproportionate burden in low and middle-income countries (LMIC). Despite the vast proportions of this public health challenge, the availability of epidemiological data for TBI in children is incomplete and continues to be lacking.[5,6]

According to the World Health Organization (WHO), TBI will surpass many diseases as the major cause of mortality and morbidity by the year 2020 to become the third largest cause of global disease.[3,4,7] It is estimated that TBI affects over 50 million people annually worldwide (over 90% of which are mild cases) and it is estimated that about half the world's population will have one or more TBIs over their lifetime.[4,6]

Reported incidence rates of TBI globally vary greatly by country. Substantial gaps exist in robust data for many parts of the world, particularly LMICs, where TBI rates are likely to be high. Population-based studies with broad definitions of TBI lead to substantially higher incidence rates.[8]

The global incidence of TBI in children has been reported at 193 per 100,000, with significantly higher rates in developing countries, as high as 359 per 100,000 in Sub-Sahara Africa. [9,10,11] It is estimated that children presenting to an emergency department with a minor TBI will require admission in 16.3% of cases amounting to a staggering patient load.[4]

Since 1983, trauma has been identified as 'the number one killer of children' globally.[12] Knobel et al. found over a 15-year period that 25.5% of non-natural deaths in children (aged under 15 years) in the Cape Peninsula could be attributed to TBI specifically.[13]

As the leading cause of long-term disability among children internationally, TBI has grave implications that disrupt the lives of individuals and their families. Survivors experience a substantial burden of physical, psychiatric, emotional, and cognitive disabilities. The effects of TBI in a child may be long-term, many victims are rendered incapable of looking after themselves. TBI may impact the child's future ability to work and earn a salary. These disabilities are not restricted to severe TBIs, but frequently occur after moderate and mild cases.[6,14]

TBI is a critical public health problem that continues to be a source of economic concern and impacts heavily on an already strained health system. To reduce the burden and societal costs of TBI, deficiencies in prevention, care, and research need to be addressed urgently. TBI is a complex condition and optimisation of systems of care should be high on the policy agenda. [6,14]

Although the aetiology of significant TBI varies between developed and developing nations, Road Traffic Crashes (RTCs) remain the most common cause globally (60%), followed by falls (20-30%), inter-personal violence (10%) and injuries related to sports and work place activities (10%). [4]

In 2015 the WHO rated Africa's roads the world's deadliest. South Africa's road fatalities were 25.1 per 100, 000 population, well above the 9.2 per 100,000 for Europe and the worldwide estimate of 17.4 per 100,000.[15] Even in children the South African road fatality rate was almost twice the global average. Pedestrian related RTCs accounted for 54.74% of severe TBIs in children admitted to the Red Cross War Memorial Children's Hospital (RCWCH) during a retrospective review for the period of June 2006 to April 2011.[5]

Furthermore, South Africa (SA) is one of the few countries where rates of intentional injury exceed the rates of unintentional injury. The homicide rate (56 per 100,000) is five times that in the United States of America (USA).[16,17]

Prevention is the most accessible tool to suppress the impact of this global epidemic.[14] It is the identification of aetiological factors and compiling a demographic profile of children sustaining TBIs that will lay the foundation and identify trends for preventative policy administration and intervention strategies. [5]

Trauma, and particularly TBI, is a public health challenge that demands a co-ordinated multi-faceted response from various stakeholders.[18] The HIV/AIDS pandemic has been rolled back, within a decade, from a dismal situation to that of the management of a widespread chronic disease. This remarkable achievement was based on knowledge gained from numerous clinical audits that accurately described and quantified the situation at ground level. In contrast to this successful multi-faceted response to the HIV/AIDS pandemic, TBI has not been subjected to the same adequate investigations and surveillance. Even globally it would appear that in contrast to other public health problems such as cardiac disease and infectious diseases, TBI has been the neglected epidemic.[2,18,19]

In South Africa we have a unique set of conditions: a high proportion of pedestrian vehicle accidents, a high incidence of intentional inter-personal violence resulting in TBIs and limited and unequal availability of health care resources. Improved TBI epidemiological data are needed to develop and implement policies for better prevention and coordinated systems of care to improve outcomes for individuals with TBI. Increased awareness of the scale of the challenge posed by TBI to motivate politically for resources, programmes, and legislation will be vital for progress in the field. [6,20]

Chapter 2. Study Objectives

Primary aim

The primary aim of the study was to prospectively collect epidemiological data for preadolescent children presenting with head trauma to a tertiary hospital. Specifically, the aim was to collect data in the following areas: age, presenting characteristics, time and day of presentation to the trauma unit, severity of TBI, CT scans performed, admission rate, associated injuries and mortality rate.

Four important factors contributed to the rationale for the present study:

Firstly, recent epidemiological data for the South African paediatric TBI population is limited.[4,21] TBI is a major global epidemic that is underreported. In South Africa, with its excessive trauma burden, no national registry exists to tract the epidemic in general. There are only a handful of single centre reports and audits which document paediatric TBI in South Africa.[18,19,21,22]

This study would provide epidemiological data of children who presented to the Red Cross War Memorial Children's Hospital (RCWCH) with the history of possible traumatic brain injury. This is also valuable for audit purposes the results can be compared with previous studies at this centre to examine possible changes over the last two decades.

Secondly, epidemiology data on paediatric TBI is also lacking in other developing countries. This study will not only benefit the local context but may establish principles and patterns that may be applicable to other developing world circumstances.

Thirdly, identifying causative factors and trends can direct targets for community-based injury prevention programmes. Different environments alter the causative factors to such an extent that extrapolation from one country to another and even from one region to another is limited. Primary prevention programmes are needed to help reduce this burden of disease.

Finally, a national trauma registry in SA is long overdue. Despite a few reports on TBI, this forgotten epidemic is largely ignored. The study aims to increase awareness of the scale of the challenge posed by TBI and for efforts to develop a nationwide trauma registry.

Secondary aims

There were several secondary aims to the study, namely:

1. To critically examine the institutional indications(s) for cranial CT scan and whether these complied with criteria listed in the CHALICE, PECARN, and CATCH clinical decision rules. The criteria for these Clinical Decision Rules were established in developed countries. These may or may not be appropriate for a developing world setting. Currently there is no data to evaluate this.

2. To document the time from presentation to RCWCH to CT scan.

3. To document the accuracy of CT scan assessment by the treating physician.

4. To examine the safety knowledge of health care workers by means of a Road Safety Questionnaire.

Chapter 3. Overview of Traumatic Brain Injury

3.1 Terminology

The terms ‘traumatic brain injury’ (TBI) and ‘head injury’ (HI) are often used carelessly and interchangeably in medical literature. The definitions of TBI vary considerably between different organisations, resulting in difficulties in diagnosis and case ascertainment. [4,6]

Head injury (HI) refers to trauma to the head. It potentially covers not only those injuries resulting in a change in brain function, but also injuries to the bone and soft tissues of the face and head. A patient with a HI may or may not have injuries involving the brain. In referring to injuries of the brain the term ‘traumatic brain injury’ is preferred over the use of the more generic and less specific ‘head injury’ term.[4]

Traumatic brain injury (TBI) is defined by the National Institute of Neurological Disorders and Stroke as an alteration in brain function, or evidence of brain pathology, caused by an external force. This statement suggests that symptomatology, imaging findings, details of the incident, and wider context should all be taken in to account to inform diagnosis.[23]

The alteration in brain function can be temporary or permanent and can manifest as:

- Any alteration in mental state (confusion, disorientation, feeling dizzy, etc.)
- Any period of loss of consciousness
- Any loss of memory for events immediately before or after the accident
- Seizures,
- Coma, or
- Focal neurological deficit(s) that may or may not be transient.[3,4,23,24]

The external force can be direct or indirect:

- Blunt force trauma (e.g. blow to the head)
- Penetrating trauma (e.g. gunshot)
- Indirect trauma to the head as found in the rapid acceleration or deceleration in a motor vehicle crash. [23]

A skull fracture may suggest the presence of an underlying TBI, but it is the presence of neurological symptoms or the demonstration of intracranial pathology that is needed to establish the diagnosis of TBI.[3,4]

TBI is best viewed as a collection of different disease processes with multiple faces, i.e.:

- Sheared brain: axonal injury
- Bruised brain: contusional brain injury
- Brain under pressure: typical an epidural haematoma
- Disconnected brain: white matter loss[6]

These different clinical patterns need to be identified as each requires different approaches to diagnose and manage and will ultimately lead to different outcomes.[6]

The overall number of patients presenting with a HI may be high, but actual intracranial pathology is less often encountered. As one enters the controversial field of whether a CT scan should be obtained for a paediatric patient with a HI, the emphasis shifts to the identification of clinical important TBI (ciTBI).[25]

During the development of the PECARN Paediatric Head Injury Prediction Rule, the aim was to identify children at very low risk of clinically important brain injuries in whom CT scans could safely be omitted.[25]

Clinical important TBI (ciTBI) are defined by any of the following descriptions:

- Death from TBI
- Neurosurgical intervention for TBI (e.g. craniotomy, intracranial pressure monitoring)
- Intubation for more than 24 hours for TBI
- Hospital admission of 2 nights or more for the TBI.[25]

Individuals can react very differently to similar injury patterns. It is important to distinguish between the immediate primary injury and the secondary injury that will develop over time. [6]

Primary brain injury is the damage inflicted at the moment of impact and includes contusion, damage to blood vessels and axonal shearing. Primary brain injury is an independent factor that can only be controlled by preventing the injury and moment of impact.[6,26]

Secondary brain injury refers to the changes that evolve over hours, days, weeks, months or even over a lifetime in some cases after the primary brain injury. Secondary brain injury is driven by host responses to the primary injury. These responses include an entire cascade (over hours to days) of cellular, chemical, tissue, or blood vessel changes in the brain that contributes to further destruction and neurological deterioration. The goal of treatment for patients with suspected TBI is to prevent secondary brain injury. Providing adequate oxygenation and maintaining blood pressure at a level that is sufficient to perfuse the brain are important ways to limit secondary brain injury and thereby improve the patient’s outcome.[6,26]

3.2 Classification of severity of TBI

In terms of classification of severity, TBI is historically classified as mild, moderate, or severe by using the Glasgow Coma Scale (GCS). [27]

More than forty years later, the GCS is still the most frequently used objective clinical measurement tool to assess coma and impaired level of consciousness. Since Graham Teasdale and Bryan Jennett, professors of neurosurgery at the University of Glasgow's Institute of Neurological Sciences described the GCS in 1974, it has been internationally further recognized as the neurological scale for rating severity of TBI. The classification is fairly crude, relying only on assessment of level of consciousness, where in reality a multitude of factors are at play.[6,28]

The GCS consists of three components: (Appendix 1)

- Eye opening (E)
- Best Verbal response (V)
- Best Motor response (M)[28]

The patient's response is assessed in three domains and individual scores are summed to produce a total score. The total score provides a classification of TBI severity during the acute phase of injury. [27]

Severity	GCS score
Mild	13-15
Moderate	9-12
Severe	3-8

Table 3.1. Classification of TBI by clinical severity with the Glasgow Coma Scale score. [6,27]

The lowest possible GCS score is 3 (deep coma or death), while the highest is 15 (fully awake person). The original 14-point scale did not include the category of "abnormal flexion". The 15-point score is now predominantly in use. [27]

Prediction of functional outcome and mortality is essential for determining treatment strategies and allocation of available resources for patients with TBI. There is an inverse relationship between the GCS score and the incidence of positive findings on CT after TBI. In adult TBI patients the rate of intracranial injury and need for neurosurgical intervention doubles when the GCS drops from 15 to 14. [29,30]

It has been found that severe TBI in children (15 years and younger) is associated with a lower mortality rate than adults and superior functional outcome. Paediatric patients suffering from a TBI could benefit from early and aggressive treatment. Many predictive factors for predicting mortality and functional outcome have been identified: hypoxia, hypotension and the presence of other injuries. Age at the time of injury is known to be one of the single most important predictors of morbidity and mortality.[31]

Mortality figures differ widely depending on resources available, socio-economic circumstances and age. In patients across all ages with a mild TBI (GCS 13-15) mortality has been reported as low as 0.1% compared to figures up to 40% for patients with severe TBI and a GCS of 3.[32]

Pre-resuscitation GCS (P-GCS) score is frequently incorporated into mortality prediction. It is well recognized however that current mortality prediction models need to be modified to account for the non-linear relationship between P-GCS and mortality. Given the variability in mortality rates and functional outcomes, the P-GCS is not a good clinical tool for mortality prediction in individual TBI patients. [33]

The predictive value of the GCS score for mortality in children after severe TBI were studied in a small group of children (n=59) admitted to the Paediatric Intensive Care Unit (PICU) of Kaunas University of Medicine Hospital, Lithuania during a 30-month period. The potential mortality in children after severe TBI increased significantly with a post resuscitation GCS scores of 5 or less.[34]

Due to the higher incidence of intracranial injury and poor outcomes in patients with a GCS of 13, many authors recommend that these patients should be classified as moderate instead of minor.[35,36,37] Clinical guidelines in Australia recognized the increase in morbidity associated with a GCS of 13, and limit the classification of mild TBI to those patients with a GCS score of 14 or 15.[38]

The standard GCS has limited applicability to children, especially below the age of 36 months. The normal verbal and motor response required by the standard GCS are not attainable during early childhood.[39] Several rating scales have been developed to overcome these age-related issues. Preference of scoring system in pre-verbal children varies between centres. The most favourable ones are:

i.) Paediatric GCS (PGCS) -Appendix 2

The Paediatric GCS uses the standard GCS criteria, with modifications for verbal responses and realistic age-related motor responses. It has the same maximum and minimum scores as the standard GCS. [39]

ii.) Children's Coma Scale (CCS) -Appendix 3

Raimondi and Hirschauer developed a coma score for children in 1984. The eye-opening component of the GCS was replaced with ocular response. This score has a maximum score of 11 and is very useful for TBI in infants and toddlers.[40]

The International Multicenter Study of Head Injury in Children was a prospective study of 3 years duration (August 1995-November 1998) in 5 countries (Argentina, Brazil, France, Hong-Kong and Spain). [41] Although this study was done 20 years ago it is still referred to by recent global reviews. [4]

A total of 2478 patients (0-15 years) were enrolled in this study. Minor HI accounted for 56.4% of children in this study cohort, moderate HI for 38.9%, and severe HI for 4.7%. The mortality rate was 1.6%.

3.3 Challenges comparing paediatric TBI studies

Efforts to quantify the magnitude of the paediatric TBI epidemic in South Africa are hampered by several factors.

Poor reporting systems and lack of accuracy in defining TBI contributes to the scarcity of data in LMIC, and South Africa is typical in this regard. TBI has not been the focus of adequate investigation or surveillance. Despite the excessive trauma burden in South Africa, there is no national trauma registry to track this epidemic. There are only a handful of local reports and audits which document TBI as it pertains to South Africa. [5,18,19]

There are inconsistencies in defining TBI. Researchers often use HI and TBI interchangeably. Available data capture only a proportion of all TBIs, therefore the scale of the problem is likely to be considerably greater than current figures suggest. Some reports would focus on all head injuries (potentially covering injuries to the bones and soft tissues of the face and head, but not involving the brain) and others only on severe TBIs (patients with GCS score of less than or equal to 8). [5,18,19]

Although moderate to severe TBI survivors develop the most significant disabilities and require the most intensive treatment and rehabilitation, mild TBIs can also create long lasting and persistent problems. According to a prospective study on epidemiology, treatment and outcomes of all degrees of TBIs in a population in Germany, one year after the injury, 50% of all patients (90% classified as mild TBI) still required treatment.[42]

Mild TBI cases often go unrecognised and are under-reported given its silent nature. Patients or parents with children who sustained a mild TBI often do not seek medical attention. Even if a patient with a mild TBI did present to the family physician or regional clinic, these cases would not be included in hospital-based cohorts. If these patients were seen at the hospital, they might have been discharged without any follow-up care. Cognitive deficits, post-concussion symptoms, behavioural and mood changes can persist months post-TBI. The full effects of TBI particularly in paediatric patients, may not be apparent for some years. [3,43]

On the severe TBI side of the spectrum, patients who succumbed to a severe TBI before hospital admission, will also be excluded from the hospital-based reports. A study in Germany noted that an alarming 68% of head injury fatalities occurred before arriving at hospital.[44]

A tri-modal age-specific TBI incidence is often found in population-based studies with peaks in early childhood (0-4 years), late adolescence/early adulthood (15-25 years) and in the elderly (over 75 years). [4,45] Local reports and audits in South Africa on paediatric TBI have different age cut-offs, i.e. patients under 13, 15, and 18 years respectively. [2,5,13,18,19,22] Injury aetiology varies with age. Inclusion of patients in the 15-25-year-old group will have a significant impact on the findings. Falls would be a prominent cause of injury among young children, whereas RTC injuries are more frequent among older children. Interpersonal injury becomes more common in adolescents and young adults. Age-adjusted data is required for valid comparisons between different regions or countries. [5]

Even though TBI is so common, accurate data on incidence, longer term outcomes and the effects of TBI on the family are scarce. Whilst the burden of TBI is significant globally, the scale varies by region. The burden of TBIs in South Africa and other LMIC are greater than in high-income countries. [3,4]

3.4 Literature review: TBI in children

TBI is a commonly affects children all over the world and represents a global public health concern. The effects of childhood TBI extend beyond the personal injury, with burdens on the health-care system, scarce resources for rehabilitation and school systems, and a substantial socioeconomic impact on families.[4]

TBI remains the leading cause of mortality in children in developed countries. Children have the highest rate of emergency department visits for TBI of all age groups.[8] In 2013 in the United States there were approximately 640 000 TBI-related emergency department visits among children aged 14 years and younger, 18 000 TBI-related hospitalizations and 1500 TBI-related deaths. Data from large health networks suggest that 80% of children with mild TBI present to primary health care physicians and centres and not to hospitals, indicating that the true incidence is severely underestimated.[46]

Paediatric TBI differs from adult TBI. A child's developmental trajectory can be disrupted by an injury of any severity to the developing brain. Although most children recover well physically, they often experience changes in cognition and behaviour that may only emerge over time. Post-TBI health problems that affect learning, self-regulation, and social participation are associated with significant social and financial challenges in becoming productive adults. [4,46]

Incidence and Prevalence

TBI affects children worldwide and the incidence ranges broadly, with substantial gaps in robust data particularly in LMICs. Broad definitions of TBI and differences in study methodology contributes to enormous differences between countries. Accurate data for TBI prevalence is even more limited. [6,47]

Age-adjusted hospital discharge rates after TBI were available for the USA, Canada, Europe and South Africa. Despite uniform approaches to collect data, experience in Europe has shown that wide variation in reported incidence and mortality rates exists between countries. Interpretation of such data are thus restricted. No reliable nationwide data are available on the incidence of TBI in China and India (population of 1.3 billion each).[6]

Country	Age-adjusted hospital discharge rates after TBI per 100 000
USA [8]	69.7 – 106.3
Canada [48]	47.5 – 83.1
Europe [49]	81.0 – 643.5
South Africa [50]	316.4

Table 3.2. Age-adjusted hospital discharge rates after TBI. [6]

Population-based incidence rates were only available for the USA, Canada and New Zealand.[6]

Country	Population-based incidence rates per 100 000 per year
USA [8]	823.7
Canada [48]	979.1
New Zealand [51]	811.0

Table 3.3. Population-based incidence rates. [6]

There is a paucity in data regarding the TBI rate in children and only a few single centre studies are available of patients presenting to single centres, with limited and varied inclusion criteria (e.g. ICU admissions only). Some demographic information can be gained from these, but no accurate incidence rates.

Author (Year)	Country	Number	Study Design	TBI Rate (Age in years)
Greene et al. (2014) [52]	United States	71476	Retrospective; 25/50 US states sampled; TBI severity/cause not indicated	25.1% (0-4) 12.2% (5-9) 18.3% (10-14) 44.4% (15-19)
Crowe et al. (2009) [53]	Australia	1115	Retrospective; Single center	16.5% (<1) 49.1% (<3)
Parslow et al. (2005) [14]	United Kingdom	623	Retrospective; ICU admissions only	5.1 per 100 000 (0-4) 4.8 per 100 000 (5-9) 6.9 per 100 000 (10-14)
Schrieff et al. (2013) [5]	South Africa	137	Retrospective; Single center; Severe TBI only	Peaks: 4, 6 ,7 & 10 years
Lalloo et al. (2004) [19]	South Africa	37 610	Retrospective; Single center; Extracted from database	9% of children who presented to hospital had TBI
Zhu et al. (2014) [54]	China	455	Retrospective; Single center; Mild TBI; Survey-based outcomes	63.3% (0-2) 31.9% (3-9) 4.8% (10-14)
Udoh et al. (2013) [55]	Nigeria	127	Prospective; Single center; Small study design	28.3% (0-3) 17.3% (4-6) 26.8% (7-10)

				27.6% (11-17)
Chabok et al. (2012) [56]	Iran	668	Retrospective; Single center	25% (0-5) 20% (6-9) 17% (10-13) 40% (14-18)
Kim et al. (2012) [57]	Korea	2856	Prospective; Utilized ICD coding	55.5% (0-4) 24.9% (5-9) 18.9% (10-14) 9.5% (15-18)
Agrawal et al. (2008) [58]	Nepal	43	Retrospective; Single center; Small sample size	27.9% (0-4) 32.6% (5-8) 18.6% (9-12) 20.9% (13-16)

Table 3.4. Some examples of limited studies on paediatric TBI worldwide.

Gender

Males consistently show a higher incidence of TBI with ratios ranging from 1.5:1 in the US to 2.8:1 in the UK. [53,59] Male to female (M:F) incidence ratios are similar across developed and developing contexts. In boys less than 10 years old there is a 1.4-times higher incidence of TBI and a 2.2-times higher incidence in boys aged 10 years or older compared to girls.[60]

Lalloo and Van As showed a M:F ratio of 1.4:1 in South African children (aged 13 years and below) who presented to RCWCH over a decade.[19] In Denmark, a similar M:F ratio (1.4:1) was reported in 0-14 year olds.[61] The M:F ration in rural China was 2.5:1 for children 0-15 years of age. [54]

The M:F ratio in Sweden was 1.46:1 across all ages.[62] Epidemiological data in other developed and developing countries showed a much higher trend towards male predominance in populations including adults. A M:F ratio of 3:1 was reported in Aquitain, France.[63] Data from Pakistan revealed a similar trend in distribution of incidence across gender for all ages with a M:F ratio of 3:1.[64] Nell and Brown reported a M:F ration of 4:1 for TBI in South African adults, considerably higher than those in other developing countries.[50]

A possible reason for the higher incidence of TBI found in males compared to females could be the increased risk-taking behaviour. This difference becomes more pronounced with increased age. Interpersonal violence accounted for 41.5% of all nonfatal TBI and 34.6% of fatal TBIs in individuals 15 years and older, providing some explanatory hypotheses for the skewing of the incidence of TBI in South Africa.[4,50]

Age

TBI affects individuals across the lifespan. The incidence of TBI varies considerably among different age groups in both developed and developing countries.

Bruns and Hauser identified a tri-modal age-specific TBI incidence in a US-based study, with peaks in:

- early childhood (0-4 years),
- late adolescence/ early adulthood (15-24 years) and in
- the elderly (over 75 years).[4,45]

Similarly, Bauer and Fritz found two peak periods of TBI in children:

- < 4 years old and in
- mid- to late adolescence.[65]

In developed countries, a higher TBI incidence is reported for children younger than 1 year of age (190-350 per 100 000) than children aged 1-4 years (100-345 per 100 000). Incident rates further decline in 5-15-year olds (146-273 per 100 000).[45] The overall incidence rate for the paediatric population in developed countries was higher than the general population, with the highest TBI incidence rate in the US in the age group 0-4 years (118.5 per 100 000).[66]

TBI incidence in South African adults differ from the trends seen in developed countries. Earlier research in Johannesburg reported the highest peak in incidence (409 per 100 000) in the 25-44-year age group, considerably higher than the incidence in the 15-24 year age group (360 per 100 000).[45] Furthermore, a decline in incidence was observed in elderly South Africans (63 per 100 000), in contrast with the increasing trend observed in developed countries entering the seventh to eighth decade of life.[45,50]

Trends in paediatric incidence of TBI in South Africa appear to be similar to developed countries. In the profile of children with head injuries treated at the trauma unit of RCWCH (1991-2001), half the sample was observed to be under the age of 5 years and 20% under the age of 2 years. [19]

3.5 Literature Review: Mechanism of Injury

The leading causes of severe TBI in most of Africa are RTCs, interpersonal violence, and falls.[4]

The three main categories were identified by De Villiers et al in 1984 and together accounted for 88.4% of all causes of HI in their study. The main causes of HI vary significantly ($p<0.01$) with age. Falls accounted for most injuries in children under 1 year old. In the 1-5-year age group and the 6-14-year age group, transport-related injuries were the most common cause of admission.[67] In Laloo's study, falls were the leading cause of TBI admissions (41%), followed by RTCs (19%).[19] Pedestrians were the victims in more than half of RTCs across 4 studies from Africa, Asia and India. [5,54,54,68] On the other hand, vehicle occupants were more likely to suffer a TBI in several reports from Australia, Europe, and the US.[14,69,70,71]

The distribution of causes of fatal TBI across the age groups are RTCs (72.4%), assault/abuse (7.5%) and falls (5.5%).[13]

CDC data from the Unites States indicates that falls predominate in the 0-4-year age group. Falls and being struck by an object are equally common in the 5-14-year age group. RTCs predominates in the 15-24-year cohort.[46] In the US a high proportion of the population lives in apartments above the ground floor, creating a dangerous environment in which a young child might fall from a significant height.[5,72,73]

The leading causes of TBI seem to be similar in Europe and the UK, with falls leading earlier in childhood and RTCs in older children. [4,46,59] In most of Africa (including South Africa) the main role players are RTC's, falls and intentional injuries.[4]

3.5.1 Road Traffic Crash Injuries

According to the WHO, nearly 60% of TBIs are due to RTC injuries.[4] A worldwide increase in motorization has brought more motor vehicle crashes, particularly in LMIC.[74] In the last two decades there were a 46% increase in deaths due to RTCs. RTC injuries are the leading cause of death, significantly above HIV/AIDS mortality rates in children aged 5-14 years in Cape Town, South Africa.[75]

Unrestrained Passengers

The most effective way to reduce injury severity and to save lives in motor vehicle collisions is the use of appropriate restraints. Unrestrained passengers in a frontal crash are most likely to suffer a head injury.[76] It is known since 1984, through studies done in the United States, that child safety seats which are correctly installed can reduce or prevent injury and death in children by 70-90%.[77]

Failure to apply adequate child restraints in a motor vehicle is a major risk factor for death and serious injury. Despite overwhelming evidence of the benefits of appropriate child restraints in motor vehicles, the rate of use varies considerably across countries with the lowest rates reported in LMICs. Rates as low as 10% have been observed in SA by Kling et al in 2011.[78]

According to the South African National Road Traffic Act (NRTA) 93 of 1996 (Regulation 213(6A) in force from 1 May 2015, all children under the age of 3 years will be required to only travel in a car if they are secured in a car seat. The car seat must be on the rear seat and rear facing until the age of 1 year old. Failure to strap a child under the age of three into a car seat will result in a traffic fine being issued.[79]

Sadly, despite legislation and 25 years of campaigning to promote road safety, the number of appropriately restrained passengers has not improved significantly from 1991 to 2015. Of the 4517 documented passengers in RTCs seen during this period at RCWCH, only 27% (n=1 222) were restrained.[80,81]

Passengers traveling on the back of a goods vehicle

SA is a developing country and mobility in any shape and form is valuable. People expose themselves to risks travelling to work, school, or hospital. A common example of this risk-taking behaviour is passengers on goods vehicles (i.e. traveling on the back of a bakkie).[81]

In November 2016 the government published two amendments to the laws regulating transport of passengers within the goods department of a vehicle.

- Regulation 250 of the NRTA No. 93 of 1996 now specifically states that ‘No person shall on a public road carry any person for reward in the goods compartment of a motor vehicle.’ [82] The new legislation does however not forbid the conveyance of persons (adults or children) in the goods compartment of a bakkie, if they are conveyed without any charge being levied for the journey.

- Regulation 247 of the NRTA No. 93 of 1996 permits passengers in the goods compartment of a vehicle if the sides of the vehicle are enclosed to a height of at least 350mm above the seating surface or 900mm above the surface on which the person is standing.[82] There is no need for a roof covering and roughly the length of a ruler is offered as protection as enclosure.

Both these above mentioned potential causes, unrestrained minors, and transport of passengers in a goods compartment can cause severe morbidity and mortality.[19] Remarkable success in changing lifestyle health concerns, such as smoking and obesity has been reached worldwide.[75] It is the responsibility of every health care worker to emphasize the value of seat belts and the necessity of proper child restraints, and actively promoting the new legal requirements.[81]

Pedestrian RTCs

Transport-related TBIs were the most frequent cause of injury in a retrospective study undertaken in the Cape Peninsula (1966-1981). Pedestrian RTCs formed the largest subgroup (71%) in this aetiological category.[67] These findings were echoed in the subsequent investigations done over the last two decades. [2,5,18,19,22,83]

Selekci et al. identified the high incidence of pedestrian injury in childhood in the year 1968. They claimed that 'the high risk of neurotrauma of pedestrian children seems obviously related to the need for children to cross roads on the way to schools, friends, or playgrounds, and perhaps, sadly, to the absence of play areas or streets in some localities. Another factor is, no doubt, children's lack of awareness of the danger from road traffic.' [84]

Amongst children younger than 15 years, those between 5 to 9 years have been shown to be at greatest risk of RTC injury and mortality.[15] The cognitive processes involved in judgement, decision-making, reasoning and impulse control in children at that age group are rudimentary and therefore this age group are at an increased vulnerability in the road environment.[85]

Studies are needed to describe epidemiology of child road traffic injuries, to form targeted prevention strategies and to strengthen evidence needed to persuade policy makers to provide adequate prevention measures.[86]

3.5.2 Falls

Falls are one of the leading mechanisms of injury (41%) in young children admitted to hospital with a head injury. Most of these HIs are minor but can be associated with morbidity from post-concussion syndrome. A small proportion result in cranial or intracranial injury. Most falls resulting in TBI occur in and around the home. Infants and very young children are at the greatest risk and the prevalence decreases with age.[19,87]

Falls may be the most common cause of injury in samples of children with mild-to-moderate rather than severe TBIs.[83] The demographic profile of severe TBI admissions to RCWCH (2006-2011) established that falls were not the leading cause of injury in the 0-4 age group. Falls accounted for only 10.2% of TBIs in this young age group, third most common cause to pedestrian (44.9%) and passenger RTC (22.45%) incidents.[5]

The risk of severe TBI from a fall in a young child is ill defined. Falls produce impacts of low velocity and lead to focal insults. RTCs often lead to diffuse axonal injury with far worse or even fatal outcomes.[88]

Very little is known about the about the different fall mechanisms that have the potential to cause skull fractures or intracranial injury and subsequently lead to potential neuropsychological morbidity.[87] Most infant falls are short vertical falls.[89] There are two schools of thought about the significance of these falls: one emphasis that mortality is rare while the other highlights the potential for fatality.[90,91]

Estimating a fall height threshold for serious TBI is a much-debated topic. This is particularly important when the likelihood of a stated mechanism being the cause of the injury, a situation common when non-accidental injury may have occurred. The largest collection of controlled laboratory experiments of infant skull fracture reported in the literature to date are the Weber studies of 1984 and 1985.[92,93] The Weber studies consisted of drop tests using 50 infant cadavers ranging in maturity from newborn to 9 months. The supine test subject was allowed to fall freely from a height of 82cm (32") recreating a posterior head impact onto different surfaces. During the first Weber study the impact surfaces were stone tile, carpet with 0.3cm foam, and 1-cm foam-backed linoleum. During the follow-up study in 1985 the impact surface was changed to a 2-cm foam rubber mat and 8-cm folded camel hair blanket. A 100% (15/15) incidence of fracture was found during the first study onto hard impact surfaces. A sizable difference in fracture incidence was documented during the impact onto soft surfaces (14% - 5/35). [92,93]

Impact Surface	Number of Test Subjects	Fracture Incidence
Stone Tile	5	100% (5/5)
Carpet (with 0.3cm foam)	5	100% (5/5)
Linoleum (with 1cm foam-backed)	5	100% (5/5)
Foam rubber mat (2cm)	10	10% (1/10)
Folded camel hair blanket	25	16% (4/25)

Table 3.5. Data summary of the Weber 1984 and 1985 studies.[92,93]

The usefulness of these results in the development of infant skull fracture tolerance levels is limited as the test subjects and the impact surfaces were not instrumented. The impact force and head acceleration associated with the different impact surfaces and fracture outcomes unfortunately remain undefined.[91]

Another limitation of the Weber studies is that no detail was provided regarding storage methods used for the infant cadavers. Proper freezer storage will maintain the response of bone. In contrast, extensive dehydration and embalming can result in increased brittleness of bone.[94]

Weber concluded that each fall of an infant from the height of a table may cause a cranial fracture, which might be fatal. From the forensic aspect it remains the duty of the treating physician to suspect child mishandling and all circumstances must be taken into consideration.[92,93]

Since the Weber studies the tolerance of the paediatric head to trauma has been the focus of a great deal of research and effort. Experimental studies have been very informative, but are limited in their predictions by sample size, experimental methods, equipment, and study focus. The 2009 International Mechanical Engineering Congress and Exposition stated that given these reports and consistency of the results, it appears that the Weber cadaver fracture response was representative of more recent injury assessment test devices.[91,95,96,97]

The UK-based Confidential Enquiry into Head Injury in Childhood (2009) formed a large dataset and provided the opportunity to describe the object fallen from, the neurophysiological status and CT scan findings in children under the age of 6 years. The original dataset included 5700 children aged 0-15 years, 2634 of whom presented following a fall and aged below 6 years.[87]

The study did not include the many children who were assessed in the emergency department and discharged home. Due to the uncertainty about mechanism, children referred to social services were excluded. Data were collected during a 6-month winter period and seasonal variation in injury type were missed.[87]

Despite these limitations, this study added valuable information and extends our understanding of HI from falls and the risk of skull fractures or intracranial injury given the age of the child and item fallen from:

- The greatest proportion of children admitted to hospital following a possible HI from a fall were under 1 year of age.
- The mechanism of fall with the highest risk of acquiring skull fracture or intracranial injury is an infant who is dropped from a carer’s arms. The odds ratio of skull fracture or intracranial injury compared to fall from standing or sitting were found to be 6.94 (3.54 to 13.6; $p<0.001$).

- Children dropped on the stairs had a greater likelihood of an abnormal CT scan [23.3% (95% CI 13.2% to 37.8%) (10/43)] compared with those dropped on the floor [14.2% (95% CI 10% to 19.9%) (27/190)].
- Children who fell from infant products (i.e. changing table or baby carriage) or from a building (i.e. window, wall, attic) also had an increased risk of injury.
- Falls down stairs were one of the most common reasons for hospital admission, second only to falls from standing or sitting. Despite the culture of anxiety concerning children falling down stairs, these falls resulted in a low prevalence (3.4%) of skull fracture or TBI.
- One fifth of children had a CT scan performed to confirm or exclude TBI.
- 5.9% of these children had abnormal CT scans.
- The most common finding was a simple linear skull fracture.
- 1 in 4 of patients with a skull fracture had an underlying extra-axial haemorrhage.[87]

Multiple factors should be considered when evaluating an individual for possible TBI sustained from a fall:

- Angle of the fall
- Impact surface
- Landing position. [87,89,91,98]

These data can be applied by treating physicians to inform decisions about the plausibility of injury explanations when assessing infants and young children with suspected physical abuse. The importance of carrying children safely, particularly while ascending or descending a flight of stairs, should be emphasized to promote prevention initiatives.[87]

3.5.3 Intentional Injuries

Child abuse or non-accidental injury(NAI) is a unique aspect of TBI in children. Abusive trauma is a common cause of childhood death and in infants < 6 months old, child abuse is second only to sudden infant death syndrome. The reported incidence of non-accidental head trauma in infants is variable. The consensus is that in children under 2 years of age, the leading cause of serious TBI is NAI.[99,100]

Risk Factors for NAI

The risk is inversely proportional to age. Young children are particularly vulnerable, they are defenceless, the skull is thin, neck muscles are weak and being non-verbal or sometimes too injured, they are unable to provide a reliable history. Investigations by the Department of Social Development are required to eliminate further risks for the injured child and any other children in the home environment.[99,101]

Violence against children contributes greatly to the TBI disease burden. Africa's homicide rate for under 5-year-old children is more than six times the incidence in Western countries- unenviably the highest in the world.[102,103] Child abuse is a distressing reality for children worldwide and occurs among all income categories and all cultures.[99]

Many factors may contribute to child abuse: the background of parents, the environmental situation, and attributes of the child themselves. Children are not responsible for the harm inflicted upon them, but certain characteristics have been identified that increase their risk of being maltreated.[104]

Parental factors	Environmental factors	Child factors
• Young age • Low education • Single parenthood • Large number of dependent children • Lack parenting skills	• Family is experiencing multiple stresses • Social isolation • Disorganized family • Intimate partner violence • Overcrowding	• Child younger than 4 years of age • Child who is the product of an abusive relationship • Male children

• Non-biological caregivers living in home • Substance abuse and/or mental health issues • Depression in family • Unwanted pregnancy • History of child abuse in family of origin	• Poverty, unemployment, or lack of opportunity to improve the family's resources	• Lack of attachment between child and parent, i.e. those born prematurely, non-biological children • Special needs that may increase caregiver burden (e.g. mental health issues, chronic physical illness, disabilities) • Unwanted baby

Table 3.6. Risk factors for Child abuse. [104]

Non-accidental injury results from a deliberate action by an individual who intentionally threatens, attempts, or inflicts physical harm on another. Accidental injury results from unforeseen events that cause physical trauma to the body, without the intent to cause harm.[104]

A retrospective chart review of children presenting to the RCWCH trauma unit with a diagnosis of non-accidental HI found that 53% of the children were deliberately injured (median age 2 years) while 47% were allegedly not the intended target of the aggressor (median age 9 months). The majority (85%) of these assaults occurred in the child's own home. This so-called shielding phenomenon includes a broad spectrum, from the child sustaining injuries as an innocent spectator to cases where an adult target positions the child in defence against an attacker.[103,105]

Neuro-imaging in NAI

Radiological abnormalities may provide the initial and occasionally the only evidence that abuse has taken place. The literature dates to the last century (1860) when Tardieu published what appears to be the first article in which the concept of the battered child was described.[106]

Almost a century later, John Caffey (1946) described the association of multiple fractures of the long bones in infants with chronic subdural haematoma.[107] Since these two landmark papers the various physical manifestations of NAI have been extensively reported and the body of literature has grown significantly.[108,109,110]

Skull fractures caused by NAI may not necessarily differ from those occurring in accidental trauma. Any type of fracture might occur. In certain cases, abuse is suspicious if features which are not usually seen in uncomplicated accidental trauma are found. Knowledge of the biomechanics of typical childhood injuries is vital when assessing any injury as a possibly NAI.[100,111]

- Complex fractures
- Bilateral skull fractures
- Multiple skull fractures
- Skull fractures of various ages
- Depressed fractures, particularly of the occiput
- Diastatic fractures

Table 3.7. Suspicious features found more commonly in skull fractures caused by NAI. [100,111]

The two main causative mechanisms in NAI that result in intracranial manifestations are direct impact forces (blow to the head) and indirect shearing forces (violent shaking).[100,111]

The largest age group for shaking type injuries is in children less than 1 year of age (shaken infant syndrome), but it may occur up to the age of 2 years old. The small infant has a relatively large head in relation to the body, and weak neck muscles resulting in poor head support. The infant’s brain is relatively small in relation to the size of the cranial vault and as the meninges are loose, it moves in different directions which generates shearing forces within the skull and brain and produces the associated subdural haemorrhage.[109,111,112,113]

The major intracranial injuries in abuse are subdural haemorrhage, cerebral oedema, and hypoxic ischaemic encephalopathy. There are features of subdural haematomas (SDH) that are unusual in accidental trauma and suspicious of NAI (Table 7). Intracerebral and intraventricular haemorrhage, extradural haematoma and shear injuries with petechial haemorrhages are infrequent manifestations.[100,113]

- SDH without a skull fracture implies shear forces and possible shaking injury - Bilateral SDHs - SDHs of different ages - In the presence of retinal haemorrhages acceleration-deceleration force is implied - Acute interhemispheric fissure or falx haemorrhage – in accidental trauma subdural bleeds do not usually extend into the falx.

Table 3.8. Features of SDH suspicious of NAI. [100,113]

From a systematic review in 2009 by the Welsh Child Protection Group, the recommended imaging strategy for an infant with a suspected NAI brain injury is an early CT scan, followed by MRI (magnetic resonance imaging) in cases of abnormality or where there are ongoing concerns. MRI revealed new information regarding SDH or another intracranial abnormality in a quarter of cases. SDH or subarachnoid haemorrhage were the most common additional findings. The importance that these images in suspected NAI cases should be reviewed by radiologists with expertise in paediatric neuroradiology and who are familiar with the patterns of injury seen in intentional injuries.[114]

Reporting cases of suspected NAI and SA law

All professionals or indeed anyone who encounters children, have a moral but in South Africa also a legal responsibility to report cases of suspected child abuse.[115]

The Children's Act (Act 38 of 2005, as amended by Children's Amendment Act 41 of 2007) states that reporting cases of suspected child abuse is mandatory, and it is important to note that proof of abuse is not required:

'failure to report a reasonable conclusion that a child has been abused or deliberately neglected would make the health professional liable to be found guilty of an offence and liable for conviction…'

The same Act protects those who report suspected child abuse in good faith:

'There will be no legal proceedings against such a person if the notification was given in good faith in accordance with the Act.' [115]

It is thus the responsibility of every health care worker and any person responsible for children to detect, report and prevent child abuse. Doctors, nurses, dentists, social workers and teachers, and persons employed by or managing a children's home have a statutory duty to report child abuse. Failure to recognise these children at risk can have disastrous consequences for such children. Studies have shown that 60% of abused children are liable for further injuries if not followed up, and 10% will eventually receive fatal injuries.[116]

3.6 Literature review: Previous reports on paediatric TBIs in South Africa

Most reports on paediatric TBIs in SA are hospital based and limited to two single centres, i.e. RCWCH in Cape Town and the King Edward VIII Hospital in Durban.[2,5,19,22,83]

RCWCH is the centre that has most consistently reported on paediatric TBI in SA. Three reports on children presenting with HIs spanned over more than three decades (1984-2001). [19,67,83] The largest profile (n = 37 610) described by Lalloo and Van As analysed records over a 10-year period.[19] The data collection form used in the RCWCH Trauma Unit was designed primarily for record keeping. Kibel et al. identified in their 5-year review a low overall number of coding errors (0.7% of all items). The percentage error for the coding of cause of injury was found to be the highest (6.8 ± 6.4%).[83] Two additional reports from RCWCH focused solely on severe TBI.[2,5]

The mechanism of injury varies as a function of age. While falls dominate in the under 1-year old group (70%), RTC injuries (specifically pedestrian vehicle accidents) contribute to the majority of TBI in the 1-to-5-year-old and 6-to-14-year-old groups (64%). Transport-related injuries falls and assault/abuse together accounted for 88.4% of all causes of head injury.[67] In all 5 of the above-mentioned reports most children with severe TBIs were victims of pedestrian vehicle accidents and falls accounted for the largest number of injuries overall. Boys (±60%) outnumbered girls in all these reports.[2,5,19,67,83]

The two retrospective reviews from Kwazulu-Natal included children <15 years and <18 years respectively. The inclusion of the 15-to-18-year-old group showed the increase in incidence of assault as these adolescents approached adulthood. The median age for TBI children (0 to 18 years) treated by the Pietermaritzburg Metropolitan Trauma Service (PMTS) was 6.4 years. In the group of patients that sustained a TBI as result of an assault, the median age was 15 years.[18]

Although RTCs were identified as the greatest cause of paediatric head injury in the King Edward VIII Hospital setting, no breakdown was given of pedestrian, passenger or other transport related injuries.[22]

The first report published in 1984 that demonstrated the alarming number of non-natural deaths in children obtained information from the South African Police Mortuary. The majority of fatal TBIs (72.4%) were caused by RTCs. Three decades later transport related injuries remain the area where successful intervention and prevention could make the biggest impact.[13]

Despite the heterogeneity in defining HI versus TBI and the lack of national reports on paediatric TBI in SA, one fact remains clear: The importance of TBI in children is neglected. Research focusing on primary prevention, emergency care and long-term effects of TBI on the patient and society should be promoted.[2,5,13,18,19,22,67,83]

Author (ref) Year of publication	Knobel et al, 1984. [13]	De Villiers et al, 1984. [67]	Kibel et al, 1990. [83]	Semple et al, 1998. [2]	Lalloo and Van As, 2004.[19]	Okyere-Dede et al, 2013. [22]	Schrieff et al, 2013. [5]	Buitendag et al, 2017. [18]
Study Participants (n)	819	1820	7009	102	37 610	506	137	563
Inclusion criteria	Fatal head injuries	Head injury patients	Head injury patients	Severe TBI	Head injury patients	Head injury patients	Severe TBI	TBI patients
Study design	Retrospective analysis of official death register at the South African Police Mortuary in Cape Town	Retrospective analysis from hospital records of head injury patients admitted to RCWCH and Groote Schuur Hospital.	Retrospective analysis of computerized data base of children who presented to the RCWCH Trauma Unit	Retrospective analysis of all children admitted to the RCWCH Trauma Unit with severe TBI	Retrospective analysis of computerized data base of children who presented to the RCWCH Trauma Unit	Retrospective review of prospectively collected electronic database of children who presented to the King Edward VIII Hospital	Retrospective review of all patients with severe TBI who required intracranial monitoring at RCWCH	Retrospective review of prospectively collected electronic database of children who were admitted by the Pietermaritzburg Metropolitan Trauma Service
Study period	15-year period 1 July 1966 – 30 June 1981	15-year period July 1966 -June 1981	5-year period 24 April 1984 – 31 March 1989	4-year period 1990 – 1993	10-year period January 1991 – December 2001	3-year period 1999 – 2001	5-year period June 2006 – April 2011	4-year period December 2012 – December 2016
Age range	< 15 years	< 15 years	< 15 years	< 14 years	< 13 years	< 12 years	0-15 years	≤18 years
Median age (years)	ND	ND	4.9	ND	4.9	6	6.1	6.4
Male (%)	67	66.74	ND	56	59	65	65	71
MOI (%)								
Transport	72.4	46.98	19.66	ND	19.1	63	79.56	43
Pedestrian RTC	ND	23.19	15.18	83	12.4	ND	54.74	33
Passenger RTC	ND	2.42	2.44	ND	3.9	ND	21.17	10
Other RTC	7.5	21.37	2.04	ND	2.8	ND	3.65	ND
Assault/Abuse	5.5	8.52	3.34	ND	1	5	8.03	19
Falls	14.6	30.99	57.54	11	41.2	23	5.11	18
Other mechanism	36.19	13.51	19.46	6	20.4	9	7.3	20
Severity (%)								
Mild	ND	ND	ND	0	81.9	ND	0	81
Moderate	ND	ND	ND	0	16.3	ND	0	12
Severe	ND	ND	ND	100	1.8	9	100	7
Outcome (%)								
Surgical	0	ND	ND	9	ND	3.8	ND	11
Mortality	100	4.2	ND	56.86	0.2	3.6	14.6	1.5

Table 3.9. Summary of literature on paediatric TBIs in South Africa.

Chapter 4. CT scanning

4.1. Evolution of the CT scanner and clinicalpractice

On presentation to the emergency department (ED), a delay in the diagnosis of a severe TBI may result in permanent disability or death. Currently computer tomography (CT) is the main imaging modality used to provide rapid identification and management of children with these injuries.[117]

The 1960s is perceived as a decade of design revolution. The Beatles had their first recording session with Electrical Musical Industries, Ltd (EMI) in 1962. The money generated by record sales and the Beatles' meteoric success changed the history of modern radiology and medicine forever. The EMI basic science researchers thrived in a cash-rich environment. Dr Godfrey Hounsfield, an electrical and computer engineer spent years exploring methods of producing an image by using differential X-ray attenuation values.[118,119]

The first experimental computer axial tomography (CAT) scan was constructed in 1967. It required 4 minutes per slice and 7 minutes per reconstruction. The scan of the mouse took 9 days to complete but produced a recognizable image.[118,119]

Dr Allan Cormack, a particle physicist of South Africa showed that multiple measures of radiograph attenuation around a target enabled one to compute an image of that target. There was unfortunately little practical application of this concept without more powerful computers.[120]

More than a decade later (1979) Hounsfield and Cormack, who never met, both received the Nobel Prize in Physics and Medicine for the CAT scan, the 'greatest advance in radiologic medicine since the discovery of the X-ray.' [121]

Computed axial tomography (CAT) gradually morphed into computed tomography (CT). CT scanning has come a long way since the 1960s and with each technical advance, new CT scan applications arose. CT images were obtained one slice at a time and required 30 or 45 minutes to complete. The helical CT scanner, also called spiral CT scanner obtains a volume of X-rayed tissue and can be performed in less than five minutes. Being much faster, more user friendly and with less need for sedation in children helical CT scans have become the main diagnostic imaging tool in the radiology department.[122]

There has been a steady increase in the number of CT scans performed for evaluating TBI in children. Between 1995 and 2005 the use of CT scans for TBI has doubled.[123,124]

A multitude of reasons have been proposed for the increased use of CT scanning:

- CT scanners are now widely available, and ease of access resulted in overuse of imaging in patients with low risk of intracranial pathology. In a study by a team from Inova Fairfax Hospital for Children in Falls Church, Virginia, a significant number of children (40%) who received CT scans did not have clinical justification for the procedure. [125,126]
- Obtaining a normal CT scan in a patient with a mild TBI can facilitate safe discharge.[127,128]
- The majority (40-60%) of neuroimaging are due to minor head injuries, with only 10% - 14% demonstrating findings of intracranial pathology.[125,127]
- Following transfer of a patient to a paediatric trauma centre, CT examinations are duplicated in some instances. [127,128]

4.2. Associated risks

Radiation risk

Obtaining a CT scan of the brain is resource intensive and has associated negative effects. CT scans exposes patients to ionizing radiation that causes cell damage and an increased lifetime excess cancer risk. [129,130,131,132,133]

The understanding of the hazards of radiation are largely based on studies of survivors of the atomic bombings of Hiroshima and Nagasaki in Japan during the final stages of World War II (1945). Relative risk models were generated that showed genetics, sex, age at exposure and time since exposure all need to be factored in when calculating susceptibility to radiation cancer mortality risk.[129,130,131]

The casual approach to the use of CT scans changed in 2001 when Dr David Brenner, a physicist at the Columbia University's Centre for Radiological Research made the following statements that caught the attention of both the academic and popular press:

- Children's cells divide more rapidly than adults to assist in their rapid rate of growth. However, this renders them more radiosensitive than adults and the younger the child the higher the radiation-induced cancer risk.
- CT scans may cause lethal malignancies later in life and children have more years of their life to await the potential impact of the radiation.
- Lifetime cumulative radiation exposure is associated with increased risk of malignancy.
- The lifetime excess risk of any incident cancer for a CT head scan is about 1 per 1000 head scans for children younger than 5 years old, decreasing to about 1 per 2000 scans for exposure at age 15 years.
- The lifetime cancer mortality risk attributable to the ionising radiation dose from a single CT head scan is about 1 in 1500 in a 1 year old and about 1 in 5000 in a 10-year-old.
- The lifetime excess risk of any incident cancer for children are 1 per 500 scans irrespective of age at exposure for an abdominal or pelvic CT scan.[129,130]

The methodology used by Brenner to derive radiation-induced cancer risk has been debated. The CT scan is irrefutable the most important imaging modality available to the trauma patient. Nevertheless, we did become more sensitive to the fact that this study offers a low but not insignificant dose of radiation. It is the shared responsibility of the clinician and radiologist to be aware of these risks to make a responsible decision regarding the use of medical imaging.[130,133]

Cause of Death	Deaths per 1000 individuals per year
Cancer not related to radiation exposure	228
Road Traffic Crash	12
Living with a smoker	10
One abdominal CT scan in a child (any age)	2
One head CT scan in a child (<5years)	1
Drowning	0.9

Table 4.1 Lifetime mortality risk per 1000 people.[134]

Exposure	Dose (mSv)
Arm x-ray	0.001
Dental x-ray	0.005
Chest x-ray	0.010
Domestic airline flight in the US (5hrs)	0.017
Smoking 1 pack of cigarettes per day (1 year)	0.36
CT Head	2.0
Natural background US per year	3.1
CT Chest	4 – 7
CT Abdo/Pelvis	8 – 10
Coronary CT angiography	16
Astronaut on space station for one year	72

Table 4.2. Common radiation exposure sources. mSv = millisieverts [135]

CT dose reduction should be a priority:

- Reduce CT related doses in individual patients, by following
  - child-sized protocols, [136]
  - the ‘image gently’ initiative [136] and
  - the ‘as low as reasonably achievable’ (ALARA) principle. [137,138]
- When appropriate, replace CT scan use with non-ionized radiation modalities, i.e. MRI, Ultrasonography. [122]
- Avoid multiple or unnecessary CT scans. [122]

Sedation associated risks

Cooperation for diagnostic studies is a frequent indication for procedural sedation in children. This leads to sedation-acquired risks. Controversies exist regarding the safest and most effective agent for procedural sedation in children who require a CT scan.[139]

Hypoventilation
Apnea
Airway obstruction
Aspiration
Cardiopulmonary arrest

Table 4.3. Risks of Procedural sedation [139,140]

A variety of sedative agents have been evaluated:

- Chloral hydrate [139]
- Pentobarbital [139]
- Propofol [141]
- Midazolam [140]
- Etomidate [142,143]
- Ketamine [144,145,146]

In the cited literature, pentobarbital outperformed most.[139,140,141] Pentobarbital is not readily available in South Africa.[146]

Agent compared to Pentobarbital	Pentobarbital outperformed agent
Chloral hydrate	Less adverse effects
Midazolam	More successful sedations
Propofol	Less adverse effects

Table 4.4. Sedative agents compared to pentobarbital.[139,140,141]

In comparison to etomidate, pentobarbital was however overshadowed with respect to successful sedations, shorter sedation time, and less adverse effects. Etomidate is a strong contender to be the safest and most effective sedative agent for children undergoing CT head scans. [142,143]

Ketamine is a rapid-acting dissociative agent that produce rapid onset of deep sedation and analgesia with minimal respiratory depression and cardiovascular side effects. Potential side effects of ketamine are more commonly noted in adults and the presence of these adverse events in the paediatric population is controversial. Compared with other narcotic agents, ketamine is unique because it provides deep sedation while still maintaining upper airway patency. [144,145,146]

Ketamine provides an attractive alternative for sedation in these patients. Its use might be limited when total immobility is required during longer imaging procedures, as ketamine is sometimes associated with non-purposeful movements. [144,145,146]

More common potential reactions	Other reported reactions, less clinical important
• Hallucinations • Delusions • Emergence Delirium (Less common in children) • Increased production of tracheobronchial secretions and saliva • Hypercarbia • Sympathomimetic action (Tachycardia and hypertension- not seen in sedative dose)	• Ataxia • Nystagmus • Myoclonus • Random limb movements • Opisthotonus

Table 4.5. Potential side effects of ketamine. [144,145,146]

4.3. Clinical Decision Rules

Guidelines agree that for children with moderate or severe TBI (with a GCS < 13), a CT scan is recommended. However, many studies have found conflicting evidence over the use of clinical indicators to predict intracranial injury in children presenting with a mild head injury. Altered mental state, loss of consciousness, vomiting, and an abnormal neurological examination have been identified to be more prevalent among children with a TBI. Unfortunately, inconsistent results regarding the specificity and predictive value of these variables have been observed. [25,147,148,149,150]

Despite the significant increase in the use of CT scans, a small but important number of paediatric intracranial injuries are missed at the first visit to the ED. Cranial CT scans might potentially reduce morbidity and mortality, but it is costly, may be difficult to obtain in children, and exposes patients to radiation.[147]

A retrospective review of CT scans and skull x-rays (SXR) over a 1-year period at RCWCH was done to determine whether fractures identified on SXR can be added to the clinical indications for a CT scan in mild TBIs. In the group of 381 children with mild TBI, 31% had an intracranial abnormality. Of the 49% of patients with a skull fracture, almost half (49%) had an intracranial abnormality identified on CT scan. All children with mild TBI who had drainable collections had an associated fracture. In developing countries where CT scans are not readily available, fractures identified on SXR can improve detection of drainable intracranial collections in these patients with subtle clinical signs. Omitting CT scans in patients with mild TBI could result in missed intracranial abnormalities.[151]

In the 3-year International Multicentre Study of Head Injury in Children, a mere 6.4% (158/2478) of CT scans were pathologic. During this study period skull x-rays were still routinely in use. The incidence of TBI in the minor HI group was as low as 1.6%.[41]

Since this study, there are more than 20 clinical decision rules (CDR) available regarding children presenting to the ED after HIs.[147] These rules aim to help clinicians cope with the uncertainty of medical decision making and make it easier to identify children at low risk of serious brain injury.[148] Clinically important intracranial injuries in children with mild head injury are rare (5%), and injuries requiring neurosurgical intervention occur in less than 1% of children. Nevertheless, it is estimated that one third of children with minor HIs undergo CT scans.[25]

The three CDRs considered to be of highest quality and accuracy are:[25,147,149,152]

i.) CHALICE -Children's Head Injury Algorithm for the prediction of Important Clinical Events (UK, 2006). These guidelines were introduced as a paediatric section to the previous NICE (National Institute for Health and Clinical Excellence) guidelines of 2003. [Appendix 4][149]

ii.) PECARN -The Pediatric Emergency Care Applied Research Network's prediction rule for the identification of children at very low risk of clinical important traumatic brain injury developed by the (US, 2009). [Appendix 5][25]

iii.) CATCH -Canadian Assessment of Tomography for Childhood Head injury (Canada, 2010). [Appendix 6][147]

While these three CDRs are superficially similar, these three CDRs have considerable differences in key areas, namely study population, predictor variables (mechanism of injury, clinical history, and clinical examination), inclusion and exclusion criteria and outcomes.[25,147,149]

During the development of the CHALICE rule, 37.77% (281/744) of CT scan were documented as being abnormal. The study population included patients (0-16 years) with any severity of head injury. Of the 22 722 patients enrolled in this study, only 3.27% (744/22722) had a cranial CT scan.[149]

The PECARN and CATCH studies focused solely on children with minor HI that occurred within 24 hours. The PECARN study included patients under 18 years of age and the CATCH study included patients under 16 years of age. CT scans were performed in 35.3% (14969/42412) and 52.85% (2043/3866) of patients respectively. Abnormalities were identified in 5.2% of the PECARN group and 4.1% of the CATCH group. [25,147]

Despite large cohorts, the prevalence of neurosurgical injury varies from 0.11% to 3.4%, highlighting their heterogeneity. Predictor variables for cranial CT used by clinicians in South African EDs might differ from these CDRs, i.e. outside the developed countries were these CDRs were derived.[117,153]

	CHALICE	PECARN	CATCH
Year	2006	2009	2010
Study Population	UK Multicentre cohort 10 hospitals	US Multicentre cohort 25 emergency departments	Canada Multicentre cohort 10 paediatric teaching hospitals
Age	< 16 years old; mean age 5.7 years	< 18 years old; mean age 7.1 years	< 16 years old; 9.2 years
Study Design	Prospective cohort	Prospective cohort	Prospective cohort
Study Period	31 months February 2000 – August 2002	18 months June 2004 – March 2006	53 months July 2001 – November 2005
Inclusion criteria	All children presenting to the ED Any severity of head injury	Children presenting within 24 hours of head trauma. GCS 14 – 15	Blunt head trauma within 24 hours of injury GCS 13 – 15
Exclusion criteria	Refusal to consent to entry into the study	Penetrating trauma Known brain tumours Pre-existing neurological disorders Neuro-imaging at an outside hospital before transfer Trivial injuries, i.e.: -Ground-level falls -Walking/running into stationary objects -No signs or symptoms of head trauma other than scalp abrasion and lacerations	Penetrating trauma Acute focal neurological deficit Obvious depressed skull fracture Chronic generalized developmental delay Suspected child abuse Patients returning for reassessment Pregnant patients
Study Participants (n)	22 722	42 412	3 866
CT scans performed	744 (3.27%)	14 969 (35.3%)	2 043 (52.85%)
Abnormal CT scans	281 (37.77%)	780 (5.2%); 376 (0.9%) ciTBI	159 (4.1%)
Admissions	1 461 (6.4%)	3 821 (9.0%)	2043 (52.85%) those who had CT
Neurosurgical operation	136	60	24
Intubation or ICP monitoring	157	Excluded from study	6
Mortality	15 (0.1% of admissions)	Excluded from study	0
Sensitivity	98% (95% CI 96.0-100.0)	<2 years: 100% (95% CI 86.3-100.0) ≥2 years: 96.8% (95% CI 89.0-99.6)	98.1% (95% CI 94.6-99.4)
Specificity	87% (95% CI 86.0 to 87.0)	<2 years: 53% (95% CI 51.6-55.8) ≥2 years: 59.8% (95% CI 58.6-61.0)	50.1% (95% CI 48.5-51.7)

Table 4.6 Comparison of CHALICE, PECARN, and CATCH rules. [25,147,149]

ICP, intracranial pressure; CI, confidence interval.

Predictor Variables	CHALICE	PECARN <2	PECARN ≥2	CATCH
HISTORY				
Period after injury	Any	Within 24 hours	Within 24 hours	Within 24 hours
LOC	≥ 5 minutes	≥ 5 seconds	Any	Any*
Vomiting	≥ 3 episodes	-	Any	More than one, 15 minutes apart*
Headache	-	-	Severe	Worsening
Acting abnormal according to parents	-	Any	-	Any disorientation*
Amnesia	>5 min	-	-	Any*
Seizure	Any	-	-	-
Concern for NAI	Any	-	-	-
Severe mechanism	Any	Any	Any	Any
PHYSICAL				
Abnormal mental state	Drowsy	Any	Any	Irritable
Skull fracture	Penetrating, depressed, or basilar	Any	Basilar	Open, depressed, or basilar
GCS score	<14	<15	<15	<15 at 2h post injury
Neurological deficit	Any	-	-	-
Scalp hematoma	>5cm if <1year old	Nonfrontal	-	Large, boggy

Table 4.7. Predictor variables used in CDRs for CT acquisition in children with minor head injury. [25,147,149,150]

*Minor head injury according to the CATCH rule was defined as injury within the past 24 hours associated with witnessed loss of consciousness, definite amnesia, witnessed disorientation, persistent vomiting (more than one episode, 15 minutes apart) or persistent irritability (in a child under two years of age) in a patient with a Glasgow Coma Scale score of 13-15.

Strengths and weaknesses of the CHALICE rule

This large multicentre UK-based study included all children (< 16 years of age) presenting to the ED with any severity of HI. The CHALICE rule was the first head injury decision rule derived entirely from prospective data. The CHALICE-derived NICE guidelines for cranial CT scan in children under 16 years of age have not been validated in any population but form the basis for management decisions in 85% of ED in the UK.[149,154]

The inclusion criteria for this study were as wide as possible (excluding only children for whom consent to enter the study was refused). This emphasized the fact that injuries that might initially seem trivial, might lead to clinical important TBIs.[91,149]

Considering that all HI patients were included, irrespective of the severity of injury, an overall low percentage (3.27%; 744) of patients (n=22 722) underwent CT imaging and only 6.4% (1 461) required admission. 37.77% of CT scans identified abnormalities.[149,155]

Despite evidence that strongly support a lower threshold to perform a CT scan in younger children (<2 years of age) due to their higher risk of significant injury after blunt head trauma[89,90,91], the only differentiations listed in the CHALICE rule regarding age are:

- GCS < 14 in any patient, GCS < 15 in < 1 year old
- Specific mention of a tense fontanelle
- Presence of a bruise, swelling or laceration > 5 cm if < 1 year old.[149]

These are all very important factors to emphasize, but no specific mention of the 1-2-year-old child is made.[149]

The definition of a 'dangerous or severe mechanism of injury' might be the biggest inconsistent factor when one compares the three CDRs. The CHALICE rule defines a fall from a staggering 3-meter height as significant, with no mention of the role the age of the patient and the relevant height may play.[149,155]

CHALICE	PECARN	CATCH
RTC as occupant, pedestrian, or cyclist greater than 40 miles/hour (64 km/h)	RTC with patient ejection, death of another occupant, or rollover; pedestrian or cyclist without helmet struck by vehicle.	RTC related- not specified Bicycle fall without helmet
Fall greater than 3 meters	Fall greater than 0.9 meters (3ft) if younger than 2 years Fall greater than 1.5 meters (5ft) if > 2 years	Fall greater than 0.9 meters (3ft) or 5 stairs
Head struck by high-speed projectile	Head struck by high-speed projectile	Not defined

Table 4.8. Dangerous mechanism as defined by CHALICE, PECARN, and CATCH. [25,147,149,150]

Overall the CHALICE rule is a practical guideline with an impressive sensitivity (98%; 95% CI 96.0-100.0) and the highest specificity (87%; 95% CI 86.0-87.0) of all three CDRs.[149]

Strengths and weaknesses of the PECARN rule

The PECARN rule is the only CDR that has been validated outside the derivation population, it appears to be the best rule for both children and infants, with the largest study cohort (n=42 412) and highest sensitivity (for < 2 years: 100%; 95% CI 86.3-100.0 and ≥ 2 years: 96.8%; 95% CI 89.0-99.6) for clinical important TBI (ciTBI). [25,154,155]

The purpose of the PECARN rule differs significantly from the others. In contrast to the CHALICE and CATCH rules that identifies children who required a cranial CT, the aim of the PECARN rule is to identify children at very low risk of ciTBI after HI who do not require a cranial CT. [25,147,149,153,156]

The suggested course of action by PECARN is more complex than CATCH and CHALICE. The PECARN rule is not simply the reverse of the other two. CATCH and CHALICE suggest a cranial CT if any predictor variable is present and no CT if none is present. PECARN however states that if no predictor variable is present then a CT scan is unnecessary. However, if any predictor variable is present the PECARN rule provides an expression of risk of intracranial injury correlated with each predictor variable. Much is left to clinical discretion for those not in the low risk group ('observation' versus 'CT based on other clinical factors'). [25,153,156]

PECARN limited their study population to focus on minor TBI. They used multiple inclusion and exclusion criteria to exclude those with severe injury or those in whom HI is so mild that no physician would consider a cranial CT. Interestingly, vomiting was not listed as a predictor variable in the under 2-year-old group. In the ≥ 2-year-old age group only mention of signs of a basilar skull fracture is listed in their algorithm, with no reference to possible open or depressed skull fracture.[25]

CT scans were performed in 35.3% (14 969 / 42 412) of study participants. Only 5.2% (780) of these scans were interpreted as abnormal and a ciTBI was identified in a mere 0.9% (376) of cases.[25,153]

One of the difficulties in deriving paediatric TBI CDRs is the variability in clinical signs and symptoms from birth to adolescence. PECARN was the only CDR to address this challenge by creating separate pathways for preverbal (< 2 years) and verbal children (≥ 2 years). The upper age limit differed, including patients < 18 years old (CATCH included children 0-16 years and CHALICE included patients < 16 years of age). [25,147,149]

The PECARN rule gives the most comprehensive definition of a dangerous mechanism, compared to CHALICE and CATCH (Table 3.8). It is the only rule identifying a fall from different heights as being significant for the two age groups. Even though their study population included older children (up to 18 years old), the maximum height noted to be of a dangerous nature is 1.5 meters (5ft). This is half the 3-meter distance noted by CHALICE for all ages.[25,147,149]

Using the positive predictive values of the data, for identifying one ciTBI PECARN would scan approximately 50 children whereas CHALICE would scan 18. For identifying one neurosurgical injury PECARN would scan over 200 children while CHALICE would scan 24.[154]

The PECARN rule is easy to use. Little et.al., Pickering et.al. and Easter et.al. concluded that the PECARN rule outperformed the other two CDRs for cranial CT use in injured children and infants. They do however concur that broad application of this rule would result in an unacceptably high rate of CT scans per injury. Therefore, continued use of the CHALICE-based NICE guidelines represents an appropriate alternative.[153,154,155]

Strengths and weaknesses of the CATCH rule

The CATCH rule is by far the most concise of the three CDRs, listing 7 predictor variables for a cranial CT scan in minor TBI.[147]

This multicentre, prospective study spanned over the longest period of the three CDRs (53 months), enrolling the smallest number of participants (n= 3866). One of the limitations they described is the small number (n=277) of children included who are < 2 years old.[147,153]

Although the focus of the CATCH rule is, as for the PECARN rule, on children with minor TBI, each defined it differently. The CATCH rule included patients with a GCS of 13, were as these patients were excluded in the PECARN rule (including children with GCS 14-15). Both these rules only included children if the injury occurred within 24 hours, defending this decision that a delayed presentation probably indicated a trivial injury.[25,147]

Witnessed loss of consciousness, definite amnesia, persistent vomiting, and any disorientation are not included in the list of predictor variabilities but were listed as part of the findings in cases of minor HI. While most of the exclusion criteria are clear, the CATCH rule excludes children with chronic generalized developmental delay, leaving this categorisation to the discretion of the treating clinician.[147]

Each CDR defined a different primary outcome. CHALICE used 'clinical significant intracranial injury', defined as death due to HI, neurosurgical intervention or marked abnormalities on cranial CT.[149] PECARN used ciTBI defined as death from TBI, need for neurosurgical intervention, intubation > 24 hours for TBI or hospital admission of ≥ 2 nights associated with TBI.[25] CATCH used 'need for neurosurgical intervention', a composite of death from TBI or specified procedures secondary to the HI within 7 days.[147]

The CATCH rule has and acceptable sensitivity of 98% (95% CI 94.6-99.4) but the lowest specificity (50.1%; 95% CI 48.5-51.7) than any other approach.[25,147,149] Of the 2043 CT scans performed, 159 (4.1%) were abnormal. CATCH have not yet been widely implemented.[147]

The definition used by the CATCH rule for a 'dangerous mechanism of injury' lists only three criteria (Table 3.8.): Any RTC-related injury (not specified), a bicycle fall without a helmet and a fall greater than 0.9 meters (3ft) or 5 stairs. Again, no differentiation between the different age groups and the height of the fall was made. No mention of the head being struck by a high-speed projectile were made.[147]

All three CDRs highlights the absence of a well derived, evidence based and widely accepted rule for the management of paediatric HI. The CDRs have been derived to manage different severities of HI, it is impossible to directly compare the consequent impact oncranial CT rates.[153]

Chapter 5. Study Design and Research Methods

5.1. Methodology and Study Design

Study Objective

The focus of the study is on epidemiological data for head trauma in the pre-adolescent child. This is a unique group of patients with a specific epidemiology- very different from adults.

It is of utmost importance to address the deficiency of this data in the current literature.

Study Design and Study Setting

This was a prospective, descriptive study of a paediatric cohort of patients (under 13 years of age) conducted in a single centre. All patients included in this study had sustained a HI and presented to the RCWCH Trauma Unit.

The RCWCH's Trauma Unit is a tertiary referral centre for paediatric trauma cases in the Cape Town Metropole, South Africa. Children were identified from the patient registry in the trauma unit, ward admissions and the electronic list of patients undergoing a cranial CT scan.

Data was collected prospectively on a standardized case report form (CRF) (Appendix 7) as each patient was seen in the trauma unit. These patients were entered into the existing Registry for Traumatic Brain Injury Cases (R029/2015). Data was analysed with specific focus points in a descriptive study.

Study population

A total of 3010 patients who presented to RCWCH Trauma Unit with the history of possible head trauma during the period of 1 August 2015 – 31 January 2017, were included in this study.

Inclusion and exclusion criteria

There is no universally agreed category of trivial HI for which there is no risk for major intracranial complication. Therefore, the inclusion criteria for this study were as wide as possible. Any child under the age of 13 years who presented to the Trauma Unit at RCWCH with a history or signs of injury to the head was eligible for inclusion into the study.

The only exclusion criteria were patients 13 years and older and patients who requested that their data should not be included into the study. Three patients were excluded based on being 13 years and older. A total of 3007 patients were included in the final analysis.

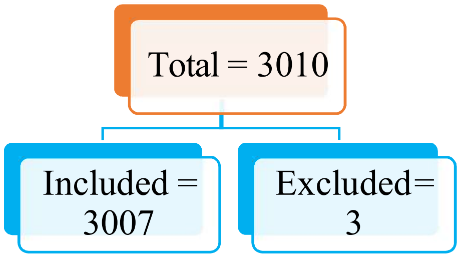


Figure 5.1: Participants: Included and excluded

Patients in the existing Registry for Traumatic Brain Injury Cases (R029/2015) have already consented, no additional data were collected. There was no compensation for participants. Treatment received is the current standard of practice with no special research visits and minimal risk of entry into the study.

Data sources

Data collection was performed by a paediatric trauma physician, who is also the primary investigator (PI) of this study. Data was collected on the standardised CRF and saved anonymously onto a secure and confidential Microsoft® Excel® spreadsheet.

Data analysis

The following data was collected: age, gender, date of injury, date of presentation to the Trauma Unit, mechanism of injury, clinical signs and indications for cranial CT scan, time to cranial CT, number of cranial CT scans performed, cranial CT scan findings, initial management needed, the length of hospital stay and outcome after injury.

Clinical severity of patients was recorded according to the initial GCS for children more than 3 years of age (Appendix 1): [6,27]

- GCS 13-15 = Mild
- GCS 9-12 = Moderate

- GCS 3-8 = Severe

Children 3 years and younger were classified according to the Children's Coma Score (Appendix 3): [40]

- CCS 10-11 = Mild
- CCS 9 = Moderate
- CCS 3-8 = Severe

In terms of disposition, patients were either admitted to RCWCH, discharged from the trauma unit, transferred for rehabilitation, or demised in the trauma unit or during their hospital stay.

The presenting characteristics were retrospectively assessed to determine which of the previously mentioned three clinical decision rules were met by each CT scan that was obtained. [25,147,149,152]

- CHALICE (Appendix 4) [149]
- PECARN (Appendix 5) [25]
- CATCH (Appendix 6) [147]

It was further also evaluated whether the CT request were compliant with the protocol in RCWCH's Trauma Unit. (Appendix 8)

The radiologist's CT report was compared with findings by the treating trauma physician and neurosurgeon. Study participants benefitted from critical examination of their treatment and dedicated follow-up, specifically with regards to the results of the cranial CT scan. Through this process patients were identified with injuries that might have been missed on initial evaluation of the CT scan. These patients were called for follow-up, where they would have been lost under normal circumstances in an overcrowded system.

Unexpected or incidental findings on the CT scan that were encountered during entering of the data on the CRF were addressed and referred appropriately.

A Road Safety Questionnaire (Appendix 9) consisting of 15 multiple choice questions was filled by 50 voluntary participants. The questionnaires were completed anonymously. It was a selected group of individuals employed by or studying at RCWCH. The participant's occupation and whether he/she has children at home were the only information gathered.

Statistical Methods

Data were entered into an Excel spreadsheet and analysed using Stata 13.0 (StataCorp, USA). Descriptive analyses were generated from demographic characteristics and injury mechanisms.

Approval for this study was granted by the Human Ethics Committee of the University of Cape Town (HREC Ref: 869/2016) as well as the Research Committee of the Red Cross War Memorial Children's Hospital.

This study complies with:

- the latest version of the Declaration of Helsinki (Brazil, 2013) [http://www.wma.net/en/30publications/10policies/b3/index.html] and

- the Department of Health: Ethics in Health Research: Principles Structures and Processes (2004) [http://www.doh.gov.za/docs/factsheets/guidelines/ethics].

5.2. Results

During the 18-month period under review (1 August 2015 – 31 January 2017), a total of 3010 children presented to the RCWCH's Trauma Unit with a possible head injury. Three patients were excluded due to age (13 years or older). A total of 3007 patients were enrolled in this study.

Trauma unit at RCWCH

13 113 patients presented to the RCWCH's Trauma Unit during this study period, on average 728 patients per month (maximum = 863 in the summer; minimum = 568 in the month of June). Patients with a history or signs of a head injury totalled 22.95% (3010/13113) of cases seen during this time.

Age

The median age was 5.6 years (mean: 4.6 years; range: 1 week to 12 years).

The highest incidence of TBI occurred in the under 5-year-old age group (Figure 5.2). Approximately 30% of patients were under the age of 2 years (n=884; 29.40%), 34.02% (n=1023) were between 2- and 5-years-old; therefore, almost two thirds of patients were of pre-school age (n=1907; 63.42%).

Gender

There were more males (n=1975; 65.64%) than females (n=1032; 34.32%). The male:female ratio (M:F) was most prominent in the 10-12 year age group (3.8:1) and decreased in younger children, with the under 2-year age group ratio almost equal at 1.3:1.

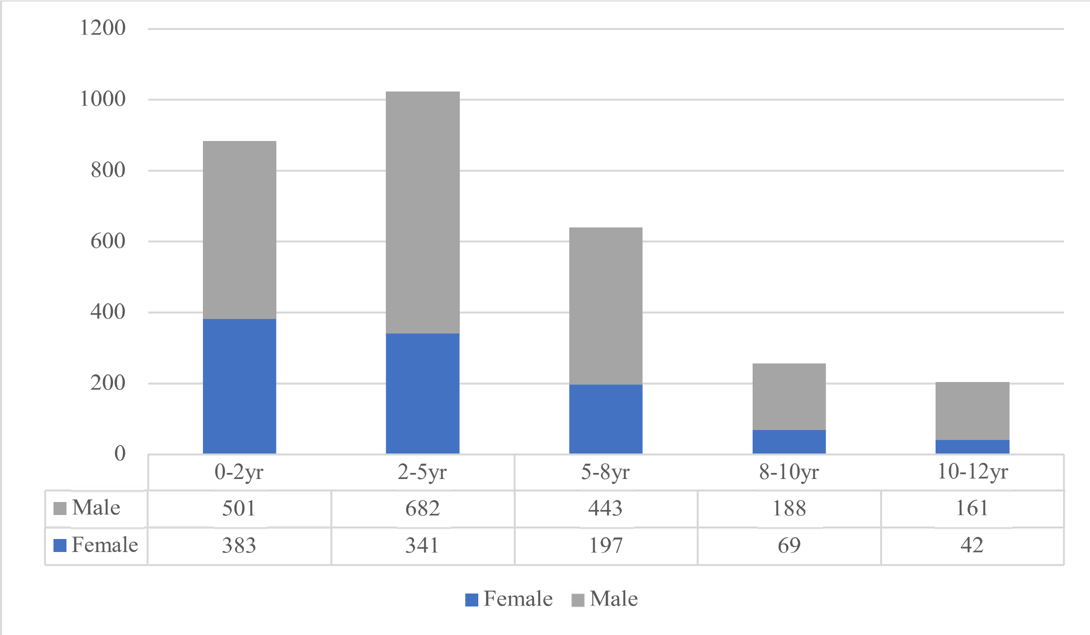
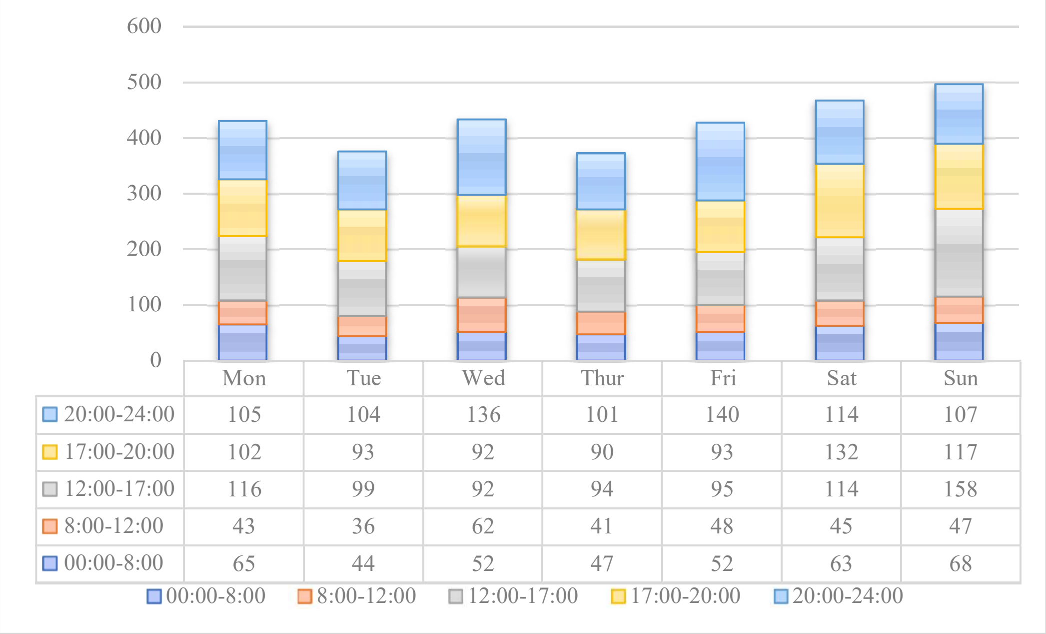


Figure 5.2: Age and gender distribution.

Time and day of presentation

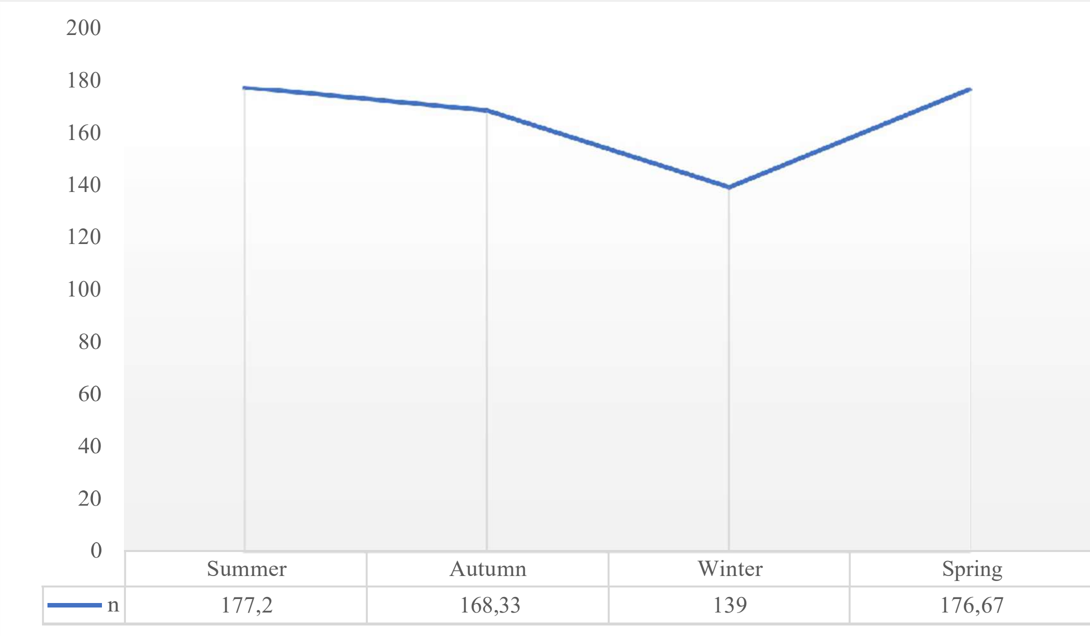
Most patients presented on Saturdays and Sundays. Numbers progressively increase from 12:00 to 17:00, then further from 17:00-20:00, with a peak from 20:00-24:00 on all days.

Summer was the busiest season, followed by spring, autumn and winter (177.20, 176.67, 168.33 and 139.00 patients per month respectively).



	Mon	Tue	Wed	Thur	Fri	Sat	Sun
20:00-24:00	105	104	136	101	140	114	107
17:00-20:00	102	93	92	90	93	132	117
12:00-17:00	116	99	92	94	95	114	158
8:00-12:00	43	36	62	41	48	45	47
00:00-8:00	65	44	52	47	52	63	68

Figure 5.3: Time and day of presentation.



	Summer	Autumn	Winter	Spring
n	177,2	168,33	139	176,67

Figure 5.4: Seasonal variation. n=Number of patients calculated per month

Severity of injury

The severity of TBI was classified according to the initial GCS score for children older than 3 years old. (Appendix 1: Standard Glasgow Coma Scale)

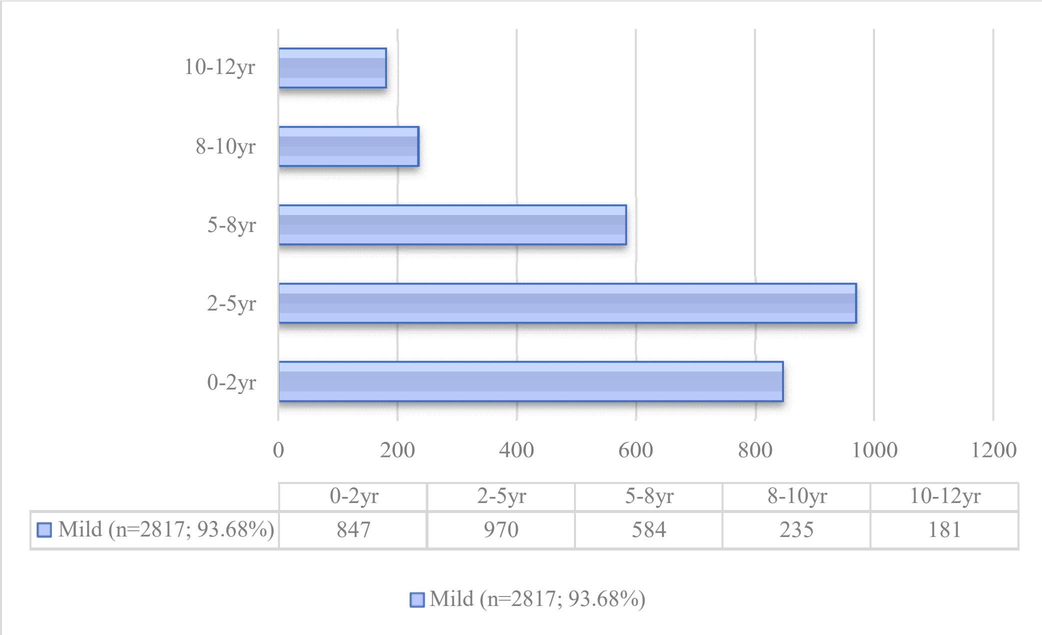
- Mild GCS = 13-15
- Moderate GCS = 9-12
- Severe GCS = 3-8

As mentioned before (Chapter 3.2), many authors recommend that patients with a GCS of 13 should be classified as moderate instead as minor, due to the higher incidence of intracranial injury and morbidity. A total of 38 patients older than three years old presented with a GCS of 13.

The standard GCS score has limited applicability in children 3 years and younger. The normal verbal and motor response required by the standard GCS are not attainable during early childhood. This group of patients were scored according to Raimondi and Hirschauer's Children's Coma Score (CCS) (Appendix 3).

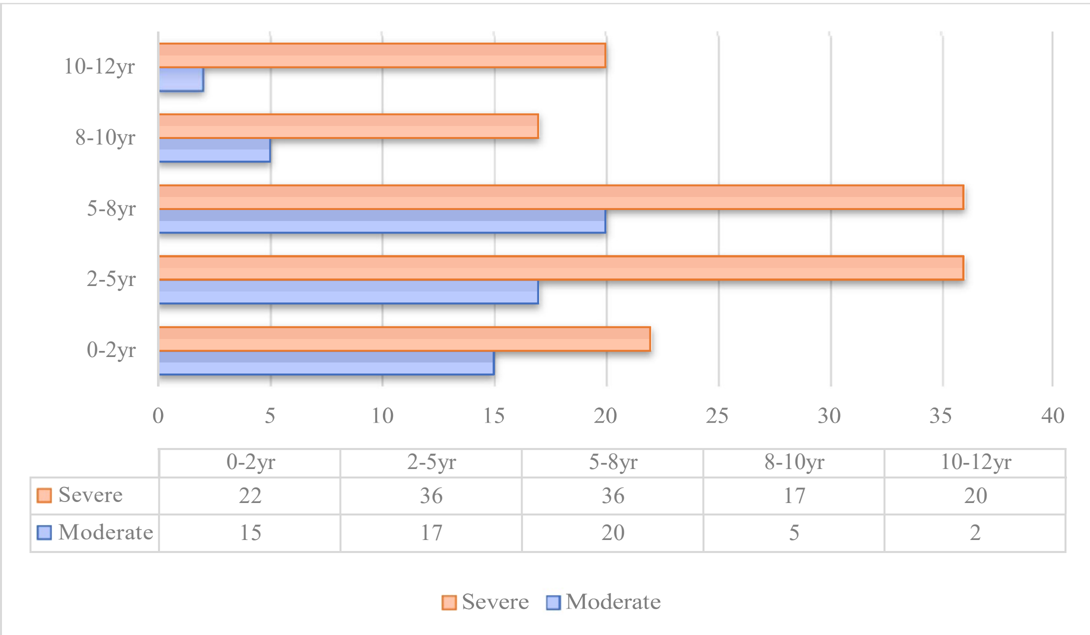
- Mild CCS = 10-11
- Moderate CCS = 9
- Severe CCS = 3-8

Most patients were classified with a mild TBI (n=2817; 93.68%) with 1817 (64.50%) falling in the 5-year-and-under age group. Only 1.96% (n=59) of patients presented with a GCS (9-12) or CCS (9) in the moderate range, and 4.36% (n=131) were severe. Moderate TBIs were less common than severe TBIs in all age groups.



	0-2yr	2-5yr	5-8yr	8-10yr	10-12yr
Mild (n=2817; 93.68%)	847	970	584	235	181

Figure 5.5: Mild TBI according to GCS and CCS.



	0-2yr	2-5yr	5-8yr	8-10yr	10-12yr
Severe	22	36	36	17	20
Moderate	15	17	20	5	2

Figure 5.6: Moderate and Severe TBI classified according to GCS and CCS.

Cranial CT scan

A total of 1784 (59.33%) patients had a cranial CT scan, of which 610 (34.19%; 610/1784) had an abnormality (skull fracture and/or intracranial pathology).

As noted before, most children (34.02%; n=1023) were in the 2-to-5-year old age group. With increase in age after the age of 5 years old, the percentage of children presenting with a HI per age group decreased. However, the percentage of cranial CT scans performed increased with each age group, with a maximum percentage of 70.94% in the 10-12-year olds.

An abnormal cranial CT scan was defined as identifying a skull fracture and/or an intra-cranial bleed. The highest incidence of abnormal CT scans was found in the oldest (10-12-year old) age group (46.53%), followed by the youngest (0-2-year old) age group (36.72%).

Age group	Number (% of total)	Cranial CT scan (% per age group)	Abnormal CT result (% of CT scans per age group)
0 – 2 years	884 (29.40%)	482 (54.52%)	177 (36.72%)
2 – 5 years	1023 (34.02%)	568 (55.52%)	164 (28.87%)
5 – 8 years	640 (21.28%)	409 (63.91%)	143 (34.96%)
8 – 10 years	257 (8.55%)	181 (70.43%)	59 (32.60%)
10 – 12 years	203 (6.75%)	144 (70.94%)	67 (46.53%)
Total	3007 (100%)	1784 (59.33%)	610 (34.19%)

Table 5.1: Cranial CT scan performed per different age groups.

An abnormal CT result was defined as a skull fracture and/or intracranial pathology.

Time to CT scan

Two thirds (63.45%; 1132/1784) of these scans were done within 6 hours of the injury. (Figure 5.7.)

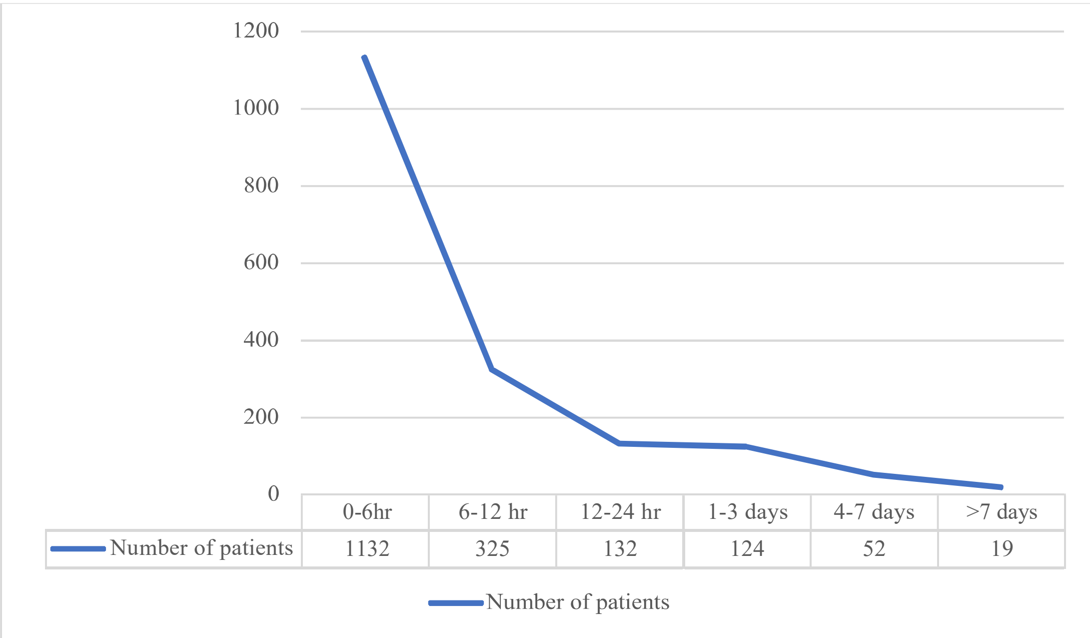


Figure 5.7: Time of injury to Cranial CT scan

Two of the most common reasons for a delay in obtaining the CT scan of more than 6 hours post injury were either symptoms that presented at a later stage (e.g persistent vomiting/headache/drowsiness or increase in scalp swelling) or a delay in transport from the referring institute. Suspected non-accidental injury cases (n=34) often presented more than 24 hours post injury.

Only two patients required a delayed cranial CT scan as result of worsening symptoms or concern upon admission.

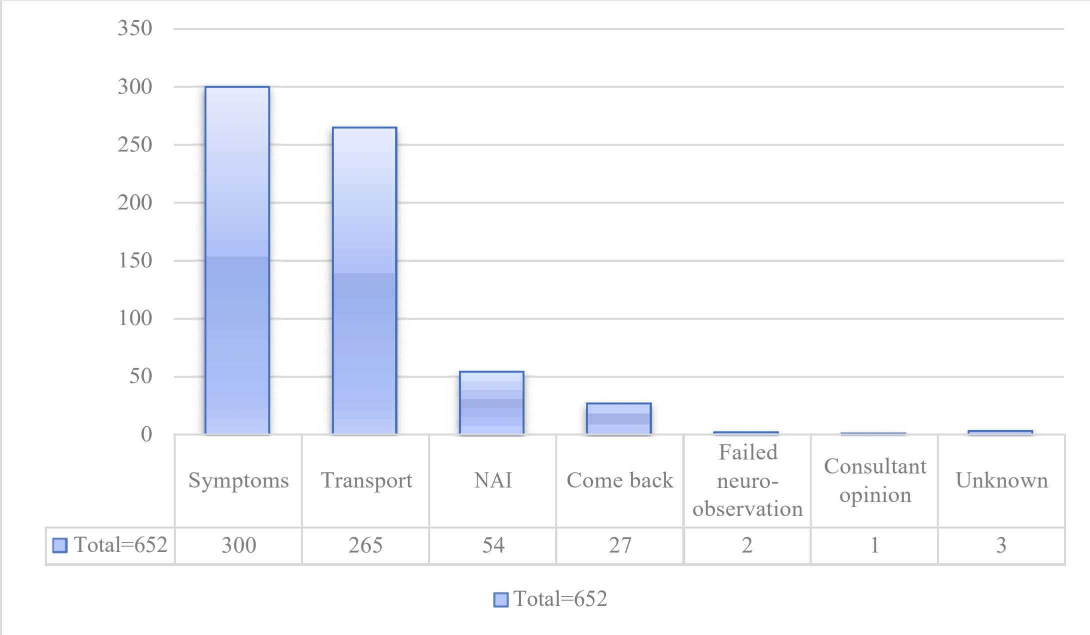


Figure 5.8: Reason for delay in CT scan more than 6 hours post injury.

Intravenous ketamine was the agent used in cases were sedation were required for obtaining the CT scan. A total of 163 patients (9.14%) needed sedation for the CT. 52.14% (n=85) were in the 0-2-year-old age group and a further 41.72% (n=68) were 2-5 years old.

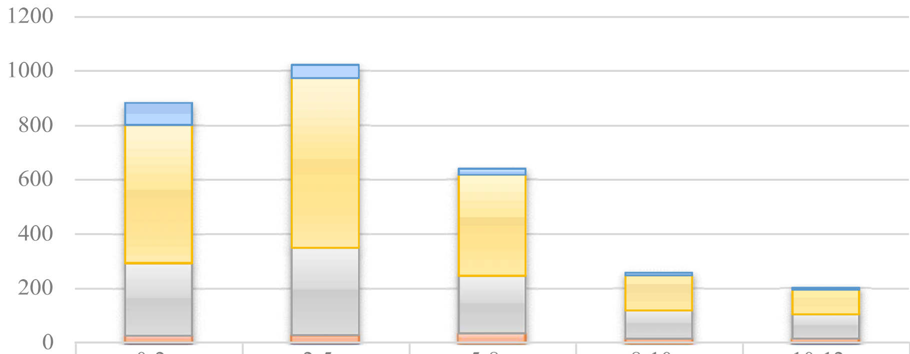
Disposition

The peaks in admission by age occurred in the two groups: 0-2 years and 2-5 years old. Six patients demised before admission, 4 of these patients were less than 5 years old.

Only one patient absconded before admission, a 13-month-old boy who fell from a bed and presented with the history of impact seizures. He had a normal cranial CT scan, but left before admission for neuro-observation.

A total of 122 patients were intubated during the primary survey. 6 of these patients demised before admission, 3 were extubated in the trauma unit and 113 required intensive care.

Paediatric Intensive Care Unit (PICU) admission were highest in the 5-8-year old group (5.47%; 35/640), almost double the PICU admissions in the 0-2-year old group (2.83%; 25/884) and the 2-5-year old group (2.54%; 26/1023). Admissions to PICU were lowest in the 8-10-year old group (5.84%; 15/257) and the 10-12-year old group (6.40%; 13/203).



	0-2yr	2-5yr	5-8yr	8-10yr	10-12yr
Medical referral	81	49	22	9	7
Discharged	509	625	371	128	92
Admission	266	321	212	105	89
ICU	25	26	35	15	13
Deceased	2	2	0	0	2

Figure 5.9: Disposition per age groups.

Across all age groups, 57.37% (1725/3007) of patients were discharged, 36.81% (1107/3007) were admitted of which 10.3% (114/1107) to PICU and 6 patients (0.2%) demised before admission.

5.59% (168/3007) required referral for medical evaluation once a TBI was excluded. These patients initially presented with symptoms (e.g. vomiting, drowsiness) that were attributed to a head injury by the caregivers. The number of patients who required referral for medical evaluation for their symptoms increased in younger children, with the highest number in the 0-2-year old group (9.16%; 81/884).

Of the 1784 patients who had a CT scan, 1174 (65.64%) did not show a fracture or intracranial pathology. Of these, 573 (48.81%) patients were discharged home and did not require admission for neurological observation. Of the 610 patients with an abnormal CT scan, 58 (9.5%) were discharged.

An additional 21 patients returned for reassessment and had a CT scan, 14 (66.67%) were abnormal and required admission.

Mortalities

A total of 22 patients who were enrolled in this study demised, 72% (16/22) of these deaths occurred during the months of summer (8 cases) and spring (8 cases).

The youngest patient was 4-months old, the oldest 11 years and the median age was 5 years.

The M:F ratio was 1.75:1.

Of the fatalities, most were pedestrian related RTIs (45.45%; 10/22), including the 4-month-old girl who was in her mother's arms at the time of the injury.

Two patients (9.09%) were unrestrained passengers, 3 and 5 years old respectively.

Four patients (18.18%) were injured as result of interpersonal violence: Two were firearm-related (6-month-old girl and 6-year-old boy), 1 patient was stabbed with a knife (7 months old) and 1 patient was assaulted with a brick (4 years old).

An 8-year-old boy sustained a fatal TBI after a fall from a roof. A 4-year-old demised after a fall from a 4-storey balcony. A 5-year-old boy was killed after a free-standing truck tyre toppled over onto him.

One patient (4 years old) presented with the history of a minor fall and possible HI. The cranial CT scan revealed brain swelling and concerns were raised regarding a non-accidental injury.

Two of the deaths could not be attributed to a TBI. A wall collapsed on to a 5-year-old boy, he had abrasions to the head but a normal CT scan and demised as result of intra-abdominal exsanguination and abdominal compartment syndrome. A 12-year-old boy was brought to the Trauma Unit with a history of a minor fall from a bed (2 days prior) and complaining of worsening drowsiness. However, the cranial CT scan revealed complicated frontal sinusitis with empyema. He succumbed to meningitis on day 8 of admission to PICU.

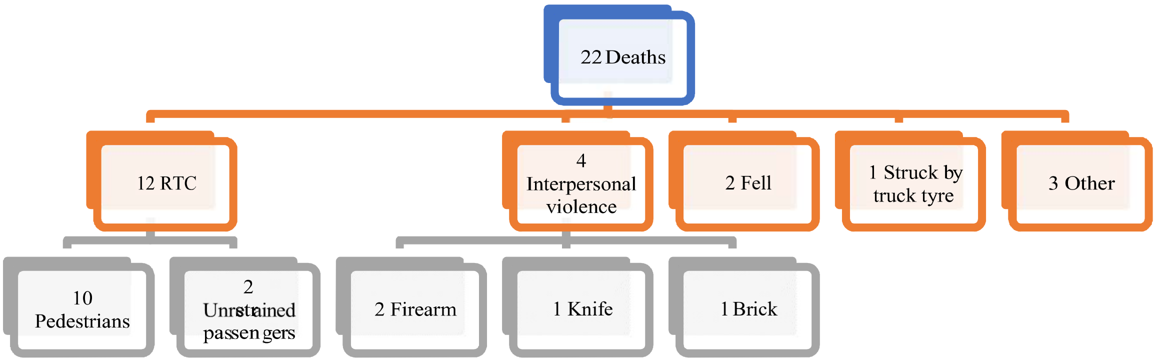


Figure 5.10: Morbidities: Mechanism of injury

Mechanism of Injury

Across all age groups 53% (n=1601) of HIs were attributed to a fall, 29% (n=864) were road traffic related, 9% (n=279) of patients were struck by or against an object. 8% (n=230) were the result of interpersonal violence.

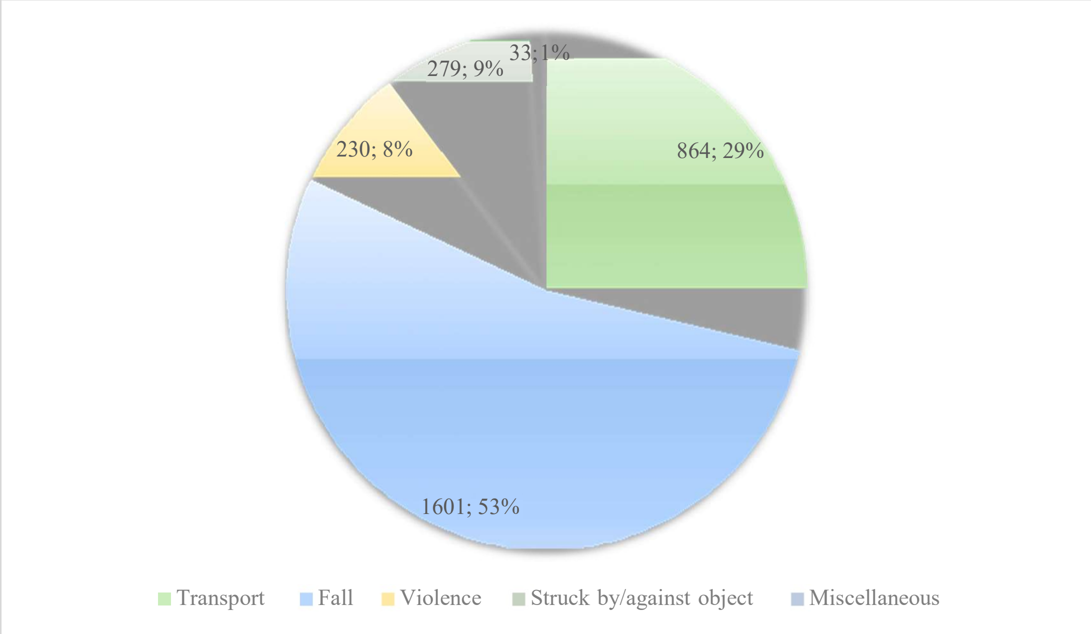
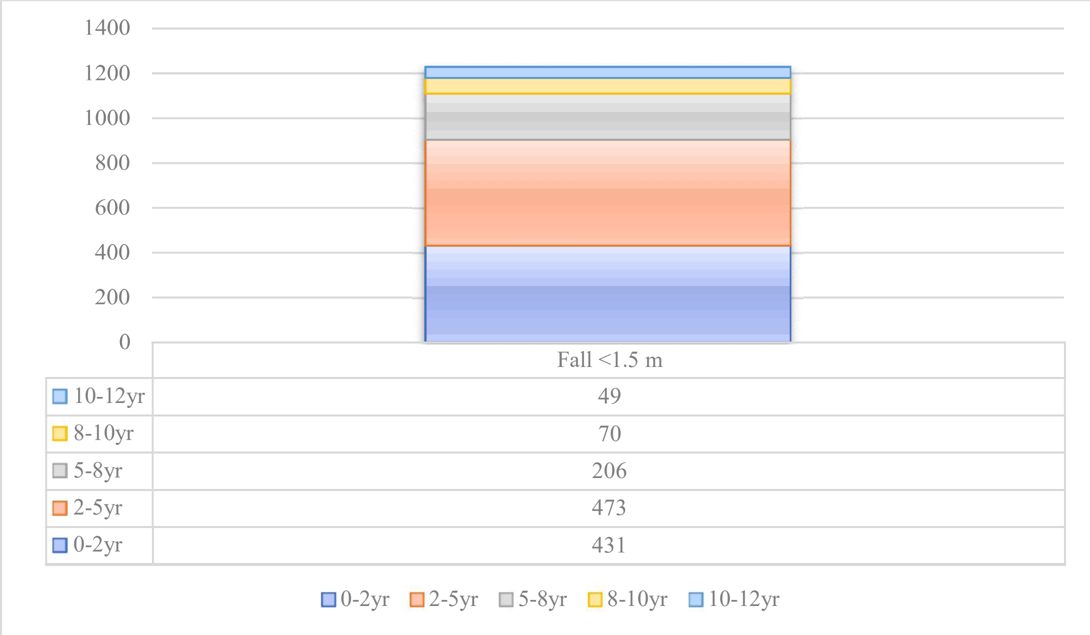


Figure 5.11: Mechanism of Injury

Falls

Figure 5.6 shows that falls were the most common mechanism of injury (53%; n=1601). Younger children were more prone to injuries because of falls. Differentiation was made between a fall from a bed, caregiver's arms or back, stairs and a height more than 1.5 meters.

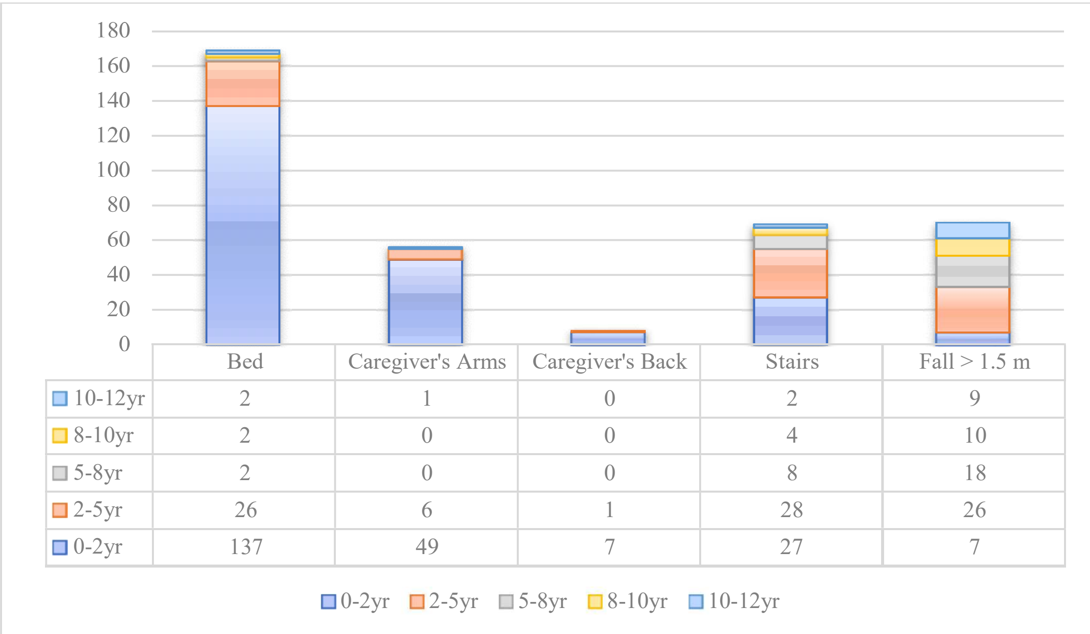
Falls from a height < 1.5m in children under 5 years old constituted 56.34% (904/1601) of all falls, with a peak in the 2-to-5-year old age group. (Figure 5.7)



	Fall <1.5 m
10-12yr	49
8-10yr	70
5-8yr	206
2-5yr	473
0-2yr	431

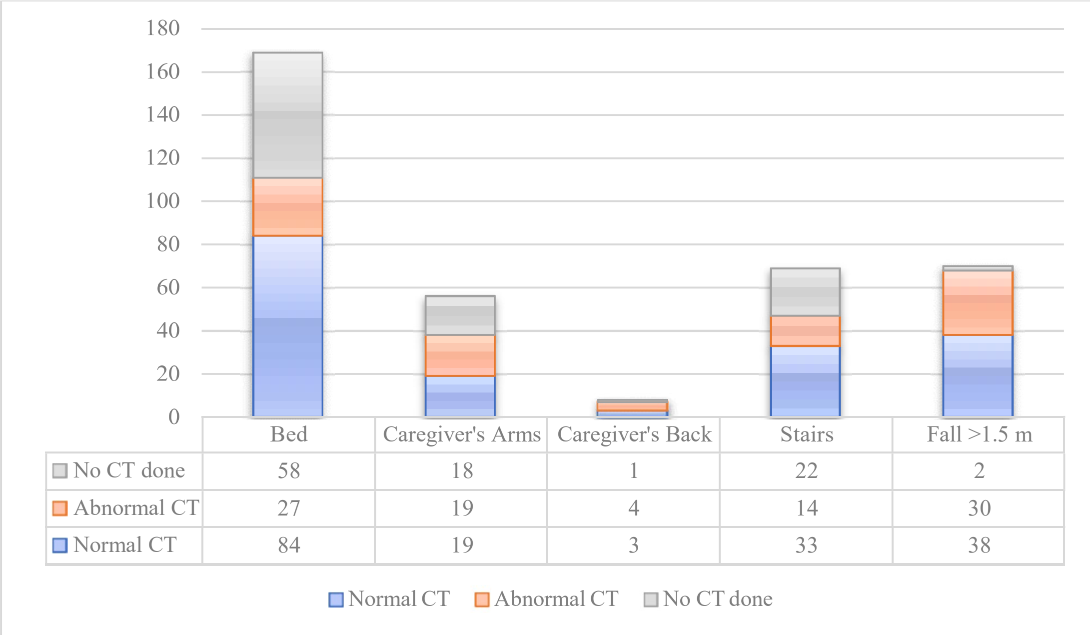
Figure 5.12: Falls < 1.5m across all age groups

Falls from a bed or a caregiver's arms or back peaked in the 0-2-year-old age group. Although falling from stairs were also most common in the under 5-year-old age group, it constituted less than 5% of all falls (3.44%; 55/1601).



	Bed	Caregiver's Arms	Caregiver's Back	Stairs	Fall > 1.5 m
10-12yr	2	1	0	2	9
8-10yr	2	0	0	4	10
5-8yr	2	0	0	8	18
2-5yr	26	6	1	28	26
0-2yr	137	49	7	27	7

Figure 5.13: Specific falls across the age groups



	Bed	Caregiver's Arms	Caregiver's Back	Stairs	Fall >1.5 m
No CT done	58	18	1	22	2
Abnormal CT	27	19	4	14	30
Normal CT	84	19	3	33	38

Table 5.14: Cranial CT scans done in patients presenting with specific falls.

Most of the abnormal CT scans occurred in children who fell from a height exceeding 1.5 meters (47.06%; 30/68); in comparison the smallest proportion of abnormal CT scans were in the patient group with a history of a fall from a bed (24.32%; 27/111).

Two thirds of patients who fell from a caregiver's arms required a CT scan and 50% (19/38) of these scans were abnormal.

29.79% (14/47) of patients who fell down stairs had an abnormal CT scan.

Road Traffic Crash Injuries

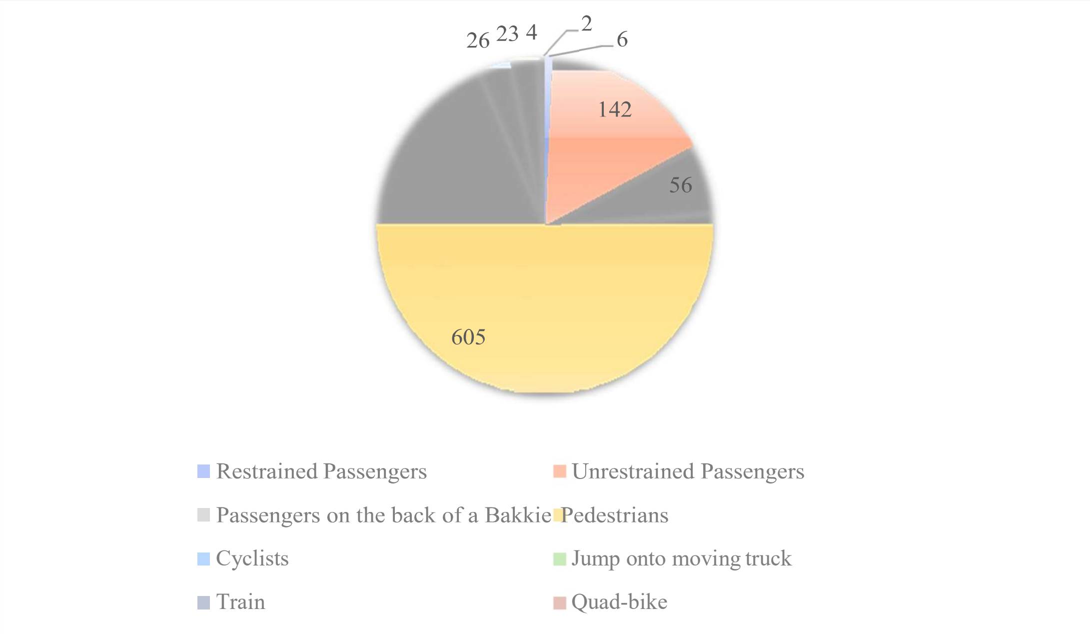


Figure 5.15: Road Traffic Crash injuries

Transport-related injuries followed as the second most common mechanism of injury (n=864; 29%). Only 6 passengers were appropriately restrained with 142 unrestrained and 56 passengers transported on the back of a bakkie. (Figure 5.10.) In the age group for children under the age of 3 years, only 1 patient was restrained, 51 patients were unrestrained and there were 6 patients transported on the back of a bakkie.

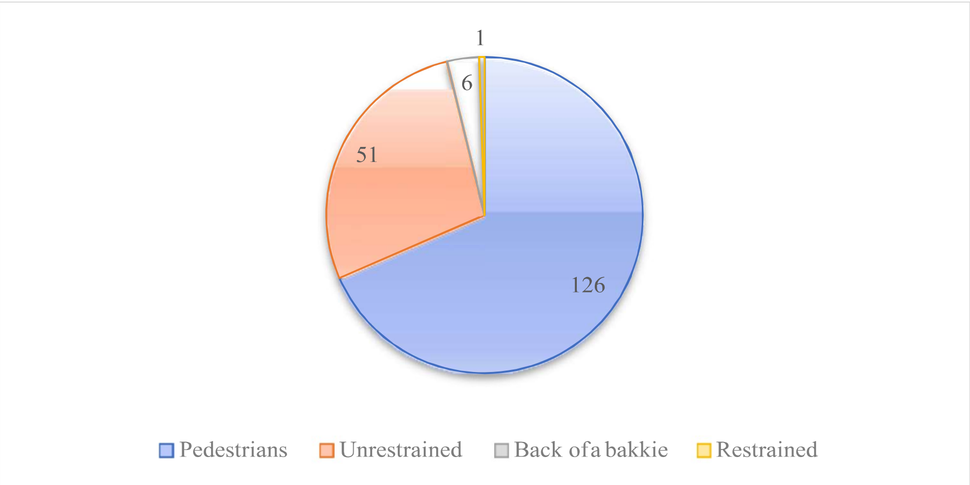
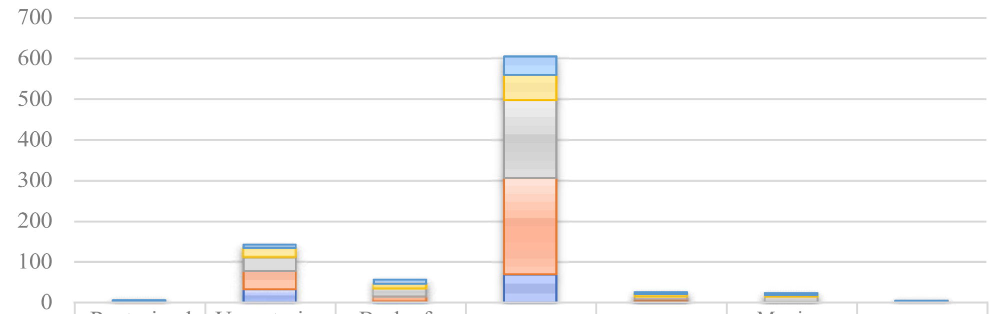


Figure 5.16: Pedestrian and passenger related RTC injuries in children 3 years and younger.

Pedestrian-related injuries were by far the largest group of RTC injuries (70.02%; 605/864) with 50.57% (306/605) of these patients being 5 years or younger. Of the 605 patients, 470 (67.27%) had a cranial CT scan. A skull fracture and/or intra-cranial bleed were found in 193 (41.06%) of cases. Most cases presented in the months of spring (37.83 pedestrians per month), followed by the summer months (33 per month), autumn (31.67 per month) and then the winter months (29.5 per month).



	Restrained passenger	Unrestrained passenger	Back of a bakkie	Pedestrian	Cyclist	Moving truck	Train
10-12yr	2	8	10	45	5	5	1
8-10yr	0	22	11	62	5	3	0
5-8yr	1	34	19	192	8	14	1
2-5yr	2	46	13	237	4	1	1
0-2yr	1	32	3	69	4	0	1

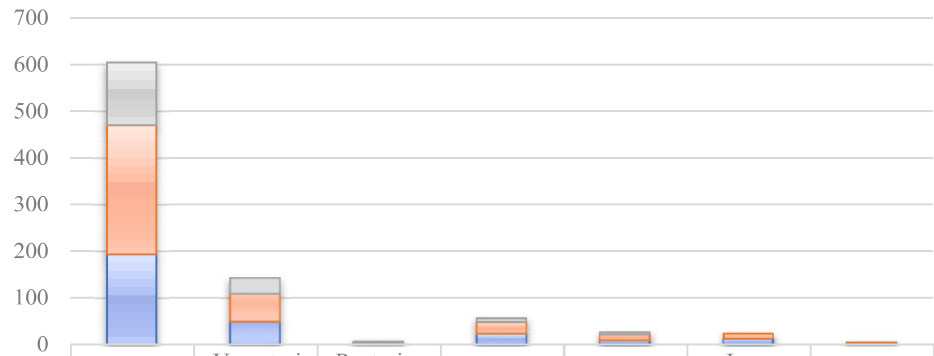
Figure 5.17: Road Traffic Crash injuries across all age groups

As demonstrated in Figure 5.16, two (33.33%) of the six restrained passengers did not require a cranial CT scan. Of the 4 CT scans done in this group, only 1 (25%) had abnormal findings. This is in contrast with the 142 unrestrained passengers, of whom 109 (76%) had a CT. In this group 44.95% of CT scan had an abnormal finding. Of the 56 passengers transported on the back of a bakkie, 48 (85%.71) had a CT scan with 47.91% (n=23) abnormal.

Twenty-three children were injured while jumping of the back of a moving truck, 14 of these were in the 5-8year old age group. All these children (n=23) had a CT scan with 52.17% (n=12) abnormal.

Four patients were involved in a train-related accident. Two boys fell from a moving train, 6 and 11 years old respectively. Two girls were in an adult's care during the time of the injury. A 2- year-old girl was pushed from the train while in the mother's arms and a 3-year-old girl was knocked over by the train together with her caregiver. All four of these patients had a cranial CT scan and only the 11-year-old boy had no TBI.

Of the 26 bicycle related injuries, 4 patients were 2 years or younger (tricycle or scooter bike related injuries). Only 5 patients did not have a cranial CT scan. Of the total of 21 CT scans done is this group, 42.86% (n=9) showed an abnormality. No helmets were worn in any of these cases.



	Pedestrians	Unrestrained Passengers	Restrained Passengers	Back of a Bakkie	Cyclists	Jump onto moving truck	Train
No CT	135	33	2	8	5	0	0
Normal CT	277	60	3	25	12	11	1
Abnormal CT	193	49	1	23	9	12	3

Abnormal CT Normal CT No CT

Figure 5.18: Cranial CT scans in RTC related injuries

The two transport related injuries not mentioned above, were a 10-year-old boy involved in a go-cart accident (normal CT scan) and an 8-year-old boy involved in a quad-bike accident (abnormal CT scan).

Intentional injuries

Interpersonal violence caused 8% of all injuries (n=230). (Figure 5.19.)

Assaults were divided into 4 main groups: Intentional assault by an adult, shield injuries, firearm related injuries and assault by a minor (person <18 years old).

	Intentional (adult)	Shielding	Firearm	Intentional (brick/stone)	Intentional (other)
10-12yr	10	0	1	18	2
8-10yr	9	0	0	17	1
5-8yr	9	0	2	28	4
2-5yr	23	0	2	26	6
0-2yr	27	6	3	2	2

0-2yr 2-5yr 5-8yr 8-10yr 10-12yr

Figure 5.19: Intentional injuries across all age groups

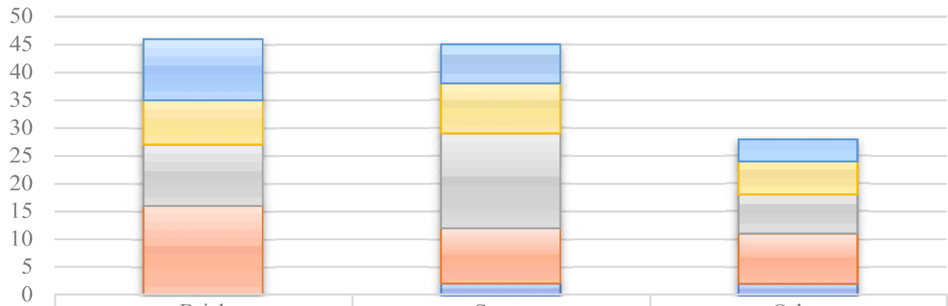
Intentional injuries inflicted by an adult were most common (34.62%; 27/78) in the pre-verbal group (2 years and under) and a similar incidence was found in the 2-to-5-year old age group as well (29.49%; 23/78). Seventeen of these cases did not have the required cranial CT scan. Of the 61 CT's that were done, 36.07% were abnormal. All 6 shielding injuries were in the under 2- year-old group. A cranial CT scan was done in 5 of these cases, with only one abnormal CT. Physical abuse cases were 4 times more likely to present in spring (4.1 patients per month) compared to winter (0.75 patients per month), with approximately 3 patients per month in summer and autumn.

Eight firearm-related cases were recorded, of which 7 were with a hand gun and 1 with an air rifle. Six patients had an abnormal CT scan. Two patients died, one before the CT scan was done. Three patients were under 1 year of age. Half of the cases were seen during the summer of 2016. All but one patient, who had only a soft tissue injury to the scalp, had severe debilitating injuries.

Age	Gender	Cranial CT	Outcome
6 years	Male	Abnormal	Demised
3 years	Male	Abnormal	Eye eviscerated
8 years	Female	Abnormal	Neurological deficit
7 months	Female	Abnormal	Facial fractures
6 months	Female	Not done	Demised
3 months	Male	Normal	Scalp graze wound
11 years	Male	Abnormal	Behaviour abnormalities
3 years (air rifle)	Male	Abnormal	Optic nerve injury

Table 5.2: Firearm related injuries

Interpersonal violence among minors constituted 52.22% (102/230) of the intentional injuries, particularly intentional assault with a stone/brick. The peak incidence was in the 2-5 and 5-8- year-old age groups. More than 50% of the CT scans done were abnormal, 55.88% (19/34) for patients struck by a brick and 50% (14/28) for patients struck by a stone. Of the patients struck by a brick, 26.09% (12/46) of patients did not have a CT scan. 37.78% (17/45) of patients struck by a stone did not have a CT scan. Spring (39.56; 36/91) and summer (29.67%; 27/91) months showed a peak in incidence.



	Brick	Stone	Other
10-12yr	11	7	4
8-10yr	8	9	6
5-8yr	11	17	7
2-5yr	16	10	9
0-2yr	0	2	2

0-2yr 2-5yr 5-8yr 8-10yr 10-12yr

Figure 5.20: Intentional injuries among minors

Cranial CT scans were done in 20 cases as part of the investigations in suspected physical abuse cases where the primary injury did not include the head (e.g. femur fracture). In 25% (5/20) an additional injury was identified on the cranial CT scan. Again, a predominance of cases in spring (40%; 8/20) and summer (25%; 5/20) were seen.

Other Mechanisms of Injury

Dog bite

A total of 12 cases with a dog bite to the head were identified. Ten of these cases were very young children (three years and younger). A male predominance of 3:1 was found. Only two patients did not have a cranial CT scan and did not require admission. Of the ten CT scans done, 6 were abnormal of which 4 patients required intensive care. The median length of hospital stay was 5 days. Most cases (66.67%; 8/12) presented during spring and summer.

Age	Gender	Cranial CT	Length of hospital stay
3 years	Male	Abnormal	Total: 5 days
2 years 9 months	Male	Normal	Total: 5 days
6 years	Male	Not done	Discharged
3 years	Male	Normal	Total: 2 days
3 years	Male	Normal	Total: 2 days
17 months	Male	Abnormal	PICU: 3 days; Total: 8 days
12 months	Male	Abnormal	PICU: 5 days; Total: 8 days
2 years 8 months	Male	Abnormal	Total: 6 days
11 months	Female	Abnormal	PICU: 7 days; Total: 20 days
9 years	Female	Normal	Total: 3 days
21 months	Female	Not done	Discharged
21 months	Male	Abnormal	PICU: 2 days; Total: 7 days

Table 5.3: Dog bite related injuries

PICU= Paediatric Intensive Care Unit

Gate

A common phenomenon was children who were injured climbing on or hanging onto an iron gate in a driveway. Forty-five patients sustained a head injury in this way due to the gate toppling over. The male to female ratio was 2:1. The median age was 4 years. A cranial CT was done in 35 cases (77.78%), 9 (25.71%) were abnormal. Two patients require a follow-up CT scan. The average hospital stay was approximately 2 days. 37% of cases presented during the months of spring.

Appliances

Appliances that were not correctly installed in a fixed and secure position also caused injury when pulled over: 10 Television (TV) sets, 2 microwave ovens and 2 fridges were involved.
M:F ratio were 2.3:1 and a median age of 4 years.

There were 10 cases were a TV toppled over onto a child. Six of these cases had a cranial CT scan with 3 (50%) scans abnormal. Five patients did not need admission. Four patients were admitted for 1 or 2 days of observation. One patient had a severe TBI, was discharged on day 14 with an ataxic gate and a cranial nerve III paralysis. Four of the incidents took place in the winter months, 3 in summer, 2 in spring and 1 in autumn.

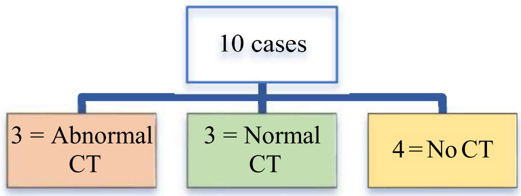


Figure 5.21: TV set falling from furniture onto child

Two children were injured by microwave ovens that were not securely installed and were pulled over, a boy of 13 months old and girl of 3 years old. The 3-year-old girl had a severe TBI requiring PICU and neurosurgical care.

A fridge was pulled over in two cases. The two boys were 3 and 7 years old respectively. Both had a normal CT scan and were discharged.

Clinical decision rules recommending a cranial CT scan in children who sustained a HI

Of the 3007 patients enrolled in this study, 1784 (59.33%) had a cranial CT scan.

RCWCH protocol

According to the RCWCH protocol 1751 patients required a CT scan.

RCWCH protocol: CT scan indicated	Normal CT scan	Abnormal CT scan	CT scan not done	Patient demised before CT scan done
Yes (n=1751)	1101	600	47	3
No (n=1256)	73	10	1173	0

Table 5.4: RCWCH protocol compared to cranial CT scans done.

CHALICE Clinical decision rule

The CHALICE CDR focuses on children under 16 years old who sustained a HI of any severity, the algorithm aims to predict a HI of clinical importance.[149]

All 3007 patients were evaluated according to the CHALICE variables to determine whether a CT scan is indicated.

CHALICE CDR CT scan recommended	Normal CT Scan	Abnormal CT scan	CT scan not done	Patient demised before CT scan done
Yes (n=1705)	1052	574	76	3
No (n=1302)	122	36	1144	0

Table 5.5: CHALICE CDR recommendations compared to cranial CT scans done.

PECARN Clinical decision rule

Kuppermann et al. compiled the PECARN rule from a large multicentre study. Their study included patients up to 18 years and only analysed data for minor HI's (specified as a GCS score of 14-15, thus a GCS score of 13 was excluded) who presented within 24 hours of injury. The aim of the PECARN rule is to identify a child unlikely to have a clinically important TBI.[25]

A total of 591 (19.65%) of the patients in our study cohort could not be evaluated according to the PECARN rule.

Exclusion Criteria	Severe TBI	Moderate TBI	GCS = 13	>24hrs post injury	Suspected child abuse	Penetrating trauma	Pre-existing neurological disorders
Total (n = 591)	130	59	32	248	91	19	12

Table 5.6: Patients excluded from the PECARN rule.

A total of 2416 patients fulfilled the inclusion criteria of the PECARN rule and were evaluated according to their algorithm for a suggested CT scan. A patient will fall in one of three categories: CT recommended, CT not recommended, or observation versus CT scan based on other clinical factors. Of the cohort of minor HI's selected by the PECARN criteria, only 10.63% (257/2416) required a CT scan in this, for 46.64% (1127/2416) a CT scan was not suggested, and 42% (1032/2416) were categorized in the observation versus CT group.

PECARN CT scan recommendation	Normal CT scan	Abnormal CT scan	CT scan not done
YES (n = 257)	129	120	8
NO (n = 1127)	32	7	1088
Observation vs CT (n = 1032)	767	208	57

Table 5.7: PECARN CDR recommendations compared to cranial CT scans done.

CATCH Clinical decision rule

The CATCH CDR was compiled from a Canadian study with the aim to identify a patient under 18 years old with a significant TBI for the use of a CT scan in children with minor HI within 24 hours post trauma.[147]

A total of 728 patients were excluded according to various criteria.

Exclusion Criteria	Severe TBI	Moderate TBI	>24hrs post injury	Suspected child abuse	Penetrating trauma	Generalized developmental	Return for reassessment	Obvious depressed skull	Acute focal neurological	Post traumatic seizure
Total (n =728)	130	59	248	91	19	12	11	30	14	114

Table 5.8: Patients excluded from the CATCH rule.

A total of 2279 patients were evaluated according to the CATCH rule, 40.59% (925/2279) required a CT scan.

CATCH CDR CT scan recommended	Normal CT Scan	Abnormal CT scan	CT scan not done
Yes (n=925)	590	275	60
No (n=1354)	293	22	1093

Table 5.9: CATCH CDR recommendations compared with cranial CT scans done.

CT scan interpretation

Once a cranial CT scan was done, it is reviewed by the treating physician in the trauma unit. The CT scan is reported by a radiology registrar during office hours and at random intervals over weekends. The neurosurgical registrar will only review CT scans of patients referred to them.

All 1784 scans were reviewed by a trauma doctor and radiologist, only 616 were reviewed by the neurosurgeon on duty, 485 of these being abnormal.

Incongruencies in the CT findings were found in 149 cases (8.3%), 107 of these were trauma related. Most of the pathology was missed by the trauma doctor (55; 51.40%) or both the trauma doctor and neurosurgeon on duty (19; 17.76%). Radiology differed in 19 cases in their report.

Overall, 10 Chiari malformations were not noted by trauma. Other incidental findings that were less often encountered and missed by some of the parties involved were craniosynostosis (9) fibrous dysplasia (2), white matter densities (5), severe adenoidal hypertrophy (4).

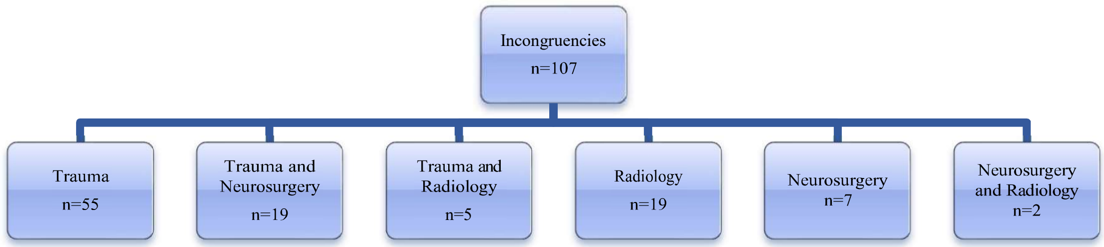


Figure 5.22: Trauma related incongruencies in CT findings.

In clinical practice the radiology report was considered the gold standard. Assessment of a cranial CT scan can be very subjective, especially the interpretation of brain swelling and subdural haemorrhage on the tent.

There are mechanisms in place in our unit aiming to prevent missed pathology such as weekly radiology meetings, consultant review of patients admitted to trauma ward and radiology consultant review of CT scans.

A total of 58 fractures were missed, with linear occipital, base of skull, and temporomandibular joint fractures most frequent. Sixteen intracranial bleeds (subdural and subarachnoid) were missed. Brain swelling were not noted in a few cases (9). Other causes (26) for incongruent findings were pneumocranium, inner or outer table fractures, C1 or C2 cervical spine fractures, retro-clival haematomas and carotid canal injuries.

Most missed cases were picked up during admission and treatment were adjusted accordingly.

19 cases were flagged as potential adverse events during the study:

- 9 patients had to be called for follow-up due to a missed fracture or intra-cranial bleed,
- 4 patients had to be called back for possible non-accidental injury work up,
- 4 patients needed follow-up with maxillo-facial department for missed temporomandibular joint fractures,
- 1 patient with a small subdural haemorrhage came back with symptoms of vomiting and headache and was admitted for neuro-observation and
- 1 patient was inappropriately referred to the paediatricians with vomiting, but with a missed linear parietal fracture.

Road Safety Questionnaire

A short 15-question multiple choice survey (Appendix 9) was done by 50 participants employed by or studying at RCWCH. Awareness regarding the new regulations in the NRTA were tested approximately one-year post implementation.

Only one participant (a consultant surgeon) had all 15 questions correct, the lowest number of correct answers were 5, and the average 10.

No single question was answered correctly by all. The questionnaire was answered anonymously by 18 resident doctors, 10 student doctors, 8 specialist consultants, 9 members of the nursing staff, 4 doctors post internship and 1 dentist.

Twenty two of the 50 participants in this questionnaire do not have children. Interestingly the only person who scored full marks does not have children and the person with the lowest score (5) has 3 children under the age of 13 years.

Participants who have no children scored 10.77 on average. Participants who have children scored 9.79 on average.

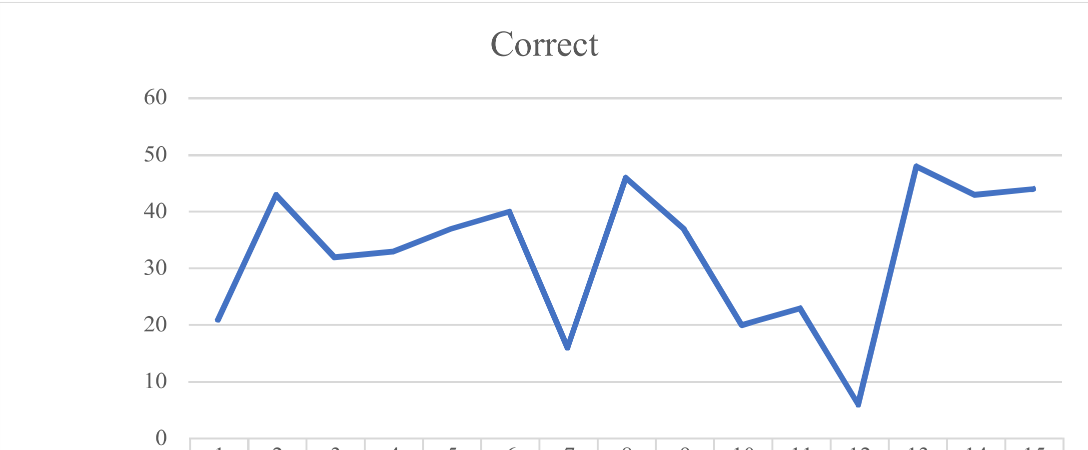
Question 12 was answered incorrect by most (88%; 44/50). Participants were thus under the impression that it is illegal to transport school children in the goods compartment of a vehicle (on the back of a bakkie), unaware of the specification in the NRTA that is only considered a violation if these passengers are carried for reward.

Only about a third (32%; 16/50) of participants were aware that it is recommended that a child remains on the rear seat of a vehicle until the age of 12 (Question 7).

Awareness regarding the mandatory regulation regarding children under the age of 3 years being appropriately secured in car seats was poor (Questions 1-6). Only 21 (42%) of participants were aware that the age limit is 3 years, 19% (19/50) thought that this regulation is only valid for children under the age of 1 year of age and 20% (10/50) thought it acceptable to secure the child on an adult's lap.

The benefits of a correctly installed car seat were mostly underestimated, 60% (30/50) underestimated the mortality benefit for a child between 1 and 4 years of age (Question 10). Approximately one fifth (26%; 13/50) of participants did not know that a correctly installed car seat can reduce the risk of death by 70% in an infant (Question 9).

Seat belt use for rear seat passengers (Question 8) and pedestrians on national highways (Question 13 and 14) were answered well.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Correct	21	43	32	33	37	40	16	46	37	20	23	6	48	43	44

Figure 5.23: Road Safety Questionnaire: Number of correct answers per question.

5.3. Discussion

This study evaluated 3007 children under the age of 13 years who presented to the RCWCH's Trauma Unit, which comprised 22.95% of the total trauma cases seen during the 18-month study period. It is difficult to compare this incidence to other studies as definitions and inclusion criteria vary quite significantly in previous reports.

Age

The mean age of 4.6 years is similar to that found previously by Lalloo et al. at RCWCH from 1991-2001 (4.9 years). However, half their sample size was under 5 years of age, with 20% under 2 years of age.[19] In our study (15 years later) there were more young children, with 63.42% under the age of 5 years and 29.40% under the age of 2 years. The peak in early childhood reflects the bi-modal and tri-modal age specific TBI incidence noted by Bauer et al. [4,65] and Bruns et al.[45] across all age groups. The other peak periods (mid- to late adolescence and the elderly) did not fall in our study cohort of patients under 13 years of age.

The study population of all three CDRs were older than in our study. In the CHALICE cohort of minor HI's (United Kingdom data; including patients under 16 years of age) the mean age was 5.7 years and 56% were documented under 5 years of age.[149] The mean age in the American PECARN rule study was 7.1 years with 25.3% under 2 years of age.[25] The Canadian CATCH study participants had a mean age of 9.2 years, with only 7.17% (n=277) under the age of 2 years.[147]

Gender

The higher incidence of TBI found in males compared to females were more pronounced with increased age, 3.8:1 M:F ratio in the 10-12-year-old age group. This finding was similar to Nell and Brown's study (4:1) of TBI in South Africa in adults.[50] The ratio was almost equal for the under 2-year-old group (1.3:1). An increase in risk taking behaviour amongst boys could be a possible reason for the higher M:F ratio with increased age and was a common trend across studies worldwide.

Time and day of presentation

The seasonal variation peaked in the summer and spring months, as expected. RCWCH is in the Cape Town Metropole in the Western Cape province of South Africa, a winter rainfall region. Children tend to be more active and outside during the warmer months.

RCWCH is a tertiary referral hospital. Most children presented between 20:00 and 24:00 (26.84%; 807/3007) to the trauma unit, delayed by ambulance transport from community health centres or awaiting parents to return home from work. A third of patients (32.10%; 965/3007) presented over weekends.

Severity of injury

The International Multicentre Study of Head Injury in Children across 5 countries published in 1999 is still referenced to provide a global perspective.[4,41] Most patients presented with a mild TBI 56%, followed by a moderate TBI (39%), and severe TBI (5%). The case fatality rate was 1.6%. Mild TBI accounted for the largest proportion (93.68%) of cases in our study, 4.36% were severe and only 1.96% moderate. Of note was that moderate TBI was less common than severe TBIs in all age groups. (Figure 5.6) The mortality rate was 0.73%.

These were similar to that of a smaller (n=563) retrospective study done over a 4-year study period in the Pietermaritzburg metropole, KwaZulu-Natal, South Africa. Although this study included adolescents as well (patients under 18 years of age), mild TBI accounted for 81% of their study group, followed by moderate (12%) and severe (7%).[18]

The mortality rate in our study (0.73%) was far less than the 3.6% mortality rate documented in the KwaZulu-Natal (KZN) study. This perhaps provides a glimpse into the multitude of factors involved in determining the prognosis of a patient with a TBI. For optimal outcome, a well-oiled multidisciplinary team is of utmost importance: Pre-hospital and Trauma centre care, the prevention of secondary TBI, availability of paediatric neurosurgical management and expertise, PICU management and rehabilitation. Different inclusion and exclusion criteria (e.g. the bigger adolescent group of patients in the KZN study) makes these studies not comparable.[18]

Different terminology used with respect to HI and TBI and inconsistencies in classifying a patient as mild, moderate, or severe, made it very difficult to fairly compare the literature. The Children's Coma Score for children under 3 years of age is used at RCWCH with a maximum score of 11. Interpretation of a score of 10 is problematic, and it is unclear whether it should be classified as mild or moderate. For children over the age of 3 years old the same problem unfolds with a GCS score of 13. Historically, such a case was classified as mild, but a new trend has started in Australia to consider a GCS score of 13 as a moderate injury.[35,36,37,38]

A total of 38 patients older than 3 years presented with a GCS score of 13, and 55 patients 3 years and younger had a score of 10 on the Children's Coma Score. Thus, even if one takes these differences in terminology and definitions into account, the moderate group (5.05%; 152/30070) would still be significantly less than the mild TBI group (90.59%; 2724/3007). However, the moderate group would then be slightly more prevalent than the severe group (4.36%).

Cranial CT scans

Despite the large proportion of minor TBIs, 59.33% (1784/3007) of patients had a cranial CT scan, of which 34.19% (610/1784) had a skull fracture and/or intra-cranial bleed. Although the proportion of CT scans done in our study was much higher than the 3.3% in the CHALICE study, the proportion of abnormal CT findings are in keeping with their 36.68%.[149] This may reflect a lower threshold for seeking medical attention and ease of access to medical facilities and image modalities in Canada compared to our circumstances.

An interesting finding was that the largest proportion of abnormal CT scan were found in the oldest (10-12 year; 46.53%) and youngest (0-2 year; 36.72%) age groups, and that the proportion of children who had a cranial CT scan increased with increased age. The 10-12-year-old age group represented the smallest proportion (6.75%; 203/3007) overall, but 70.94% of patients in this group had a CT scan compared with only 54.2% in the 0-2-year-old age group. This might result from more scans done in younger children because of the limitations of the neurological examination, especially in a preverbal child, and limited capacity for them to complain of concerning symptoms.

Intravenous Ketamine was safely and successfully used in 9.14% (163/1784) as sedation to obtain a CT scan. Non-purposeful movements did not create any motion artefacts during the rapid helical CT scan.

Disposition

Across all age groups, 57.37% (1725/3007) of children were discharged home. This marks an increase compared to the 41% of patients who were discharged during the previous review at RCWCH (1991-2001).[19]

Admission rates in the CHALICE study were very low (6.4%), reflecting the large proportion of minor HIs seen in this study and perhaps consistent with the low proportion of CT scan obtained (3.27%) as discussed before.[149]

Of concern is the 9.5% (58/610) of children with an abnormal CT scan who were inappropriately discharged. Nineteen of these were flagged as possible adverse events as discussed before. None of these patients needed neuro-surgical intervention and there were no mortalities.

Additionally, two thirds (66.67%; 14/21) of patients who returned for reassessment (due to parental concern) had an abnormal CT scan on their return visit. Only one patient needed neuro- surgical intervention. A 9-year old girl returned day 3 post injury with vomiting and required a craniotomy for an extra-dural haematoma and was discharged on day 3 after surgery.

A further 5.59% (168/3007) of patients required referral for medical evaluation with a normal CT scan. These would typically be patients presenting with a history of a minor HI, mostly more than 24 hours ago, presenting with vomiting +/- drowsiness. A CT scan would be obtained to exclude a TBI, almost half of these children were in the 0-2-year-old age group (48.21%;81/168). The symptoms were then attributed to possible infective causes and not to the minor fall or bump a few days ago.

In all the above-mentioned cases the care system for these patients needs improvement and this highlights the need for guidelines regarding the management of TBI patients in a unit with inexperienced doctors, working in the trauma unit for short periods of time (6 weeks to 3 months).

Mechanism of Injury

Falls

Falls were the most common mechanism of injury (53%), in keeping with local and international data.[5,19,87]

The typical peak in the young child was reflected in our analysis as well, with a fall from a height less than < 1.5 m in a child under 5 years old constituting more than half (56.34%) of all falls.

International literature stated that one fifth of children presenting with a fall had a cranial CT to confirm or exclude TBI. An abnormal CT scan was detected in 5.9% of these cases.[87] 46.91% (751/1601) of our study population had a cranial CT scan post fall, with 26.90% (202/751) showing a skull fracture and/or intracranial pathology. With a pick-up rate five times higher than noted in international literature, it may imply that we still do too few cranial CT scans than too many.

From the 69 patients who fell down stairs, 68.12% (47/69) had a CT scan of which 29.78% (14/47) was abnormal. This is almost 10 times higher than the 3.4% noted in a cross-sectional study of HI's in children admitted to UK hospitals; maybe reflecting the low threshold for CT scan and ease of access to image modalities.[87]

A third of patients who fell from a caregiver's arms had a normal CT scan (33.93%; 19/56), a third had an abnormal CT scan (33.93%; 19/56) and the remaining third (32.14%; 18/56) was discharge without a CT scan. Children in Africa are traditionally carried tied with a blanket or towel on a caregiver's back. Only 8 children were seen with the history of a fall from this position. Seven of these patients had a CT scan, with an abnormal CT in 4 of these cases.

Despite the danger of the mechanism of a fall from a height more than 1.5 m, 2 of the 70 children in this group were discharged without a CT scan. 47.06% (30/68) of the CT scans that were done were abnormal.

The risk of severe TBI from a fall remains ill defined. Two of the mortalities in this series were attributed to a fall from a height (8-year-old boy who fell from a roof and a 4-year-old boy who fell from a fourth storey balcony).

The age-related trends regarding the mechanism of falls were similar to previous studies in developed countries, but the number of abnormal CT scans was significantly higher in our study population. A fall from a caregiver's arms was flagged in international literature as having a higher risk of injury for a skull fracture or intracranial injury compared to a fall from standing or sitting position.[98]

Road Traffic Crash injuries

Transport-related injuries followed the trend in the rest of Africa and were the second most common mechanism of injury (29%; 864/3007).

Despite overwhelming evidence and decades of campaigning for road safety, a staggering number of pedestrian victims (70%; 605/864) and unrestrained passengers (16.43%; 142/864) was documented.

Pedestrian-related RTCs increased even further from the 65% noted in the 1991-2001 study at RCWCH.[19] Even more alarming was the 69 pedestrian victims under the age of 2 years. This is in discord with data from the developed world were children were more frequent passengers than pedestrians. Ten of the 22 fatalities (45.45%) were victims of pedestrian RTCs, and 4 of these patients were under 5 years of age, the youngest being 4 months old carried in her mother's arms.

Only 1 child in the age group (0-3 years) was appropriately secured. The rest of the 32 unrestrained passengers under the age of 3 years violated Regulation 213(6A) of the NRTA implemented from the 1st of May 2015.[82]

In total, only 6 patients presented with the history of being safely and appropriately secured according to their age and height. This is a mere 0.9% (6/611) of passengers seen during the study period, far worse than the 10% observed by Kling et al. at RCWCH in 2011.[78]

The importance of appropriately securing a child passenger was highlighted by the fact that restrained passengers required fewer CT scans and only 1 of the 5 CT scans was abnormal (25%). In the unrestrained passenger group 44.97% (49/109) had an abnormal CT scan and two of these patients (3-year-old girl and 6-year-old boy) succumbed to the severity of their TBI.

A further concern is young passengers transported in the goods department of a vehicle (e.g. on the back of a bakkie). It is a common method of transporting children to school and 71.42% (40/56) of these children were of school-going age, 28.57% (16/56) of these passengers were young children under the age of 5 years. According to the NRTA it is legal to carry passengers in the goods department of a vehicle if it fulfils the requirements and if not for reward. An enclosure roughly the length of a ruler (350mm above the seating surface) is the only protection and there is no need for a roof covering.[82] A significant number of CT scans (47.91%) were abnormal in this group.

Another RTC-related matter that the study highlights, was children jumping and hanging onto the back of a moving vehicle. A peak incidence was found in primary school children (5 to 8 years old). This dangerous game led to 52.17% of abnormal CT scans in the group across all ages.

As in the rest of the developing world, RTC-related TBIs are a critical health problem. Poor compliance and ignorance regarding road safety recommendations and even to legislature are a major concern. Poor social economic circumstances lead to young and vulnerable children left unattended and wandering into harm's way.

Intentional injuries

Interpersonal violence was the fourth most common cause of injury: Falls (53%), RTCs (29%), struck by or against an object (9%) and interpersonal violence (8%).

Again, it is noted that especially young children are at risk for intentional injury by an adult, with two thirds under the age of 5 years old (64.100%; 50/78). Only 6 (7.14%; 6/84) shielding injuries were documented, very few compared to the 47% in a previous retrospective chart review at RCWCH. The median age of 9 months was in keeping with our results.

No firearm injuries were documented in the KwaZulu-Natal study.[18] Penetrating injuries and firearm-related injuries were grouped together in the 1991-2001 RCWCH study and the incidence given as 2.7%.[19] Four gunshot wounds were listed in the study on severe TBIs during an almost 5-year period (June 2006 – April 2011) at RCWCH.[5] International data includes a study of 71 cases of gunshot wounds (birth – 18 years; mean age of 14 years) seen over an eighteen year (1996-2013) period in Memphis [157] and 115 cases treated in Houston, Texas from July 1990 to July 1993 (ages 3 to 17 years).[158] All of this considered, 8 firearm TBI in 18-months, with 3 patients under the age of 1 year is cause for great concern.

Violence among adults is known to lead to violence among children. 52.22% (102/230) of the intentional injuries were amongst minors, throwing bricks, stones, and other objects at each other. More than 50% of the CT scans done were abnormal, creating a significant burden of disease.

Cranial CT scan are readily available and can be performed rapidly to identify acute haemorrhage, skull fractures, soft tissue swelling and facial fractures. It is standard practice at RCWCH to perform a CT scan in a pre-verbal child (2 years and younger) in cases of suspected child abuse and this is in keeping with international guidelines. CT has been found a sensitive method for evaluating intracranial lesions in abused children that might not be evident on clinical examination of the child alone, but not as sensitive as MRI. The main drawback to obtaining a CT scan is the exposure of the patient to ionizing radiation. A quarter (5/20) of cranial CT scans done as part of this routine work-up revealed signs of TBI. Unfortunately, MRI is not routinely available and often requires general anaesthesia in young children.

Other Mechanisms of Injury

Although not unique to South Africa, dog bites, TVs and appliances falling from furniture, and poor maintenance of iron gates causing it to topple over onto children are all a further indication of young children being left unattended. Prevention should be emphasized in all these cases.

In the US, 1 child is injured by a TV every 30 minutes, but only 2.6% required admission.[159] Of the 10 cases documented in our study, 30% had an abnormal CT scan, similar to the 37.7% of skull fractures noted in a US literature review.[160] These figures may change as technology changes the types of televisions in many households.

Clinical decision rules and cranial CT scan

All three of the CDRs considered in the literature to be of the highest quality were based on studies in developed countries (UK, US and Canada).[25,147,149]

While all these rules can provide valuable guidance in the decision-making process whether a CT scan should be obtained, it must be noted that all three study populations differed significantly from the HI cases seen in our setting. For example, all three CDRs study cohorts included patients much older than the pre-adolescent children seen at RCWCH, introducing age- related differences in mechanism of injury and presentation.

PECARN and CATCH focused on minor HIs and excluded patients who presented more than 24 hours after injury.[25,147] In our setting transport and limited access to health care may cause significant delay: 6.4% (195/3007) of patients in our study presented more than 24 hours post injury. There is a need for special guidelines regarding imaging in this group as well.

As mentioned before, many of the treating physicians in our Trauma Unit work there for only a short period of time and are far more experienced in adult trauma. CDRs such as the PECARN rule that categorises patients in a group for observation or CT based on clinical opinion, can create a decision-making dilemma where there is variation in physician experience.

CHALICE Clinical decision rule

The CHALICE study included patients with a head injury of any severity and the mean age was 5.7 years. Of all three CDRs, their study population was the most similar to the one in our study.[149]

The CHALICE CDR could be applied to all the patients in our study and had a sensitivity of 94% and a specificity of 89%.

It was a practical and relatively easy rule to apply. Many of the clinical variables listed under "History" overlapped with the protocol used at RCWCH as standard practice. Specific variables listed are seizures after a HI, 3 or more vomits after a head injury, abnormal drowsiness, suspicion, or signs of penetrating, depressed or basal skull fractures and suspicion of child abuse.

Furthermore, attention is drawn to a tense fontanelle. In our clinical experience outside the scope of this study this is a sign often overlooked on clinical examination by doctors not familiar with paediatric trauma.

The following variables had specific criteria that would lead to a CT scan not being recommended according to CHALICE, but were subsequently done in our setting with abnormal results:[149]

- The biggest concern regarding the CHALICE rule was that there was no age-related specification regarding what constitutes a fall from a height. The only distance specified were >3m. This is of concern particularly in the very young age group, in which case a fall from a distance as low as a caregiver's arms could be significant.
- A bruise, swelling, or laceration in a < 1 year old is specified as being significant if greater than 5 cm. It is our clinical impression that a 5cm wound is large for young children.
- Although not stated formally as an indication for CT Scan in our protocol, a boggy or fluctuant haematoma are used in our setting as a subjective indication. The age of the patient, location of the haematoma and what exactly comprises a boggy haematoma are all factors that contributes to an indication not easily defined.
- In fact, penetrating, depressed and basal skull fractures are listed under signs to look out for under clinical examination. No mention of a possible linear skull fracture in a child older than 1 year were made. Based on their rule, a young patient who is alert on presentation, fell from a height < 3m, and sustained a linear parietal fracture with possible extra-dural haematoma would not be recommended for a CT scan. For example, no clear guidelines are given regarding a child older than 1 who presents with an occipital scalp haematoma.

- RTCs are specified according to the CHALICE rule as a dangerous mechanism only if defined as a high-speed accident (speed greater than 64km/hr (40m/h)). This is difficult to quantify, and the history provided may be unreliable in many cases. The version of the driver may be at odds with the version of onlookers; sometimes the accident had no witnesses. Accidents such as a driver reversing in a driveway over a child would not be included in this group but could be the cause of a devastating TBI.
- A high-speed injury from a projectile or an object was not described. Whether a stone or a brick thrown by a child < 5 years old would be considered as a high-speed projectile is unclear. Similarly, as a mechanism iron gates and TV sets toppling over are another grey area.

Overall, the CHALICE CDR provided valuable recommendations in our setting, but there are several areas of uncertainty that are common in our clinical circumstances.

PECARN

The biggest strength of the PECARN rule may be the distinction between children older and younger than 2 years old. Specifically, recognising that a fall from 1.5m rather than 3m is significant in a young child may be of great value.[25]

Unfortunately, a large proportion (19.65%; 591/3007) of patients in our study were excluded from evaluation by the PECARN rule: Severe and moderate TBIs, GCS score of 13, delay in presentation > 24 hours, suspected child abuse, penetrating trauma, and pre-existing neurological disorders.

A total of 2416 patients were evaluated according to the PECARN rule, with a sensitivity of 94% and a specificity of 80%. It is noted that the PECARN rule aims to identify children at very low risk of clinically important brain injuries and not abnormalities on the CT scan.

Clinically important brain injuries are a very contentious issue. It was defined in the PECARN study as:

- Death from TBI
- Neurosurgical intervention for TBI
- Intubated for more than 24 hrs for TBI

- Hospital admission of 2 nights or more for TBI

No mention was made of neuropsychological sequelae that may occur after a mild TBI and can be debilitating for the patient and devastating for the family. PECARN also excludes so called “trivial injuries”. The role of PECARN (and other decision rules) is not to determine whether the HI may have consequences in the long run, they are about determining whether CT scan yields information that requires intervention- whether admission, medical or surgical treatment.[25] However, it is important to note that these trivial injuries might still lead to clinical important TBIs.

The PECARN CDR identifies whether a child should have a cranial CT scan or not. However, a third group also exist where a child would either be observed or a CT scan would be done according to physician experience. This group was the largest in our study (42%; 1032/2416).

Some of the variables listed in this group as recommendations were found to be non-specific and subjective:

- Physician experience
- Parental preference

Others were more objective:

- Multiple versus isolated findings
- Worsening symptoms or signs after emergency department observation
- Age < 3 months

This is one of the areas that must be viewed in context and as such cannot be generalized across the world in widely differing conditions, especially in low- and middle-income countries. In our setting, for example, admitting 1032 patients for neuro-observation would strain an already overburdened health system. Also, parents do not always have reliable transport that is readily available should a problem arise at home. During our study 573 patients had a normal CT scan and could be discharged. Therefore, a more reliable exclusion of intracranial pathology requiring intervention is of great value in our setting.

There were 9 patients in our study for whom an immediate CT scan was not recommended by the PECARN algorithm and who had intracranial pathology. They were alert, fell from a height < 3meters, but had an extradural bleed on CT scan.

Signs of a basilar skull fracture are the only fracture specified in the child over 2 years of age. Post traumatic seizures are not specified and are grouped together with "loss of consciousness". These patients fall in the "observation group" and not the "CT recommended" group.

From our perspective, the PECARN CDR was less user-friendly in our setting and multiple grey areas were present. In particular, the decision to scan or not is left to the discretion of the treating physician.

CATCH

The CATCH CDR is concise, listing only 7 predictor variables.[147]

Similar to PECARN, the CATCH rule also focusses on minor head injuries within 24 hours of blunt trauma to the head. A total of 728 patients in our study were excluded according to various criteria.

Some clinical variables listed in the CHALICE rule as recommendations for CT scan were included in the CATCH definition of what constitutes a minor HI: Witnessed loss of consciousness, definite amnesia and persistent vomiting. These were not considered in the CATCH rule as findings to obtain a CT scan.

No specific mention is made of post traumatic seizures. It is unclear whether seizures were classified as a focal neurological deficit or as part of a moderate injury. Seizures are listed in their table of the association between variables and presence of brain injury in children with a minor head injury, but no further explanation was given. In our study we excluded patients with a history of post traumatic seizures from evaluation by the CATCH rule.

With regards to a dangerous mechanism of injury, only one height (≥ 0.91m or 3ft) was specified for all age groups. RTCs were not elaborated on. Being struck by a high-speed projectile or object was not listed in the CATCH criteria.

The CATCH study was done over the longest study period (53 months) with the least number of participants (n=3866). The mean age was 9.2 years, with only 277 (7.1%) patients under 2 years of age.[147] As such, the study population was the least representative of ours.

In our study the CATCH CDR had the lowest sensitivity (92%) and specificity (66.81%) of all three CDRs.

RCWCH protocol

All 3007 patients were compared with the criteria listed in the RCWCH protocol (Appendix 8) to obtain a CT scan. If one followed the RCWCH protocol in our study, CT scans obtained had a sensitivity of 98% and specificity of 93%. Thus, the RCWCH protocol had the highest sensitivity and specificity compared with the CDRs.

Possible improvements to the RCWCH protocol may include:

- Tense fontanelle in a very young child
- Boggy or fluctuant scalp haematoma (although there is no consensus regarding the definition of a significant boggy or fluctuant haematoma)
- Dangerous mechanisms of injury that has not been proven as standalone criteria in this study, but which should raise attention while keeping in mind balancing risk / benefit of CT scans:
    - Struck by iron gate
    - Struck by a stone / brick
    - Dog bites can cause small puncture wounds with underlying skull fractures
    - Pedestrian, unrestrained passenger, passengers in the goods compartment of a vehicle and children jumping and hanging onto the back of a moving vehicle.
    - Fall from a height >1 m

CT scan interpretation

Once the decision to obtain a CT scan is made, one is still left to interpret the images correctly.

Although there were no mortalities as result of missed pathology, the management of the TBI patient could further be improved in our setting by creating further safety mechanisms for the 8.3% of cases in which the TBI was missed by the treating physician. Most patients presented out of office hours with no radiologist on site and there is no reporting of trauma cranial CT scans after hours. Additional support would improve the identification of pathology and decrease the number of patients sent home despite having an abnormal CT scan. This might be managed by additional training in interpreting paediatric CT scans, longer rotation in the trauma unit and after-hours availability of a radiologist report.

Road Safety Questionnaire

It is quite clear that there is great room for improvement regarding awareness of road safety guidelines and legislation. The group of participants are representative of the general public and were a selected group of professionals or students at a children's hospital. Although this was not formally examined, it did not appear that having children of one's own improved the knowledge especially regarding the way to secure a child in a vehicle in a safe and appropriate manner. An appropriately powered study would be necessary to examine this further.

Limitations of this study

This study was conducted at a single centre and it was hospital-based, but with vaguely defined catchment parameters.

Access to health care service is limited in our setting, milder TBIs may go unreported and untreated. More severe TBIs may succumb before reaching the hospital and may thus not be captured.

Physicians work in our unit for short periods of time (6 weeks to 3 months). This may have influenced compliance to the cranial CT scan protocol in RCWCH at times.

In terms of sensitivity and specificity of cranial CT based on the parameters identified, these are calculated based on the scans that were done and did not include patients for whom imaging was not obtained. Therefore, each parameter must still be interpreted in the context of an existing indication for cranial CT.

The sample of respondents to the questionnaire are not broadly representative of the community as a whole, but given that these are professionals working in a children's hospital environment, their results likely overestimate performance in the broader community. As such, it is probably safe to say that general knowledge about these issues is likely to be even weaker in the general population.

5.4. Conclusion

The prospectively collected data in this epidemiological study provided valuable insights into TBI cases in our setting. Of specific importance is the large proportion of very young children at risk of injury by all mechanisms of injury, even pedestrian-related injuries, unrestrained passengers, and interpersonal violence among minors.

The results show that the performance of the current protocol at the hospital compares favourably with decision rules published elsewhere and, arguably, it may be more appropriate for our setting. The data presented in this study also highlight the current limitations of the published decision rules applied to our context. This is not unexpected given that these were developed in environments very different from ours. Still, there are areas in which our decision rules could be improved, and these require further evaluation.

The results of the questionnaire identify important gaps in knowledge about current recommendations for road safety. These gaps need to be addressed through enhanced injury prevention programs.

Appendices:

Appendix 1

Standard Glasgow Coma Scale: Teasdale & Jennett, 1974[28]

Eye Opening		Best Verbal Response		Best Motor Response	
Spontaneous	4	Oriented	5	Follows commands	6
To verbal stimuli	3	Confused	4	Localizes pain	5
To pain	2	Inappropriate words	3	Withdraws from pain	4
None	1	Incomprehensible sounds	2	Abnormal flexion to pain (decorticate response)	3
		None	1	Abnormal extension to pain (decerebrate response)	2
				None	1

Appendix 2

Pediatric Glasgow Coma Scale [39]

Eye Opening		Best Verbal Response		Best Motor Response	
Spontaneous	4	Coos, babbles	5	Spontaneous or purposeful movement	6
To speech	3	Irritable, cries	4	Withdraws from touch	5
To pain	2	Cries to pain	3	Withdraws from pain	4
None	1	Moans to pain	2	Abnormal flexion (decorticate response)	3
		None	1	Abnormal extension (decerebrate response)	2
				None	1

Appendix 3

Children's Coma Score: Raimondi & Hirschauer, 1984 [40]

Ocular Response		Verbal Response		Motor Response	
Pursuit	4	Cries	3	Flexes and extends	4
Extra ocular muscles (EOM) intact, reactive pupils	3	Spontaneous respiration	2	Withdraws from painful stimuli	3
Fixed pupils or EOM impaired	2	Apnea	1	Hypertonic	2
Fixed pupils or EOM paralyzed	1			Flaccid	1

Appendix 4

CHALICE- The Children's Head Injury Algorithm for the prediction of Important Clinical Events [149]

A CT scan is required if any of the following criteria are present.

History
-Witnessed LOC > 5 mins
-History of amnesia (either antegrade or retrograde) > 5 mins
-Abnormal drowsiness
-≥ 3 vomits after HI
-Suspicion on NAI
-Seizure after HI
Examination
-GCS< 14, or < 15 if < 1 yr old
-Suspicion of penetrating or depressed skull fracture of tense fontanelle
-Signs of basal skull fracture
-≥Focal neurological deficit
-Presence of bruise, swelling or laceration > 5 cm if < 1 yr old
Mechanism
-High-speed road traffic accident either as pedestrian, cyclist or occupant (speed >40m/h)
-Fall of > 3m in height
-High speed injury from a projectile or an object

If none of the above variables are present, the patient is at low risk of intracranial pathology.

Appendix 5

PECARN- Paediatric Emergency Care Applied Research Network [25]

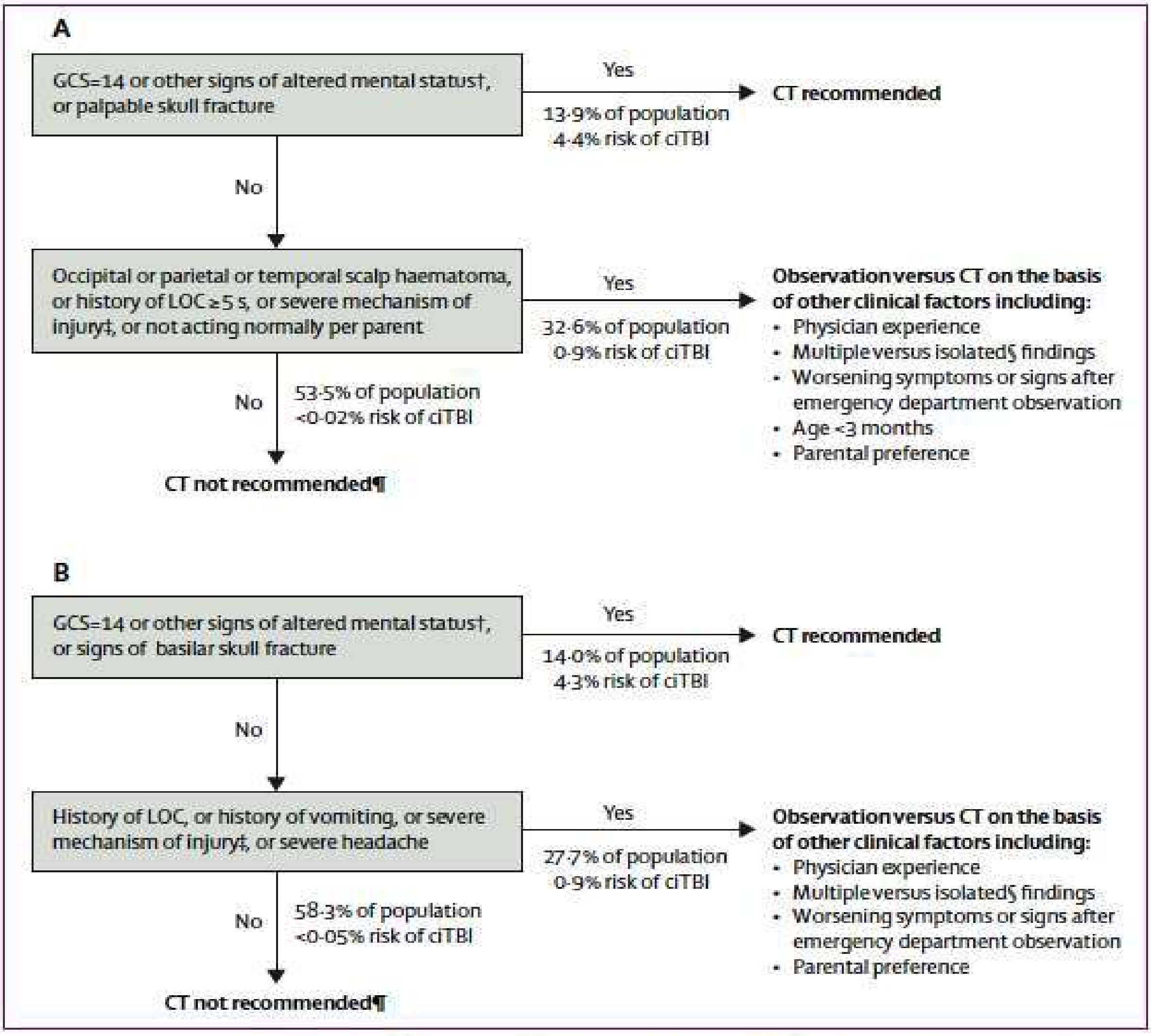


Figure 3*: Suggested CT algorithm for children younger than 2 years (A) and for those aged 2 years and older (B) with GCS scores of 14–15 after head trauma*

GCS=Glasgow Coma Scale. ciTBI=clinically-important traumatic brain injury. LOC=loss of consciousness. *Data are from the combined derivation and validation populations. †Other signs of altered mental status: agitation, somnolence, repetitive questioning, or slow response to verbal communication. ‡Severe mechanism of injury: motor vehicle crash with patient ejection, death of another passenger, or rollover; pedestrian or bicyclist without helmet struck by a motorised vehicle; falls of more than 0·9 m (3 feet) (or more than 1·5 m [5 feet] for panel B); or head struck by a high-impact object. §Patients with certain isolated findings (ie, with no other findings suggestive of traumatic brain injury), such as isolated LOC,[39,40] isolated headache,[41] isolated vomiting,[42] and certain types of isolated scalp haematomas in infants older than 3 months,[31,42] have a risk of ciTBI substantially lower than 1%. ¶Risk of ciTBI exceedingly low, generally lower than risk of CT-induced malignancies. Therefore, CT scans are not indicated for most patients in this group.

Appendix 6

The CATCH rule -Canadian Assessment of Tomography for Childhood Head injury[147]

CT of the head is required only for children with minor head injury* and any one of the following findings:

High risk (need for neurologic intervention)

1. Glasgow Coma Scale score < 15 at two hours after injury
2. Suspected open or depressed skull fracture
3. History of worsening headache
4. Irritability on examination

Medium risk (brain injury on CT scan)

5. Any sign of basal skull fracture (e.g., hemotympanum, "raccoon" eyes, otorrhea or rhinorrhea of the cerebrospinal fluid, Battle's sign)
6. Large, boggy hematoma of the scalp
7. Dangerous mechanism of injury (e.g., motor vehicle crash, fall from elevation ≥ 3 ft [≥ 91 cm] or 5 stairs, fall from bicycle with no helmet)

Note: CT = computed tomography.
*Minor head injury is defined as injury within the past 24 hours associated with witnessed loss of consciousness, definite amnesia, witnessed disorientation, persistent vomiting (more than one episode) or persistent irritability (in a child under two years of age) in a patient with a Glasgow Coma Scale score of 13–15.

Appendix 7

Case Report Form

HEAD INJURIES TRAUMA

Patient sticker

MECHANISM

AGE	

MVC	Car seat	Unrestrained	Back of bakkie	PVA
Fall-bed	Fall-arms	Fall-back	Fall-stairs	Fall-other
Assault	Intent	Shield	GSW	NAI w/u
Struck by	Sport			
Other				

INDICATION FOR CT **PVA, Ejected,Fall 5 stairs/ 3 feet*

Vomiting >2	GCS	Seizure	Suspected open/depressed #		Dangerous mechanism*
Occipital haematoma		Penetrating	NAI	? BOS # ^	
Tense fontanelle		Focal neuro deficit		*^ CSF oto/rhinorrhoea,Battle sx, raccoon,hemotymp*	
Other					
No CT done					
Ketamine needed for sedation for CT			Intubated		

TIME INTERVAL: INCIDENT TO CT

Specific Time interval:			hrs		
0-6HR	6-12HR	12-24HR	1-3 days	4-7 days	> 7 days
Reason for delay		Transport	Symptoms		
		Other:			

Time at RXH
Time of CT

CT RESULTS

Normal					
Fracture	Linear #	Depressed #	BOS#	Facial#	Suture diastasis
Location:					
Bleed	tSAH	SDH	EDH	IVH	Contusion
Location:					
Size:					
Suggestive of DAI		Brain swelling		Retroclival haematoma	
Midline shift		Size		Herniation	Pneumocranium
Soft tissue	Swelling	Degloving	Foreign body		
Other:					

Incidental finding:	

Interpreted by:	Trauma	Neuro	Radiology
Pathology missed		Yes	No
Report incongruancies			

REPEAT CT

YES	NO		Number		
Reason for repeat:		Follow-up	Neurological deterioration		Post-op
Unchanged	Improved	Worse			
Repeat scan lead to change in management				Yes	No
	New Management				

INITIAL MANAGEMENT

Trauma	ICU	D/C HIF	Refer MOPD		
Observational	Intubated				
Medical	Barbiturates		Mannitol diuresis	Hypertonic saline	Electrolytes
Surgical	ICP	Evacuation of Heamatoma			
	Fracture elavation		Wash out	CSF leak	

OTHER INJURIES

Chest		Long Bones	
Abdo			
Pelvis		Soft Tissue	

OUTCOMES

Days to D/C					
Function on discharge					
Back at pre-injury fx	Neuro deficit	Behavioural	G5	Rehab	Deceased
30 day post injury					
Back at pre-injury fx	Neuro deficit	Behavioural	G5	Rehab	Deceased

Appendix 8

RCWCH Cranial CT request protocol

IMAGING PROTOCOLS FOR HEAD INJURIES

SKULL X-RAYS

- □ SXR are NOT indicated in the management of Head Injuries in children in our setting.
- □ SXR may ONLY requested as part of the skeletal survey in suspected NAI cases and on discussion with the attending consultant.

CT HEAD INDICATIONS

- □ GCS $\leq$ 14 on assessment at hospital after adequate resuscitation
- □ Abnormal drowsiness
- □ Focal signs
- □ Penetrating injury
- □ Suspected Base of Skull fracture
- □ Clinical suspicion of occipital / sub-occipital fracture
- □ NAI
- □ Post-Traumatic Seizures
- □ Vomiting > 3 times or > 2 hours post injury

NBNB CT is NOT indicated in the setting of falls, abrasions or bumps on the head in the absence of indications documented above.

Appendix 9

Road Safety Questionnaire

Road Safety Questionnaire:

Occupation:

Community Service Doctor / Peadiatric Registrar / Other Registar / Consultant / SocialWorker / Parent / Other________

Number of Children: No children _____________

Under 1 year _____________

1-5 years _____________

6-12 years _____________

Older than 12 years _____________

1. According to the NRTA 93 of 1996 (Regulation 213(6A) in force as from 30 April 2015), all children under the age of ____ will be required to only travel in a car if they are secured in a car seat.
   a. 1 year
   b. 3 years
   c. 5 years

2. According to the NRTA 93 of 1996 (Regulation 213(6A) in force as from 30 April 2015): the car seat must be –
   a. On the front seat
   b. On the rear seat
   c. Either, as long as there is a car seat

3. According to the NRTA 93 of 1996 (Regulation 213(6A) in force as from 2015): For a 1 year old child the car seat must be –
   a. Front facing
   b. Rear facing
   c. Either, as long as the infant is in a car seat

4. Failing to comply to this new regulation, you will be issued with:
   a. A stern warning
   b. A traffic fine
   c. Imprisonment

5. What is the cost of an new SABS approved car seat?
   a. R500
   b. R2000-R5000
   c. R10000

6. If one does not own a car seat, it is acceptable to secure the child on an adults lap.
   a. True
   b. False

7. Until the age of ____ it is recommended that a child remains in the rear seat.
    a. 7 years
    b. 10 years
    c. 12 years

8. True or False – All adult passengers in the rear seat of a vehicle have to wear seatbelts.
    a. True
    b. False

9. According to Arive Alive a correctly installed Car Seat can reduce the risk of death by ____ in the infant age.
    a. 30%
    b. 50%
    c. 70%

10. According to Arive Alive a correctly installed Car Seat can reduce the risk of death by ____ in children aged 1 – 4 years.
    a. 34-43%
    b. 47-54%
    c. 56-67%

11. It is generally not before the age of _____, that a child can sense danger and can be allowed to cross a road or play ouside close to a road.
    a. 4 years
    b. 6 years
    c. 8 years

12. True or False – It is legal to transport school children on the back of a bakkie for free.
    a. True
    b. False

13. True of False – Pedestrians are allowed to cross a National highway such as the N1/N2/R300 as long as they wear bright clothing.
    a. True
    b. False

14. True or False - Pedestrians are allowed to walk next to a National highway such as the N1/N2/R300 as long as it is more than 1m from the yellow line on the side of the road.
    a. True
    b. False

15. The leading cause of injury and/or death among children over the age of 5 years in South Africa is:
    a. Drowning
    b. Infections (including HIV and TB)
    c. Motor Vehicle Crashes

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