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Challenges in the acute identification of mild traumatic brain injuries: results from an emergency department surveillance study

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ABSTRACT

Objectives: To establish the proportion of mild traumatic brain injury (mTBI) diagnosis among people presenting to an Emergency Department (ED), to determine the accuracy of recorded ED diagnoses. We also aimed to describe challenges in mTBI case identification and its acute hospital management.

Design and Setting: A retrospective chart review of all ED attendances to a major trauma hospital, over a 9-month period (June 2015-February 2016).

Participants: Adults aged 18-65 years consecutively presenting to an ED.

Primary Outcome Measures: Proportion of mTBI diagnosis among ED attendances, (i.e. confirmed mTBI based on the World Health Organization (WHO) criteria or indeterminate mTBI based on secondary criteria), and proportion of accurately recorded mTBI diagnosis by ED clinicians (i.e. 'mTBI, 'concussion').

Results: Of 30 479 ED attendances, 351 (1.15%) confirmed mTBI diagnosis and 180 (0.6%) indeterminate diagnosis were identified. Only 81 (23.1%) individuals with a confirmed mTBI had a 'mTBI diagnosis' clearly recorded in the medical notes. Of the allocated discharge diagnosis codes to the two identified cohorts, 89.8% were not indicative of mTBI. Intracranial injuries were found in 31 (8.5%) confirmed cases. Glasgow Coma Scale scores were consistently assessed in the ED but identified only 117 (33.3%) confirmed mTBI cases. Post-traumatic amnesia (PTA) testing was able to confirm acute cognitive impairment, in 113 (62.1%) of those who were tested (182, 51.3%).

Conclusions: mTBI is a prevalent, but an under-recognized cause for ED attendance. Despite challenges, the use of an operational definition such as the WHO diagnostic criteria can improve accuracy in mTBI identification. Acute management may be enhanced by rapid assessment of PTA.

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STRENGTHS AND LIMITATIONS OF THIS STUDY

- A systematic chart review of all Emergency Department attendances was employed to capture any possible mild traumatic brain injury (mTBI) case.

- The use of standard diagnostic criteria to establish the occurrence of mTBI diagnosis, ensures accuracy in identification and comparability across existing research.

- Provides novel data on proportions of rapid post-traumatic amnesia screening in NSW, Australia, where there is written recommendation around PTA screening in all Emergency Departments.

- Collecting data from single hospital site limits generalizability of study findings.

- Given the retrospective design, conclusions on mTBI occurrence and accuracy of designation were limited by the availability of documented clinical information.

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INTRODUCTION

Mild traumatic brain injuries (mTBI) are a serious public health problem that is referred to as a 'silent epidemic'.[1] Though being the least severe of all brain injuries, identification is the most challenging, with mTBI often missed at diagnosis.[2] Major barriers to mTBI identification are the wide variability in criteria used for diagnosis and the lack of sensitive standardized measures for identifying mTBI manifestations, which are commonly subtle and rapidly-resolving.[2, 3] Despite these limitations, the World Health Organization (WHO) best-evidence review estimated that hospital-treated mTBI are in the range of 100-300/100 000 population. [4] Diagnosis and management of mTBI largely occur in an emergency department (ED). [5] Little information exists, however, about the accuracy of mTBI identification in emergency settings. Two studies, conducted in three Canadian EDs [6] and two EDs in the US,[7] found that up to 50% of patients sustaining mTBI received an inaccurate ED diagnosis. Poor identification likely impacts clinical management of these patients. Given trends in increasing ED attendances for head trauma [8, 9] there is a critical need to for research that addresses the challenges in mTBI diagnosis.

Another challenge for ED clinicians is the identification of mTBI cases at major risk of complications versus those who can be safely discharged. [10] Latest research suggests that these so-called minor injuries can have long-term impacts that extend beyond the anticipated 3-month timeframe of cognitive recovery for uncomplicated cases, calling for urgent improvements in the acute management of mTBI. Long-term impacts include higher health care usage [11], psychosocial complications [12, 13] and in vulnerable subgroups chronic cognitive symptomatology [12, 14] and neural cellular alterations [15, 16] not easily detectable by routine radiological examinations that may increase the risk of neurodegeneration. [17] EDs represent a crucial point where accurate identification and early management of these patients may prevent long-term personal and economic impacts.

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Key steps to aid early and accurate identification and management of mTBI include enhanced consistency in diagnostic criteria and standardized assessment methods.[3] An internationally-recognised operational definition was developed by the WHO Task Force,[3, 4] clearly outlining the four key clinical manifestations for mTBI diagnosis. These are:(i) an altered state of consciousness, (ii) confusion or disorientation, (iii) post-traumatic amnesia (PTA) and (iv) transient neurological abnormalities, such as computed tomography (CT)-detected intracranial injuries, the latter defined as complicated mTBI (about 10% of cases).[18] Recommended objective measures to assess TBI 'severity' include conventional radiology to exclude structural lesions and the Glasgow Coma Scale (GCS) to monitor consciousness levels (i.e. mTBI is defined as GCS scores of 13-15 out of 15). However, no clear guidance is given by the WHO on the clinical assessment of the other TBI diagnostic criteria. [4] This particularly applies to PTA, which is recognized as the best prognostic indicator of mTBI outcomes. [19, 20]

PTA is a complex clinical concept reflecting an acute transient cognitive dysfunction [21] that presents not only as amnesia but more broadly as a period of inability to store new information, confusion, disorientation or behavioural changes. [3, 21] While standardized testing exist to assess the resolution of acute cognitive dysfunction (i.e. PTA) these are rarely used in the acute management of mTBI patients because many protocols are too lengthy to be administered in ED settings.[21] In NSW, Australia, the Abbreviated Westmead PTA Scale (A-WPTAS), [21] was specifically designed for ED use and recommended statewide, [22] as a brief validated measure of PTA to improve identification of traumatic brain injury events among closed head injury patients with a GCS of 13-15.[22] This measure includes five GCS orientation items plus a memory test of recall of three picture cards learnt on the first trial. The test is repeated hourly for up to four hours until optimal scores of 18 out of 18 are obtained (i.e.15 on the GCS, plus 3 on the memory test), indicating a resolution of PTA, if present.

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Though the A-WPTAS has been shown to assist with a safer discharge of people with mTBI, by identifying cases with a GCS of 15/15 who remain acutely cognitively impaired, [20] and reducing hospitalization and direct costs [23], its implementation to date appears inconsistent. Unpublished Australian data showed that rates of PTA screening in ED range from 0 to 31%, [10] while findings from a recent randomized controlled trial showed lower rates (i.e. below 13%). [24] This highlights the need for further studies to investigate the extent and possible benefit of A-WPTAS implementation in emergency settings.

Given the current challenges in mTBI diagnosis and limitations of existing epidemiological research, this study is unique as it aims to: (i) use standard diagnostic criteria to define the occurrence of mTBI diagnosis among ED attendances, and to establish what proportion of these had a clearly recorded mTBI diagnosis in their clinical records and/or else a diagnosis code suggestive of mTBI assigned by ED clinicians; (ii) describe operational issues in case identification; and (iii) acute management of mTBI, in particular the implementation of a validated measure for PTA screening in ED.

METHODS

This is a retrospective cohort study, employing chart review and standard WHO diagnostic criteria to define occurrence of mTBI among adults aged 18-65 years with ED attendances of a major trauma hospital in Sydney, Australia, over a 9-month period (from June 2015 to February 2016). Ethical approval was obtained from the Northern Sydney Local Health District Ethics, Sydney, Australia (LNR/16/HAWKE/388; LNRSSA/16/HAWKE/389). Two independent chart auditors systematically screened all ED attendances within the study period and reviewed all recorded information in ambulance reports, ED and medical notes, to determine whether mTBI occurred. Details of the study method are available. [25] Patients or

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the public were not involved in the design, or conduct, or reporting, or dissemination of our research.

The main outcomes were: (i) proportions of identified mTBI diagnosis, meeting WHO diagnostic criteria, among total ED attendances within 24 hours post-injury, meeting study age-range and timeframe, and (ii) proportions of accurately recorded mTBI diagnoses by ED clinicians based on positive mTBI-related definition documented in the medical record. A confirmed mTBI diagnosis was ascertained based on WHO criteria (Table 1-2): [4, 21] a GCS of 13–15 30 minutes after injury or on later presentation to healthcare; and/or PTA <24-hours, confusion/disorientation, loss of consciousness (LOC) of ≤30 mins and/or CT-detected intracranial injuries not requiring neurosurgery.

Despite the uniqueness of this study in using a validated measure for PTA screening in ED, initial chart review indicated PTA testing was not consistently administered. Further, optimal scores obtained during ED stay would still not be able to identify cases whose PTA resolved early post-injury [2] (i.e. optimal scores meaning that PTA, if present, had resolved). These cases could, instead, be identified by any evidence of PTA manifestations (i.e. any gap in memory, period of confusion/disorientation, behavioral changes) documented by ambulance and emergency staff in their clinical observations. Therefore, to ascertain the presence of PTA as criterium for mTBI occurrence, a summary PTA-related mTBI designation (Table 3) was developed by cross-checking any PTA-related neurological and behavioural disturbances documented in medical records, from the time of injury to hospital discharge. A positive PTA designation was defined by any of the following source: acute cognitive impairment on A-WPTAS testing, observed behavioural change suggestive of PTA (e.g. repetitive questioning, combative behaviour), as well as any observed/self-reported gap in memory, or confusion/disorientation thereby fulfilling two of the WHO criteria. [3, 21]

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In the absence of any documented WHO criterion, indeterminate evidence of mTBI [26] was defined based on the presence of any secondary criteria: [20] (i) optimal scores (i.e. 18/18) on the second trial of the A-WPTAS indicating that PTA, if present, had resolved, (ii) symptoms that may correspond to 'post-concussion symptoms' but which are not specific to mTBI,[25] (iii) transient neurological abnormalities (excluding intracranial injuries not requiring surgery), which are not common findings or clinical features of mTBI [2, 3] and are not recommended as stand-alone mTBI criteria,[2] or (iii) queried LOC/amnesia.

The accuracy of the diagnosis given by ED clinicians to the identified individuals with mTBI diagnosis was assessed by the presence of any recorded 'mTBI', 'concussion', 'post-concussion symptoms/syndrome' diagnoses in medical notes.[27] In addition, allocation of relevant mTBI-related discharge diagnosis codes (SNOWMED codes) was also explored, to inform how much routinely collected administrative data could be useful for brain injury diagnostic purpose.

RESULTS

Identified cases with mTBI diagnosis

During the study period, 30 479 adults aged 18-65 years attended the ED and were screened (Figure 1). Of the 587 mTBI-related ED presentations initially identified, 56 cases were excluded due to: (N=27) self-discharge or unclear evidence of mTBI, (N=8) confounding factors (e.g. intubation, psychosis, medical comorbidities) or possible moderate TBI (e.g. LOC/amnesia of unclear duration). Also excluded were 21 (3.9%) individuals who represented for the same mTBI event. Among total ED attendances, 351 (1.15%) confirmed mTBI diagnoses and an additional 180 (0.6%) cases with insufficient/indeterminate mTBI evidence were identified (Figure S1, Supplemental Material). Of these, two people (0.4%) sustained

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multiple mTBI (i.e. repetitive mTBI). Sociodemographic, injury-related and acute management details are illustrated in Table 1.

A clearly recorded mTBI diagnosis in ED records [27] was present only in 23.1% (N=81) of confirmed mTBI and 18.9% (N=34) of indeterminate cases. Similarly, among the 551 ED diagnosis codes (i.e. SNOWMED codes) (Table 4) allocated to the two identified cohorts, the most commonly used code descriptor was 'injury of head' (N=145, 26.3%). Only 56 of these codes (10.2%) were specifically indicative of brain injury occurrence, with 'concussion' being the most common (N=26, 46.4%). The remaining codes mostly reflected intracranial injury findings (see also Table S1, Supplemental Material, which shows the full list of ED discharge diagnosis codes).

Confirmed mTBI cases that were given a clearly-recorded mTBI diagnosis and/or a discharge code suggestive of mTBI were more likely to (Table S2, Supplemental Material): be a non-traffic-crash related mTBI ((p<.05), be admitted to a ward (p<.05), have CT-detected intracranial injuries (p<.0001), present with headaches (p<.05) and/or concentration problems (p<.05), and be recommended for follow-up care (p<.01). Furthermore, those with a clearly-recorded mTBI diagnosis were more likely to have been tested for PTA (p=.0003), while those with an allocated discharge code suggestive of mTBI were more likely to have a clearly written mTBI diagnosis in their ED records also (p=.04).

Injury-related characteristics

Cases with a confirmed mTBI diagnosis met the following WHO criteria: initial GCS of 13-14 (i.e. at the scene 30 minutes post-injury/at ED admission; N=117; 33.3%), LOC (i.e. witnessed/self-reported; N=185; 52.7%), amnesia (i.e. observed/self-reported; N=229; 65.2%), confusion/disorientation (N=97; 27.6%), and CT-detected intracranial injuries (N=31; 8.8%). Multiple WHO criteria were present in 186 cases (53%) (Table 2). Cases with an indeterminate

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mTBI diagnosis met the following secondary criteria in the absence of WHO criteria: optimal

scores of 18/18 on the A-WPTAS (N=45; 25%), presence of post-concussion symptoms (133;

73.9%), transient neurological abnormalities (N=22; 12.2%) queried LOC (N=12; 6.7%) and/or

queried amnesia (N=3; 1.7%). Multiple secondary criteria were present in 32 cases (17.8%).

Fall was the most common cause of mTBI in both confirmed (39.1%) and indeterminate

(31.1%) groups, followed by motor vehicle crash (28.2% - confirmed; 24.4% - indeterminate).

Alcohol or drug use in association with the injury was self-reported or clinically observed in

127 (36.2%) confirmed cases compared to only 19 (10.6 %) of indeterminate cases (*p*<.001).

Acute hospital management details

Brain imaging was undertaken in 75.8% of cases with a confirmed mTBI diagnosis and 40.6%

of cases with an indeterminate mTBI (*p*<.001; Table 1). Only 182 (51.8%) individuals with a

confirmed mTBI were tested for PTA (i.e. A-WPTAS or WPTAS). Of these, the majority (106;

58.4%) had a PTA duration of >1 to 12 hours, 32 (17.8%) obtained optimal scores of 18/18 (i.e.

did not fail A-WPTAS testing) and 37 (20.4%) had an unknown designation due to

incomplete/missing documentation. Median time to the first PTA testing was 3.7 (2.3-6.1)

hours post-injury for confirmed mTBI diagnosis and 2.5 (1.7-4.9) hours for indeterminate

mTBI.

The summary PTA-related mTBI designation (Table 3) including any documented

positive PTA-related findings (i.e. neurological and behavioural disturbances) in the medical

records, identified a total of 260 (74.1%) confirmed mTBI cases with PTA. The majority

(89.8%) were identified based on two WHO criteria of observed/self-reported amnesia (i.e. any

gap in memory) and/or period of confusion/ disorientation, with a further nine people deemed

in PTA only due to failing the A-WPTAS (N=8) or due to reported behavioral changes in

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medical records, (N=1) (i.e. repetitive questioning). All these nine cases, except one, also met

at least one of the other mTBI WHO criteria (e.g. LOC, GCS=13-14, intracranial injuries).

In both groups, people tested for PTA were more likely to (Table S3, Supplemental

Material): be transported to ED by ambulance ($p<.01$); sustain a traffic-related mTBI ($p<.001$);

be admitted to ED/ward ($p<.0001$). Confirmed mTBI cases were more likely tested for PTA in

the presence of other mTBI signs, such as LOC ($p=.005$), amnesia ($p<.0001$) and brain imaging

($p=0.003$) with positive findings ($p<.0001$).

DISCUSSION

By using the WHO operational criteria, our study reports an occurrence of confirmed mTBI

diagnosis among ED total attendances of 1.2% (351/30 479). These findings correspond to the

1.1-1.3% proportion observed in a preliminary study, which used the same criteria and methods

for TBI diagnosis [20, 25] therefore confirming the robustness of the proposed WHO

surveillance system for acute mTBI identification. A similar proportion of mTBI cases seeking

emergency care (1.9%; 670/35 096) was also reported in a prospective cohort study conducted

in a large metropolitan ED in New York. [28] This study employed the alike 1993 American

College of Rehabilitation Medicine criteria ,[28], as operational definition, suggesting that

using standard diagnostic criteria can enhance consistency in mTBI identification and

comparability of study findings.

Worryingly, only 23.1% (81/351) of our identified cohort with a confirmed mTBI

diagnosis (i.e. meeting the WHO criteria) had an accurate mTBI diagnosis documented in the

medical records (i.e. written diagnosis of 'concussion', 'mTBI'). The proportion of accurate

diagnoses was much lower than reported in two previous prospective studies conducted in

Canada [6] and the US [7] respectively, being ≥50%. While using a retrospective design could

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account for these differences, global challenges certainly exist in the acute identication of

'minor' TBI events. This study contributes by providing unique Australian data.

Poor accuracy in mTBI identification in ED [3, 17] could affect current estimates of 100-

300/100 000 reported in a WHO review,[4] hence, underestimating the 'true' incidence of

hospital-treated mTBI. Surveillance systems, such as accurate administrative databases, are

recommended strategies to tackle this problem. However, the use of discharge diagnosis codes,

such as ICD coding, in hospital databases has previously been shown not to be sensitive in

detecting mTBI. [27, 28] Our results confirm this gap. Only 10.7% (59/551) of ED discharge

diagnosis codes (SNOWMED codes) allocated to the identified cohorts with either a confirmed

or indeterminate mTBI diagnosis were indicative of mTBI. Despite limitations in the number of

diagnoses able to be recorded (i.e. maximum two SNOWMED codes), there seems to be a

trend for ED clinicians to better identify the more 'severe' injuries, i.e. those showing positive

CT findings, being admitted to a ward and receiving follow-up care recommendations. By

contrast, uncomplicated mTBI appears to be overlooked, by not receiving an accurate

designation in ED records or accurate coding. There was also an interchangeable use of terms

like 'concussion', '(mild/minor) head injury' and 'mTBI', as also shown in previous studies,

[3, 17, 28] that suggest a poor clarity in the distinction between those having a traumatic brain

injury versus simple head injuries, thus reiterating the scarce utility of administrative data in

mTBI identification.

While the WHO criteria can be regarded as a reliable system for the identification of

individuals who sustained a mTBI , there were challenges in its application. [2] First, it was

unclear how to interpret LOC or amnesia when it was not witnessed/observed as per WHO

recommendations for mTBI identification. It is likely that injured people report a LOC or

amnesia interchangeably, [2] thus, a self-reported LOC/amnesia at the time of the injury

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suggests a confirmed mTBI diagnosis. Conversely, when LOC/amnesia was queried by a physician this more likely suggests indeterminate evidence of mTBI.

PTA is the most important TBI prognostic indicator, yet the most challenging to evaluate because it encompasses a series of acute cognitive impairment signs and symptoms. This study is unique in its way of screening for PTA in ED by means of a validated measure. However, standard PTA testing was only available in about half of confirmed mTBI cases (51.9%), though this was considerably higher than previously reported PTA screening rates (up to 31%).[10, 24] Also, optimal scores of 18/18 on the A-WTPAS were obtained in 17.8% of those who were tested. While optimal scores clearly indicate the absence of acute cognitive dysfunction at the time of assessment (i.e. a person is not in PTA), these cannot exclude that PTA was present before that time, not being informative for mTBI diagnostic purpose.

Therefore, this study used a summary PTA-related mTBI designation, accounting for the positive presence of any PTA-related neurological and behavioural disturbances recorded in medical records.[3, 21] Using this indicator, we found 260 of the 351 cases with a confirmed mTBI diagnosis were deemed to be in PTA. Of these, the majority (89.8%) was based on the presence of observed/self-reported amnesia (i.e. a gap in memory) or confusion/disorientation (i.e. and meeting two WHO criteria), while 9 (2.6%) cases were further identified based only on evidence of acute cognitive impairment (i.e. failing PTA testing; N=8) or observed behavioral changes (N=1), the latter being repetitive questioning that is typically an indirect sign of PTA. These additional cases, except one, all met at least one of the other WHO criteria (e.g. LOC, GCS=13-14, intracranial injuries) for mTBI diagnosis.

Overall, these findings reiterate that the WHO criteria together constitute the most reliable surveillance system for mTBI identification and provide useful information to specifically identify cases whose PTA may have resolved by the time of ED admission. Additionally, the implementation of PTA testing, providing objective estimates of acute

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cognitive impairment may assist in monitoring recovery progress towards a safer discharge and enhance diagnostic accuracy of cases where mTBI indicators are unclear or unavailable. The administration of brief PTA testing (i.e. the A-WTPAS) as an extension of the GCS, which is usually assessed at the scene by the ambulance staff, [21] could provide a more accurate estimate of the presence and duration of PTA, thus of mTBI occurrence.

Another challenge was the assessment of transient neurological abnormalities, other than intracranial injuries. Ruff et al. (2009) suggested these abnormalities in isolation do notconstitute a strong basis for mTBI diagnosis because they are not common or typical features of mTBI.[2] Thus, these were considered as indeterminate evidence of mTBI. The WHO also recommends excluding cases whose TBI manifestations can be affected or due to other factors.[29] Unlike other confounders (e.g. intubation, psychiatric disorder), the influence of alcohol/drug on mTBI manifestations was particularly difficult to assess due to the lack of objective blood level measurements. Overall, these cases accounted for 36.2% of confirmed mTBI, being in the range of previous findings (30-60%). [30, 31]

This study confirms that issues exist in identifying the mildest TBIs,[2] whose clinical manifestations may resolve within <15 minutes post-injury according to the American Academy of Neurology classification.[2] Considering the amount of missing or non-informative/optimal indicators among cases with a confirmed mTBI in this study, as also reported by previous research,[32] along with PTA measured 2-3 hours post-injury,[21] it is likely that rapid-resolving LOC/amnesia were missed with a bias towards more severe mTBI. Secondary criteria were established to identify cases with indeterminate evidence of TBI. These cases constituted 0.6% of ED total attendances and, interestingly, 18.9% of these received a positive mTBI diagnosis by ED clinicians. Another study using a similar (probabilistic) approach found delayed functional recovery in the group with debatable mTBI compared to

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healthy and trauma controls, [26] raising concerns around the need for identifying and treating

less-severe mTBI that may appear to not meet diagnostic criteria.

Intracranial injuries were found in 31 (8.8%) cases with a confirmed mTBI diagnosis.

[18] Brain CT was performed in 75.8%, plus in 40% of cases with an indeterminate mTBI [18]

Clinical assessment remains the gold-standard for mTBI identification, with PTA testing being

the most promising measure. Among those who were tested, the A-WPTAS was able to detect

acute cognitive impairment in 62.1% of cases (113/182), while the GCS was able to detect only

33.5% of cases (117/349).[20] This study further suggests that when PTA is measured it

increases the likelihood of an accurate mTBI designation provided by ED clinicians.

Implementation of PTA testing in ED settings should be, thus, extended to all individuals with

a possible mTBI [21, 22] to reduce the risk of missed opportunity for mTBI identification and

to contribute to more accurate clinical decision making and safer discharge of patients.

Study Limitations

Major strengths of this study were the use of standard diagnostic criteria for the identification

of mTBI and the systematic screening of any cases with a possible mTBI diagnosis among ED

attendances. However, the retrospective design is limiting as we might not have captured

important information on confounding factors or mTBI indicators. Similarly, the absence of

documented information in medical records does not necessarily imply that standard diagnostic

criteria or assessment protocols were not applied by ED clinicians. Generalizability of findings

is limited by the following selection bias:[31] a working-age population, 9-month audit-period,

and using only a single hospital site. Some of these issues will be addressed by conducting a

multi-site study in the future.

CONCLUSIONS

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MTBI may have higher impacts on emergency care settings than previously anticipated. This study confirms the use of an operational definition, such as the WHO operational criteria as a reliable surveillance system for acute identification of mTBI, although challenges still exist in its meticulous application. Identification, prognosis and acute management of individuals with mTBI would be greatly enhanced by the implementation of standardised PTA screening (e.g. A-WPTAS) early after injury. Improvements in clinical and administrative designation of these injuries requires the use of these data to monitor and address long-term health and economic impacts of mTBI.

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Contributors: All authors - IP, SM, AK, AC, MG, KVV, AL, IDC, BG - provided inputs in study design. IP, KVV, AL, AK, SM and BG were involved in data collection and data analysis. IP and BG are responsible for publication writing. All authors reviewed and approved the final version of this manuscript.

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Table 1. Socio-demographic, injury-related and acute hospital management information of identified cases with a confirmed mTBI diagnosis (N=351) and indeterminate mTBI diagnosis (N=180) who presented to ED.

	Confirmed mTBI [WHO criteria] (N=351)	Indeterminate mTBI [Secondary criteria] (N=180)	Statistical comparison
	N (%)	N (%)	p value§
Socio-demographics			
Age (years), mean (SD)	39.9 (14.2)	36.1 (13.1)	<0.01
[median, IQR]	[40.8, 26.5-52]	[34.7, 24.1-44.5]	
Age groups (years)			
18-24	71 (20.2)	52 (28.9)	0.02
25-29	38 (10.8)	15 (8.3)	0.36
30-34	36 (10.3)	26 (14.4)	0.16
35-39	24 (6.8)	19 (10.6)	0.13
40-44	44 (12.5)	24 (13.3)	0.79
45-49	34 (9.7)	12 (6.7)	0.24
50-54	44 (12.5)	9 (5)	<0.01
55-59	25 (7.1)	11 (6.1)	0.66

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60-65	35 (10)	12 (6.7)	0.21
Sex			<0.001
Male	254 (72.4)	90 (50)	
Female	97 (27.6)	90 (50)	
Country of birth			0.50
Australia	230 (65.5)	113 (62.8)	
Other	118 (33.6)	66 (36.7)	
Language spoken at home			0.11
English	334 (95.2)	165 (91.7)	
Other	17 (4.8)	15 (8.3)	
Marital status			0.11
Married/Defacto	171 (48.7)	83 (46.1)	
Other	180 (51.3)	97 (53.9)	
Mental health history†	61 (17.4)	23 (12.8)	0.17
Substance abuse history†	36 (10.2)	1 (0.5)	
Injury-related details			
mTBI WHO criteria			
Initial GCS at the scene/ED triage			
15 points	232 (66.1)	180 (100)	
14 points	103 (29.2)	-	
13 points	14 (4)	-	
Missing	2 (0.57)	-	
LOC ≤ 30 mins			
No	71 (20.2)	-	

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Yes (witnessed/self-reported)	185 (52.7)	-	
Missing	50 (14.2)	-	
Amnesia < 24 hours			
No	40 (11.4)	-	
Yes (observed/self-reported)	229 (65.2)	-	
Missing	78 (22.2)	-	
Confusion/Disorientation	97 (27.6)	-	
Intracranial injuries on head CT	31 (8.8)	-	
Multiple mTBI WHO criteria	186 (53)	-	
mTBI Secondary criteria			
Queried LOC	45 (12.8)	12 (6.7)	<0.05
Queried amnesia	4 (1.1)	3 (1.7)	0.564
PTA testing w/ optimal scores	32 (9.1)	45 (25)	<0.001
Post-concussion symptoms #	183 (52.1)	133 (73.9)	<0.001
Headache	149 (42.4)	128 (71.1)	
Nausea/ Vomiting	103 (29.3)	79 (43.9)	
Dizziness	44 (12.5)	58 (32.2)	
Fatigue	2 (0.6)	1 (0.6)	
Memory problems	5 (1.4)	1 (0.6)	
Concentration problems	4 (1.1)	2 (1.1)	
Other	81 (23.1)	78(43.3)	
Transient neurological abnormalities#	28 (8)	22 (12.2)	
Multiple mTBI secondary criteria	-	32 (17.8)	
Injury Mechanism			0.35

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Fall	137 (39)	56 (31.1)	
Assault	27 (7.7)	14 (7.8)	
Work	9 (2.6)	7 (3.9)	
Sport	52 (14.8)	25 (13.9)	
Other	27 (7.7)	34 (18.9)	
Motor vehicle crash	99 (28.2)	44 (24.4)	<0.01
Driver	28 (28.3)	15 (34.1)	
Passenger	6 (6.1)	6 (13.6)	
Motorbike rider	8 (8.1)	10 (22.7)	
Bicyclist	44 (44.4)	5 (11.4)	
Pedestrian	10 (10.1)	5 (11.4)	
Other	3 (3)	3 (6.8)	
Reported impact to the head			<0.001
No	2 (0.6)	1 (0.5)	
Yes	269 (76.6)	164 (91.1)	
Missing	80 (22.8)	15 (8.3)	
Associated injury types†			
Soft tissue laceration	165 (47)	55 (30.6)	<0.001
Fracture	87 (24.8)	24 (13.3)	<0.01
Ligamentous	2 (0.6)	2 (1.1)	0.49
Dislocation	3 (0.8)	0	0.21
Abrasion, superficial wound, contusion	158 (45)	83 (46.1)	0.81
Multiple injury types	105 (29.9)	29 (16.1)	
Alcohol/drug use at the time of injury†	127 (36.2)	19 (10.6)	<0.001

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ED management details			
ED arrival mode			<0.001
By ambulance	250 (71.2)	56 (31.1)	
Other	101 (28.8)	124 (68.9)	
Triage category			<0.001
1. See immediately	24 (6.8)	4 (2.2)	
2. Within 10 minutes	170 (48.4)	42 (23.3)	
3. Within 30 minutes	116 (33.1)	64 (35.6)	
4. Within 1 hour	40 (11.4)	69 (38.3)	
5. Within 2 hours	1 (0.3)	1 (0.6)	
Intubation†	1 (0.3)	0	0.47
ICU admission†	7 (2)	1 (0.6)	0.19
Length of ED stay (hrs), median (IQR)	5.8 (4-8.6)	3.8 (2.6-5.7)	<0.001
Length of hospital stay (days), median (IQR)	3.4 (1.9-6.5)	2 (0.9-7.9)	
Discharge destination			<0.001
Discharged home	133 (37.9)	127 (70.6)	
Admitted to ED	121 (34.5)	36 (20)	
Admitted to ward	97 (27.6)	17 (9.4)	
Location of initial GCS†			<0.001
At the scene 30-min post-injury	216 (61.5)	52 (28.9)	
At ED presentation	130 (37)	127 (70.6)	
Brain CT performed†	266 (75.8)	73 (40.6)	<0.001
PTA measured†	182 (51.9)	46 (25.6)	<0.001

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A-WPTAS	169 (92.8)	44 (95.6)	
WPTAS	19 (10.4)	2 (4.4)	
Location of PTA testing	*(N=182)*	*(N=46)*	
In ED	166 (91.2)	44 (95.6)	0.364
In ward	28 (15.4)	2 (4.4)	<0.05
Time to PTA testing (hrs), median (IQR)	3.7 (2.3-6.1)	2.5 (1.7-4.9)	<0.05
PTA classification based on PTA testing	*(N=182)*	*(N=46)*	<0.001
Optimal scores/Did not fail	32 (17.8)	40 (87)	
6-30 minutes	2 (1.1)	-	
31-60 minutes	1 (0.1)	-	
>1-12 hours	106 (58.4)	-	
>12-24 hours	4 (2.2)	-	
Unknown/incomplete/missing	37 (20.4)	6 (13)	
Head Injury advice given†	166 (47.3)	120 (66.7)	<0.001
Follow-up recommendations	128 (36.5)	43 (23.9)	<0.01
Representations to ED (within 1 mth)	13 (3.7)	8 (4.4)	
Recorded mTBI diagnosis in the ED records			0.47
No	269 (76.9)	146 (81.1)	
Yes	81 (23.1)	34 (18.9)	

TBI: Traumatic brain injury; WHO: World Health Organization; GCS: Glasgow Coma Scale;

ED: Emergency department; ICU: Intensive care unit; LOC: Loss of consciousness; PTA: Post-

traumatic amnesia; A-WPTAS: Abbreviated Westmead Post Traumatic-Amnesia Scale;

WPTAS: Westmead Post-Traumatic Amnesia.

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† Proportion of valid cases.

§ χ2, z-test, t-test.

Note: The data contains occasional missing data values, which are assumed to be random.

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Table 2. WHO criteria distribution among the identified cohort of confirmed mTBI cases (N=351).

GCS =13-14 (N=117)	LOC ≤ 30 mins (N=185)	Amnesia < 24 hrs (N=229)	Confusion/ disorientation (N=97)	Intracranial injuries (N=31)	N (N=351)	%
✓	✓	✓	✓	✓	2	0.9
✓	✓	✓	✓		18	5.1
✓	✓	✓		✓	5	1.4
✓	✓	✓			10	2.8
✓	✓		✓		6	1.7
✓	✓				6	1.7
✓		✓	✓	✓	4	1.1
✓		✓	✓		32	9.1
✓		✓		✓	2	0.6
✓		✓			17	4.8
✓			✓		2	0.6
✓					13	3.7
	✓	✓	✓	✓	1	0.3
	✓	✓	✓		9	2.6
	✓	✓		✓	1	0.3
	✓	✓			51	14.4
	✓		✓	✓	1	0.3
	✓		✓		4	1.1

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✓			✓	3	0.8
✓				68	19.4
	✓	✓	✓	1	0.3
	✓	✓		8	2.3
	✓		✓	2	0.6
	✓			66	18.7
		✓		10	2.8
			✓	9	2.6

WHO: World Health Organization; TBI: Traumatic brain injury; GCS: Glasgow Coma Scale;

LOC: Loss of consciousness.

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Table 3. Confirmed mTBI patients (N=351) with documented PTA (N=260) based on the summary PTA-related mTBI designation, accounting for any documented PTA manifestations: observed/self-reported amnesia or confusion/disorientation fulfilling the WHO criteria, behavioural change or acute cognitive impairment on PTA testing.

Summary PTA-related mTBI designation (N=260)	Observed/self-reported Amnesia < 24 hrs [WHO criteria] (N=229)	Observed/self-reported Confusion/disorientation [WHO criteria] (N=97)	Observed Behavioural changes (N=61)	PTA testing administered (N=182)	N (N=351)	%
✓	✓	✓	✓	✓	27	7.7
✓	✓	✓	✓	-	6	1.7
✓	✓	✓	-	✓	24	6.8
✓	✓	✓	-	-	18	5.1
✓	✓	-	✓	✓	16	4.6
✓	✓	-	✓	-	6	1.7
✓	✓	-	-	✓	75	21.4
✓	✓	-	-	-	57	16.2
✓	-	✓	✓	✓	4	1.1
✓	-	✓	-	✓	6	1.7

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					Count	%
✓	-	✓	-		12	3.4
✓	-	-	✓	✓	**1**	**0.3**
✓	-	-	✓		**1^**	**0.3**
✓	-	-	-	✓	**7**	**2**
-	-	-	-	✓§	20#	5.8
-	-	-	-	-	71#	20.2

TBI: Traumatic brain injury; WHO: World Health Organization; PTA: Post-traumatic amnesia

Note: in **bold** are confirmed mTBI (N=9) based only on reported behavioural changes and/or cognitive impairment at PTA testing (i.e. PTA documented). All, expect one (^), met other mTBI WHO criteria (i.e. LOC≤ 30 mins, GCS=13-14, intracranial injuries).

Confirmed mTBI (N=91) with no documented positive findings for PTA manifestations.

§ Individuals who were tested for PTA and obtained optimal scores (i.e. not in PTA), in the absence of PTA manifestations documented in other sources.

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Table 4. Top 25 ED diagnosis codes (SNOWMED codes) and ED diagnosis codes indicative

of mTBI, for the overall mTBI cohort (confirmed mTBI cases, N=351; indeterminate mTBI,

N=180)

Top 25 ED Diagnosis Codes Description	N	%
Injury of head (disorder)	145	26.3
Motor vehicle accident victim (finding)	49	8.9
Minor head injury (disorder)	39	7.1
Traumatic injury (disorder)	37	6.7
Falls (finding)	35	6.4
Concussion (disorder)	26	4.7
Headache (finding)	11	2.0
Facial laceration (disorder)	10	1.8
Victim of physical assault (finding)	9	1.6
Alcohol intoxication (disorder)	8	1.5
Falling injury (finding)	8	1.5
Fractured nasal bones (disorder)	8	1.5
Laceration of head (disorder)	8	1.5
Post-concussion syndrome (disorder)	7	1.3
Injury of face (disorder)	6	1.1
Subarachnoid haemorrhage (disorder)	6	1.1
Neck pain (finding)	5	0.9
Backache	4	0.7
Intracranial injury without skull fracture (disorder)	4	0.7

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Laceration of forehead (disorder)	4	0.7
Closed fracture of clavicle (disorder)	3	0.5
Dizziness (finding)	3	0.5
Fracture of maxilla (disorder)	3	0.5
Fracture of rib (disorder)	3	0.5
Injury of neck (disorder)	3	0.5
ED Diagnosis Codes indicative of mTBI	**N**	**%**
Concussion (disorder)	26	4.7
Post-concussion syndrome (disorder)	7	1.3
Subarachnoid haemorrhage (disorder)	6	1.1
Intracranial injury without skull fracture (disorder)	4	0.7
Subdural hematoma (disorder)	3	0.5
Brief loss of consciousness (finding)	2	0.4
Cerebral haemorrhage (disorder)	1	0.2
Contusion of cerebrum (disorder)	1	0.2
Crushing injury of skull and intracranial contents (disorder)	1	0.2
Epidural haemorrhage (disorder)	1	0.2
Intracranial haemorrhage (disorder)	1	0.2
Loss of consciousness (finding)	1	0.2
Transient global amnesia (finding)	1	0.2
Traumatic subdural haemorrhage (disorder)	1	0.2

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FIGURE LEGENDS

Figure 1. Study recruitment flowchart.

LIST OF SUPPLEMENTAL DIGITAL CONTENT

Supplemental Material Content 1, (Table S1). Full list of ED diagnosis codes (SNOWMED

codes) and ED diagnosis codes indicative of mTBI, for the overall mTBI cohort (confirmed

mTBI cases, N=351; indeterminate mTBI, N=180).

Supplemental Material Content 2, (Table S2). Significant differences (p<.05) between people

with and without recorded mTBI diagnosis in Emergency Department (ED) records and/or ED

discharge codes indicative of mild traumatic brain injury (mTBI), among confirmed mTBI

cases (N=351).

Supplemental Material Content 3, (Table S3). Significant differences (p<.05) between people

tested for Post-traumatic Amnesia (PTA) versus those not tested, among confirmed mild

traumatic brain injury (mTBI) (N=351) and indeterminate cases (N=180).

Supplemental Material Content 4, (Figure S1). Percent of screened ED presentations aged 18-

65 years with confirmed or indeterminate mTBI (total 30 479 screened, 351 confirmed mTBI

(1.15%), 180 indeterminate mTBI (0.6%)).

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Figure 1. Study recruitment flowchart.

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Table S1. Full list of ED diagnosis codes (SNOWMED codes) and ED diagnosis codes indicative of mTBI, for the overall mTBI cohort (confirmed mTBI cases, N=351; indeterminate mTBI, N=180).

SNOWMED Codes Diagnosis Description	N	%
Injury of head (disorder)	145	26.3
Motor vehicle accident victim (finding)	49	8.9
Minor head injury (disorder)	39	7.1
Traumatic injury (disorder)	37	6.7
Falls (finding)	35	6.4
Concussion (disorder)	26	4.7
Headache (finding)	11	2.0
Facial laceration (disorder)	10	1.8
Victim of physical assault (finding)	9	1.6
Alcohol intoxication (disorder)	8	1.5
Falling injury (finding)	8	1.5
Fractured nasal bones (disorder)	8	1.5
Laceration of head (disorder)	8	1.5
Postconcussion syndrome (disorder)	7	1.3
Injury of face (disorder)	6	1.1
Subarachnoid hemorrhage (disorder)	6	1.1
Neck pain (finding)	5	0.9
Backache	4	0.7
Intracranial injury without skull fracture (disorder)	4	0.7
Laceration of forehead (disorder)	4	0.7
Closed fracture of clavicle (disorder)	3	0.5

Dizziness (finding)	3	0.5
Fracture of maxilla (disorder)	3	0.5
Fracture of rib (disorder)	3	0.5
Injury of neck (disorder)	3	0.5
Laceration - injury (disorder)	3	0.5
Soft tissue injury (disorder)	3	0.5
Subdural hematoma (disorder)	3	0.5
-	2	0.4
Abrasion of face (disorder)	2	0.4
Abrasion of head (disorder)	2	0.4
Alcohol abuse (disorder)	2	0.4
Brief loss of consciousness (finding)	2	0.4
Closed fracture of facial bone (disorder)	2	0.4
Fracture of cervical spine (disorder)	2	0.4
Fracture of face bones (disorder)	2	0.4
Fracture of phalanx of finger (disorder)	2	0.4
Fracture of vertebral column without spinal cord injury (disorder)	2	0.4
Hematoma of face (disorder)	2	0.4
Laceration of lip (disorder)	2	0.4
Motor vehicle accident passenger (finding)	2	0.4
Scalp laceration (disorder)	2	0.4
Superficial laceration of face (disorder)	2	0.4
Blunt injury (disorder)	1	0.2
Cerebral hemorrhage (disorder)	1	0.2
Closed fracture carpal bone (disorder)	1	0.2

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Closed fracture of base of skull (disorder)	1	0.2
Closed fracture of multiple ribs (disorder)	1	0.2
Closed fracture of of navicular bone of wrist (disorder)	1	0.2
Closed fracture of one or more phalanges of hand (disorder)	1	0.2
Closed fracture of orbital floor (blow-out) (disorder)	1	0.2
Closed fracture of rib (disorder)	1	0.2
Closed fracture of shaft of fibula (disorder)	1	0.2
Closed fracture of upper end of tibia (disorder)	1	0.2
Compression fracture of vertebral column (disorder)	1	0.2
Contusion (disorder)	1	0.2
Contusion of cerebrum (disorder)	1	0.2
Contusion of shoulder region (disorder)	1	0.2
Crushing injury of skull and intracranial contents (disorder)	1	0.2
Did not wait for treatment (finding)	1	0.2
Elbow fracture (disorder)	1	0.2
Epidural hemorrhage (disorder)	1	0.2
Finding related to falls (finding)	1	0.2
Floaters in visual field (finding)	1	0.2
Foot swelling (finding)	1	0.2
Fracture of distal end of radius (disorder)	1	0.2
Fracture of lumbar spine (disorder)	1	0.2
Fracture of mandible closed (disorder)	1	0.2
Fracture of multiple ribs (disorder)	1	0.2
Fracture of orbit (disorder)	1	0.2
Fracture of orbital roof (disorder)	1	0.2

Fracture of pelvis (disorder)	1	0.2
Fracture of pubis (disorder)	1	0.2
Fracture of skull (disorder)	1	0.2
Fracture of sternum (disorder)	1	0.2
Fracture of thoracic spine (disorder)	1	0.2
Fracture of upper jaw closed (disorder)	1	0.2
Fracture of vertebral column (disorder)	1	0.2
Hematoma (disorder)	1	0.2
Injury of facial nerve (disorder)	1	0.2
Injury of kidney (disorder)	1	0.2
Injury of pancreas (disorder)	1	0.2
Injury of shoulder region (disorder)	1	0.2
Intervertebral disc prolapse (disorder)	1	0.2
Intracranial hemorrhage (disorder)	1	0.2
Laceration of eye region (disorder)	1	0.2
Loss of consciousness (finding)	1	0.2
Migraine (disorder)	1	0.2
Motor vehicle accident driver (finding)	1	0.2
Multiple fractures (disorder)	1	0.2
Muscle strain (disorder)	1	0.2
Neck sprain (disorder)	1	0.2
Open fracture of nasal bones (disorder)	1	0.2
Open fracture of patella (disorder)	1	0.2
Open fracture of tibia AND fibula (disorder)	1	0.2
Open wound of lower leg (disorder)	1	0.2

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Pins and needles (finding)	1	0.2
Recurrent falls (finding)	1	0.2
Shoulder pain (finding)	1	0.2
Sprain of wrist (disorder)	1	0.2
Strain of neck muscle (disorder)	1	0.2
Superficial injury of face (disorder)	1	0.2
Superficial injury of head (disorder)	1	0.2
Syncope (disorder)	1	0.2
Transient global amnesia (finding)	1	0.2
Traumatic dislocation of clavicle (disorder)	1	0.2
Traumatic subdural hemorrhage (disorder)	1	0.2
Unexplained falls (finding)	1	0.2
Victim of trauma with multiple injuries (finding)	1	0.2
Vomiting (disorder)	1	0.2
Wound discharge (finding)	1	0.2

Table S2. Significant differences (p<.05) between people with and without recorded mTBI diagnosis in Emergency Department (ED) records and/or ED discharge codes indicative of mild traumatic brain injury (mTBI), among confirmed mTBI cases (N=351).

	Confirmed mTBI cases (N=351)					
	Cases with no recorded mTBI diagnosis (N=269)	Cases with recorded mTBI diagnosis (N=81)	Statistical comparison	Cases with no ED discharge codes indicative of mTBI (N=314)	Cases with ED discharge codes indicative of mTBI (N=37)	Statistical comparison
	N (%)	N (%)	p value§	N (%)	N (%)	p value§
Non-traffic-related injury	186 (69.1)	66 (81.5)	0.03	93 (30.6)	3 (8.1)	0.004
Discharge destination			0.0005			0.01
Discharged home	104 (38.7)	29 (35.8)		119 (37.9)	14 (37.8)	

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Admitted to ED	104 (38.7)	17 (21)		115 (36.6)	6 (16.2)	
Admitted to ward	61 (22.7)	35 (43.2)		80 (25.5)	17 (46)	
Intracranial injuries on head CT	4 (2)	26 (42.6)	<0.0001	16 (6.7)	14 (50)	<0.0001
Headache	103 (38.3)	46 (56.8)	0.009	127 (40.5)	22 (59.5)	0.03
Concentration problems	0 (0)	4 (4.9)	0.001	2 (0.6)	2 (5.4)	0.01
Follow-up recommendations	83 (30.9)	44 (54.3)	0.0003	106 (33.8)	22 (59.5)	0.002
PTA measured	125 (46.5)	56 (69.1)	0.0003	-	-	-
Recorded mTBI diagnosis in the ED records	-	-	-	85 (27.1)	16 (43.2)	0.04

§ χ2, z-test, t-test.

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Table S3. Significant differences (p<.05) between people tested for Post-traumatic Amnesia (PTA) versus those not tested, among confirmed mild traumatic brain injury (mTBI) (N=351) and indeterminate cases (N=180).

	Confirmed mTBI cases (N=351)			Indeterminate mTBI cases (N=180)		
	Confirmed mTBI not tested for PTA (N=169)	Confirmed mTBI tested for PTA (N=182)	Statistical comparison	Indeterminate mTBI not tested for PTA (N=134)	Indeterminate mTBI tested for PTA (N=46)	Statistical comparison
	N (%)	N (%)	p value§	N (%)	N (%)	p value§
Transported to ED by ambulance	108 (63.9)	142 (78)	0.004	30 (22.4)	26 (56.5)	<0.0001
Traffic-related injury	32 (18.9)	67 (36.8)	0.0002	23 (17.2)	21 (45.7)	0.0001
Discharge destination			<0.0001			<0.0001
Discharged home	98 (58)	35 (19.2)		106 (79.1)	21 (45.7)	
Admitted to ED	43 (25.4)	78 (42.9)		21 (15.7)	15 (32.6)	
Admitted to ward	28 (16.6)	69 (37.9)		7 (5.2)	10 (21.7)	

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LOC reported	49 (34.8)	85 (53.1)	0.005	-	-	-
Amnesia reported	85 (71.4)	140 (91.5)	<0.0001	-	-	-
Brain CT performed	116 (68.6)	150 (82.4)	0.003	-	-	-
Intracranial injuries on head CT	2 (1.7)	28 (18.6)	<0.0001	-	-	-

§ $\chi 2$, z-test, t-test

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Figure S1. Percent of screened ED presentations aged 18-65 years with confirmed or indeterminate mTBI (total 30 479 screened, 351 confirmed mTBI (1.15%), 180 indeterminate mTBI (0.6%)).

STROBE Statement—checklist of items that should be included in reports of observational studies
YOU MUST NOTE THE PAGE NUMBER WHERE EACH ITEM IS REPORTED INSIDE THE BRACKETS [ ]. IF NOT APPLICABLE WRITE N/A

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract **[1, 3]**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found **[3]**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported **[5-7]**
Objectives	3	State specific objectives, including any prespecified hypotheses **[7]**
Methods		
Study design	4	Present key elements of study design early in the paper **[7]**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **[7]**
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up **[7]**
		Case-control study—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls **[ ]**
		Cross-sectional study—Give the eligibility criteria, and the sources and methods of selection of participants **[ ]**
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed **[N/A]**
		Case-control study—For matched studies, give matching criteria and the number of controls per case **[ ]**
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable **[8-9]**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **[8-9]**
Bias	9	Describe any efforts to address potential sources of bias **[16]**
Study size	10	Explain how the study size was arrived at **[N/A]**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **[N/A]**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding **[N/A]**
		(*b*) Describe any methods used to examine subgroups and interactions **[N/A]**
		(*c*) Explain how missing data were addressed **[N/A]**
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed **[N/A]**
		Case-control study—If applicable, explain how matching of cases and controls was addressed **[ ]**
		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy **[ ]**
		(*e*) Describe any sensitivity analyses **[N/A]**

Continued on next page

Results

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed **[9]**
		(b) Give reasons for non-participation at each stage **[9]**
		(c) Consider use of a flow diagram **[9; Figure 1]**
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders **[9-11 ; Table 1]**
		(b) Indicate number of participants with missing data for each variable of interest **[Table 1]**
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) **[N/A]**
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time **[9-11]**
		Case-control study—Report numbers in each exposure category, or summary measures of exposure **[ ]**
		Cross-sectional study—Report numbers of outcome events or summary measures **[ ]**
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included **[proportions are presented in pg 7 and in Table 1]**
		(*b*) Report category boundaries when continuous variables were categorized **[N/A]**
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period **[N/A]**
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **[11-12]**

Discussion

Key results	18	Summarise key results with reference to study objectives **[12]**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **[12, 16-17]**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **[12-16]**
Generalisability	21	Discuss the generalisability (external validity) of the study results **[16]**

Other information

Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based **[18]**

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

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Challenges in the acute identification of mild traumatic brain injuries: results from an

emergency department surveillance study

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2

ABSTRACT

Objectives: To establish the proportion of mild traumatic brain injury (mTBI) diagnosis among people presenting to an Emergency Department (ED), to determine the accuracy of recorded ED diagnoses. We also aimed to describe challenges in mTBI case identification and its acute hospital management.

Design and Setting: A retrospective chart review of all ED attendances to a major trauma hospital, over a 9-month period (June 2015-February 2016).

Participants: Adults aged 18-65 years consecutively presenting to an ED.

Primary Outcome Measures: Proportion of mTBI diagnosis among ED attendances, (i.e. confirmed mTBI based on the World Health Organization (WHO) criteria or indeterminate mTBI based on secondary criteria), and proportion of accurately recorded mTBI diagnosis by ED clinicians (i.e. 'mTBI, 'concussion').

Results: Of 30 479 ED attendances, 351 (1.15%) confirmed mTBI diagnosis and 180 (0.6%) indeterminate diagnosis were identified. Only 81 (23.1%) individuals with a confirmed mTBI had a 'mTBI diagnosis' clearly recorded in the medical notes. Of the allocated discharge diagnosis codes to the two identified cohorts, 89.8% were not indicative of mTBI. Intracranial injuries were found in 31 (8.5%) confirmed cases. Glasgow Coma Scale scores were consistently assessed in the ED but identified only 117 (33.3%) confirmed mTBI cases. Post-traumatic amnesia (PTA) testing was able to confirm acute cognitive impairment, in 113 (62.1%) of those who were tested (182, 51.3%).

Conclusions: mTBI is a common, but an under-recognized cause for ED attendance. Despite challenges, the use of an operational definition such as the WHO diagnostic criteria can improve accuracy in mTBI identification. Acute management may be enhanced by rapid assessment of PTA.

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STRENGTHS AND LIMITATIONS OF THIS STUDY

- A systematic chart review of all Emergency Department attendances was employed to capture any possible mild traumatic brain injury (mTBI) case.

- The use of standard diagnostic criteria to establish the occurrence of mTBI diagnosis, ensures accuracy in identification and comparability across existing research.

- This study provides novel data on proportions of rapid post-traumatic amnesia screening in NSW, Australia, where there is written recommendation around PTA screening in all Emergency Departments.

- Collecting data from single hospital site limits generalizability of study findings.

- Given the retrospective design, conclusions on mTBI occurrence and accuracy of designation were limited by the availability of documented clinical information, with mTBI occurrence possibly being underestimated.

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INTRODUCTION

Mild traumatic brain injuries (mTBI) are a serious public health problem that is referred to as a 'silent epidemic'.[1] Though being the least severe of all brain injuries, identification is the most challenging, with mTBI often missed at diagnosis.[2] Major barriers to mTBI identification are the wide variability in criteria used for diagnosis and the lack of sensitive standardized measures for identifying mTBI manifestations, which are commonly subtle and rapidly-resolving.[2, 3] Despite these limitations, the World Health Organization (WHO) best-evidence review estimated that hospital-treated mTBI are in the range of 100-300/100 000 population. [4] Diagnosis and management of mTBI largely occur in an emergency department (ED). [5] Little information exists, however, about the accuracy of mTBI identification in emergency settings. Two studies, conducted in three Canadian EDs [6] and two EDs in the US,[7] found that up to 50% of patients sustaining mTBI received an inaccurate ED diagnosis. Poor identification likely impacts clinical management of these patients. Given trends in increasing ED attendances for head trauma [8, 9] there is a critical need to for research that addresses the challenges in mTBI diagnosis.

Another challenge for ED clinicians is the identification of mTBI cases at major risk of complications versus those who can be safely discharged. [10] Latest research suggests that these so-called minor injuries can have long-term impacts that extend beyond the anticipated 3-month timeframe of cognitive recovery for uncomplicated cases, calling for urgent improvements in the acute management of mTBI. Long-term impacts include higher health care usage [11], psychosocial complications [12, 13] and in vulnerable subgroups chronic cognitive symptomatology [12, 14] and neural cellular alterations [15, 16] not easily detectable by routine radiological examinations that may increase the risk of neurodegeneration. [17] EDs represent a crucial point where accurate identification and early management of these patients may prevent long-term personal and economic impacts.

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Key steps to aid early and accurate identification and management of mTBI include enhanced consistency in diagnostic criteria and standardized assessment methods.[3] An internationally-recognised operational definition was developed by the WHO Task Force,[3, 4] clearly outlining the four key clinical manifestations for mTBI diagnosis. These are:(i) level of consciousness, (ii) confusion or disorientation, (iii) post-traumatic amnesia (PTA) and (iv) transient neurological abnormalities, such as computed tomography (CT)-detected intracranial injuries, the latter defined as complicated mTBI (about 10% of cases).[18] Recommended objective measures to assess TBI 'severity' include conventional radiology to exclude structural lesions and the Glasgow Coma Scale (GCS) to monitor level of consciousness (i.e. mTBI is defined as GCS scores of 13-15 out of 15 and a loss of consciousness (LOC) of ≤30 minutes). However, no clear guidance is given by the WHO on the clinical assessment of the other TBI diagnostic criteria. [4] This particularly applies to PTA, which is recognized as the best prognostic indicator of mTBI outcomes. [19, 20]

PTA is a complex clinical concept reflecting an acute transient cognitive dysfunction [21] that presents not only as amnesia but more broadly as a period of inability to store new information, confusion, disorientation or behavioural changes. [3, 21] While standardized testing exist to assess the resolution of acute cognitive dysfunction (i.e. PTA) these are rarely used in the acute management of mTBI patients because many protocols are too lengthy to be administered in ED settings.[21] In NSW, Australia, the Abbreviated Westmead PTA Scale (A-WPTAS), [21] was specifically designed for ED use and recommended statewide (NSW Ministry of Health, Initial management of closed head injury in adults, 2011) as a brief validated measure of PTA to improve identification of traumatic brain injury events among closed head injury patients with a GCS of 13-15 (NSW Ministry of Health, Initial management of closed head injury in adults, 2011). This measure includes five GCS orientation items plus a memory test of recall of three picture cards learnt on the first trial. The test is repeated hourly

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for up to four hours until optimal scores of 18 out of 18 are obtained (i.e.15 on the GCS, plus 3

on the memory test), indicating a resolution of PTA, if present. Though the A-WPTAS has

been shown to assist with a safer discharge of people with mTBI, by identifying cases with a

GCS of 15/15 who remain acutely cognitively impaired, [20] and reducing hospitalization and

direct costs [22], its implementation to date appears inconsistent. Unpublished Australian data

showed that rates of PTA screening in ED range from 0 to 31%, [10] while findings from a

recent randomized controlled trial showed lower rates (i.e. below 13%). [23] This highlights

the need for further studies to investigate the extent and possible benefit of A-WPTAS

implementation in emergency settings.

Given the current challenges in mTBI diagnosis and limitations of existing

epidemiological research, this study primarily aimed to establish: (i) the occurrence of mTBI

diagnosis among ED attendances (i.e. meeting standard diagnostic criteria), and the proportion

of these that received a clearly recorded mTBI diagnosis (i.e. based on clinical notes and/or

diagnosis codes). A secondary aim was to describe challenges in acute identification and

management of mTBI, such as the implementation of a validated measure for PTA screening in

ED.

METHODS

This is a retrospective cohort study, employing chart review and standard WHO

diagnostic criteria to define occurrence of mTBI among adults aged 18-65 years with ED

attendances of a major trauma hospital in Sydney, Australia, over a 9-month period (from June

2015 to February 2016). Ethical approval was obtained from the Northern Sydney Local Health

District Ethics, Sydney, Australia (LNR/16/HAWKE/388; LNRSSA/16/HAWKE/389). Two

independent chart auditors systematically screened all ED attendances within the study period

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and reviewed all recorded information in ambulance reports, ED and medical notes, to determine whether mTBI occurred. Details of the study method are available. [24]

The main outcomes were: (i) proportions of identified mTBI diagnosis, meeting WHO diagnostic criteria, among total ED attendances within 24 hours post-injury, meeting study age-range and timeframe, and (ii) proportions of accurately recorded mTBI diagnoses by ED clinicians based on positive mTBI-related definition documented in the medical record. A confirmed mTBI diagnosis was ascertained based on the presence of any of the four mTBI manifestations (i.e. level of consciousness, confusion/disorientation, post-traumatic amnesia, transient neurological abnormalities), as expressed by the corresponding WHO criteria (Table 1 and Online Supplementary Table S1): [4, 21] (i) a GCS of 13–15 30 minutes after injury or on later presentation to healthcare; and/or loss of consciousness of ≤30 mins; (ii) confusion/disorientation, (iii) PTA <24-hours, and/or (iv) CT-detected intracranial injuries not requiring neurosurgery, respectively.

Despite the uniqueness of this study in using a validated measure for PTA screening in ED, initial chart review indicated PTA testing was not consistently administered. Further, optimal scores obtained during ED stay would still not be able to identify cases whose PTA resolved early post-injury [2] (i.e. optimal scores meaning that PTA, if present, had resolved). These cases could, instead, be identified by any evidence of PTA manifestations (i.e. any gap in memory, period of confusion/disorientation, behavioral changes) documented by ambulance and emergency staff in their clinical observations. Therefore, to ascertain the presence of PTA as criterium for mTBI occurrence, a summary PTA-related mTBI designation (Online Supplementary Table S2) was developed by cross-checking any PTA-related neurological and behavioural disturbances documented in medical records, from the time of injury to hospital discharge. A positive PTA designation was defined by any of the following source: acute cognitive impairment on A-WPTAS testing, observed behavioural change suggestive of PTA

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(e.g. repetitive questioning, combative behaviour), as well as any observed/self-reported gap in memory, or confusion/disorientation thereby fulfilling two of the WHO criteria. [3, 21]

In the absence of any documented WHO criterion, indeterminate evidence of mTBI [25] was defined based on the presence of any secondary criteria: [20] (i) optimal scores (i.e. 18/18) on the second trial of the A-WPTAS indicating that PTA, if present, had resolved, (ii) symptoms that may correspond to 'post-concussion symptoms' but which are not specific to mTBI,[24] (iii) transient neurological abnormalities (excluding intracranial injuries not requiring surgery), which are not common findings or clinical features of mTBI [2, 3] and are not recommended as stand-alone mTBI criteria,[2] or (iii) queried LOC/amnesia.

The accuracy of the diagnosis given by ED clinicians to the identified individuals with mTBI diagnosis was assessed by the presence of any recorded 'mTBI', 'concussion', 'post-concussion symptoms/syndrome' diagnoses in medical notes.[26] In addition, allocation of relevant mTBI-related discharge diagnosis codes (SNOWMED codes) was also explored, to inform how much routinely collected administrative data could be useful for brain injury diagnostic purpose.

Patient and Public Involvement

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination of our research.

RESULTS

Identified cases with mTBI diagnosis

During the study period, 30 479 adults aged 18-65 years attended the ED and were screened (Figure 1). Of the 587 mTBI-related ED presentations initially identified, 56 cases were

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excluded due to: (N=27) self-discharge or unclear evidence of mTBI, (N=8) confounding

factors (e.g. intubation, psychosis, medical comorbidities) or possible moderate TBI (e.g.

LOC/amnesia of unclear duration). Also excluded were 21 (3.9%) individuals who represented

for the same mTBI event. Among total ED attendances, 351 (1.15%) confirmed mTBI

diagnoses and an additional 180 (0.6%) cases with insufficient/indeterminate mTBI evidence

were identified (Online Supplementary Figure S1). Of these, two people (0.4%) sustained

multiple mTBI (i.e. repetitive mTBI). Sociodemographic, injury-related and acute management

details are illustrated in Table 1-3.

A clearly recorded mTBI diagnosis in ED records [26] was present only in 23.1% (N=81)

of confirmed mTBI and 18.9% (N=34) of indeterminate cases. Similarly, among the 551 ED

diagnosis codes (i.e. SNOWMED codes) (Table 4) allocated to the two identified cohorts, the

most commonly used code descriptor was 'injury of head' (N=145, 26.3%). Only 56 of these

codes (10.2%) were specifically indicative of brain injury occurrence, with 'concussion' being

the most common (N=26, 46.4%). The remaining codes mostly reflected intracranial injury

findings (see also Online Supplementary Table S3, which shows the full list of ED discharge

diagnosis codes).

Confirmed mTBI cases that were given a clearly-recorded mTBI diagnosis and/or a

discharge code suggestive of mTBI were more likely to (Online Supplementary Table S4): be a

non-traffic-crash related mTBI ($p<.05$), be admitted to a ward ($p<.05$), have CT-detected

intracranial injuries ($p<.0001$), present with headaches ($p<.05$) and/or concentration problems

($p<.05$), and be recommended for follow-up care ($p<.01$). Furthermore, those with a clearly-

recorded mTBI diagnosis were more likely to have been tested for PTA ($p=.0003$), while those

with an allocated discharge code suggestive of mTBI were more likely to have a clearly written

mTBI diagnosis in their ED records also ($p=.04$).

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Injury-related characteristics

Cases with a confirmed mTBI diagnosis met the following WHO criteria: initial GCS of 13-14 (i.e. at the scene 30 minutes post-injury/at ED admission; N=117; 33.3%), LOC (i.e. witnessed/self-reported; N=185; 52.7%), amnesia (i.e. observed/self-reported; N=229; 65.2%), confusion/disorientation (N=97; 27.6%), and CT-detected intracranial injuries (N=31; 8.8%). Multiple WHO criteria were present in 186 cases (53%) (Table 1). Cases with an indeterminate mTBI diagnosis met the following secondary criteria in the absence of WHO criteria: optimal scores of 18/18 on the A-WPTAS (N=45; 25%), presence of post-concussion symptoms (133; 73.9%), transient neurological abnormalities (N=22; 12.2%) queried LOC (N=12; 6.7%) and/or queried amnesia (N=3; 1.7%). Multiple secondary criteria were present in 32 cases (17.8%).

Fall was the most common cause of mTBI in both confirmed (39.1%) and indeterminate (31.1%) groups, followed by motor vehicle crash (28.2% - confirmed; 24.4% - indeterminate). Alcohol or drug use in association with the injury was self-reported or clinically observed in 127 (36.2%) confirmed cases compared to only 19 (10.6 %) of indeterminate cases (*p*<.001).

Acute hospital management details

Brain imaging was undertaken in 75.8% of cases with a confirmed mTBI diagnosis and 40.6% of cases with an indeterminate mTBI (*p*<.001; Table 3). Only 182 (51.8%) individuals with a confirmed mTBI were tested for PTA (i.e. A-WPTAS or WPTAS). Of these, the majority (106; 58.4%) had a PTA duration of >1 to 12 hours, 32 (17.8%) obtained optimal scores of 18/18 (i.e. did not fail A-WPTAS testing) and 37 (20.4%) had an unknown designation due to incomplete/missing documentation. Median time to the first PTA testing was 3.7 (2.3-6.1) hours post-injury for confirmed mTBI diagnosis and 2.5 (1.7-4.9) hours for indeterminate mTBI.

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The summary PTA-related mTBI designation (Online Supplementary Tables S2) including any documented positive PTA-related findings (i.e. neurological and behavioural disturbances) in the medical records, identified a total of 260 (74.1%) confirmed mTBI cases with PTA. The majority (89.8%) were identified based on two WHO criteria of observed/self-reported amnesia (i.e. any gap in memory) and/or period of confusion/ disorientation, with a further nine people deemed in PTA only due to failing the A-WPTAS (N=8) or due to reported behavioral changes in medical records, (N=1) (i.e. repetitive questioning). All these nine cases, except one, also met at least one of the other mTBI WHO criteria (e.g. LOC, GCS=13-14, intracranial injuries).

In both groups, people tested for PTA were more likely to (Online Supplementary Table S5): be transported to ED by ambulance ($p<.01$); sustain a traffic-related mTBI ($p<.001$); be admitted to ED/ward ($p<.0001$). Confirmed mTBI cases were more likely tested for PTA in the presence of other mTBI signs, such as LOC ($p=.005$), amnesia ($p<.0001$) and brain imaging ($p=0.003$) with positive findings ($p<.0001$).

DISCUSSION

By using the WHO operational criteria, our study reports an occurrence of confirmed mTBI diagnosis among ED total attendances of 1.2% (351/30 479). These findings correspond to the 1.1-1.3% proportion observed in a preliminary study, which used the same criteria and methods for TBI diagnosis [20, 24] therefore confirming the robustness of the proposed WHO surveillance system for acute mTBI identification. A similar proportion of mTBI cases seeking emergency care (1.9%; 670/35 096) was also reported in a prospective cohort study conducted in a large metropolitan ED in New York. [27] This study employed the alike 1993 American College of Rehabilitation Medicine criteria,[27] as operational definition, suggesting that using

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standard diagnostic criteria can enhance consistency in mTBI identification and comparability of study findings.

Worryingly, only 23.1% (81/351) of our identified cohort with a confirmed mTBI diagnosis (i.e. meeting the WHO criteria) had an accurate mTBI diagnosis documented in the medical records (i.e. written diagnosis of 'concussion', 'mTBI'). The proportion of accurate diagnoses was much lower than reported in two previous prospective studies conducted in Canada [6] and the US [7] respectively, being ≥50%. While using a retrospective design could account for these differences, global challenges certainly exist in the acute identication of 'minor' TBI events. This study contributes by providing unique Australian data and suggests that adopting standard criteria and the assessment of PTA provide so far the best approach to improve accuracy of mTBI diagnosis.

Poor accuracy in mTBI identification in ED [3, 17] could affect current estimates of 100-300/100 000 reported in a WHO review,[4] hence, underestimating the 'true' incidence of hospital-treated mTBI. Surveillance systems, such as accurate administrative databases, are recommended strategies to tackle this problem. However, the use of discharge diagnosis codes, such as ICD coding, in hospital databases has previously been shown not to be sensitive in detecting mTBI. [26, 27] Our results confirm this gap. Only 10.7% (59/551) of ED discharge diagnosis codes (SNOWMED codes) allocated to the identified cohorts with either a confirmed or indeterminate mTBI diagnosis were indicative of mTBI. Despite limitations in the number of diagnoses able to be recorded (i.e. maximum two SNOWMED codes), there seems to be a trend for ED clinicians to better identify the more 'severe' injuries, i.e. those showing positive CT findings, being admitted to a ward and receiving follow-up care recommendations. By contrast, uncomplicated mTBI appears to be overlooked, by not receiving an accurate designation in ED records or accurate coding. There was also an interchangeable use of terms like 'concussion', '(mild/minor) head injury' and 'mTBI', as also shown in previous studies,

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[3, 17, 27] that suggest a poor clarity in the distinction between those having a traumatic brain injury versus simple head injuries, thus reiterating the scarce utility of administrative data in mTBI identification.

While the WHO criteria can be regarded as a reliable system for the identification of individuals who sustained a mTBI , there were challenges in its application. [2] First, it was unclear how to interpret LOC or amnesia when it was not witnessed/observed as per WHO recommendations for mTBI identification. It is likely that injured people report a LOC or amnesia interchangeably, [2] thus, a self-reported LOC/amnesia at the time of the injury suggests a confirmed mTBI diagnosis. Conversely, when LOC/amnesia was queried by a physician this more likely suggests indeterminate evidence of mTBI.

PTA is the most important TBI prognostic indicator, yet the most challenging to evaluate because it encompasses a series of acute cognitive impairment signs and symptoms. This study is unique in its way of screening for PTA in ED by means of a validated measure. However, standard PTA testing was only available in about half of confirmed mTBI cases (51.9%), though this was considerably higher than previously reported PTA screening rates (up to 31%).[10, 23] Also, optimal scores of 18/18 on the A-WTPAS were obtained in 17.8% of those who were tested. While optimal scores clearly indicate the absence of acute cognitive dysfunction at the time of assessment (i.e. a person is not in PTA), these cannot exclude that PTA was present before that time, not being informative for mTBI diagnostic purpose.

Therefore, this study used a summary PTA-related mTBI designation, accounting for the positive presence of any PTA-related neurological and behavioural disturbances recorded in medical records.[3, 21] Using this indicator, we found 260 of the 351 cases with a confirmed mTBI diagnosis were deemed to be in PTA. Of these, the majority (89.8%) was based on the presence of observed/self-reported amnesia (i.e. a gap in memory) or confusion/disorientation (i.e. meeting two of the four WHO criteria), while 9 (2.6%) cases were further identified based

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only on evidence of acute cognitive impairment (i.e. failing PTA testing; N=8) or observed

behavioral changes (N=1), the latter being repetitive questioning that is typically an indirect

sign of PTA. These additional cases, except one, all met at least one of the other WHO criteria

(e.g. LOC, GCS=13-14, intracranial injuries) for mTBI diagnosis.

Overall, these findings reiterate that the WHO criteria together constitute the most

reliable surveillance system for mTBI identification and provide useful information to

specifically identify cases whose PTA may have resolved by the time of ED admission.

Additionally, the implementation of PTA testing, providing objective estimates of acute

cognitive impairment may assist in monitoring recovery progress towards a safer discharge and

enhance diagnostic accuracy of cases where mTBI indicators are unclear or unavailable. The

administration of brief PTA testing (i.e. the A-WTPAS) as an extension of the GCS, which is

usually assessed at the scene by the ambulance staff, [21] could provide a more accurate

estimate of the presence and duration of PTA, thus of mTBI occurrence.

Another challenge was the assessment of transient neurological abnormalities, other than

intracranial injuries. Ruff et al. (2009) suggested these abnormalities in isolation do not

constitute a strong basis for mTBI diagnosis because they are not common or typical features of

mTBI.[2] Thus, these were considered as indeterminate evidence of mTBI. The WHO also

recommends excluding cases whose TBI manifestations can be affected or due to other

factors.[28] Unlike other confounders (e.g. intubation, psychiatric disorder), the influence of

alcohol/drug on mTBI manifestations was particularly difficult to assess due to the lack of

objective blood level measurements. Overall, these cases accounted for 36.2% of confirmed

mTBI, that is, in the range of previous findings (30-60%). [29, 30] These findings confirm

intoxication is a major confound affecting accurate identification of mTBI in busy ED settings,

with day of injury blood alcohol level being associated with: failure on PTA assessment, [20] a

longer duration of LOC, and decreased GCS scores. [31] Differentiation of mTBI in these

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individuals in the ED setting is likely to be facilitated by the potential implementation of blood based biomarkers.[32]

This study confirms that issues exist in identifying the mildest TBIs,[2] whose clinical manifestations may resolve within <15 minutes post-injury according to the American Academy of Neurology classification.[2] Considering the amount of missing or non-informative/optimal indicators among cases with a confirmed mTBI in this study, as also reported by previous research,[33] along with PTA measured 2-3 hours post-injury,[21] it is likely that rapid-resolving LOC/amnesia were missed with a bias towards more severe mTBI. Secondary criteria were established to identify cases with indeterminate evidence of TBI. These cases constituted 0.6% of ED total attendances and, interestingly, 18.9% of these received a positive mTBI diagnosis by ED clinicians. Another study using a similar (probabilistic) approach found delayed functional recovery in the group with debatable mTBI compared to healthy and trauma controls, [25] raising concerns around the need for identifying and treating less-severe mTBI that may appear to not meet diagnostic criteria.

Intracranial injuries were found in 31 (8.8%) cases with a confirmed mTBI diagnosis. [18] Brain CT was performed in 75.8%, plus in 40% of cases with an indeterminate mTBI [18] Clinical assessment remains the gold-standard for mTBI identification, with PTA testing being the most promising measure. Among those who were tested, the A-WPTAS was able to detect acute cognitive impairment in 62.1% of cases (113/182), while the GCS was able to detect only 33.5% of cases (117/349).[20] This study further suggests that when PTA is measured it increases the likelihood of an accurate mTBI designation provided by ED clinicians. Implementation of PTA testing in ED settings should be, thus, extended to all individuals with a possible mTBI [21] to reduce the risk of missed opportunity for mTBI identification and to contribute to more accurate clinical decision making and safer discharge of patients.

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Study Limitations

Major strengths of this study were the use of standard diagnostic criteria for the identification

of mTBI and the systematic screening of any cases with a possible mTBI diagnosis among ED

attendances. However, the retrospective design is limiting as we might not have captured

important information on confounding factors or mTBI indicators. Similarly, the absence of

documented information in medical records does not necessarily imply that standard diagnostic

criteria or assessment protocols were not applied by ED clinicians. Generalizability of findings

is limited by the following selection bias:[30] a working-age population, 9-month audit-period,

and using only a single hospital site. Some of these issues will be addressed by conducting a

multi-site study in the future.

CONCLUSIONS

MTBI may have higher impacts on emergency care settings than previously anticipated. This

study confirms the use of an operational definition, such as the WHO operational criteria as a

reliable surveillance system for acute identification of mTBI, although challenges still exist in

its meticulous application. Identification, prognosis and acute management of individuals with

mTBI would be greatly enhanced by the implementation of standardised PTA screening (e.g.

A-WPTAS) early after injury. Improvements in clinical and administrative designation of these

injuries requires the use of these data to monitor and address long-term health and economic

impacts of mTBI.

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Competing interests: None.

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Table 1. Clinical features of mTBI diagnosis (confirmed mTBI, N=351; indeterminate mTBI, N=180) who presented to ED, illustrated by WHO diagnostic criteria and secondary criteria

	Confirmed mTBI [WHO criteria] (N=351)	Indeterminate mTBI [Secondary criteria] (N=180)	Statistical comparison
	N (%)	N (%)	p value§
mTBI WHO criteria			
(i) Level of consciousness			
Initial GCS at the scene/ED triage			
15 points	232 (66.1)	180 (100)	
14 points	103 (29.2)	-	
13 points	14 (4)	-	
Missing	2 (0.57)	-	
LOC ≤ 30 mins			
No	71 (20.2)	-	
Yes (witnessed/self-reported)	185 (52.7)	-	
Missing	50 (14.2)	-	
(ii) Confusion/Disorientation	97 (27.6)	-	
(iii) Amnesia < 24 hours			
No	40 (11.4)	-	

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Yes (observed/self-reported)	229 (65.2)	-	
Missing	78 (22.2)	-	
(iv) Intracranial injuries on brain CT	31 (8.8)	-	
Multiple mTBI WHO criteria	186 (53)	-	
mTBI Secondary criteria			
Queried LOC	45 (12.8)	12 (6.7)	<0.05
Queried amnesia	4 (1.1)	3 (1.7)	0.564
PTA testing w/ optimal scores	32 (9.1)	45 (25)	<0.001
Post-concussion symptoms #	183 (52.1)	133 (73.9)	<0.001
Headache	149 (42.4)	128 (71.1)	
Nausea/ Vomiting	103 (29.3)	79 (43.9)	
Dizziness	44 (12.5)	58 (32.2)	
Fatigue	2 (0.6)	1 (0.6)	
Memory problems	5 (1.4)	1 (0.6)	
Concentration problems	4 (1.1)	2 (1.1)	
Other	81 (23.1)	78(43.3)	
Transient neurological abnormalities#	28 (8)	22 (12.2)	
Multiple mTBI secondary criteria	-	32 (17.8)	

TBI: Traumatic brain injury; WHO: World Health Organization; GCS: Glasgow Coma Scale;

ED: Emergency department; LOC: Loss of consciousness; CT: Computer Tomography; PTA:

Post-traumatic amnesia; A-WPTAS: Abbreviated Westmead Post Traumatic-Amnesia Scale;

WPTAS: Westmead Post-Traumatic Amnesia.

† Proportion of valid cases.

§ χ2, z-test, t-test.

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Note: The data contains occasional missing data values, which are assumed to be random.

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Table 2. Socio-demographic and injury-related information of identified cases with a confirmed mTBI diagnosis (N=351) and indeterminate mTBI diagnosis (N=180) who presented to ED.

	Confirmed mTBI [WHO criteria] (N=351)	Indeterminate mTBI [Secondary criteria] (N=180)	Statistical comparison
	N (%)	N (%)	p value§
Socio-demographics			
Age (years), mean (SD)	39.9 (14.2)	36.1 (13.1)	<0.01
[median, IQR]	[40.8, 26.5-52]	[34.7, 24.1-44.5]	
Age groups (years)			
18-24	71 (20.2)	52 (28.9)	0.02
25-29	38 (10.8)	15 (8.3)	0.36
30-34	36 (10.3)	26 (14.4)	0.16
35-39	24 (6.8)	19 (10.6)	0.13
40-44	44 (12.5)	24 (13.3)	0.79
45-49	34 (9.7)	12 (6.7)	0.24
50-54	44 (12.5)	9 (5)	<0.01
55-59	25 (7.1)	11 (6.1)	0.66
60-65	35 (10)	12 (6.7)	0.21

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Sex			<0.001
Male	254 (72.4)	90 (50)	
Female	97 (27.6)	90 (50)	
Country of birth			0.50
Australia	230 (65.5)	113 (62.8)	
Other	118 (33.6)	66 (36.7)	
Language spoken at home			0.11
English	334 (95.2)	165 (91.7)	
Other	17 (4.8)	15 (8.3)	
Marital status			0.11
Married/Defacto	171 (48.7)	83 (46.1)	
Other	180 (51.3)	97 (53.9)	
Mental health history†	61 (17.4)	23 (12.8)	0.17
Substance abuse history†	36 (10.2)	1 (0.5)	
Injury-related details			
Injury Mechanism			0.35
Fall	137 (39)	56 (31.1)	
Assault	27 (7.7)	14 (7.8)	
Work	9 (2.6)	7 (3.9)	
Sport	52 (14.8)	25 (13.9)	
Other	27 (7.7)	34 (18.9)	
Motor vehicle crash	99 (28.2)	44 (24.4)	<0.01
Driver	28 (28.3)	15 (34.1)	
Passenger	6 (6.1)	6 (13.6)	

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Motorbike rider	8 (8.1)	10 (22.7)	
Bicyclist	44 (44.4)	5 (11.4)	
Pedestrian	10 (10.1)	5 (11.4)	
Other	3 (3)	3 (6.8)	
Reported impact to the head			<0.001
No	2 (0.6)	1 (0.5)	
Yes	269 (76.6)	164 (91.1)	
Missing	80 (22.8)	15 (8.3)	
Associated injury types†			
Soft tissue laceration	165 (47)	55 (30.6)	<0.001
Fracture	87 (24.8)	24 (13.3)	<0.01
Ligamentous	2 (0.6)	2 (1.1)	0.49
Dislocation	3 (0.8)	0	0.21
Abrasion, superficial wound, contusion	158 (45)	83 (46.1)	0.81
Multiple injury types	105 (29.9)	29 (16.1)	
Alcohol/drug use at the time of injury†	127 (36.2)	19 (10.6)	<0.001

TBI: Traumatic brain injury; ED: Emergency department.

† Proportion of valid cases.

§ $\chi 2$, z-test, t-test.

Note: The data contains occasional missing data values, which are assumed to be random.

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Table 3. Acute hospital management details of identified cases with a confirmed mTBI

diagnosis (N=351) and indeterminate mTBI diagnosis (N=180) who presented to ED.

	Confirmed mTBI [WHO criteria] (N=351)	Indeterminate mTBI [Secondary criteria] (N=180)	Statistical comparison
	N (%)	N (%)	p value§
ED management details			
ED arrival mode			<0.001
By ambulance	250 (71.2)	56 (31.1)	
Other	101 (28.8)	124 (68.9)	
Triage category			<0.001
1. Seen immediately	24 (6.8)	4 (2.2)	
2. Within 10 minutes	170 (48.4)	42 (23.3)	
3. Within 30 minutes	116 (33.1)	64 (35.6)	
4. Within 1 hour	40 (11.4)	69 (38.3)	
5. Within 2 hours	1 (0.3)	1 (0.6)	
Intubation†	1 (0.3)	0	0.47
ICU admission†	7 (2)	1 (0.6)	0.19
Length of ED stay (hrs), median (IQR)	5.8 (4-8.6)	3.8 (2.6-5.7)	<0.001

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Length of hospital stay (days), median (IQR)	3.4 (1.9-6.5)	2 (0.9-7.9)	
Discharge destination			<0.001
Discharged home	133 (37.9)	127 (70.6)	
Admitted to ED	121 (34.5)	36 (20)	
Admitted to ward	97 (27.6)	17 (9.4)	
Location of initial GCS†			<0.001
At the scene 30-min post-injury	216 (61.5)	52 (28.9)	
At ED presentation	130 (37)	127 (70.6)	
Brain CT performed†	266 (75.8)	73 (40.6)	<0.001
PTA measured†	182 (51.9)	46 (25.6)	<0.001
A-WPTAS	169 (92.8)	44 (95.6)	
WPTAS	19 (10.4)	2 (4.4)	
Location of PTA testing	*(N=182)*	*(N=46)*	
In ED	166 (91.2)	44 (95.6)	0.364
In ward	28 (15.4)	2 (4.4)	<0.05
Time to PTA testing (hrs), median (IQR)	3.7 (2.3-6.1)	2.5 (1.7-4.9)	<0.05
PTA classification based on PTA testing	*(N=182)*	*(N=46)*	<0.001
Optimal scores/Did not fail	32 (17.8)	40 (87)	
6-30 minutes	2 (1.1)	-	
31-60 minutes	1 (0.1)	-	
>1-12 hours	106 (58.4)	-	
>12-24 hours	4 (2.2)	-	
Unknown/incomplete/missing	37 (20.4)	6 (13)	

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Head Injury advice given†	166 (47.3)	120 (66.7)	<0.001
Follow-up recommendations	128 (36.5)	43 (23.9)	<0.01
Representations to ED (within 1 mth)	13 (3.7)	8 (4.4)	
Recorded mTBI diagnosis in the ED records			0.47
No	269 (76.9)	146 (81.1)	
Yes	81 (23.1)	34 (18.9)	

TBI: Traumatic brain injury; GCS: Glasgow Coma Scale; ED: Emergency department; ICU:

Intensive care unit; LOC: Loss of consciousness; PTA: Post-traumatic amnesia; A-WPTAS:

Abbreviated Westmead Post-TraumaticAmnesia Scale; WPTAS: Westmead Post-Traumatic

Amnesia.

† Proportion of valid cases.

§ χ2, z-test, t-test.

Note: The data contains occasional missing data values, which are assumed to be random

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Table 4. Top 25 ED diagnosis codes (SNOWMED codes) and ED diagnosis codes indicative

of mTBI, for the overall mTBI cohort (confirmed mTBI cases, N=351; indeterminate mTBI,

N=180)

Top 25 ED Diagnosis Codes Description	N	%
Injury of head (disorder)	145	26.3
Motor vehicle accident victim (finding)	49	8.9
Minor head injury (disorder)	39	7.1
Traumatic injury (disorder)	37	6.7
Falls (finding)	35	6.4
Concussion (disorder)	26	4.7
Headache (finding)	11	2.0
Facial laceration (disorder)	10	1.8
Victim of physical assault (finding)	9	1.6
Alcohol intoxication (disorder)	8	1.5
Falling injury (finding)	8	1.5
Fractured nasal bones (disorder)	8	1.5
Laceration of head (disorder)	8	1.5
Post-concussion syndrome (disorder)	7	1.3
Injury of face (disorder)	6	1.1
Subarachnoid haemorrhage (disorder)	6	1.1
Neck pain (finding)	5	0.9
Backache	4	0.7
Intracranial injury without skull fracture (disorder)	4	0.7

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	N	%
Laceration of forehead (disorder)	4	0.7
Closed fracture of clavicle (disorder)	3	0.5
Dizziness (finding)	3	0.5
Fracture of maxilla (disorder)	3	0.5
Fracture of rib (disorder)	3	0.5
Injury of neck (disorder)	3	0.5
ED Diagnosis Codes indicative of mTBI	**N**	**%**
Concussion (disorder)	26	4.7
Post-concussion syndrome (disorder)	7	1.3
Subarachnoid haemorrhage (disorder)	6	1.1
Intracranial injury without skull fracture (disorder)	4	0.7
Subdural hematoma (disorder)	3	0.5
Brief loss of consciousness (finding)	2	0.4
Cerebral haemorrhage (disorder)	1	0.2
Contusion of cerebrum (disorder)	1	0.2
Crushing injury of skull and intracranial contents (disorder)	1	0.2
Epidural haemorrhage (disorder)	1	0.2
Intracranial haemorrhage (disorder)	1	0.2
Loss of consciousness (finding)	1	0.2
Transient global amnesia (finding)	1	0.2
Traumatic subdural haemorrhage (disorder)	1	0.2

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FIGURE LEGENDS

Figure 1. Study recruitment flowchart.

LIST OF SUPPLEMENTAL DIGITAL CONTENT

Supplemental Material Content 1, (Table S1). WHO criteria distribution among the identified

cohort of confirmed mTBI cases (N=351).

Supplemental Material Content 2, (Table S2). Confirmed mTBI patients (N=351) with

documented PTA (N=260) based on the summary PTA-related mTBI designation, accounting

for any documented PTA manifestations: observed/self-reported amnesia or

confusion/disorientation fulfilling the WHO criteria, behavioural change or acute cognitive

impairment on PTA testing.

Supplemental Material Content 3, (Table S3). Full list of ED diagnosis codes (SNOWMED

codes) and ED diagnosis codes indicative of mTBI, for the overall mTBI cohort (confirmed

mTBI cases, N=351; indeterminate mTBI, N=180).

Supplemental Material Content 4, (Table S4). Significant differences (p<.05) between people

with and without recorded mTBI diagnosis in Emergency Department (ED) records and/or ED

discharge codes indicative of mild traumatic brain injury (mTBI), among confirmed mTBI

cases (N=351).

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Supplemental Material Content 5, (Table S5). Significant differences (p<.05) between people

tested for Post-traumatic Amnesia (PTA) versus those not tested, among confirmed mild

traumatic brain injury (mTBI) (N=351) and indeterminate cases (N=180).

Supplemental Material Content 6, (Figure S1). Percent of screened ED presentations aged 18-

65 years with confirmed or indeterminate mTBI (total 30 479 screened, 351 confirmed mTBI

(1.15%), 180 indeterminate mTBI (0.6%)).

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Figure 1. Study recruitment flowchart.

254x190mm (300 x 300 DPI)

Table S1. WHO criteria distribution among the identified cohort of confirmed mTBI cases (N=351).

GCS =13-14 (N=117)	LOC ≤ 30 mins (N=185)	Amnesia < 24 hrs (N=229)	Confusion/ disorientation (N=97)	Intracranial injuries (N=31)	N (N=351)	%
✓	✓	✓	✓	✓	2	0.9
✓	✓	✓	✓		18	5.1
✓	✓	✓		✓	5	1.4
✓	✓	✓			10	2.8
✓	✓		✓		6	1.7
✓	✓				6	1.7
✓		✓	✓	✓	4	1.1
✓		✓	✓		32	9.1
✓		✓		✓	2	0.6
✓		✓			17	4.8
✓			✓		2	0.6
✓					13	3.7
	✓	✓	✓	✓	1	0.3
	✓	✓	✓		9	2.6
	✓	✓		✓	1	0.3
	✓	✓			51	14.4
	✓		✓	✓	1	0.3
	✓		✓		4	1.1

✓			✓	3	0.8
✓				68	19.4
	✓	✓	✓	1	0.3
	✓	✓		8	2.3
	✓		✓	2	0.6
	✓			66	18.7
		✓		10	2.8
			✓	9	2.6

WHO: World Health Organization; TBI: Traumatic brain injury; GCS: Glasgow Coma Scale;

LOC: Loss of consciousness.

Table S2. Confirmed mTBI patients (N=351) with documented PTA (N=260) based on the summary PTA-related mTBI designation, accounting for any documented PTA manifestations: observed/self-reported amnesia or confusion/disorientation fulfilling the WHO criteria, behavioural change or acute cognitive impairment on PTA testing.

Summary PTA-related mTBI designation (N=260)	Observed/self-reported Amnesia < 24 hrs [WHO criteria] (N=229)	Observed/self-reported Confusion/ disorientation [WHO criteria] (N=97)	Observed Behavioural changes (N=61)	PTA testing administered (N=182)	N (N=351)	%
✓	✓	✓	✓	✓	27	7.7
✓	✓	✓	✓	-	6	1.7
✓	✓	✓	-	✓	24	6.8
✓	✓	✓	-	-	18	5.1
✓	✓	-	✓	✓	16	4.6
✓	✓	-	✓		6	1.7
✓	✓	-	-	✓	75	21.4
✓	✓	-	-		57	16.2
✓	-	✓	✓	✓	4	1.1
✓	-	✓	-	✓	6	1.7
✓	-	✓	-		12	3.4

✓	-	-	✓	✓	**1**	**0.3**
✓	-	-	✓		**1^**	**0.3**
✓	-	-	-	✓	**7**	**2**
-	-	-	-	✓§	20#	5.8
-	-	-	-	-	71#	20.
						2

TBI: Traumatic brain injury; WHO: World Health Organization; PTA: Post-traumatic amnesia

Note: in **bold** are confirmed mTBI (N=9) based only on reported behavioural changes and/or

cognitive impairment at PTA testing (i.e. PTA documented). All, expect one (^), met other

mTBI WHO criteria (i.e. LOC≤ 30 mins, GCS=13-14, intracranial injuries).

Confirmed mTBI (N=91) with no documented positive findings for PTA manifestations.

§ Individuals who were tested for PTA and obtained optimal scores (i.e. not in PTA), in the

absence of PTA manifestations documented in other sources.

Table S3. Full list of ED diagnosis codes (SNOWMED codes) and ED diagnosis codes indicative of mTBI, for the overall mTBI cohort (confirmed mTBI cases, N=351; indeterminate mTBI, N=180).

SNOWMED Codes Diagnosis Description	N	%
Injury of head (disorder)	145	26.3
Motor vehicle accident victim (finding)	49	8.9
Minor head injury (disorder)	39	7.1
Traumatic injury (disorder)	37	6.7
Falls (finding)	35	6.4
Concussion (disorder)	26	4.7
Headache (finding)	11	2.0
Facial laceration (disorder)	10	1.8
Victim of physical assault (finding)	9	1.6
Alcohol intoxication (disorder)	8	1.5
Falling injury (finding)	8	1.5
Fractured nasal bones (disorder)	8	1.5
Laceration of head (disorder)	8	1.5
Postconcussion syndrome (disorder)	7	1.3
Injury of face (disorder)	6	1.1
Subarachnoid hemorrhage (disorder)	6	1.1
Neck pain (finding)	5	0.9
Backache	4	0.7
Intracranial injury without skull fracture (disorder)	4	0.7
Laceration of forehead (disorder)	4	0.7
Closed fracture of clavicle (disorder)	3	0.5

Dizziness (finding)	3	0.5
Fracture of maxilla (disorder)	3	0.5
Fracture of rib (disorder)	3	0.5
Injury of neck (disorder)	3	0.5
Laceration - injury (disorder)	3	0.5
Soft tissue injury (disorder)	3	0.5
Subdural hematoma (disorder)	3	0.5
-	2	0.4
Abrasion of face (disorder)	2	0.4
Abrasion of head (disorder)	2	0.4
Alcohol abuse (disorder)	2	0.4
Brief loss of consciousness (finding)	2	0.4
Closed fracture of facial bone (disorder)	2	0.4
Fracture of cervical spine (disorder)	2	0.4
Fracture of face bones (disorder)	2	0.4
Fracture of phalanx of finger (disorder)	2	0.4
Fracture of vertebral column without spinal cord injury (disorder)	2	0.4
Hematoma of face (disorder)	2	0.4
Laceration of lip (disorder)	2	0.4
Motor vehicle accident passenger (finding)	2	0.4
Scalp laceration (disorder)	2	0.4
Superficial laceration of face (disorder)	2	0.4
Blunt injury (disorder)	1	0.2
Cerebral hemorrhage (disorder)	1	0.2
Closed fracture carpal bone (disorder)	1	0.2

Closed fracture of base of skull (disorder)	1	0.2
Closed fracture of multiple ribs (disorder)	1	0.2
Closed fracture of of navicular bone of wrist (disorder)	1	0.2
Closed fracture of one or more phalanges of hand (disorder)	1	0.2
Closed fracture of orbital floor (blow-out) (disorder)	1	0.2
Closed fracture of rib (disorder)	1	0.2
Closed fracture of shaft of fibula (disorder)	1	0.2
Closed fracture of upper end of tibia (disorder)	1	0.2
Compression fracture of vertebral column (disorder)	1	0.2
Contusion (disorder)	1	0.2
Contusion of cerebrum (disorder)	1	0.2
Contusion of shoulder region (disorder)	1	0.2
Crushing injury of skull and intracranial contents (disorder)	1	0.2
Did not wait for treatment (finding)	1	0.2
Elbow fracture (disorder)	1	0.2
Epidural hemorrhage (disorder)	1	0.2
Finding related to falls (finding)	1	0.2
Floaters in visual field (finding)	1	0.2
Foot swelling (finding)	1	0.2
Fracture of distal end of radius (disorder)	1	0.2
Fracture of lumbar spine (disorder)	1	0.2
Fracture of mandible closed (disorder)	1	0.2
Fracture of multiple ribs (disorder)	1	0.2
Fracture of orbit (disorder)	1	0.2
Fracture of orbital roof (disorder)	1	0.2

Fracture of pelvis (disorder)	1	0.2
Fracture of pubis (disorder)	1	0.2
Fracture of skull (disorder)	1	0.2
Fracture of sternum (disorder)	1	0.2
Fracture of thoracic spine (disorder)	1	0.2
Fracture of upper jaw closed (disorder)	1	0.2
Fracture of vertebral column (disorder)	1	0.2
Hematoma (disorder)	1	0.2
Injury of facial nerve (disorder)	1	0.2
Injury of kidney (disorder)	1	0.2
Injury of pancreas (disorder)	1	0.2
Injury of shoulder region (disorder)	1	0.2
Intervertebral disc prolapse (disorder)	1	0.2
Intracranial hemorrhage (disorder)	1	0.2
Laceration of eye region (disorder)	1	0.2
Loss of consciousness (finding)	1	0.2
Migraine (disorder)	1	0.2
Motor vehicle accident driver (finding)	1	0.2
Multiple fractures (disorder)	1	0.2
Muscle strain (disorder)	1	0.2
Neck sprain (disorder)	1	0.2
Open fracture of nasal bones (disorder)	1	0.2
Open fracture of patella (disorder)	1	0.2
Open fracture of tibia AND fibula (disorder)	1	0.2
Open wound of lower leg (disorder)	1	0.2

Pins and needles (finding)	1	0.2
Recurrent falls (finding)	1	0.2
Shoulder pain (finding)	1	0.2
Sprain of wrist (disorder)	1	0.2
Strain of neck muscle (disorder)	1	0.2
Superficial injury of face (disorder)	1	0.2
Superficial injury of head (disorder)	1	0.2
Syncope (disorder)	1	0.2
Transient global amnesia (finding)	1	0.2
Traumatic dislocation of clavicle (disorder)	1	0.2
Traumatic subdural hemorrhage (disorder)	1	0.2
Unexplained falls (finding)	1	0.2
Victim of trauma with multiple injuries (finding)	1	0.2
Vomiting (disorder)	1	0.2
Wound discharge (finding)	1	0.2

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Table S4. Significant differences (p<.05) between people with and without recorded mTBI diagnosis in Emergency Department (ED) records and/or ED discharge codes indicative of mild traumatic brain injury (mTBI), among confirmed mTBI cases (N=351).

	Confirmed mTBI cases (N=351)					
	Cases with no recorded mTBI diagnosis (N=269)	Cases with recorded mTBI diagnosis (N=81)	Statistical comparison	Cases with no ED discharge codes indicative of mTBI (N=314)	Cases with ED discharge codes indicative of mTBI (N=37)	Statistical comparison
	N (%)	N (%)	p value§	N (%)	N (%)	p value§
Non-traffic-related injury	186 (69.1)	66 (81.5)	0.03	93 (30.6)	3 (8.1)	0.004
Discharge destination			0.0005			0.01
Discharged home	104 (38.7)	29 (35.8)		119 (37.9)	14 (37.8)	

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Admitted to ED	104 (38.7)	17 (21)		115 (36.6)	6 (16.2)	
Admitted to ward	61 (22.7)	35 (43.2)		80 (25.5)	17 (46)	
Intracranial injuries on head CT	4 (2)	26 (42.6)	<0.0001	16 (6.7)	14 (50)	<0.0001
Headache	103 (38.3)	46 (56.8)	0.009	127 (40.5)	22 (59.5)	0.03
Concentration problems	0 (0)	4 (4.9)	0.001	2 (0.6)	2 (5.4)	0.01
Follow-up recommendations	83 (30.9)	44 (54.3)	0.0003	106 (33.8)	22 (59.5)	0.002
PTA measured	125 (46.5)	56 (69.1)	0.0003	-	-	-
Recorded mTBI diagnosis in the ED records	-	-	-	85 (27.1)	16 (43.2)	0.04

§ χ2, z-test, t-test.

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Table S5. Significant differences (p<.05) between people tested for Post-traumatic Amnesia (PTA) versus those not tested, among confirmed mild traumatic brain injury (mTBI) (N=351) and indeterminate cases (N=180).

	Confirmed mTBI cases (N=351)			Indeterminate mTBI cases (N=180)		
	Confirmed mTBI not tested for PTA (N=169)	Confirmed mTBI tested for PTA (N=182)	Statistical comparison	Indeterminate mTBI not tested for PTA (N=134)	Indeterminate mTBI tested for PTA (N=46)	Statistical comparison
	N (%)	N (%)	p value§	N (%)	N (%)	p value§
Transported to ED by ambulance	108 (63.9)	142 (78)	0.004	30 (22.4)	26 (56.5)	<0.0001
Traffic-related injury	32 (18.9)	67 (36.8)	0.0002	23 (17.2)	21 (45.7)	0.0001
Discharge destination			<0.0001			<0.0001
Discharged home	98 (58)	35 (19.2)		106 (79.1)	21 (45.7)	
Admitted to ED	43 (25.4)	78 (42.9)		21 (15.7)	15 (32.6)	
Admitted to ward	28 (16.6)	69 (37.9)		7 (5.2)	10 (21.7)	

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LOC reported	49 (34.8)	85 (53.1)	0.005	-	-	-
Amnesia reported	85 (71.4)	140 (91.5)	<0.0001	-	-	-
Brain CT performed	116 (68.6)	150 (82.4)	0.003	-	-	-
Intracranial injuries on head CT	2 (1.7)	28 (18.6)	<0.0001	-	-	-

§ $\chi 2$, z-test, t-test

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Figure S1. Percent of screened ED presentations aged 18-65 years with confirmed or indeterminate mTBI (total 30 479 screened, 351 confirmed mTBI (1.15%), 180 indeterminate mTBI (0.6%)).

14

STROBE Statement—checklist of items that should be included in reports of observational studies
YOU MUST NOTE THE PAGE NUMBER WHERE EACH ITEM IS REPORTED INSIDE THE BRACKETS [ ]. IF NOT APPLICABLE WRITE N/A

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract **[1, 3]**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found **[3]**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported **[5-7]**
Objectives	3	State specific objectives, including any prespecified hypotheses **[7]**
Methods		
Study design	4	Present key elements of study design early in the paper **[7]**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **[7]**
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up **[7]**
		Case-control study—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls **[ ]**
		Cross-sectional study—Give the eligibility criteria, and the sources and methods of selection of participants **[ ]**
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed **[N/A]**
		Case-control study—For matched studies, give matching criteria and the number of controls per case **[ ]**
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable **[8-9]**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **[8-9]**
Bias	9	Describe any efforts to address potential sources of bias **[16]**
Study size	10	Explain how the study size was arrived at **[N/A]**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **[N/A]**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding **[N/A]**
		(*b*) Describe any methods used to examine subgroups and interactions **[N/A]**
		(*c*) Explain how missing data were addressed **[N/A]**
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed **[N/A]**
		Case-control study—If applicable, explain how matching of cases and controls was addressed **[ ]**
		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy **[ ]**
		(*e*) Describe any sensitivity analyses **[N/A]**

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Results

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed **[9]**
		(b) Give reasons for non-participation at each stage **[9]**
		(c) Consider use of a flow diagram **[9; Figure 1]**
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders **[9-11 ; Table 1]**
		(b) Indicate number of participants with missing data for each variable of interest **[Table 1]**
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) **[N/A]**
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time **[9-11]**
		Case-control study—Report numbers in each exposure category, or summary measures of exposure **[ ]**
		Cross-sectional study—Report numbers of outcome events or summary measures **[ ]**
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included **[proportions are presented in pg 7 and in Table 1]**
		(*b*) Report category boundaries when continuous variables were categorized **[N/A]**
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period **[N/A]**
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **[11-12]**

Discussion

Key results	18	Summarise key results with reference to study objectives **[12]**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **[12, 16-17]**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **[12-16]**
Generalisability	21	Discuss the generalisability (external validity) of the study results **[16]**

Other information

| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based **[18]** |

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

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Challenges in the acute identification of mild traumatic brain injuries: results from an emergency department surveillance study

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Abstract: 260/300; Text: 3797/400; Tables: 4; Figures: 1; Supplementary material:6.

2

ABSTRACT

Objectives: To establish the proportion of mild traumatic brain injury (mTBI) diagnosis among

people presenting to an Emergency Department (ED), to determine the accuracy of recorded

ED diagnoses. We also aimed to describe challenges in mTBI case identification and its acute

hospital management.

Design and Setting: A retrospective chart review of all ED attendances to a major trauma

hospital, over a 9-month period (June 2015-February 2016).

Participants: Adults aged 18-65 years consecutively presenting to an ED.

Primary Outcome Measures: Proportion of mTBI diagnosis among ED attendances, (i.e.

confirmed mTBI based on the World Health Organization (WHO) criteria or indeterminate

mTBI based on secondary criteria), and proportion of accurately recorded mTBI diagnosis by

ED clinicians (i.e. 'mTBI, 'concussion').

Results: Of 30 479 ED attendances, 351 (1.15%) confirmed mTBI diagnosis and 180 (0.6%)

indeterminate diagnosis were identified. Only 81 (23.1%) individuals with a confirmed mTBI

had a 'mTBI diagnosis' clearly recorded in the medical notes. Of the allocated discharge

diagnosis codes to the two identified cohorts, 89.8% were not indicative of mTBI. Intracranial

injuries were found in 31 (8.5%) confirmed cases. Glasgow Coma Scale scores were

consistently assessed in the ED but identified only 117 (33.3%) confirmed mTBI cases. Post-

traumatic amnesia (PTA) testing was able to confirm acute cognitive impairment, in 113

(62.1%) of those who were tested (182, 51.3%).

Conclusions: mTBI is a common, but an under-recognized cause for ED attendance. Despite

challenges, the use of an operational definition such as the WHO diagnostic criteria can

improve accuracy in mTBI identification. Acute management may be enhanced by rapid

assessment of PTA.

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STRENGTHS AND LIMITATIONS OF THIS STUDY

- A systematic chart review of all Emergency Department attendances was employed to capture any possible mild traumatic brain injury (mTBI) case.

- The use of standard diagnostic criteria to establish the occurrence of mTBI diagnosis, ensures accuracy in identification and comparability across existing research.

- This study provides novel data on proportions of rapid post-traumatic amnesia screening in NSW, Australia, where there is written recommendation around PTA screening in all Emergency Departments.

- Collecting data from single hospital site limits generalizability of study findings.

- Given the retrospective design, conclusions on mTBI occurrence and accuracy of designation were limited by the availability of documented clinical information, with mTBI occurrence possibly being underestimated.

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INTRODUCTION

Mild traumatic brain injuries (mTBI) are a serious public health problem that is referred to as a 'silent epidemic'.[1] Though being the least severe of all brain injuries, identification is the most challenging, with mTBI often missed at diagnosis.[2] Major barriers to mTBI identification are the wide variability in criteria used for diagnosis and the lack of sensitive standardized measures for identifying mTBI manifestations, which are commonly subtle and rapidly-resolving.[2, 3] Despite these limitations, the World Health Organization (WHO) best-evidence review estimated that hospital-treated mTBI are in the range of 100-300/100 000 population. [4] Diagnosis and management of mTBI largely occur in an emergency department (ED). [5] Little information exists, however, about the accuracy of mTBI identification in emergency settings. Two studies, conducted in three Canadian EDs [6] and two EDs in the US,[7] found that up to 50% of patients sustaining mTBI received an inaccurate ED diagnosis. Poor identification likely impacts clinical management of these patients. Given trends in increasing ED attendances for head trauma [8, 9] there is a critical need to for research that addresses the challenges in mTBI diagnosis.

Another challenge for ED clinicians is the identification of mTBI cases at major risk of complications versus those who can be safely discharged. [10] Latest research suggests that these so-called minor injuries can have long-term impacts that extend beyond the anticipated 3-month timeframe of cognitive recovery for uncomplicated cases, calling for urgent improvements in the acute management of mTBI. Long-term impacts include higher health care usage [11], psychosocial complications [12, 13] and in vulnerable subgroups chronic cognitive symptomatology [12, 14] and neural cellular alterations [15, 16] not easily detectable by routine radiological examinations that may increase the risk of neurodegeneration. [17] EDs represent a crucial point where accurate identification and early management of these patients may prevent long-term personal and economic impacts.

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Key steps to aid early and accurate identification and management of mTBI include enhanced consistency in diagnostic criteria and standardized assessment methods.[3] An internationally-recognised operational definition was developed by the WHO Task Force,[3, 4] clearly outlining the four key clinical manifestations for mTBI diagnosis. These are:(i) level of consciousness, (ii) confusion or disorientation, (iii) post-traumatic amnesia (PTA) and (iv) transient neurological abnormalities, such as computed tomography (CT)-detected intracranial injuries, the latter defined as complicated mTBI (about 10% of cases).[18] Recommended objective measures to assess TBI 'severity' include conventional radiology to exclude structural lesions and the Glasgow Coma Scale (GCS) to monitor level of consciousness (i.e. mTBI is defined as GCS scores of 13-15 out of 15 and a loss of consciousness (LOC) of ≤30 minutes). However, no clear guidance is given by the WHO on the clinical assessment of the other TBI diagnostic criteria. [4] This particularly applies to PTA, which is recognized as the best prognostic indicator of mTBI outcomes. [19, 20]

PTA is a complex clinical concept reflecting an acute transient cognitive dysfunction [21] that presents not only as amnesia but more broadly as a period of inability to store new information, confusion, disorientation or behavioural changes. [3, 21] While standardized testing exist to assess the resolution of acute cognitive dysfunction (i.e. PTA) these are rarely used in the acute management of mTBI patients because many protocols are too lengthy to be administered in ED settings.[21] In NSW, Australia, the Abbreviated Westmead PTA Scale (A-WPTAS), [21] was specifically designed for ED use and recommended statewide (NSW Ministry of Health, Initial management of closed head injury in adults, 2011) as a brief validated measure of PTA to improve identification of traumatic brain injury events among closed head injury patients with a GCS of 13-15 (NSW Ministry of Health, Initial management of closed head injury in adults, 2011). This measure includes five GCS orientation items plus a memory test of recall of three picture cards learnt on the first trial. The test is repeated hourly

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for up to four hours until optimal scores of 18 out of 18 are obtained (i.e.15 on the GCS, plus 3

on the memory test), indicating a resolution of PTA, if present. Though the A-WPTAS has

been shown to assist with a safer discharge of people with mTBI, by identifying cases with a

GCS of 15/15 who remain acutely cognitively impaired, [20] and reducing hospitalization and

direct costs [22], its implementation to date appears inconsistent. Unpublished Australian data

showed that rates of PTA screening in ED range from 0 to 31%, [10] while findings from a

recent randomized controlled trial showed lower rates (i.e. below 13%). [23] This highlights

the need for further studies to investigate the extent and possible benefit of A-WPTAS

implementation in emergency settings.

Given the current challenges in mTBI diagnosis and limitations of existing

epidemiological research, this study primarily aimed to establish: (i) the occurrence of mTBI

diagnosis among ED attendances (i.e. meeting standard diagnostic criteria), and the proportion

of these that received a clearly recorded mTBI diagnosis (i.e. based on clinical notes and/or

diagnosis codes). A secondary aim was to describe challenges in acute identification and

management of mTBI, such as the implementation of a validated measure for PTA screening in

ED.

METHODS

This is a retrospective cohort study, employing chart review and standard WHO

diagnostic criteria to define occurrence of mTBI among adults aged 18-65 years with ED

attendances of a major trauma hospital in Sydney, Australia, over a 9-month period (from June

2015 to February 2016). Ethical approval was obtained from the Northern Sydney Local Health

District Ethics, Sydney, Australia (LNR/16/HAWKE/388; LNRSSA/16/HAWKE/389). Two

independent chart auditors systematically screened all ED attendances within the study period

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and reviewed all recorded information in ambulance reports, ED and medical notes, to

determine whether mTBI occurred. Details of the study method are available. [24]

The main outcomes were: (i) proportions of identified mTBI diagnosis, meeting WHO

diagnostic criteria, among total ED attendances within 24 hours post-injury, meeting study age-

range and timeframe, and (ii) proportions of accurately recorded mTBI diagnoses by ED

clinicians based on positive mTBI-related definition documented in the medical record. A

confirmed mTBI diagnosis was ascertained based on the presence of any of the four mTBI

manifestations (i.e. level of consciousness, confusion/disorientation, post-traumatic amnesia,

transient neurological abnormalities), as expressed by the corresponding WHO criteria (Table 1

and Online Supplementary Table S1): [4, 21] (i) a GCS of 13–15 30 minutes after injury or on

later presentation to healthcare; and/or loss of consciousness of ≤30 mins; (ii)

confusion/disorientation, (iii) PTA <24-hours, and/or (iv) CT-detected intracranial injuries not

requiring neurosurgery, respectively.

Despite the uniqueness of this study in using a validated measure for PTA screening in

ED, initial chart review indicated PTA testing was not consistently administered. Further,

optimal scores obtained during ED stay would still not be able to identify cases whose PTA

resolved early post-injury [2] (i.e. optimal scores meaning that PTA, if present, had resolved).

These cases could, instead, be identified by any evidence of PTA manifestations (i.e. any gap in

memory, period of confusion/disorientation, behavioral changes) documented by ambulance

and emergency staff in their clinical observations. Therefore, to ascertain the presence of PTA

as criterium for mTBI occurrence, a summary PTA-related mTBI designation (Online

Supplementary Table S2) was developed by cross-checking any PTA-related neurological and

behavioural disturbances documented in medical records, from the time of injury to hospital

discharge. A positive PTA designation was defined by any of the following source: acute

cognitive impairment on A-WPTAS testing, observed behavioural change suggestive of PTA

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(e.g. repetitive questioning, combative behaviour), as well as any observed/self-reported gap in memory, or confusion/disorientation thereby fulfilling two of the WHO criteria. [3, 21]

In the absence of any documented WHO criterion, indeterminate evidence of mTBI [25] was defined based on the presence of any secondary criteria: [20] (i) optimal scores (i.e. 18/18) on the second trial of the A-WPTAS indicating that PTA, if present, had resolved, (ii) symptoms that may correspond to 'post-concussion symptoms' but which are not specific to mTBI,[24] (iii) transient neurological abnormalities (excluding intracranial injuries not requiring surgery), which are not common findings or clinical features of mTBI [2, 3] and are not recommended as stand-alone mTBI criteria,[2] or (iii) queried LOC/amnesia.

The accuracy of the diagnosis given by ED clinicians to the identified individuals with mTBI diagnosis was assessed by the presence of any recorded 'mTBI', 'concussion', 'post-concussion symptoms/syndrome' diagnoses in medical notes.[26] In addition, allocation of relevant mTBI-related discharge diagnosis codes (SNOWMED codes) was also explored, to inform how much routinely collected administrative data could be useful for brain injury diagnostic purpose.

Patient and Public Involvement

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination of our research.

RESULTS

Identified cases with mTBI diagnosis

During the study period, 30 479 adults aged 18-65 years attended the ED and were screened (Figure 1). Of the 587 mTBI-related ED presentations initially identified, 56 cases were

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excluded due to: (N=27) self-discharge or unclear evidence of mTBI, (N=8) confounding

factors (e.g. intubation, psychosis, medical comorbidities) or possible moderate TBI (e.g.

LOC/amnesia of unclear duration). Also excluded were 21 (3.9%) individuals who represented

for the same mTBI event. Among total ED attendances, 351 (1.15%) confirmed mTBI

diagnoses and an additional 180 (0.6%) cases with insufficient/indeterminate mTBI evidence

were identified (Online Supplementary Figure S1). Of these, two people (0.4%) sustained

multiple mTBI (i.e. repetitive mTBI). Sociodemographic, injury-related and acute management

details are illustrated in Table 1-3.

A clearly recorded mTBI diagnosis in ED records [26] was present only in 23.1% (N=81)

of confirmed mTBI and 18.9% (N=34) of indeterminate cases. Similarly, among the 551 ED

diagnosis codes (i.e. SNOWMED codes) (Table 4) allocated to the two identified cohorts, the

most commonly used code descriptor was 'injury of head' (N=145, 26.3%). Only 56 of these

codes (10.2%) were specifically indicative of brain injury occurrence, with 'concussion' being

the most common (N=26, 46.4%). The remaining codes mostly reflected intracranial injury

findings (see also Online Supplementary Table S3, which shows the full list of ED discharge

diagnosis codes).

Confirmed mTBI cases that were given a clearly-recorded mTBI diagnosis and/or a

discharge code suggestive of mTBI were more likely to (Online Supplementary Table S4): be a

non-traffic-crash related mTBI ($p<.05$), be admitted to a ward ($p<.05$), have CT-detected

intracranial injuries ($p<.0001$), present with headaches ($p<.05$) and/or concentration problems

($p<.05$), and be recommended for follow-up care ($p<.01$). Furthermore, those with a clearly-

recorded mTBI diagnosis were more likely to have been tested for PTA ($p=.0003$), while those

with an allocated discharge code suggestive of mTBI were more likely to have a clearly written

mTBI diagnosis in their ED records also ($p=.04$).

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Injury-related characteristics

Cases with a confirmed mTBI diagnosis met the following WHO criteria: initial GCS of 13-14 (i.e. at the scene 30 minutes post-injury/at ED admission; N=117; 33.3%), LOC (i.e. witnessed/self-reported; N=185; 52.7%), amnesia (i.e. observed/self-reported; N=229; 65.2%), confusion/disorientation (N=97; 27.6%), and CT-detected intracranial injuries (N=31; 8.8%). Multiple WHO criteria were present in 186 cases (53%) (Table 1). Cases with an indeterminate mTBI diagnosis met the following secondary criteria in the absence of WHO criteria: optimal scores of 18/18 on the A-WPTAS (N=45; 25%), presence of post-concussion symptoms (133; 73.9%), transient neurological abnormalities (N=22; 12.2%) queried LOC (N=12; 6.7%) and/or queried amnesia (N=3; 1.7%). Multiple secondary criteria were present in 32 cases (17.8%).

Fall was the most common cause of mTBI in both confirmed (39.1%) and indeterminate (31.1%) groups, followed by motor vehicle crash (28.2% - confirmed; 24.4% - indeterminate). Alcohol or drug use in association with the injury was self-reported or clinically observed in 127 (36.2%) confirmed cases compared to only 19 (10.6 %) of indeterminate cases (*p*<.001).

Acute hospital management details

Brain imaging was undertaken in 75.8% of cases with a confirmed mTBI diagnosis and 40.6% of cases with an indeterminate mTBI (*p*<.001; Table 3). Only 182 (51.8%) individuals with a confirmed mTBI were tested for PTA (i.e. A-WPTAS or WPTAS). Of these, the majority (106; 58.4%) had a PTA duration of >1 to 12 hours, 32 (17.8%) obtained optimal scores of 18/18 (i.e. did not fail A-WPTAS testing) and 37 (20.4%) had an unknown designation due to incomplete/missing documentation. Median time to the first PTA testing was 3.7 (2.3-6.1) hours post-injury for confirmed mTBI diagnosis and 2.5 (1.7-4.9) hours for indeterminate mTBI.

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The summary PTA-related mTBI designation (Online Supplementary Tables S2) including any documented positive PTA-related findings (i.e. neurological and behavioural disturbances) in the medical records, identified a total of 260 (74.1%) confirmed mTBI cases with PTA. The majority (89.8%) were identified based on two WHO criteria of observed/self-reported amnesia (i.e. any gap in memory) and/or period of confusion/ disorientation, with a further nine people deemed in PTA only due to failing the A-WPTAS (N=8) or due to reported behavioral changes in medical records, (N=1) (i.e. repetitive questioning). All these nine cases, except one, also met at least one of the other mTBI WHO criteria (e.g. LOC, GCS=13-14, intracranial injuries).

In both groups, people tested for PTA were more likely to (Online Supplementary Table S5): be transported to ED by ambulance ($p<.01$); sustain a traffic-related mTBI ($p<.001$); be admitted to ED/ward ($p<.0001$). Confirmed mTBI cases were more likely tested for PTA in the presence of other mTBI signs, such as LOC ($p=.005$), amnesia ($p<.0001$) and brain imaging ($p=0.003$) with positive findings ($p<.0001$).

DISCUSSION

By using the WHO operational criteria, our study reports an occurrence of confirmed mTBI diagnosis among ED total attendances of 1.2% (351/30 479). These findings correspond to the 1.1-1.3% proportion observed in a preliminary study, which used the same criteria and methods for TBI diagnosis [20, 24] therefore confirming the robustness of the proposed WHO surveillance system for acute mTBI identification. A similar proportion of mTBI cases seeking emergency care (1.9%; 670/35 096) was also reported in a prospective cohort study conducted in a large metropolitan ED in New York. [27] This study employed the alike 1993 American College of Rehabilitation Medicine criteria,[27] as operational definition, suggesting that using

standard diagnostic criteria can enhance consistency in mTBI identification and comparability of study findings.

Worryingly, only 23.1% (81/351) of our identified cohort with a confirmed mTBI diagnosis (i.e. meeting the WHO criteria) had an accurate mTBI diagnosis documented in the medical records (i.e. written diagnosis of 'concussion', 'mTBI'). The proportion of accurate diagnoses was much lower than reported in two previous prospective studies conducted in Canada [6] and the US [7] respectively, being ≥50%. While using a retrospective design could account for these differences, global challenges certainly exist in the acute identication of 'minor' TBI events. This study contributes by providing unique Australian data and suggests that adopting standard criteria and the assessment of PTA provide so far the best approach to improve accuracy of mTBI diagnosis.

Poor accuracy in mTBI identification in ED [3, 17] could affect current estimates of 100-300/100 000 reported in a WHO review,[4] hence, underestimating the 'true' incidence of hospital-treated mTBI. Surveillance systems, such as accurate administrative databases, are recommended strategies to tackle this problem. However, the use of discharge diagnosis codes, such as ICD coding, in hospital databases has previously been shown not to be sensitive in detecting mTBI. [26, 27] Our results confirm this gap. Only 10.7% (59/551) of ED discharge diagnosis codes (SNOWMED codes) allocated to the identified cohorts with either a confirmed or indeterminate mTBI diagnosis were indicative of mTBI. Despite limitations in the number of diagnoses able to be recorded (i.e. maximum two SNOWMED codes), there seems to be a trend for ED clinicians to better identify the more 'severe' injuries, i.e. those showing positive CT findings, being admitted to a ward and receiving follow-up care recommendations. By contrast, uncomplicated mTBI appears to be overlooked, by not receiving an accurate designation in ED records or accurate coding. There was also an interchangeable use of terms like 'concussion', '(mild/minor) head injury' and 'mTBI', as also shown in previous studies,

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[3, 17, 27] that suggest a poor clarity in the distinction between those having a traumatic brain injury versus simple head injuries, thus reiterating the scarce utility of administrative data in mTBI identification.

While the WHO criteria can be regarded as a reliable system for the identification of individuals who sustained a mTBI , there were challenges in its application. [2] First, it was unclear how to interpret LOC or amnesia when it was not witnessed/observed as per WHO recommendations for mTBI identification. It is likely that injured people report a LOC or amnesia interchangeably, [2] thus, a self-reported LOC/amnesia at the time of the injury suggests a confirmed mTBI diagnosis. Conversely, when LOC/amnesia was queried by a physician this more likely suggests indeterminate evidence of mTBI.

PTA is the most important TBI prognostic indicator, yet the most challenging to evaluate because it encompasses a series of acute cognitive impairment signs and symptoms. This study is unique in its way of screening for PTA in ED by means of a validated measure. However, standard PTA testing was only available in about half of confirmed mTBI cases (51.9%), though this was considerably higher than previously reported PTA screening rates (up to 31%).[10, 23] Also, optimal scores of 18/18 on the A-WTPAS were obtained in 17.8% of those who were tested. While optimal scores clearly indicate the absence of acute cognitive dysfunction at the time of assessment (i.e. a person is not in PTA), these cannot exclude that PTA was present before that time, not being informative for mTBI diagnostic purpose.

Therefore, this study used a summary PTA-related mTBI designation, accounting for the positive presence of any PTA-related neurological and behavioural disturbances recorded in medical records.[3, 21] Using this indicator, we found 260 of the 351 cases with a confirmed mTBI diagnosis were deemed to be in PTA. Of these, the majority (89.8%) was based on the presence of observed/self-reported amnesia (i.e. a gap in memory) or confusion/disorientation (i.e. meeting two of the four WHO criteria), while 9 (2.6%) cases were further identified based

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only on evidence of acute cognitive impairment (i.e. failing PTA testing; N=8) or observed

behavioral changes (N=1), the latter being repetitive questioning that is typically an indirect

sign of PTA. These additional cases, except one, all met at least one of the other WHO criteria

(e.g. LOC, GCS=13-14, intracranial injuries) for mTBI diagnosis.

Overall, these findings reiterate that the WHO criteria together constitute the most

reliable surveillance system for mTBI identification and provide useful information to

specifically identify cases whose PTA may have resolved by the time of ED admission.

Additionally, the implementation of PTA testing, providing objective estimates of acute

cognitive impairment may assist in monitoring recovery progress towards a safer discharge and

enhance diagnostic accuracy of cases where mTBI indicators are unclear or unavailable. The

administration of brief PTA testing (i.e. the A-WTPAS) as an extension of the GCS, which is

usually assessed at the scene by the ambulance staff, [21] could provide a more accurate

estimate of the presence and duration of PTA, thus of mTBI occurrence.

Another challenge was the assessment of transient neurological abnormalities, other than

intracranial injuries. Ruff et al. (2009) suggested these abnormalities in isolation do not

constitute a strong basis for mTBI diagnosis because they are not common or typical features of

mTBI.[2] Thus, these were considered as indeterminate evidence of mTBI. The WHO also

recommends excluding cases whose TBI manifestations can be affected or due to other

factors.[28] Unlike other confounders (e.g. intubation, psychiatric disorder), the influence of

alcohol/drug on mTBI manifestations was particularly difficult to assess due to the lack of

objective blood level measurements. Overall, these cases accounted for 36.2% of confirmed

mTBI, that is, in the range of previous findings (30-60%). [29, 30] These findings confirm

intoxication is a major confounding affecting accurate identification of mTBI in busy ED

settings, with day of injury blood alcohol level being associated with: failure on PTA

assessment, [20] a longer duration of LOC, and decreased GCS scores. [31] Differentiation of

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mTBI in these individuals in the ED setting is likely to be facilitated by the potential

implementation of blood based biomarkers.[32]

This study confirms that issues exist in identifying the mildest TBIs,[2] whose clinical

manifestations may resolve within <15 minutes post-injury according to the American

Academy of Neurology classification.[2] Considering the amount of missing or non-

informative/optimal indicators among cases with a confirmed mTBI in this study, as also

reported by previous research,[33] along with PTA measured 2-3 hours post-injury,[21] it is

likely that rapid-resolving LOC/amnesia were missed with a bias towards more severe mTBI.

Secondary criteria were established to identify cases with indeterminate evidence of TBI. These

cases constituted 0.6% of ED total attendances and, interestingly, 18.9% of these received a

positive mTBI diagnosis by ED clinicians. Another study using a similar (probabilistic)

approach found delayed functional recovery in the group with debatable mTBI compared to

healthy and trauma controls, [25] raising concerns around the need for identifying and treating

less-severe mTBI that may appear to not meet diagnostic criteria.

Intracranial injuries were found in 31 (8.8%) cases with a confirmed mTBI diagnosis.

[18] Brain CT was performed in 75.8%, plus in 40% of cases with an indeterminate mTBI [18]

Clinical assessment remains the gold-standard for mTBI identification, with PTA testing being

the most promising measure. Among those who were tested, the A-WPTAS was able to detect

acute cognitive impairment in 62.1% of cases (113/182), while the GCS was able to detect only

33.5% of cases (117/349).[20] This study further suggests that when PTA is measured it

increases the likelihood of an accurate mTBI designation provided by ED clinicians.

Implementation of PTA testing in ED settings should be, thus, extended to all individuals with

a possible mTBI [21] to reduce the risk of missed opportunity for mTBI identification and to

contribute to more accurate clinical decision making and safer discharge of patients.

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Study Limitations

Major strengths of this study were the use of standard diagnostic criteria for the identification of mTBI and the systematic screening of any cases with a possible mTBI diagnosis among ED attendances. However, the retrospective design is limiting as we might not have captured important information on confounding factors or mTBI indicators. Similarly, the absence of documented information in medical records does not necessarily imply that standard diagnostic criteria or assessment protocols were not applied by ED clinicians. Generalizability of findings is limited by the following selection bias:[30] a working-age population, 9-month audit-period, and using only a single hospital site. Some of these issues will be addressed by conducting a multi-site study in the future.

CONCLUSIONS

The findings from this study indicate that mTBI is likely to be under-diagnosed in an emergency care setting. This study confirms the use of an operational definition, such as the WHO operational criteria as a reliable surveillance system for acute identification of mTBI, although challenges still exist in its meticulous application. Identification, prognosis and acute management of individuals with mTBI would be greatly enhanced by the implementation of standardised PTA screening (e.g. A-WPTAS) early after injury. Improvements in clinical and administrative designation of these injuries requires the use of these data to monitor and address long-term health and economic impacts of mTBI.

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Contributors: All authors - IP, SM, AK, AC, MG, KVV, AL, IDC, BG - provided inputs in

study design. IP, KVV, AL, AK, SM and BG were involved in data collection and data

analysis. IP and BG are responsible for publication writing. All authors reviewed and approved

the final version of this manuscript.

Data availability statement: All data relevant to the study are included in the article or

uploaded as supplementary information.

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Table 1. Clinical features of mTBI diagnosis (confirmed mTBI, N=351; indeterminate mTBI, N=180) who presented to ED, illustrated by WHO diagnostic criteria and secondary criteria

	Confirmed mTBI [WHO criteria] (N=351)	Indeterminate mTBI [Secondary criteria] (N=180)	Statistical comparison
	N (%)	N (%)	p value§
mTBI WHO criteria			
(i) Level of consciousness			
Initial GCS at the scene/ED triage			
15 points	232 (66.1)	180 (100)	
14 points	103 (29.2)	-	
13 points	14 (4)	-	
Missing	2 (0.57)	-	
LOC ≤ 30 mins			
No	71 (20.2)	-	
Yes (witnessed/self-reported)	185 (52.7)	-	
Missing	50 (14.2)	-	
(ii) Confusion/Disorientation	97 (27.6)	-	
(iii) Amnesia < 24 hours			
No	40 (11.4)	-	

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Yes (observed/self-reported)	229 (65.2)	-	
Missing	78 (22.2)	-	
(iv) Intracranial injuries on brain CT	31 (8.8)	-	
Multiple mTBI WHO criteria	186 (53)	-	
mTBI Secondary criteria			
Queried LOC	45 (12.8)	12 (6.7)	<0.05
Queried amnesia	4 (1.1)	3 (1.7)	0.564
PTA testing w/ optimal scores	32 (9.1)	45 (25)	<0.001
Post-concussion symptoms #	183 (52.1)	133 (73.9)	<0.001
Headache	149 (42.4)	128 (71.1)	
Nausea/ Vomiting	103 (29.3)	79 (43.9)	
Dizziness	44 (12.5)	58 (32.2)	
Fatigue	2 (0.6)	1 (0.6)	
Memory problems	5 (1.4)	1 (0.6)	
Concentration problems	4 (1.1)	2 (1.1)	
Other	81 (23.1)	78(43.3)	
Transient neurological abnormalities#	28 (8)	22 (12.2)	
Multiple mTBI secondary criteria	-	32 (17.8)	

TBI: Traumatic brain injury; WHO: World Health Organization; GCS: Glasgow Coma Scale;

ED: Emergency department; LOC: Loss of consciousness; CT: Computer Tomography; PTA:

Post-traumatic amnesia; A-WPTAS: Abbreviated Westmead Post Traumatic-Amnesia Scale;

WPTAS: Westmead Post-Traumatic Amnesia.

† Proportion of valid cases.

§ χ2, z-test, t-test.

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Note: The data contains occasional missing data values, which are assumed to be random.

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Table 2. Socio-demographic and injury-related information of identified cases with a confirmed mTBI diagnosis (N=351) and indeterminate mTBI diagnosis (N=180) who presented to ED.

	Confirmed mTBI [WHO criteria] (N=351)	Indeterminate mTBI [Secondary criteria] (N=180)	Statistical comparison
	N (%)	N (%)	p value§
Socio-demographics			
Age (years), mean (SD)	39.9 (14.2)	36.1 (13.1)	<0.01
[median, IQR]	[40.8, 26.5-52]	[34.7, 24.1-44.5]	
Age groups (years)			
18-24	71 (20.2)	52 (28.9)	0.02
25-29	38 (10.8)	15 (8.3)	0.36
30-34	36 (10.3)	26 (14.4)	0.16
35-39	24 (6.8)	19 (10.6)	0.13
40-44	44 (12.5)	24 (13.3)	0.79
45-49	34 (9.7)	12 (6.7)	0.24
50-54	44 (12.5)	9 (5)	<0.01
55-59	25 (7.1)	11 (6.1)	0.66
60-65	35 (10)	12 (6.7)	0.21

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Sex			<0.001
Male	254 (72.4)	90 (50)	
Female	97 (27.6)	90 (50)	
Country of birth			0.50
Australia	230 (65.5)	113 (62.8)	
Other	118 (33.6)	66 (36.7)	
Language spoken at home			0.11
English	334 (95.2)	165 (91.7)	
Other	17 (4.8)	15 (8.3)	
Marital status			0.11
Married/Defacto	171 (48.7)	83 (46.1)	
Other	180 (51.3)	97 (53.9)	
Mental health history†	61 (17.4)	23 (12.8)	0.17
Substance abuse history†	36 (10.2)	1 (0.5)	
Injury-related details			
Injury Mechanism			0.35
Fall	137 (39)	56 (31.1)	
Assault	27 (7.7)	14 (7.8)	
Work	9 (2.6)	7 (3.9)	
Sport	52 (14.8)	25 (13.9)	
Other	27 (7.7)	34 (18.9)	
Motor vehicle crash	99 (28.2)	44 (24.4)	<0.01
Driver	28 (28.3)	15 (34.1)	
Passenger	6 (6.1)	6 (13.6)	

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Motorbike rider	8 (8.1)	10 (22.7)	
Bicyclist	44 (44.4)	5 (11.4)	
Pedestrian	10 (10.1)	5 (11.4)	
Other	3 (3)	3 (6.8)	
Reported impact to the head			<0.001
No	2 (0.6)	1 (0.5)	
Yes	269 (76.6)	164 (91.1)	
Missing	80 (22.8)	15 (8.3)	
Associated injury types†			
Soft tissue laceration	165 (47)	55 (30.6)	<0.001
Fracture	87 (24.8)	24 (13.3)	<0.01
Ligamentous	2 (0.6)	2 (1.1)	0.49
Dislocation	3 (0.8)	0	0.21
Abrasion, superficial wound, contusion	158 (45)	83 (46.1)	0.81
Multiple injury types	105 (29.9)	29 (16.1)	
Alcohol/drug use at the time of injury†	127 (36.2)	19 (10.6)	<0.001

TBI: Traumatic brain injury; ED: Emergency department.

† Proportion of valid cases.

§ $\chi 2$, z-test, t-test.

Note: The data contains occasional missing data values, which are assumed to be random.

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Table 3. Acute hospital management details of identified cases with a confirmed mTBI

diagnosis (N=351) and indeterminate mTBI diagnosis (N=180) who presented to ED.

	Confirmed mTBI [WHO criteria] (N=351)	Indeterminate mTBI [Secondary criteria] (N=180)	Statistical comparison
	N (%)	N (%)	p value§
ED management details			
ED arrival mode			<0.001
By ambulance	250 (71.2)	56 (31.1)	
Other	101 (28.8)	124 (68.9)	
Triage category			<0.001
1. Seen immediately	24 (6.8)	4 (2.2)	
2. Within 10 minutes	170 (48.4)	42 (23.3)	
3. Within 30 minutes	116 (33.1)	64 (35.6)	
4. Within 1 hour	40 (11.4)	69 (38.3)	
5. Within 2 hours	1 (0.3)	1 (0.6)	
Intubation†	1 (0.3)	0	0.47
ICU admission†	7 (2)	1 (0.6)	0.19
Length of ED stay (hrs), median (IQR)	5.8 (4-8.6)	3.8 (2.6-5.7)	<0.001

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Length of hospital stay (days), median (IQR)	3.4 (1.9-6.5)	2 (0.9-7.9)	
Discharge destination			<0.001
Discharged home	133 (37.9)	127 (70.6)	
Admitted to ED	121 (34.5)	36 (20)	
Admitted to ward	97 (27.6)	17 (9.4)	
Location of initial GCS†			<0.001
At the scene 30-min post-injury	216 (61.5)	52 (28.9)	
At ED presentation	130 (37)	127 (70.6)	
Brain CT performed†	266 (75.8)	73 (40.6)	<0.001
PTA measured†	182 (51.9)	46 (25.6)	<0.001
A-WPTAS	169 (92.8)	44 (95.6)	
WPTAS	19 (10.4)	2 (4.4)	
Location of PTA testing	*(N=182)*	*(N=46)*	
In ED	166 (91.2)	44 (95.6)	0.364
In ward	28 (15.4)	2 (4.4)	<0.05
Time to PTA testing (hrs), median (IQR)	3.7 (2.3-6.1)	2.5 (1.7-4.9)	<0.05
PTA classification based on PTA testing	*(N=182)*	*(N=46)*	<0.001
Optimal scores/Did not fail	32 (17.8)	40 (87)	
6-30 minutes	2 (1.1)	-	
31-60 minutes	1 (0.1)	-	
>1-12 hours	106 (58.4)	-	
>12-24 hours	4 (2.2)	-	
Unknown/incomplete/missing	37 (20.4)	6 (13)	

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Head Injury advice given†	166 (47.3)	120 (66.7)	<0.001
Follow-up recommendations	128 (36.5)	43 (23.9)	<0.01
Representations to ED (within 1 mth)	13 (3.7)	8 (4.4)	
Recorded mTBI diagnosis in the ED records			0.47
No	269 (76.9)	146 (81.1)	
Yes	81 (23.1)	34 (18.9)	

TBI: Traumatic brain injury; GCS: Glasgow Coma Scale; ED: Emergency department; ICU: Intensive care unit; LOC: Loss of consciousness; PTA: Post-traumatic amnesia; A-WPTAS: Abbreviated Westmead Post-TraumaticAmnesia Scale; WPTAS: Westmead Post-Traumatic Amnesia.

† Proportion of valid cases.

§ χ2, z-test, t-test.

Note: The data contains occasional missing data values, which are assumed to be random

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Table 4. Top 25 ED diagnosis codes (SNOWMED codes) and ED diagnosis codes indicative

of mTBI, for the overall mTBI cohort (confirmed mTBI cases, N=351; indeterminate mTBI,

N=180)

Top 25 ED Diagnosis Codes Description	N	%
Injury of head (disorder)	145	26.3
Motor vehicle accident victim (finding)	49	8.9
Minor head injury (disorder)	39	7.1
Traumatic injury (disorder)	37	6.7
Falls (finding)	35	6.4
Concussion (disorder)	26	4.7
Headache (finding)	11	2.0
Facial laceration (disorder)	10	1.8
Victim of physical assault (finding)	9	1.6
Alcohol intoxication (disorder)	8	1.5
Falling injury (finding)	8	1.5
Fractured nasal bones (disorder)	8	1.5
Laceration of head (disorder)	8	1.5
Post-concussion syndrome (disorder)	7	1.3
Injury of face (disorder)	6	1.1
Subarachnoid haemorrhage (disorder)	6	1.1
Neck pain (finding)	5	0.9
Backache	4	0.7
Intracranial injury without skull fracture (disorder)	4	0.7

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Laceration of forehead (disorder)	4	0.7
Closed fracture of clavicle (disorder)	3	0.5
Dizziness (finding)	3	0.5
Fracture of maxilla (disorder)	3	0.5
Fracture of rib (disorder)	3	0.5
Injury of neck (disorder)	3	0.5
ED Diagnosis Codes indicative of mTBI	**N**	**%**
Concussion (disorder)	26	4.7
Post-concussion syndrome (disorder)	7	1.3
Subarachnoid haemorrhage (disorder)	6	1.1
Intracranial injury without skull fracture (disorder)	4	0.7
Subdural hematoma (disorder)	3	0.5
Brief loss of consciousness (finding)	2	0.4
Cerebral haemorrhage (disorder)	1	0.2
Contusion of cerebrum (disorder)	1	0.2
Crushing injury of skull and intracranial contents (disorder)	1	0.2
Epidural haemorrhage (disorder)	1	0.2
Intracranial haemorrhage (disorder)	1	0.2
Loss of consciousness (finding)	1	0.2
Transient global amnesia (finding)	1	0.2
Traumatic subdural haemorrhage (disorder)	1	0.2

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FIGURE LEGENDS

Figure 1. Study recruitment flowchart.

LIST OF SUPPLEMENTAL DIGITAL CONTENT

Supplemental Material Content 1, (Table S1). WHO criteria distribution among the identified

cohort of confirmed mTBI cases (N=351).

Supplemental Material Content 2, (Table S2). Confirmed mTBI patients (N=351) with

documented PTA (N=260) based on the summary PTA-related mTBI designation, accounting

for any documented PTA manifestations: observed/self-reported amnesia or

confusion/disorientation fulfilling the WHO criteria, behavioural change or acute cognitive

impairment on PTA testing.

Supplemental Material Content 3, (Table S3). Full list of ED diagnosis codes (SNOWMED

codes) and ED diagnosis codes indicative of mTBI, for the overall mTBI cohort (confirmed

mTBI cases, N=351; indeterminate mTBI, N=180).

Supplemental Material Content 4, (Table S4). Significant differences (p<.05) between people

with and without recorded mTBI diagnosis in Emergency Department (ED) records and/or ED

discharge codes indicative of mild traumatic brain injury (mTBI), among confirmed mTBI

cases (N=351).

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Supplemental Material Content 5, (Table S5). Significant differences (p<.05) between people

tested for Post-traumatic Amnesia (PTA) versus those not tested, among confirmed mild

traumatic brain injury (mTBI) (N=351) and indeterminate cases (N=180).

Supplemental Material Content 6, (Figure S1). Percent of screened ED presentations aged 18-

65 years with confirmed or indeterminate mTBI (total 30 479 screened, 351 confirmed mTBI

(1.15%), 180 indeterminate mTBI (0.6%)).

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Figure 1. Study recruitment flowchart.

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Table S1. WHO criteria distribution among the identified cohort of confirmed mTBI cases (N=351).

GCS =13-14 (N=117)	LOC ≤ 30 mins (N=185)	Amnesia < 24 hrs (N=229)	Confusion/ disorientation (N=97)	Intracranial injuries (N=31)	N (N=351)	%
✓	✓	✓	✓	✓	2	0.9
✓	✓	✓	✓		18	5.1
✓	✓	✓		✓	5	1.4
✓	✓	✓			10	2.8
✓	✓		✓		6	1.7
✓	✓				6	1.7
✓		✓	✓	✓	4	1.1
✓		✓	✓		32	9.1
✓		✓		✓	2	0.6
✓		✓			17	4.8
✓			✓		2	0.6
✓					13	3.7
	✓	✓	✓	✓	1	0.3
	✓	✓	✓		9	2.6
	✓	✓		✓	1	0.3
	✓	✓			51	14.4
	✓		✓	✓	1	0.3
	✓		✓		4	1.1

✓			✓	3	0.8
✓				68	19.4
	✓	✓	✓	1	0.3
	✓	✓		8	2.3
	✓		✓	2	0.6
	✓			66	18.7
		✓		10	2.8
			✓	9	2.6

WHO: World Health Organization; TBI: Traumatic brain injury; GCS: Glasgow Coma Scale;

LOC: Loss of consciousness.

Table S2. Confirmed mTBI patients (N=351) with documented PTA (N=260) based on the summary PTA-related mTBI designation, accounting for any documented PTA manifestations: observed/self-reported amnesia or confusion/disorientation fulfilling the WHO criteria, behavioural change or acute cognitive impairment on PTA testing.

Summary PTA-related mTBI designation (N=260)	Observed/self-reported Amnesia < 24 hrs [WHO criteria] (N=229)	Observed/self-reported Confusion/disorientation [WHO criteria] (N=97)	Observed Behavioural changes (N=61)	PTA testing administered (N=182)	N (N=351)	%
✓	✓	✓	✓	✓	27	7.7
✓	✓	✓	✓	-	6	1.7
✓	✓	✓	-	✓	24	6.8
✓	✓	✓	-	-	18	5.1
✓	✓	-	✓	✓	16	4.6
✓	✓	-	✓		6	1.7
✓	✓	-	-	✓	75	21.4
✓	✓	-	-		57	16.2
✓	-	✓	✓	✓	4	1.1
✓	-	✓	-	✓	6	1.7
✓	-	✓	-		12	3.4

✓	-	-	✓	✓	**1**	**0.3**
✓	-	-	✓		**1^**	**0.3**
✓	-	-	-	✓	**7**	**2**
-	-	-	-	✓§	20#	5.8
-	-	-	-	-	71#	20.2

TBI: Traumatic brain injury; WHO: World Health Organization; PTA: Post-traumatic amnesia

Note: in **bold** are confirmed mTBI (N=9) based only on reported behavioural changes and/or cognitive impairment at PTA testing (i.e. PTA documented). All, expect one (^), met other mTBI WHO criteria (i.e. LOC≤ 30 mins, GCS=13-14, intracranial injuries).

Confirmed mTBI (N=91) with no documented positive findings for PTA manifestations.

§ Individuals who were tested for PTA and obtained optimal scores (i.e. not in PTA), in the absence of PTA manifestations documented in other sources.

Table S3. Full list of ED diagnosis codes (SNOWMED codes) and ED diagnosis codes indicative of mTBI, for the overall mTBI cohort (confirmed mTBI cases, N=351; indeterminate mTBI, N=180).

SNOWMED Codes Diagnosis Description	N	%
Injury of head (disorder)	145	26.3
Motor vehicle accident victim (finding)	49	8.9
Minor head injury (disorder)	39	7.1
Traumatic injury (disorder)	37	6.7
Falls (finding)	35	6.4
Concussion (disorder)	26	4.7
Headache (finding)	11	2.0
Facial laceration (disorder)	10	1.8
Victim of physical assault (finding)	9	1.6
Alcohol intoxication (disorder)	8	1.5
Falling injury (finding)	8	1.5
Fractured nasal bones (disorder)	8	1.5
Laceration of head (disorder)	8	1.5
Postconcussion syndrome (disorder)	7	1.3
Injury of face (disorder)	6	1.1
Subarachnoid hemorrhage (disorder)	6	1.1
Neck pain (finding)	5	0.9
Backache	4	0.7
Intracranial injury without skull fracture (disorder)	4	0.7
Laceration of forehead (disorder)	4	0.7
Closed fracture of clavicle (disorder)	3	0.5

Dizziness (finding)	3	0.5
Fracture of maxilla (disorder)	3	0.5
Fracture of rib (disorder)	3	0.5
Injury of neck (disorder)	3	0.5
Laceration - injury (disorder)	3	0.5
Soft tissue injury (disorder)	3	0.5
Subdural hematoma (disorder)	3	0.5
-	2	0.4
Abrasion of face (disorder)	2	0.4
Abrasion of head (disorder)	2	0.4
Alcohol abuse (disorder)	2	0.4
Brief loss of consciousness (finding)	2	0.4
Closed fracture of facial bone (disorder)	2	0.4
Fracture of cervical spine (disorder)	2	0.4
Fracture of face bones (disorder)	2	0.4
Fracture of phalanx of finger (disorder)	2	0.4
Fracture of vertebral column without spinal cord injury (disorder)	2	0.4
Hematoma of face (disorder)	2	0.4
Laceration of lip (disorder)	2	0.4
Motor vehicle accident passenger (finding)	2	0.4
Scalp laceration (disorder)	2	0.4
Superficial laceration of face (disorder)	2	0.4
Blunt injury (disorder)	1	0.2
Cerebral hemorrhage (disorder)	1	0.2
Closed fracture carpal bone (disorder)	1	0.2

Closed fracture of base of skull (disorder)	1	0.2
Closed fracture of multiple ribs (disorder)	1	0.2
Closed fracture of of navicular bone of wrist (disorder)	1	0.2
Closed fracture of one or more phalanges of hand (disorder)	1	0.2
Closed fracture of orbital floor (blow-out) (disorder)	1	0.2
Closed fracture of rib (disorder)	1	0.2
Closed fracture of shaft of fibula (disorder)	1	0.2
Closed fracture of upper end of tibia (disorder)	1	0.2
Compression fracture of vertebral column (disorder)	1	0.2
Contusion (disorder)	1	0.2
Contusion of cerebrum (disorder)	1	0.2
Contusion of shoulder region (disorder)	1	0.2
Crushing injury of skull and intracranial contents (disorder)	1	0.2
Did not wait for treatment (finding)	1	0.2
Elbow fracture (disorder)	1	0.2
Epidural hemorrhage (disorder)	1	0.2
Finding related to falls (finding)	1	0.2
Floaters in visual field (finding)	1	0.2
Foot swelling (finding)	1	0.2
Fracture of distal end of radius (disorder)	1	0.2
Fracture of lumbar spine (disorder)	1	0.2
Fracture of mandible closed (disorder)	1	0.2
Fracture of multiple ribs (disorder)	1	0.2
Fracture of orbit (disorder)	1	0.2
Fracture of orbital roof (disorder)	1	0.2

Fracture of pelvis (disorder)	1	0.2
Fracture of pubis (disorder)	1	0.2
Fracture of skull (disorder)	1	0.2
Fracture of sternum (disorder)	1	0.2
Fracture of thoracic spine (disorder)	1	0.2
Fracture of upper jaw closed (disorder)	1	0.2
Fracture of vertebral column (disorder)	1	0.2
Hematoma (disorder)	1	0.2
Injury of facial nerve (disorder)	1	0.2
Injury of kidney (disorder)	1	0.2
Injury of pancreas (disorder)	1	0.2
Injury of shoulder region (disorder)	1	0.2
Intervertebral disc prolapse (disorder)	1	0.2
Intracranial hemorrhage (disorder)	1	0.2
Laceration of eye region (disorder)	1	0.2
Loss of consciousness (finding)	1	0.2
Migraine (disorder)	1	0.2
Motor vehicle accident driver (finding)	1	0.2
Multiple fractures (disorder)	1	0.2
Muscle strain (disorder)	1	0.2
Neck sprain (disorder)	1	0.2
Open fracture of nasal bones (disorder)	1	0.2
Open fracture of patella (disorder)	1	0.2
Open fracture of tibia AND fibula (disorder)	1	0.2
Open wound of lower leg (disorder)	1	0.2

Pins and needles (finding)	1	0.2
Recurrent falls (finding)	1	0.2
Shoulder pain (finding)	1	0.2
Sprain of wrist (disorder)	1	0.2
Strain of neck muscle (disorder)	1	0.2
Superficial injury of face (disorder)	1	0.2
Superficial injury of head (disorder)	1	0.2
Syncope (disorder)	1	0.2
Transient global amnesia (finding)	1	0.2
Traumatic dislocation of clavicle (disorder)	1	0.2
Traumatic subdural hemorrhage (disorder)	1	0.2
Unexplained falls (finding)	1	0.2
Victim of trauma with multiple injuries (finding)	1	0.2
Vomiting (disorder)	1	0.2
Wound discharge (finding)	1	0.2

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Table S4. Significant differences (p<.05) between people with and without recorded mTBI diagnosis in Emergency Department (ED) records and/or ED discharge codes indicative of mild traumatic brain injury (mTBI), among confirmed mTBI cases (N=351).

	Confirmed mTBI cases (N=351)					
	Cases with no recorded mTBI diagnosis (N=269)	Cases with recorded mTBI diagnosis (N=81)	Statistical comparison	Cases with no ED discharge codes indicative of mTBI (N=314)	Cases with ED discharge codes indicative of mTBI (N=37)	Statistical comparison
	N (%)	N (%)	p value§	N (%)	N (%)	p value§
Non-traffic-related injury	186 (69.1)	66 (81.5)	0.03	93 (30.6)	3 (8.1)	0.004
Discharge destination			0.0005			0.01
Discharged home	104 (38.7)	29 (35.8)		119 (37.9)	14 (37.8)	

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Admitted to ED	104 (38.7)	17 (21)		115 (36.6)	6 (16.2)	
Admitted to ward	61 (22.7)	35 (43.2)		80 (25.5)	17 (46)	
Intracranial injuries on head CT	4 (2)	26 (42.6)	<0.0001	16 (6.7)	14 (50)	<0.0001
Headache	103 (38.3)	46 (56.8)	0.009	127 (40.5)	22 (59.5)	0.03
Concentration problems	0 (0)	4 (4.9)	0.001	2 (0.6)	2 (5.4)	0.01
Follow-up recommendations	83 (30.9)	44 (54.3)	0.0003	106 (33.8)	22 (59.5)	0.002
PTA measured	125 (46.5)	56 (69.1)	0.0003	-	-	-
Recorded mTBI diagnosis in the ED records	-	-	-	85 (27.1)	16 (43.2)	0.04

§ χ2, z-test, t-test.

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Table S5. Significant differences (p<.05) between people tested for Post-traumatic Amnesia (PTA) versus those not tested, among confirmed mild traumatic brain injury (mTBI) (N=351) and indeterminate cases (N=180).
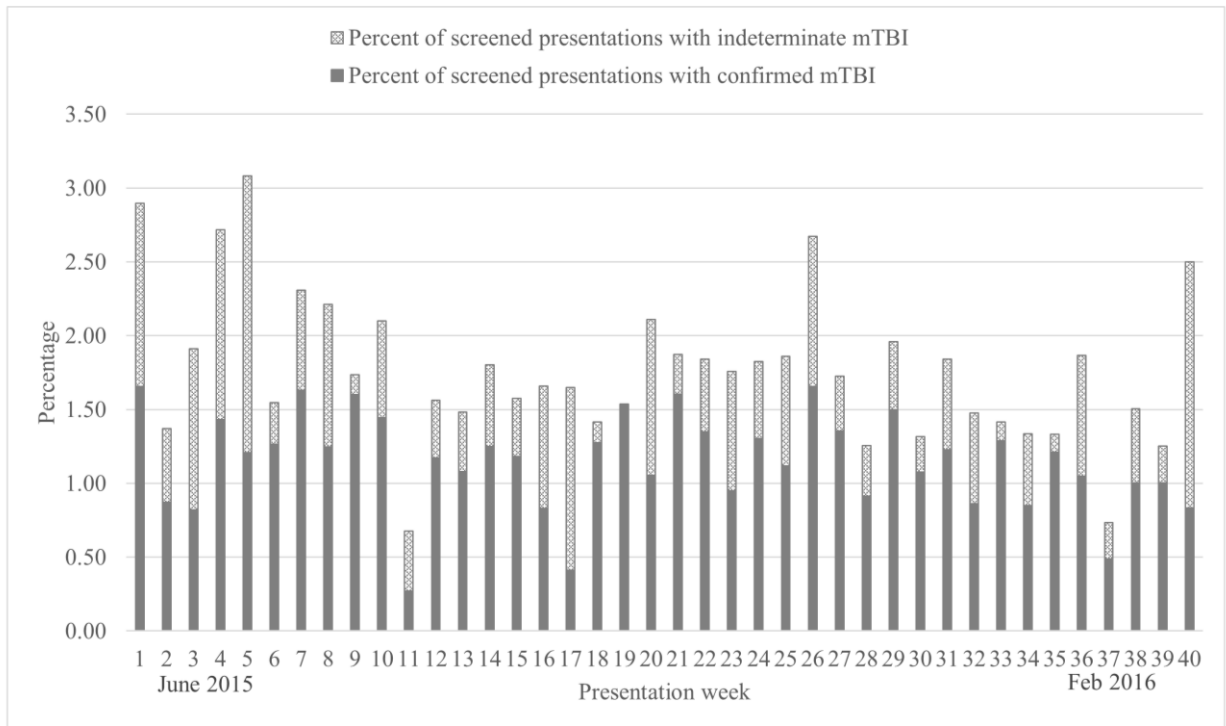
	Confirmed mTBI cases (N=351)			Indeterminate mTBI cases (N=180)		
	Confirmed mTBI not tested for PTA (N=169)	Confirmed mTBI tested for PTA (N=182)	Statistical comparison	Indeterminate mTBI not tested for PTA (N=134)	Indeterminate mTBI tested for PTA (N=46)	Statistical comparison
	N (%)	N (%)	p value§	N (%)	N (%)	p value§
Transported to ED by ambulance	108 (63.9)	142 (78)	0.004	30 (22.4)	26 (56.5)	<0.0001
Traffic-related injury	32 (18.9)	67 (36.8)	0.0002	23 (17.2)	21 (45.7)	0.0001
Discharge destination			<0.0001			<0.0001
Discharged home	98 (58)	35 (19.2)		106 (79.1)	21 (45.7)	
Admitted to ED	43 (25.4)	78 (42.9)		21 (15.7)	15 (32.6)	
Admitted to ward	28 (16.6)	69 (37.9)		7 (5.2)	10 (21.7)	

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LOC reported	49 (34.8)	85 (53.1)	0.005	-	-	-
Amnesia reported	85 (71.4)	140 (91.5)	<0.0001	-	-	-
Brain CT performed	116 (68.6)	150 (82.4)	0.003	-	-	-
Intracranial injuries on head CT	2 (1.7)	28 (18.6)	<0.0001	-	-	-

§ $\chi 2$, z-test, t-test

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Figure S1. Percent of screened ED presentations aged 18-65 years with confirmed or indeterminate mTBI (total 30 479 screened, 351 confirmed mTBI (1.15%), 180 indeterminate mTBI (0.6%)).

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STROBE Statement—checklist of items that should be included in reports of observational studies
YOU MUST NOTE THE PAGE NUMBER WHERE EACH ITEM IS REPORTED INSIDE THE BRACKETS [ ]. IF NOT APPLICABLE WRITE N/A

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract **[1, 3]**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found **[3]**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported **[5-7]**
Objectives	3	State specific objectives, including any prespecified hypotheses **[7]**
Methods		
Study design	4	Present key elements of study design early in the paper **[7]**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **[7]**
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up **[7]**
		Case-control study—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls **[ ]**
		Cross-sectional study—Give the eligibility criteria, and the sources and methods of selection of participants **[ ]**
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed **[N/A]**
		Case-control study—For matched studies, give matching criteria and the number of controls per case **[ ]**
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable **[8-9]**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **[8-9]**
Bias	9	Describe any efforts to address potential sources of bias **[16]**
Study size	10	Explain how the study size was arrived at **[N/A]**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **[N/A]**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding **[N/A]**
		(*b*) Describe any methods used to examine subgroups and interactions **[N/A]**
		(*c*) Explain how missing data were addressed **[N/A]**
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed **[N/A]**
		Case-control study—If applicable, explain how matching of cases and controls was addressed **[ ]**
		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy **[ ]**
		(*e*) Describe any sensitivity analyses **[N/A]**

Continued on next page

Results

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed **[9]**
		(b) Give reasons for non-participation at each stage **[9]**
		(c) Consider use of a flow diagram **[9; Figure 1]**
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders **[9-11 ; Table 1]**
		(b) Indicate number of participants with missing data for each variable of interest **[Table 1]**
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount) **[N/A]**
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time **[9-11]**
		Case-control study—Report numbers in each exposure category, or summary measures of exposure **[ ]**
		Cross-sectional study—Report numbers of outcome events or summary measures **[ ]**
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included **[proportions are presented in pg 7 and in Table 1]**
		(*b*) Report category boundaries when continuous variables were categorized **[N/A]**
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period **[N/A]**
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **[11-12]**

Discussion

Key results	18	Summarise key results with reference to study objectives **[12]**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **[12, 16-17]**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **[12-16]**
Generalisability	21	Discuss the generalisability (external validity) of the study results **[16]**

Other information

Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based **[18]**

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.