BMJ Open

Traumatic Brain Injury in England and Wales: epidemiology, complications and standardised mortality

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2016-012197
Article Type:	Research
Date Submitted by the Author:	07-Apr-2016
Complete List of Authors:	Lawrence, Thomas; Trauma Audit & Research Network, Helmy, Adel; University of Cambridge, Division of Neurosurgery, Department of Clinical Neurosciences Bouamra, Omar; Trauma Audit & Research Network, Woodford, Maralynn; Trauma Audit and Research Network, Lecky, Fiona; University of Sheffield/ Salford Royal Hospitals NHS Trust, Emergency Medicine; Trauma Audit and Research Network, Institute of Population Health Hutchinson, Peter; University of Cambridge, Clinical Neurosciences
Primary Subject Heading:	Surgery
Secondary Subject Heading:	Emergency medicine, Health policy, Intensive care
Keywords:	Neurological injury < NEUROLOGY, NEUROSURGERY, ACCIDENT & EMERGENCY MEDICINE, TRAUMA MANAGEMENT, Organisation of health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT

Traumatic Brain Injury in England and Wales: epidemiology, complications and standardised mortality

Lawrence T*[1], Helmy A*[2,3], O Bouamra[1], Woodford M[1], Lecky F[4], Hutchinson PJ[2,3]

* Joint First Authors

1. Trauma Audit and Research Network, Manchester Medical Academic Health Sciences Centre, Institute of Population Health, University of Manchester, 3rd Floor, The Mayo Building, Salford Royal Hospital, Salford M6 8HD
2. Division of Neurosurgery, Department of Clinical Neuroscience, University of Cambridge, Box 167, Cambridge Biomedical Campus, Cambridge, CB2 0QQ
3. Department of Neurosurgery, Addenbrooke's Hospital, Cambridge, CB2 0QQ
4. Centre for Urgent and Emergency care Research (CURE), Health Services Research Section, School of Health and Related Research (ScHARR), University of Sheffield, Regents Court, 30 Regent Street, Sheffield, S1 4DA

Corresponding Author:

Mr Adel Helmy

University Lecturer in Neurosurgery

Division of Neurosurgery

Department of Clinical Neuroscience

University of Cambridge

Box 167

Cambridge Biomedical Campus

Cambridge

CB2 0QQ

adelhelmy@cantab.net

Abstract

Objectives: To provide a comprehensive assessment of the management of Traumatic Brain Injury relating to epidemiology, complications and standardised mortality across specialist units.

Design: The Trauma Audit and Research Network collects data prospectively on patients suffering trauma across England and Wales. We analysed all data collected on Traumatic Brain Injury patients between April 2014 and June 2015.

Setting: Data was collected on patients presenting to emergency departments across hospitals with and without specialist neurosurgical services. The frequency and timing of secondary transfer to neurosurgical centres was assessed.

Results: We identified 15820 patients with TBI presenting to neurosurgical centres directly (6258), transferred from a district hospital to a neurosurgical centre (3682) and remaining in a district general hospital (5880). The commonest mechanisms of injury were falls in the elderly and road traffic collisions in the young, which were more likely to present in coma. In severe TBI (GCS≤8), the median time from admission to imaging with CT scan is 0.5 hours. Median time to craniotomy from admission is 2.6 hours and median time to ICP monitoring is 3 hours . The most frequently documented complication of severe TBI is bronchopneumonia in 5% of patients. Risk adjusted W scores derived from the $Ps14^{n}$ model indicate that no neurosurgical unit fell outside the 3 standard deviation limits on a funnel plot.

Conclusions: We provide the first comprehensive report of the management of TBI in England and Wales, including data from all neurosurgical units. This data provides transparency and suggests equity of access to high quality of TBI management provided in England and Wales.

Introduction

Traumatic Brain Injury (TBI) is a major cause of mortality and morbidity. In England and Wales approximately 1.4 million patients per year attend hospital following head injury and it is the most common cause of death under the age of 40 years[1]. Over the past 30 years advances in management including the introduction of Advanced Trauma Life Support[2], NICE guidelines[1], and protocol driven therapy have improved outcome[3]. More recently Regional Trauma Networks have been implemented in the UK. It is recognised, however, that major gains are still needed in terms of increasing our understanding of the pathophysiology of this heterogeneous condition and defining and optimising individual treatment strategies.

The UK national neurosurgical society, The Society of British Neurological Surgeons (SBNS), has established the Neurosurgical National Audit Programme (NNAP)[4], the first comprehensive national audit of both emergency and elective activity in an acute surgical specialty with a complex case-mix, as a mechanism for driving quality improvement and maintaining high standards of clinical governance. Hospital and Consultant Surgeon level data has been collected and the first year of data relating to elective activity was published on the 1st December 2014. The management of TBI differs from other aspects of neurosurgical care, in that it is heavily reliant on multi-disciplinary care, including Emergency Medicine, Neurointensive Care, Neurosurgery and Rehabilitation Medicine. In this way, surgeon specific data is less useful and the aggregate performance of a whole unit is more indicative of the quality of care that is delivered. For this reason, the SBNS and the Trauma Audit and Research Network (TARN) have collaborated in order to produce detailed data on the management of several aspects of TBI management across the UK in over 15000 patients.

The objective of this study was to undertake an audit of Traumatic Brain Injury in England and Wales during a 15 month epoch (April 2014 – June 2015) specifically to define the demography, mechanism of injury, arrival mode, to characterise transfers and direct admissions to Neurosurgical Units, length of stay, complications and outcome in terms of mortality. We specifically sought to ascertain compliance with NICE guidance and variation in mortality according to neurosurgical centre.

Materials and Methods

The information shown in this report is derived from the TARN registry. TARN has Health Research Authority (PIAGG Section 20) approval to conduct research on anonymised data. There was no patient involvement in the design or implementation of the study. Patients of all ages are eligible for entry to the TARN database if they suffer injuries leading to a hospital stay of 3 or more days, admission to intensive or high dependency care, inter-hospital transfer or death. Patients aged over 65 years old with an isolated neck of femur fracture or those with isolated closed limb fractures are excluded. Those that died at the incident scene and were not transported to hospital are not eligible. Currently the TARN database contains information on over 69000 eligible major trauma patients admitted to hospitals in England and Wales over the period of the study (April 2014 – June 2015). Each patient's injuries are centrally coded and scored reproducibly by TARN co-ordination centre staff using the Abbreviated Injury Scale (AIS) Dictionary[5] – each injury attracts a threat to life severity code between 1(minimal) to 6(maximal /incompatible with life). Of these 15820 suffered a TBI (defined as an AIS 3 or greater injury to the head). Severe TBI was defined as an initial Glasgow Coma Score (GCS) of 8 or less in combination with an AIS 3 or greater traumatic brain injury, moderate and mild TBI were defined as GCS 9 – 13 and GCS 14 – 15 respectively. Simple cross tabulations and percentages were used to describe the study demography, injury mechanisms and features of the care pathway (intubation, imaging, transfer, surgery and complications) by severity of TBI for the whole study sample.

The following analysis focuses on these 15820 patients. Some analyses use subsets of this cohort; patients admitted directly from the scene of injury and those admitted to a neurosurgical centre. As a result of relatively small numbers of patients treated exclusively at sites without neurosurgery, these are not included in the risk adjusted outcome analysis, this group is further filtered to only include patients whose outcome is recorded on the TARN database.

Outcome, measured as mortality is considered by using a derivation of the Ps14 multivariate logistic regression model[6] ($Ps14^n$). The Ps14 model calculates a probability of survival for each patient based on their age, gender, initial GCS, injury severity score (ISS) and any pre-existing medical conditions. The $Ps14^n$ model adds pupillary reactivity due to its prognostic importance in head injury[7 8]. The $Ps14^n$ model was generated using 33715 cases admitted between 2010 and 2013 (inclusive) following head injury.

Missing GCS and pupil reactivity values were imputed and patients with missing pre-existing medical condition data were categorised as such. Details of the model, including coefficients can be found in Appendix 1.

In order to compare mortality across different centres the predicted survival rate, derived from the probability of survival values assigned to patients admitted to a given institution is subtracted from the observed survival rate to generate a 'W' score. This is then risk standardised (Ws) to allow direct comparison between units by compensating for variations in admission patterns[9]. A positive Ws score therefore indicates a better than expected rate of survival.

Results

Figure 1 provides a summary flow chart of the numbers of patients in each cohort of the study audit, namely: those admitted directly to a neurosurgical centre (n=6358), those with a secondary admission (via a district general hospital, n=3682) to a neurosurgical centre and those not admitted to a neurosurgical centre (n=5880).

Demographics and Mechanism of Injury

For all TBI severities there is a unimodal age distribution with a peak in those aged between 80 and 90 and this cohort represents more than 1 in 5 of those recorded as suffering from a TBI. For those with severe TBI there is a smaller peak between age 20 and 30 representing just over 15% of cases. Younger patients are more likely to be injured as a result of road traffic collisions and assaults while with increasing age there is a concurrent increase in the proportion of patients injured following falls under 2m. Of those patients with a documented admission GCS (n=15080), the cohort is dominated by mild TBI (68%), with 26% with a severe TBI and only 6% with moderate TBI.

Transfer to Hospital and Airway Management

Table 1 summarises data on hospital transfers and airway management stratified by severity of injury of TBI. The most common mode of transport to hospital is ambulance (74% overall). 7% of patients are

recorded as being transported by helicopter, although, in patients with severe TBI this increases to 19%. Direct admission to a neurosurgical centre from the scene of injury occurred in approximately 40% of patients overall and over 60% of patients with severe TBI. This proportion was lower for moderate and mild TBI patients (41% and 33%) but significant proportions were subsequently transferred (20%, 22% respectively).

Table 1. Hospital Transfers and Airway Management

Category	Group	Severe TBI n (%)	Moderate TBI n (%)	Mild TBI n (%)	GCS Not recorded n (%)	*Total n (%)*
Total number of patients		3915	899	10266	742	15822
Mode of arrival (direct admissions, n = 13824)	Ambulance	2504 (71.6%)	662 (83.8%)	6951 (76.6%)	51 (11.1%)	10168 (73.5%)
	Car	3 (0.1%)	1 (0.1%)	65 (0.7%)	7 (1.5%)	76 (0.5%)
	Helicopter	660 (18.9%)	27 (3.4%)	309 (3.4%)	0 (0%)	996 (7.2%)
	Other	1 (0%)	1 (0.1%)	38 (0.4%)	1 (0.2%)	41 (0.3%)
	Unknown	329 (9.4%)	99 (12.5%)	1714 (18.9%)	402 (87.2%)	2544 (18.4%)
Transfer status (all patients), n = 15820	Direct admission to neurocentre	2353 (60.1%)	365 (40.6%)	3374 (32.9%)	167 (22.5%)	6259 (39.6%)
	Transfer into neurocentre	945 (24.1%)	181 (20.1%)	2298 (22.4%)	259 (34.9%)	3683 (23.3%)
	No neurocentre visit	617 (15.8%)	353 (39.3%)	4594 (44.7%)	316 (42.6%)	5880 (37.2%)
Hours to arrival at neurocentre (n = 9940)	0 - 4	2225 (67.5%)	303 (55.5%)	2621 (46.2%)	46 (10.8%)	5195 (52.3%)
	4 - 12	438 (13.3%)	64 (11.7%)	733 (12.9%)	19 (4.5%)	1254 (12.6%)
	12 - 24	57 (1.7%)	21 (3.8%)	252 (4.4%)	8 (1.9%)	338 (3.4%)
	24 - 48	32 (1%)	9 (1.6%)	147 (2.6%)	6 (1.4%)	194 (2%)
	48 - 72	3 (0.1%)	1 (0.2%)	73 (1.3%)	1 (0.2%)	78 (0.8%)
	72+	23 (0.7%)	13 (2.4%)	249 (4.4%)	16 (3.8%)	301 (3%)
	Unknown	520 (15.8%)	135 (24.7%)	1597 (28.2%)	330 (77.5%)	2582 (26%)
Intubation location (direct admissions, n = 13824)	Pre-hospital	765 (21.9%)	0 (0%)	0 (0%)	0 (0%)	765 (5.5%)
	ED	2236 (63.9%)	0 (0%)	0 (0%)	0 (0%)	2236 (16.2%)
	Critical Care	142 (4.1%)	71 (9%)	257 (2.8%)	21 (4.6%)	491 (3.6%)
	Ward	0 (0%)	0 (0%)	4 (0%)	2 (0.4%)	6 (0%)
	Not intubated	354 (10.1%)	719 (91%)	8815 (97.1%)	438 (95%)	10326 (74.7%)

Over 80% of severe TBI patients were admitted to a neurosurgical centre within 12 hours of injury with 68% within 4 hours. 86% of patients presenting with a severe TBI had definitive airway management (defined as endotracheal intubation, tracheostomy or cricothyroidotomy) pre-hospital or in the emergency department. Definitive airway management was rarely required for patients with less severe injuries.

Time to Intervention

Table 2 summarises the data on the time intervals from injury and admission to investigation and intervention. In those patients admitted directly from the scene of injury with a GCS ≤ 8, a median of 0.5 hours was taken to image with CT scan. Median time from arrival to imaging was 0.9 hours for moderate TBI and 1.7 hours for mild injuries. The median time taken from admission to craniotomy was 2.6 hours for severe TBI and 8.6 hours for moderate TBI. If the time to craniotomy, in severe TBI, is calculated from the time of the incident this increases to 4 hours for direct transfers to a neurosurgical centre and 7.3 hours for those who required a secondary transfer. Median time to ICP monitoring following admission to a neurosurgical centre was 3.1 hours following severe TBI. Smaller numbers of mild or moderate TBI patients required craniotomy (3.1% and 2.7% respectively) or ICP monitoring (0.7% and 2.1% respectively) and in general this was performed within 24 hours of arriving in hospital.

Table 2. Median time to CT scanning, Craniotomy and ICP monitoring from hospital arrival / incident†.

† Hospital arrival time is recorded in almost 100% of cases; incident time is recorded in approximately 75% of cases. Intervals measured from incident time include patients that are transferred between hospitals; those measured from arrival time only include patients admitted directly from the scene of injury.

* n values relate to the number of observations in each cohort. For example 3307 patients with a severe TBI underwent CT scanning and have their arrival and CT scan dates and times recorded.

TBI severity	Measured from	Category	n	Median hours	IQR lower bound	IQR upper bound
Severe TBI	Arrival time	CT	3307	0.5	0.3	0.8
		Craniotomy	457	2.6	1.6	10.1
		ICP monitoring	411	3.1	1.8	7.4

	Incident time	CT	3565	2.0	1.5	3.2
		Craniotomy (direct)	423	4.0	2.9	17.2
		Craniotomy (transfer)	262	7.3	5.3	19.0
		ICP monitoring	571	5.8	3.5	11.3
Moderate TBI	Arrival time	CT	766	0.9	0.5	1.9
		Craniotomy	45	8.6	2.8	47.9
		ICP monitoring	16	8.4	2.7	47.9
	Incident time	CT	751	2.5	1.8	5.5
		Craniotomy (direct)	42	15.8	5.3	65.8
		Craniotomy (transfer)	24	38.3	9.7	226.0
		ICP monitoring	19	8.6	6.1	48.8
Mild TBI	Arrival time	CT	8740	1.7	0.7	3.3
		Craniotomy	218	19.2	6.6	97.3
		ICP monitoring	41	11.6	5.8	28.6
	Incident time	CT	8173	3.7	2.3	8.6
		Craniotomy (direct)	170	21.4	7.4	119.2
		Craniotomy (transfer)	320	53.2	16.3	240.6
		ICP monitoring	69	18.3	8.4	38.0
GCS not recorded	Arrival time	CT	367	3.5	1.4	16.5
		Craniotomy	14	15.4	8.5	36.8
		ICP monitoring	2	10.1	0.0	0.0
	Incident time	CT	202	8.5	2.4	36.6
		Craniotomy (direct)	4	189.1	0.0	0.0
		Craniotomy (transfer)	19	40.0	12.4	560.3
		ICP monitoring	7	11.3	10.0	11.7

Complications in Hospital

Table 3 summarises the documented complications following TBI. Overall, over 19% of patients are recorded as suffering a complication, and in the severe TBI cohort this incidence increases to almost 30%. There are a wide range of complications; the most frequent in the severe TBI cohort were bronchopneumonia (4.9%), in-hospital seizure (2.9%), sepsis (3.1%) and pleural effusion (2%). These were also the most common complications in the cohort as a whole.

Table 3. Inpatient Complications Stratified by Severity of Injury

Complication	Severe TBI	Moderate TBI	Mild TBI	GCS not recorded	Total

Aspiration	63 (1.5%)	8 (0.9%)	48 (0.5%)	5 (0.6%)	124 (0.8%)
Bronchopneumonia	203 (4.9%)	32 (3.4%)	209 (2%)	17 (2.2%)	461 (2.8%)
Pleural Effusion	84 (2%)	9 (1%)	68 (0.7%)	12 (1.6%)	173 (1.1%)
Seizure In Hospital	119 (2.9%)	22 (2.4%)	141 (1.4%)	15 (1.9%)	297 (1.8%)
Sepsis	129 (3.1%)	9 (1%)	107 (1%)	13 (1.7%)	258 (1.6%)
Other	624 (15%)	106 (11.4%)	836 (8%)	88 (11.4%)	1654 (10.1%)
Not complications recorded	**2944 (70.7%)**	**744 (80%)**	**9027 (86.5%)**	**623 (80.6%)**	**13338 (81.8%)**

Risk adjusted Outcomes at Neurosurgical Units

Figure 2 shows a funnel plot of the risk adjusted W scores derived using the $Ps14^n$ model (Ws^n) for each unit on the y-axis against a precision (1 / standard error) based rank on the x-axis. A positive Ws^n indicates that a site is performing better than the model predicts, a negative value indicates worse performance. The 'funnel' refers to the 2 and 3 standard deviation (SD) lines, plotted around the mean Ws that narrow as the precision increases. All units are within the 3 SD lines and most units fall within the 2 SD lines; 4 units are outside the -2 SD line and 2 units are above the +2 line. The Ws^n value for a given site, relative to the position of the SD lines indicates if their performance significantly differs from that of their peers.

Discussion

This audit incorporates prospectively collected data on a large number of patients, including from every neurosurgical unit the UK, and provides the most comprehensive and up to date report of outcomes following TBI in the UK.

Demographics and Mechanism of Injury

The cohort of patients in the TARN database mimics data from other large TBI databases and the demographics and mechanism of injury closely mirror those from other series of TBI patients in the developed world [10 11]. The most common injuries are those in elderly people following trips and falls while in younger patients the most common causes are road traffic collisions and assault and these are more likely to present as severe TBI. Interestingly, only 6% of TBI patients fall into the moderate (GCS 9-13) category

calling into question whether the current GCS thresholds for severity accurately reflect the underlying condition: intuitively, one might expect that more severe injuries are increasingly rare.

Transfer to hospital

While the majority of patients are transported to hospital by land ambulance, there is an increasing use of helicopter ambulance for those patients with severe TBI. These patients are increasingly being transported directly to Major Trauma Centres (MTCs) as part of the NHS plan to centralise the management of complex trauma. The choice of mode of transport to hospital and choice of local hospital versus a neurosurgical or MTC is a complex one. Factors such as the physiological stability of a patient on scene and the geography of local emergency services dictates individualisation of decision making and it is difficult to mandate transport of a group of patients to a given location. A recent publication [12] found no association between the duration of the pre-hospital interval and deteriorating physiological parameters. There are also challenges with the reliable identification of TBI in the prehospital environment and current strategies suffer from significant under and over triage rates making secondary transfer into neurosurgery a necessary pathway for some TBI patients[13]. However, in patients with severe TBI, who are likely to survive and require treatment, we would expect transfer to a neurosurgical centre once physiological stability has been achieved[14]. This is supported by NICE guidance – in our series 84% of severe TBI patients received neuroscience care which suggests reasonable adherence. For mild and moderate TBI, an individual decision is required as to the need and rapidity of transfer to a neurosurgical centre. In a resource-limited environment however, an efficient use of specialist beds necessitates some degree of triage at local centres before transfer to a specialist centre.

Time to Intervention

The median and upper quartile time to CT is within the one hour from ED arrival target defined by the NICE head injury guidelines[14] for patients at high risk of TBI requiring neurosurgery (GCS<13 = moderate/severe TBI), NICE recommends CT brain scan for medium risk GCS 15 patients within 8 hours of injury. Mild TBI patients with GCS 13-14 on arrival at hospital should have CT within an hour if the GCS does not reach 15 within 2 hours of injury. Sequential ED GCS readings are not recorded on TARN but Table 2 suggests that this NICE recommendation also has reasonable adherence. The Brain Trauma Foundation surgical

guidelines[15] recommend that acute intracranial haemorrhages are treated as quickly as possible in those patients presenting in coma. The evidence for rapid treatment by craniotomy is strongest in those presenting with a fixed, dilated pupil[16]. In this regard, our data show direct transfer to a neurosurgical centre facilitates more rapid surgery and as such we support current ambulance service trauma triage guidelines that direct primary transportation from scene to a neurosurgical centre for patients with a unilateral fixed, dilated pupil in the context of severe TBI and a patent airway[13]. Consideration should also be given to establishing guidelines for direct transfer of other TBI patients from the scene to Neurosurgical Units, notwithstanding the difficulty in accurate identification of patients in the pre-hospital setting, and refining referral mechanisms from district hospitals / trauma units to major trauma centres with neurosurgical capability. Any guidelines must reflect the low requirement for craniotomy and ICP monitoring in mild (3.1% and 0.7%) and moderate (2.7% and 2.1%) TBI, such that in the majority of these patients expedited transfer to a neurosurgical centre may be unnecessary.

Risk adjusted Outcomes at Neurosurgical Units

Patients with TBI are susceptible to a wide range of complications as evidenced by the reported complications. Respiratory complications predominate as would be expected in critically ill patients with a reduced conscious state or those in an intensive care environment. The analysis shows that 5 units lie outside of the 2 standard deviation (SD) control limits, however they and all other units are within the 3 SD limits. A single centre is close to the positive 3 SD limit, but this is one of the units with lower precision where we expect to see larger variation from the mean. As such these data suggest that there are no outlying units in terms of risk adjusted mortality in neurosurgical care for patients suffering TBI in England & Wales. Further studies are required to address the quality of survival in terms of outcome beyond mortality.

Study Limitations

Although this audit is comprehensive, there are certain limitations to using aggregate data of this type. Firstly, as with many studies that utilise GCS, we have used a composite score rather than the individual components, despite each component of the GCS being on a categorical scale. This is partly addressed by the validation of this approach by the IMPACT model[17 18]. Secondly, there is some variability in the reporting of GCS, such that 'first' GCS is sometimes used interchangeably with 'post-resuscitation' GCS[18]. Thirdly,

we have not addressed the decision making with regards to transfer of patients from peripheral to neurosurgical centres, and the possibility of regional variation. This could potentially have an effect on TBI survival rates in specialist centres if there is a variation in transfer criteria, particularly for older patients who may have poorer prognosis[19]. Lastly there is some variability in patient recruitment into the TARN database, over the time period of the study neuroscience centres recruited almost 100% of relevant patients, outside of these hospitals however the average is roughly 65%. Nevertheless, we hope by compiling data on more than 15,000 patients, we are able to provide robust data on UK TBI management.

Conclusion

This report provides the first UK audit of its type with a large number of patients that is commensurate with the largest cohorts of patients currently published in TBI, namely the CRASH and IMPACT studies. This provides a robust baseline for further comparisons of outcomes in a transparent and reproducible fashion. The data we present confirms that UK trauma management broadly meets the NICE guidelines and achieves a consistent standard across all regions and neurosurgical units. The increasing need for public engagement with regards to surgical outcomes, and the related political imperative to provide this within the NHS will become the *status quo*.

Article Summary

-Traumatic Brain Injury causes high morbidity and mortality with both financial and social implications

-National guidelines have improved consistency of care of trauma patients

-The current practice in England and Wales is consistent with current NICE guidelines

-All neurosurgical units in England and Wales all within 3 standard deviations of standardised mortality following traumatic brain injury

-Craniotomy and ICP monitoring is rarely required in patients with mild (GCS14-15) and moderate (GCS9-13) TBI.

Footnotes

The sponsor has had no role in the design or conduct of this study.

Contributors: FL and PJH conceived of the study and have provided detailed review of the results. AH and TL have written the manuscript. TL, OB and MW have carried out the statistical analysis.

Funding: AH is supported by the University of Cambridge, UK and Medical Research Council/ Royal College of Surgeons of England Clinical Research Training Fellowship (Grant no. G0802251). P.J.H.is supported by National Institute for Health Research Professorship, Academy of Medical Sciences/Health Foundation Senior Surgical Scientist Fellowship and the National Institute for Health Research Biomedical Research Centre, Cambridge.

Competing interests: All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: financial support as described above; no other financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Data sharing: no additional data available.

Transparency declaration: The lead authors (FL, PJH) affirm that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained

References

1. Head Injury: Triage, Assessment, Investigation and Early Management of Head Injury in Children, Young People and Adults. National Institute for Health and Care Excellence (UK) 2014.
2. Advanced Trauma Life Support (ATLS): the Ninth Edition. American College of Surgeons 2012.
3. Patel HC, Menon DK, Tebbs S, et al. Specialist neurocritical care and outcome from head injury. Intensive care medicine 2002;**28**(5):547-53.
4. Neurosurgical National Audit Programme 2014 [Available from: www.hed.nhs.uk/SBNS/.
5. Abbreviated Injury Scale (AIS) 2014 [Available from: http://www.aaam.org/about-ais.html.
6. Bouamra O, Jacques R, Edwards A, et al. Prediction modelling for trauma using comorbidity and 'true'30-day outcome. Emergency Medicine Journal 2015:emermed-2015-205176.
7. Marmarou A, Lu J, Butcher I, et al. Prognostic value of the Glasgow Coma Scale and pupil reactivity in traumatic brain injury assessed pre-hospital and on enrollment: an IMPACT analysis. Journal of neurotrauma 2007;**24**(2):270-80.
8. Murray GD, Butcher I, McHugh GS, et al. Multivariable prognostic analysis in traumatic brain injury: results from the IMPACT study. Journal of neurotrauma 2007;**24**(2):329-37.
9. Hollis S, Yates D, Woodford M, et al. Standardized comparison of performance indicators in trauma: a new approach to case-mix variation. Journal of Trauma and Acute Care Surgery 1995;**38**(5):763-66.
10. Peeters W, van den Brande R, Polinder S, et al. Epidemiology of traumatic brain injury in Europe. Acta neurochirurgica 2015;**157**(10):1683-96.
11. Maas AI, Murray GD, Roozenbeek B, et al. Advancing care for traumatic brain injury: findings from the IMPACT studies and perspectives on future research. The Lancet Neurology 2013;**12**(12):1200-10.
12. Fuller G, Lawrence T, Woodford M, et al. Emergency medical services interval and mortality in significant head injury: a retrospective cohort study. European Journal of Emergency Medicine 2015;**22**(1):42-48.
13. Lecky F, Russell W, Fuller G, et al. The Head Injury Transportation Straight to Neurosurgery (HITS-NS) randomised trial: a feasibility study. Health Technol Assess 2016;**20**(1).
14. NICE. Triage, assessment, investigation and early management of head injury in children, young people and adults 2014 [Available from: http://www.nice.org.uk/guidance/cg176/evidence.
15. Guidelines for the management of severe traumatic brain injury 2007 [Available from: https://www.braintrauma.org/.
16. Clusmann H, Schaller C, Schramm J. Fixed and dilated pupils after trauma, stroke, and previous intracranial surgery: management and outcome. J Neurol Neurosurg Psychiatry 2001;**71**(2):175-81.
17. Marmarou A, Lu J, Butcher I, et al. Prognostic value of the Glasgow Coma Scale and pupil reactivity in traumatic brain injury assessed pre-hospital and on enrollment: an IMPACT analysis. J Neurotrauma 2007;**24**(2):270-80.
18. Reith FC, Van den Brande R, Synnot A, et al. The reliability of the Glasgow Coma Scale: a systematic review. Intensive Care Med 2016;**42**(1):3-15.
19. Kirkman MA, Jenks T, Bouamra O, et al. Increased mortality associated with cerebral contusions following trauma in the elderly: bad patients or bad management? J Neurotrauma 2013;**30**(16):1385-90.

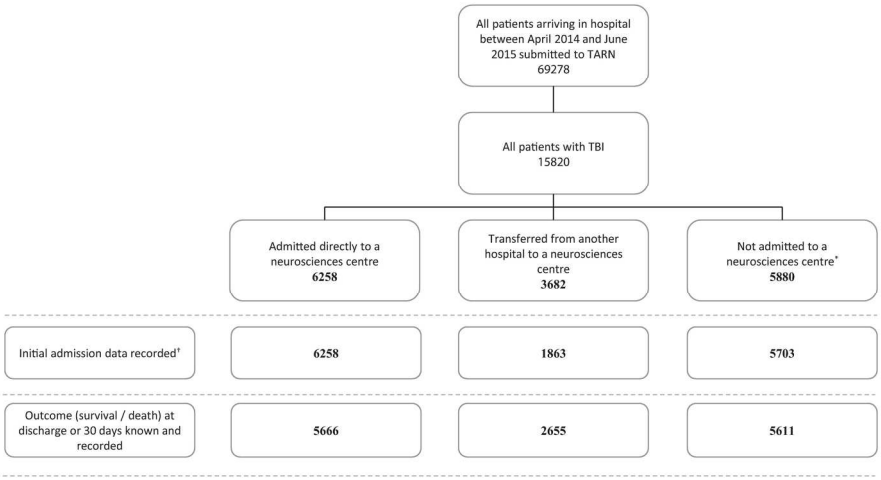
Figure Legends

Figure 1. Flow chart delineating the derivation of the TBI cohort studied.

Figure 2. Proportion of all TBI patients by age and mechanism of injury.

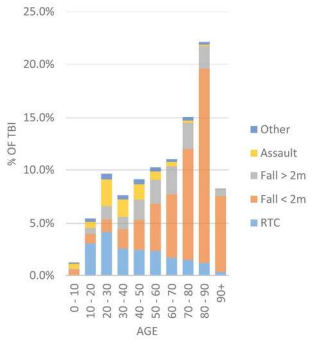
Figure 3. Proportion of patients with severe TBI (TBI in combination with GCS ≤ 8) by age and mechanism of injury.

Figure 4. Funnel plot showing the Wsn for neurosurgical units in England & Wales between April 2014 and June 2015.



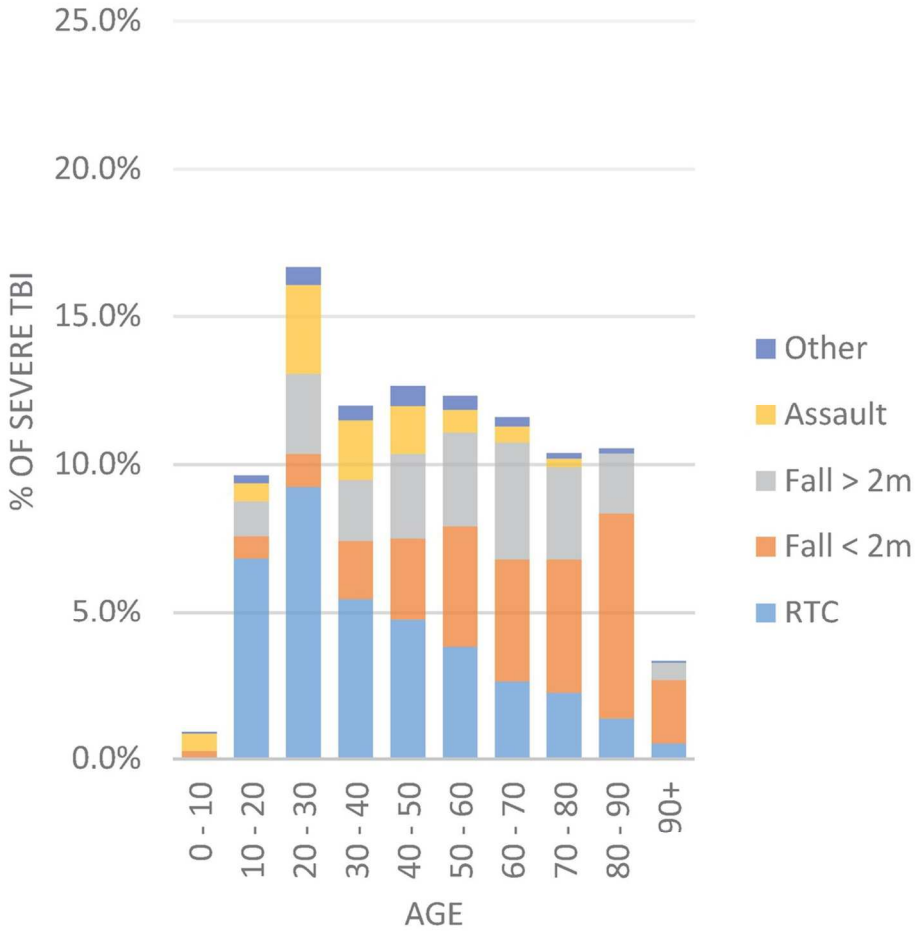
* Patients initially admitted to and treated entirely at hospitals without neuroscience care
† Data from the scene of injury and initial hospital admitted to is recorded on TARN

190x142mm (300 x 300 DPI)



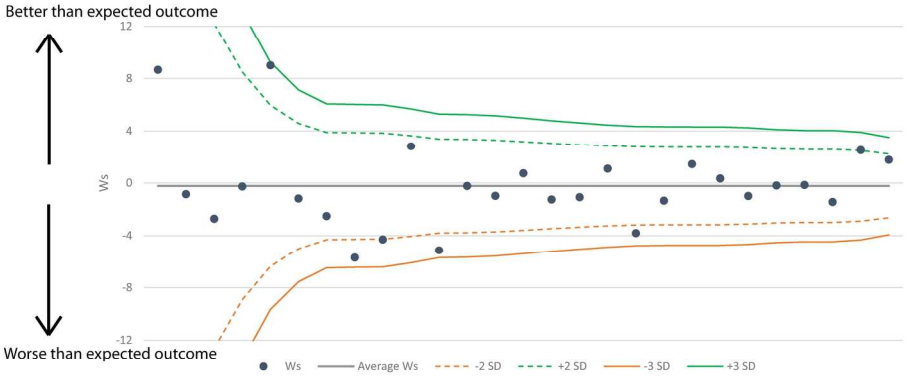
Figures 2. Proportion of patients with TBI by age and mechanism of injury.

190x142mm (300 x 300 DPI)



Figures 3. Proportion of patients with severe TBI (TBI in combination with GCS < 9) by age and mechanism of injury.

106x124mm (300 x 300 DPI)



190x142mm (300 x 300 DPI)

Appendix

The Ps14^{n} model is a modification of the Ps14 model as described by Bouamra in 2015 with the addition of pupil reactivity. It has been derived from 39451 patients recorded in the TARN database with head injuries of AIS 3 or greater severity admitted to hospital between 2012 and 2015. Table 1 describes the characteristics of these patients and table 2 contains the regression coefficients of which the prediction model is formed.

The model is shown to have good discriminant power (AuROC 0.882, 95% CI 0.878 to 0.887).

Table 1. Characteristics of the patients

n	39451
Age	
Median (IQR)	62.6 (35.8 - 81.4)
ISS	
Median (IQR)	24 (16 - 26)
GCS	
Median (IQR)	14 (11 - 15)
Gender	
Female	13927 (35.3%)
Male	25524 (64.7%)
Comorbidity	
No comorbidity	19776 (50.1%)
1 - 5	10617 (26.9%)
6 - 10	3417 (8.7%)
> 10	1585 (4.0%)
Not recorded	4056 (10.3%)
Mortality	16.0%

Table 2. Coefficients of the model

Variables	Regression Coefficients	p-value	Odds ratio 95% CI	
$(10/ISS)^2$ - 0.1920	3.3294	<0.0001	3.13	3.52
$(10/ISS)^2*\log_e(ISS/10)$-0.1584	8.2092	<0.0001	7.45	8.96
GCS				
GCS =3	-3.0652	<0.0001	-3.20	-2.93
GCS 4 -5	-2.6485	<0.0001	-2.82	-2.47
GCS 6 -8	-1.8352	<0.0001	-1.98	-1.69
GCS 9 -12	-1.3348	<0.0001	-1.45	-1.22
GCS 13 - 14	-0.4704	<0.0001	-0.57	-0.37
GCS 15 (reference)	0.0000		1.00	1.00
Intubated	-2.5212	<0.0001	-2.82	-2.23
Charlson Index				
0 (reference)	0.0000		1.00	1.00
1 - 5	-0.4593	<0.0001	-0.55	-0.37
6 - 10	-0.7754	<0.0001	-0.89	-0.66
>10	-1.1841	<0.0001	-1.33	-1.03
Not recorded	-0.6575	<0.0001	-0.77	-0.54
Age				
0 - 5	-0.0236	0.92	-0.46	0.41
6 - 10	0.5668	0.07	-0.05	1.18
11 - 15	0.0356	0.87	-0.40	0.47
16 - 44 (reference)	0.0000		1.00	1.00
45 - 54	-0.5065	<0.0001	-0.68	-0.33
55 - 64	-1.0091	<0.0001	-1.18	-0.83
65 - 75	-1.6125	<0.0001	-1.77	-1.45
>75	-2.7684	<0.0001	-2.91	-2.63
Gender				
Male (reference)	0.0000		1.00	1.00
Female	-0.0216	0.84	-0.24	0.19
Age by gender interaction				
0 - 5 & Female	-0.1968	0.55	-0.85	0.46
6 - 10 & Female	-0.3357	0.55	-1.43	0.76
11 - 15 & Female	0.8354	0.11	-0.19	1.87
45 - 54 & Female	-0.2911	0.11	-0.65	0.07
55 - 64 & Female	0.2989	0.09	-0.05	0.65
65 - 75 & Female	-0.0281	0.85	-0.32	0.26
>75 & Female	0.1084	0.36	-0.12	0.34
Pupil reactivity				
Both reactive (reference)	0.0000		1.00	1.00
Abnormal (both reactive)	-0.4383	<0.0001	-0.56	-0.31
Abnormal (1 reactive)	-0.5325	<0.0001	-0.70	-0.37
Neither reactive	-2.0874	<0.0001	-2.23	-1.94

Constant	4.9208	<0.0001	4.78	5.06

BMJ Open

Traumatic Brain Injury in England and Wales: epidemiology, complications and standardised mortality

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2016-012197.R1
Article Type:	Research
Date Submitted by the Author:	16-Jun-2016
Complete List of Authors:	Lawrence, Thomas; Trauma Audit & Research Network, Helmy, Adel; University of Cambridge, Division of Neurosurgery, Department of Clinical Neurosciences Bouamra, Omar; Trauma Audit & Research Network, Woodford, Maralynn; Trauma Audit and Research Network, Lecky, Fiona; University of Sheffield/ Salford Royal Hospitals NHS Trust, Emergency Medicine; Trauma Audit and Research Network, Institute of Population Health Hutchinson, Peter; University of Cambridge, Clinical Neurosciences
Primary Subject Heading:	Surgery
Secondary Subject Heading:	Emergency medicine, Health policy, Intensive care
Keywords:	Neurological injury < NEUROLOGY, NEUROSURGERY, ACCIDENT & EMERGENCY MEDICINE, TRAUMA MANAGEMENT, Organisation of health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT

Traumatic Brain Injury in England and Wales: epidemiology, complications and standardised mortality

Lawrence T*[1], Helmy A*[2,3], O Bouamra[1], Woodford M[1], Lecky F[4], Hutchinson PJ[2,3]

* Joint First Authors

1. Trauma Audit and Research Network, Manchester Medical Academic Health Sciences Centre, Institute of Population Health, University of Manchester, 3rd Floor, The Mayo Building, Salford Royal Hospital, Salford M6 8HD
2. Division of Neurosurgery, Department of Clinical Neuroscience, University of Cambridge, Box 167, Cambridge Biomedical Campus, Cambridge, CB2 0QQ
3. Department of Neurosurgery, Addenbrooke's Hospital, Cambridge, CB2 0QQ
4. Centre for Urgent and Emergency care Research (CURE), Health Services Research Section, School of Health and Related Research (ScHARR), University of Sheffield, Regents Court, 30 Regent Street, Sheffield, S1 4DA

Corresponding Author:

Mr Adel Helmy

University Lecturer in Neurosurgery

Division of Neurosurgery

Department of Clinical Neuroscience

University of Cambridge

Box 167

Cambridge Biomedical Campus

Cambridge

CB2 0QQ

Abstract

Objectives: To provide a comprehensive assessment of the management of Traumatic Brain Injury relating to epidemiology, complications and standardised mortality across specialist units.

Design: The Trauma Audit and Research Network collects data prospectively on patients suffering trauma across England and Wales. We analysed all data collected on Traumatic Brain Injury patients between April 2014 and June 2015.

Setting: Data was collected on patients presenting to emergency departments across 187 hospitals including 26 with specialist neurosurgical services, incorporating factors previously identified in the $Ps14^{n}$ multivariate TBI outcome prediction model. The frequency and timing of secondary transfer to neurosurgical centres was assessed.

Results: We identified 15820 patients with TBI presenting to neurosurgical centres directly (6258), transferred from a district hospital to a neurosurgical centre (3682) and remaining in a district general hospital (5880). The commonest mechanisms of injury were falls in the elderly and road traffic collisions in the young, which were more likely to present in coma. In severe TBI (GCS≤8), the median time from admission to imaging with CT scan is 0.5 hours. Median time to craniotomy from admission is 2.6 hours and median time to ICP monitoring is 3 hours. The most frequently documented complication of severe TBI is bronchopneumonia in 5% of patients. Risk adjusted W scores derived from the $Ps14^{n}$ model indicate that no neurosurgical unit fell outside the 3 standard deviation limits on a funnel plot.

Conclusions: We provide the first comprehensive report of the management of TBI in England and Wales, including data from all neurosurgical units. This data provides transparency and suggests equity of access to high quality of TBI management provided in England and Wales.

Introduction

Traumatic Brain Injury (TBI) is a major cause of mortality and morbidity. In England and Wales approximately 1.4 million patients per year attend hospital following head injury and it is the most common cause of death under the age of 40 years[1]. Over the past 30 years advances in management including the introduction of Advanced Trauma Life Support[2], NICE guidelines[1], and protocol driven therapy have improved outcome[3] and reduced mortality[4]. More recently Regional Trauma Networks have been implemented in England and Wales. It is recognised, however, that major gains are still needed in terms of increasing our understanding of the pathophysiology of this heterogeneous condition and defining and optimising individual treatment strategies. The largest existing TBI datasets in the literature are from the CRASH[5] study, approximately 10,000 patients within a randomised control study of corticosteroids, and IMPACT[6], a collated dataset of approximately 9,800 patients from 8 randomised and 3 observational studies.

The UK national neurosurgical society, The Society of British Neurological Surgeons (SBNS), has established the Neurosurgical National Audit Programme (NNAP)[7], the first comprehensive national audit of both emergency and elective activity in an acute surgical specialty with a complex case-mix, as a mechanism for driving quality improvement and maintaining high standards of clinical governance. Hospital and Consultant Surgeon level data has been collected and the first year of data relating to elective activity was published on the 1st December 2014. The management of TBI differs from other aspects of neurosurgical care, in that it is heavily reliant on multi-disciplinary care, including Emergency Medicine, Neurointensive Care, Neurosurgery and Rehabilitation Medicine. In this way, surgeon specific data is less useful and the aggregate performance of a whole unit is more indicative of the quality of care that is delivered. For this reason, the SBNS and the Trauma Audit and Research Network (TARN) have collaborated in order to produce detailed data on the management of several aspects of TBI management across Engalnd and Wales in over 15000 patients.

The objective of this study was to undertake an audit of Traumatic Brain Injury in England and Wales during a 15 month epoch (April 2014 – June 2015) specifically to define the demography, mechanism of injury, arrival mode, to characterise transfers and direct admissions to Neurosurgical Units, length of stay, self-reported complications and outcome in terms of mortality. We specifically sought to ascertain compliance with NICE guidance and variation in mortality according to neurosurgical centre.

Materials and Methods

The information shown in this report is derived from the TARN registry, a prospective, observational registry of hospitalised major trauma patients in England & Wales. TARN has Health Research Authority (PIAGG Section 20) approval to conduct research on anonymised data. There was no patient involvement in the design or implementation of the study other than the oversight presented by the patient and public representatives on the TARN Board. Patients of all ages are eligible for entry to the TARN database if they suffer injuries leading to a hospital stay resulting in any of: 3 or more days in hospital, admission to intensive or high dependency care, inter-hospital transfer or death from injury. Patients aged over 65 years old with an isolated neck of femur fracture or those with isolated closed limb fractures are excluded. Those that died at the incident scene and were not transported to hospital are not eligible. Currently the TARN database contains information on over 69000 eligible major trauma patients admitted to hospitals in England and Wales over the period of the study (April 2014 – June 2015). Each patient's injuries are centrally coded and scored reproducibly by TARN co-ordination centre staff using the Abbreviated Injury Scale (AIS) Dictionary[8] – each injury attracts a threat to life severity code between 1(minimal) to 6(maximal /incompatible with life). Of these 15820 suffered a TBI (defined as an AIS 3 or greater injury to the head). Severe TBI was defined as an initial Glasgow Coma Score (GCS) of 8 or less in combination with an AIS 3 or greater traumatic brain injury, moderate and mild TBI were defined as GCS 9 – 13 and GCS 14 – 15 respectively. GCS is a composite score incorporating three categorical variables: best eye opening (E), verbal (V) and motor (M) scores and is, *de facto,* the most widely used stratification metric for TBI patients. Simple cross tabulations and percentages were used to describe the study demography, injury mechanisms and features of the care pathway (endotracheal intubation, imaging with CT scan, transfer to a neurosurgical centre, surgical interventions and in-hospital complications) by severity of TBI for the whole study sample. Bias was avoided by collecting data on all available patients.

The following analysis focuses on these 15820 patients. Some analyses use subsets of this cohort; patients admitted directly from the scene of injury and those admitted to a neurosurgical centre. As a result of relatively small numbers of patients treated exclusively at sites without neurosurgery, these are not included in the risk adjusted outcome analysis, this group is further filtered to only include patients whose outcome is recorded on the TARN database.

Outcome, measured as mortality is considered by using a derivation of the Ps14 multivariate logistic regression model[9] ($Ps14^n$). The $Ps14^n$ model calculates a probability of survival for each patient based on their age, gender, initial GCS, injury severity score (ISS) and any pre-existing medical conditions. The $Ps14^n$ model adds pupillary reactivity due to its prognostic importance in head injury[6 10]. The $Ps14^n$ model was generated using 33715 cases admitted between 2010 and 2013 (inclusive) following head injury. Missing GCS and pupil reactivity values were imputed and patients with missing pre-existing medical condition data were categorised as such. The model was internally validated using bootstrap simulation. Details of the model, including coefficients and calibration information can be found in the supplementary information.

In order to compare mortality across different centres the predicted survival rate at 30 days or discharge (whichever is earliest), derived from the probability of survival values assigned to patients admitted to a given institution is subtracted from the observed survival rate at 30 days or discharge to generate a 'W' score. This is then risk standardised (Ws) to allow direct comparison between units by compensating for variations in admission patterns[11]. A positive Ws score therefore indicates a better than expected rate of survival.

Results

Figure 1 provides a summary flow chart of the numbers of patients in each cohort of the study audit, namely: those admitted directly to a neurosurgical centre (n=6358), those with a secondary admission (via a district general hospital, n=3682) to a neurosurgical centre and those not admitted to a neurosurgical centre (n=5880).

Demographics and Mechanism of Injury

For all TBI severities there is a unimodal age distribution with a peak in those aged between 80 and 90 and this cohort represents more than 1 in 5 of those recorded as suffering from a TBI (Figure 2). For those with severe TBI there is a smaller peak between age 20 and 30 representing just over 15% of cases (Figure 3). Younger patients are more likely to be injured as a result of road traffic collisions and assaults while with increasing age there is a concurrent increase in the proportion of patients injured following falls under 2m.

Of those patients with a documented admission GCS (n=15080), the cohort is dominated by mild TBI (68%), with 26% with a severe TBI and only 6% with moderate TBI (Table 1).

Transfer to Hospital and Airway Management

Table 1 summarises data on hospital transfers and airway management stratified by severity of injury of TBI. The most common mode of transport to hospital is ambulance (74% overall). 7% of patients are recorded as being transported by helicopter, although, in patients with severe TBI this increases to 19%. Direct admission to a neurosurgical centre from the scene of injury occurred in approximately 40% of patients overall and over 60% of patients with severe TBI. This proportion was lower for moderate and mild TBI patients (41% and 33%) but significant proportions were subsequently transferred (20%, 22% respectively).

Table 1. Hospital Transfer, Airway Management and Length of Stay

Category	Group	Severe TBI n (%)	Moderate TBI n (%)	Mild TBI n (%)	GCS Not recorded n (%)	*Total n (%)*
Total number of patients		3915	899	10266	742	15822
Mode of arrival (direct admissions, n = 13824)	Ambulance	2504 (71.6%)	662 (83.8%)	6951 (76.6%)	51 (11.1%)	10168 (73.5%)
	Car	3 (0.1%)	1 (0.1%)	65 (0.7%)	7 (1.5%)	76 (0.5%)
	Helicopter	660 (18.9%)	27 (3.4%)	309 (3.4%)	0 (0%)	996 (7.2%)
	Other	1 (0%)	1 (0.1%)	38 (0.4%)	1 (0.2%)	41 (0.3%)
	Unknown	329 (9.4%)	99 (12.5%)	1714 (18.9%)	402 (87.2%)	2544 (18.4%)
Transfer status (all patients), n = 15820	Direct admission to neurocentre	2353 (60.1%)	365 (40.6%)	3374 (32.9%)	167 (22.5%)	6259 (39.6%)
	Transfer into neurocentre	945 (24.1%)	181 (20.1%)	2298 (22.4%)	259 (34.9%)	3683 (23.3%)
	No neurocentre visit	617 (15.8%)	353 (39.3%)	4594 (44.7%)	316 (42.6%)	5880 (37.2%)
Hours to arrival at neurocentre (n = 9940)	0 - 4	2225 (67.5%)	303 (55.5%)	2621 (46.2%)	46 (10.8%)	5195 (52.3%)
	4 - 12	438 (13.3%)	64 (11.7%)	733 (12.9%)	19 (4.5%)	1254 (12.6%)
	12 - 24	57 (1.7%)	21 (3.8%)	252 (4.4%)	8 (1.9%)	338 (3.4%)
	24 - 48	32 (1%)	9 (1.6%)	147 (2.6%)	6 (1.4%)	194 (2%)
	48 - 72	3 (0.1%)	1 (0.2%)	73 (1.3%)	1 (0.2%)	78 (0.8%)
	72+	23 (0.7%)	13 (2.4%)	249 (4.4%)	16 (3.8%)	301 (3%)
	Unknown	520 (15.8%)	135 (24.7%)	1597 (28.2%)	330 (77.5%)	2582 (26%)
Median length of stay (days) (IQR) n = 15820		12 (3 - 33)	11 (5 - 24)	9 (5 - 18)	10 (5 - 21)	9 (4 - 21)

Intubation location (direct admissions, n = 13824)	Pre-hospital	765 (21.9%)	0 (0%)	0 (0%)	0 (0%)	765 (5.5%)
	ED	2236 (63.9%)	0 (0%)	0 (0%)	0 (0%)	2236 (16.2%)
	Critical Care	142 (4.1%)	71 (9%)	257 (2.8%)	21 (4.6%)	491 (3.6%)
	Ward	0 (0%)	0 (0%)	4 (0%)	2 (0.4%)	6 (0%)
	Not intubated	354 (10.1%)	719 (91%)	8815 (97.1%)	438 (95%)	10326 (74.7%)

Over 80% of severe TBI patients were admitted to a neurosurgical centre within 12 hours of injury with 68% within 4 hours. 86% of patients presenting with a severe TBI had definitive airway management (defined as endotracheal intubation, tracheostomy or cricothyroidotomy) pre-hospital or in the emergency department. Definitive airway management was rarely required for patients with less severe injuries.

Time to Intervention

Table 2 summarises the data on the time intervals from injury and admission to investigation and intervention. In those patients admitted directly from the scene of injury with a GCS ≤ 8, a median of 0.5 hours was taken to image with CT scan. Median time from arrival to imaging was 0.9 hours for moderate TBI and 1.7 hours for mild injuries. The median time taken from admission to craniotomy was 2.6 hours for severe TBI and 8.6 hours for moderate TBI. If the time to craniotomy, in severe TBI, is calculated from the time of the incident this increases to 4 hours for direct transfers to a neurosurgical centre and 7.3 hours for those who required a secondary transfer. Median time to ICP monitoring following admission to a neurosurgical centre was 3.1 hours following severe TBI. Smaller numbers of mild or moderate TBI patients required craniotomy (3.1% and 2.7% respectively) or ICP monitoring (0.7% and 2.1% respectively) and in general this was performed within 24 hours of arriving in hospital.

Table 2. Median time to CT scanning, Craniotomy and ICP monitoring from hospital arrival / incident†.

† Hospital arrival time is recorded in almost 100% of cases; incident time is recorded in approximately 75% of cases. Intervals measured from incident time include patients that are transferred between hospitals;

those measured from arrival time only include patients admitted directly from the scene of injury.

* n values relate to the number of observations in each cohort. For example 3307 patients with a severe TBI underwent CT scanning and have their arrival and CT scan dates and times recorded.

TBI severity	Measured from	Category	n	Median hours	IQR lower bound	IQR upper bound
Severe TBI	Arrival time	CT	3307	0.5	0.3	0.8
		Craniotomy	457	2.6	1.6	10.1
		ICP monitoring	411	3.1	1.8	7.4
	Incident time	CT	3565	2.0	1.5	3.2
		Craniotomy (direct)	423	4.0	2.9	17.2
		Craniotomy (transfer)	262	7.3	5.3	19.0
		ICP monitoring	571	5.8	3.5	11.3
Moderate TBI	Arrival time	CT	766	0.9	0.5	1.9
		Craniotomy	45	8.6	2.8	47.9
		ICP monitoring	16	8.4	2.7	47.9
	Incident time	CT	751	2.5	1.8	5.5
		Craniotomy (direct)	42	15.8	5.3	65.8
		Craniotomy (transfer)	24	38.3	9.7	226.0
		ICP monitoring	19	8.6	6.1	48.8
Mild TBI	Arrival time	CT	8740	1.7	0.7	3.3
		Craniotomy	218	19.2	6.6	97.3
		ICP monitoring	41	11.6	5.8	28.6
	Incident time	CT	8173	3.7	2.3	8.6
		Craniotomy (direct)	170	21.4	7.4	119.2
		Craniotomy (transfer)	320	53.2	16.3	240.6
		ICP monitoring	69	18.3	8.4	38.0
GCS not recorded	Arrival time	CT	367	3.5	1.4	16.5
		Craniotomy	14	15.4	8.5	36.8
		ICP monitoring	2	10.1	0.0	0.0
	Incident time	CT	202	8.5	2.4	36.6
		Craniotomy (direct)	4	189.1	0.0	0.0
		Craniotomy (transfer)	19	40.0	12.4	560.3
		ICP monitoring	7	11.3	10.0	11.7

Complications in Hospital

Table 3 summarises the documented complications following TBI. Overall, over 19% of patients are recorded as suffering a complication, and in the severe TBI cohort this incidence increases to almost 30%.

There is a wide range of complications; the most frequent in the severe TBI cohort were bronchopneumonia (4.9%), in-hospital seizure (2.9%), sepsis (3.1%) and pleural effusion (2%). These were also the most common complications in the cohort as a whole.

Table 3. Inpatient Complications Stratified by Severity of Injury

Complication	Severe TBI	Moderate TBI	Mild TBI	GCS not recorded	Total
Aspiration	63 (1.5%)	8 (0.9%)	48 (0.5%)	5 (0.6%)	124 (0.8%)
Bronchopneumonia	203 (4.9%)	32 (3.4%)	209 (2%)	17 (2.2%)	461 (2.8%)
Pleural Effusion	84 (2%)	9 (1%)	68 (0.7%)	12 (1.6%)	173 (1.1%)
Seizure In Hospital	119 (2.9%)	22 (2.4%)	141 (1.4%)	15 (1.9%)	297 (1.8%)
Sepsis	129 (3.1%)	9 (1%)	107 (1%)	13 (1.7%)	258 (1.6%)
Other	624 (15%)	106 (11.4%)	836 (8%)	88 (11.4%)	1654 (10.1%)
Not complications recorded	**2944 (70.7%)**	**744 (80%)**	**9027 (86.5%)**	**623 (80.6%)**	**13338 (81.8%)**

Risk adjusted Outcomes at Neurosurgical Units

Figure 4 shows a funnel plot[12] of the risk adjusted W scores derived using the Ps14^n model (Ws^n) for each unit on the y-axis against a precision (1 / standard error) based rank on the x-axis. A positive Ws^n indicates that a site is performing better than the model predicts, a negative value indicates worse performance. The 'funnel' refers to the 2 and 3 standard deviation (SD) lines, plotted around the mean Ws that narrow as the precision increases. All units are within the 3 SD lines and most units fall within the 2 SD lines; 4 units are outside the -2 SD line and 2 units are above the +2 line. The Ws^n value for a given site, relative to the position of the SD lines indicates if their performance significantly differs from that of their peers.

Discussion

This audit incorporates prospectively collected data on a large number of patients, including from every neurosurgical unit in England and Wales, and provides the most comprehensive and up to date report of outcomes following TBI in England and Wales.

Demographics and Mechanism of Injury

The cohort of patients in the TARN database mimics data from other large TBI databases and the demographics and mechanism of injury closely mirror those from other series of TBI patients in the developed world [13-15]. The most common injuries are those in elderly people following trips and falls while in younger patients the most common causes are road traffic collisions and assault and these are more likely to present as severe TBI. We have provided a breakdown of delay to transfer to neurosurgical centre and complication rates by 10 year age bracket in the supplementary information. This demonstrates that despite comparable transfer times between adult groups, there are a smaller number of children aged 0-10 years transferred within 4 hours (32%) as compared to adult age brackets (range 45-61%). This does not lead to an increased frequency of complications and we speculate that this is due to specialised transfer team involvement for young children (Children's Acute Transfer Service, CATS). Interestingly, only 6% of TBI patients fall into the moderate (GCS 9-13) category calling into question whether the current GCS thresholds for severity accurately reflect the underlying condition: intuitively, one might expect that more severe injuries are increasingly rare. Other epidemiological studies in high-income countries reinforce this pattern of falls as a common aetiology in elderly patients[15].

Transfer to hospital

While the majority of patients are transported to hospital by land ambulance, there is an increasing use of helicopter ambulance for those patients with severe TBI. These patients are increasingly being transported directly to Major Trauma Centres (MTCs) as part of the NHS plan to centralise the management of complex trauma. The choice of mode of transport to hospital and choice of local hospital versus a neurosurgical or MTC is a complex one. Factors such as the physiological stability of a patient on scene and the geography of local emergency services dictates individualisation of decision making and it is difficult to mandate transport of a group of patients to a given location. A recent publication from the TARN registry[16] found no association between the duration of the pre-hospital interval and deteriorating physiological parameters. There are also challenges with the reliable identification of TBI in the prehospital environment and current strategies suffer from significant under and over triage rates making secondary transfer into neurosurgery a necessary pathway for some TBI patients[17]. However, in patients with severe TBI, who are likely to survive and require treatment, we would expect transfer to a neurosurgical centre once physiological stability has been achieved[18]. This is supported by NICE guidance – in our series 84% of severe TBI patients received neuroscience care, suggesting reasonable adherence. For mild and moderate TBI, an

individual decision is required as to the need and rapidity of transfer to a neurosurgical centre. In a resource-limited environment however, an efficient use of specialist beds necessitates some degree of triage at local centres before transfer to a specialist centre.

Time to Intervention

The median and upper quartile time to CT is within the one hour from ED arrival target defined by the NICE head injury guidelines[18] for patients at high risk of TBI requiring neurosurgery (GCS<13 = moderate/severe TBI), NICE recommends CT brain scan for GCS 15 patients with additional risk factors but not high risk, within 8 hours of injury. Mild TBI patients with GCS 13-14 on arrival at hospital should have CT within an hour if the GCS does not reach 15 within 2 hours of injury. Sequential ED GCS readings are not well recorded on TARN but Table 2 suggests that this NICE recommendation also has reasonable adherence. The Brain Trauma Foundation surgical guidelines[19] recommend that acute intracranial haemorrhages are treated as quickly as possible in those patients presenting in coma. The evidence for rapid treatment by craniotomy is strongest in those presenting with a fixed, dilated pupil[20]. In this regard, our data show direct transfer to a neurosurgical centre facilitates more rapid surgery and as such we support current ambulance service trauma triage guidelines that direct primary transportation from scene to a neurosurgical centre for patients with a unilateral fixed, dilated pupil in the context of severe TBI and a patent airway[17]. Consideration should also be given to establishing guidelines for direct transfer of other TBI patients from the scene to Neurosurgical Units, notwithstanding the difficulty in accurate identification of patients in the pre-hospital setting, and refining referral mechanisms from district hospitals / trauma units to major trauma centres with neurosurgical capability. Any guidelines must reflect the low requirement for craniotomy and ICP monitoring in mild (3.1% and 0.7%) and moderate (2.7% and 2.1%) TBI, such that in the majority of these patients expedited transfer to a neurosurgical centre may be unnecessary.

Complications and Risk adjusted outcomes at Neurosurgical Units

Patients with TBI are susceptible to a wide range of complications as evidenced by the reported complications. Respiratory complications predominate as would be expected in critically ill patients with a reduced conscious state or those in an intensive care environment. The analysis shows that 5 units lie outside of the 2 standard deviation (SD) control limits, however they and all other units are within the 3 SD

limits. A single centre is close to the positive 3 SD limit, but this is one of the units with lower precision where we expect to see larger variation from the mean. As such these data suggest that there are no outlying units in terms of risk adjusted mortality in neurosurgical care for patients suffering TBI in England & Wales. Further studies are required to address the quality of survival in terms of outcome beyond mortality. On the basis of the funnel plot, it appears that there is a slight excess of units falling below the expected standardised mortality ratio (worse than expected outcome). This is most likely due to the expected (average) value being skewed upwards by the two centres with low precision and very high Ws^n scores. In addition, a significant proportion of the centres below the expected value are those with lower precision, the higher precision units on the right side of the plot are more evenly balanced.

Study Limitations

Although this audit is comprehensive, there are certain limitations to using aggregate data of this type. Firstly, as with many studies that utilise GCS, we have used a composite score rather than the individual components, despite each component of the GCS being on a categorical scale. This is partly addressed by the validation of this approach by the IMPACT model[21 22]. Secondly, there is some variability in the reporting of GCS, such that 'first' GCS is sometimes used interchangeably with 'post-resuscitation' GCS[22]. Thirdly, we have not addressed the decision making with regards to transfer of patients from peripheral to neurosurgical centres, and the possibility of regional variation. This could potentially have an effect on TBI survival rates in specialist centres if there is a variation in transfer criteria, particularly for older patients who may have poorer prognosis[23]. Lastly there is some variability in patient recruitment into the TARN database, over the time period of the study neuroscience centres recruited almost 100% of relevant patients, outside of these hospitals however the average is roughly 65%. Nevertheless, we hope by compiling data on more than 15,000 patients, we are able to provide robust data on TBI management in England and Wales.

Conclusion

This report provides the first England and Wales audit of its type with a large number of patients that is commensurate with the largest cohorts of patients currently published in TBI, namely the CRASH and IMPACT studies. This provides a robust baseline for further comparisons of outcomes in a transparent and reproducible fashion. The data we present confirms that England and Wales trauma management broadly

meets the NICE guidelines and achieves a consistent standard across all regions and neurosurgical units. The NICE guidelines are broad and rightly err on the side of caution in the necessity for CT imaging and discussion with specialist centres[18]. Specifically, they are for the management of Head Injury, rather than Traumatic Brain Injury, and the recommendations address CT imaging and appropriate transfer to neurosurgical centres, rather than ICP monitoring and the need for craniotomy, although this is a possibility in the future. The need for these guidelines to be used in a range of ED settings necessitates this approach, although data presented here highlights that neurosurgical intervention is rarely required for those presenting with mild or moderate TBI. The increasing need for public engagement with regards to surgical outcomes, and the related political imperative to provide this within the NHS will become the *status quo*.

Article Summary

-Traumatic Brain Injury causes high morbidity and mortality with both financial and social implications

-National guidelines have improved consistency of care of trauma patients

-The current practice in England and Wales is consistent with current NICE guidelines

-All neurosurgical units in England and Wales are within 3 standard deviations of standardised mortality following traumatic brain injury

-Craniotomy and ICP monitoring is rarely required in patients with mild (GCS14-15) and moderate (GCS9-13) TBI.

Footnotes

The sponsor has had no role in the design or conduct of this study.

Contributors: FL and PJH conceived of the study and have provided detailed review of the results. AH and TL have written the manuscript. TL, OB and MW have carried out the statistical analysis.

Funding: AH is supported by the University of Cambridge, UK and Medical Research Council/ Royal College of Surgeons of England Clinical Research Training Fellowship (Grant no. G0802251). P.J.H.is supported by National Institute for Health Research Professorship, Academy of Medical Sciences/Health Foundation Senior Surgical Scientist Fellowship and the National Institute for Health Research Biomedical Research Centre, Cambridge.

Competing interests: All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: financial support as described above; no other financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Data sharing: no additional data available.

Transparency declaration: The lead authors (FL, PJH) affirm that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained

References

1. Head Injury: Triage, Assessment, Investigation and Early Management of Head Injury in Children, Young People and Adults. National Institute for Health and Care Excellence (UK) 2014.
2. Advanced Trauma Life Support (ATLS): the Ninth Edition. American College of Surgeons 2012.
3. Patel HC, Menon DK, Tebbs S, et al. Specialist neurocritical care and outcome from head injury. Intensive care medicine 2002;**28**(5):547-53.
4. Stein SC, Georgoff P, Meghan S, et al. Relationship of aggressive monitoring and treatment to improved outcomes in severe traumatic brain injury. J Neurosurg 2010;**112**(5):1105-12.
5. Collaborators MCT, Perel P, Arango M, et al. Predicting outcome after traumatic brain injury: practical prognostic models based on large cohort of international patients. BMJ 2008;**336**(7641):425-9.
6. Murray GD, Butcher I, McHugh GS, et al. Multivariable prognostic analysis in traumatic brain injury: results from the IMPACT study. Journal of neurotrauma 2007;**24**(2):329-37.
7. Neurosurgical National Audit Programme 2014 [Available from: http://www.hed.nhs.uk/SBNS/.
8. Abbreviated Injury Scale (AIS) 2014 [Available from: http://www.aaam.org/about-ais.html.
9. Bouamra O, Jacques R, Edwards A, et al. Prediction modelling for trauma using comorbidity and 'true'30-day outcome. Emergency Medicine Journal 2015:emermed-2015-205176.
10. Marmarou A, Lu J, Butcher I, et al. Prognostic value of the Glasgow Coma Scale and pupil reactivity in traumatic brain injury assessed pre-hospital and on enrollment: an IMPACT analysis. Journal of neurotrauma 2007;**24**(2):270-80.
11. Hollis S, Yates D, Woodford M, et al. Standardized comparison of performance indicators in trauma: a new approach to case-mix variation. Journal of Trauma and Acute Care Surgery 1995;**38**(5):763-66.
12. Spiegelhalter DJ. Funnel plots for comparing institutional performance. Stat Med 2005;**24**(8):1185-202.
13. Peeters W, van den Brande R, Polinder S, et al. Epidemiology of traumatic brain injury in Europe. Acta neurochirurgica 2015;**157**(10):1683-96.
14. Maas AI, Murray GD, Roozenbeek B, et al. Advancing care for traumatic brain injury: findings from the IMPACT studies and perspectives on future research. The Lancet Neurology 2013;**12**(12):1200-10.
15. Walder B, Haller G, Rebetez MM, et al. Severe traumatic brain injury in a high-income country: an epidemiological study. J Neurotrauma 2013;**30**(23):1934-42.
16. Fuller G, Lawrence T, Woodford M, et al. Emergency medical services interval and mortality in significant head injury: a retrospective cohort study. European Journal of Emergency Medicine 2015;**22**(1):42-48.
17. Lecky F, Russell W, Fuller G, et al. The Head Injury Transportation Straight to Neurosurgery (HITS-NS) randomised trial: a feasibility study. Health Technol Assess 2016;**20**(1).
18. NICE. Triage, assessment, investigation and early management of head injury in children, young people and adults 2014 [Available from: http://www.nice.org.uk/guidance/cg176/evidence.
19. Guidelines for the management of severe traumatic brain injury 2007 [Available from: https://www.braintrauma.org/.
20. Clusmann H, Schaller C, Schramm J. Fixed and dilated pupils after trauma, stroke, and previous intracranial surgery: management and outcome. J Neurol Neurosurg Psychiatry 2001;**71**(2):175-81.
21. Marmarou A, Lu J, Butcher I, et al. Prognostic value of the Glasgow Coma Scale and pupil reactivity in traumatic brain injury assessed pre-hospital and on enrollment: an IMPACT analysis. J Neurotrauma 2007;**24**(2):270-80.
22. Reith FC, Van den Brande R, Synnot A, et al. The reliability of the Glasgow Coma Scale: a systematic review. Intensive Care Med 2016;**42**(1):3-15.
23. Kirkman MA, Jenks T, Bouamra O, et al. Increased mortality associated with cerebral contusions following trauma in the elderly: bad patients or bad management? J Neurotrauma 2013;**30**(16):1385-90.

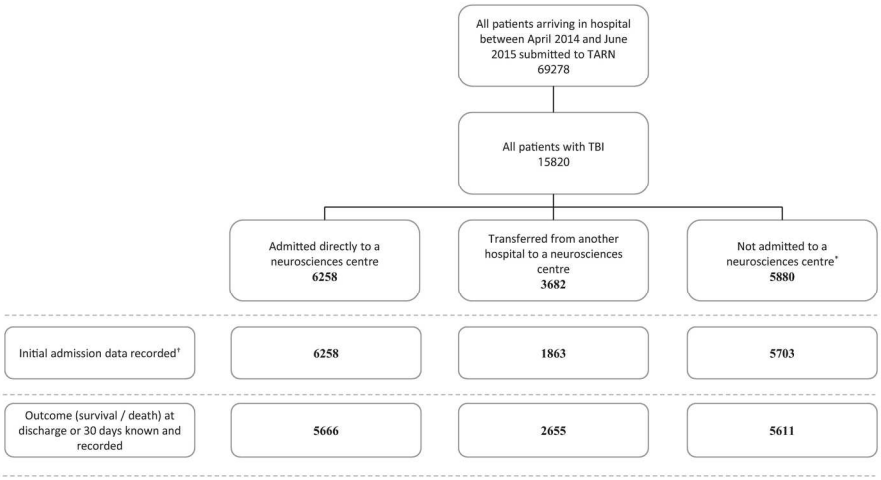
Figure Legends

Figure 1. Flow chart delineating the derivation of the TBI cohort studied.

Figure 2. Proportion of all TBI patients by age and mechanism of injury.

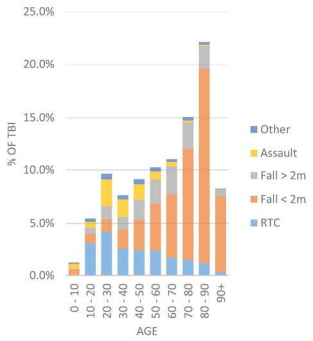
Figure 3. Proportion of patients with severe TBI (TBI in combination with GCS ≤ 8) by age and mechanism of injury.

Figure 4. Funnel plot showing the Wsn for neurosurgical units in England & Wales between April 2014 and June 2015.



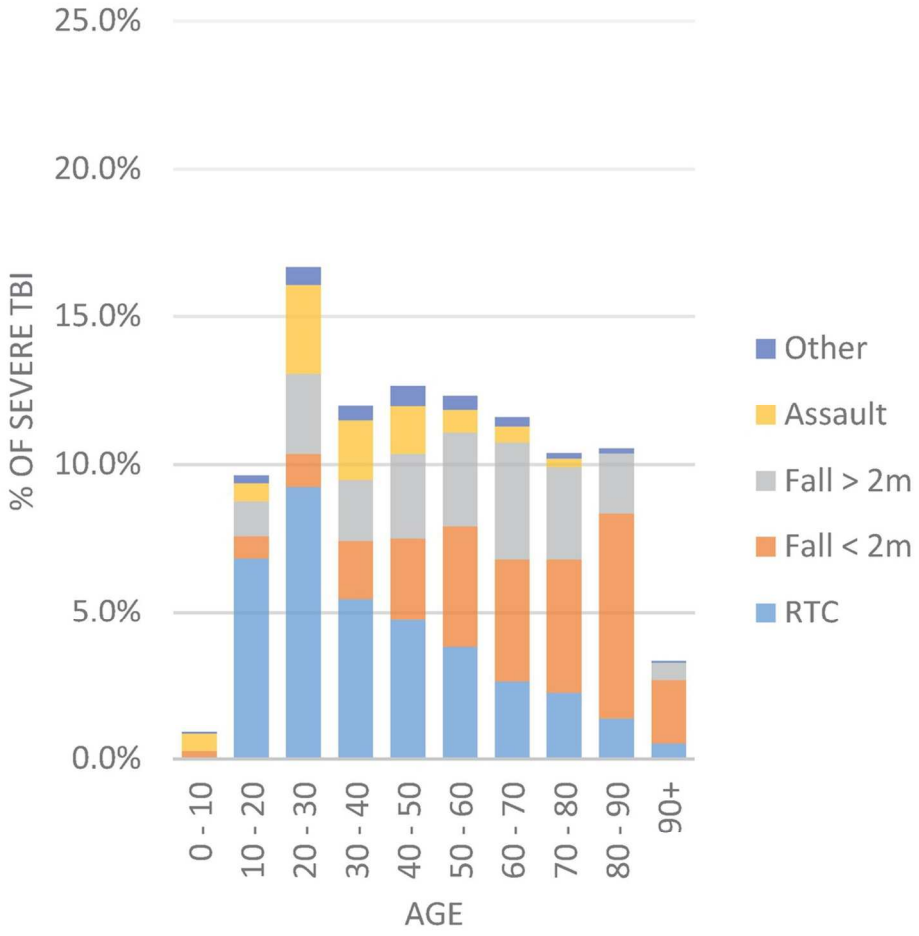
* Patients initially admitted to and treated entirely at hospitals without neuroscience care
† Data from the scene of injury and initial hospital admitted to is recorded on TARN

190x142mm (300 x 300 DPI)



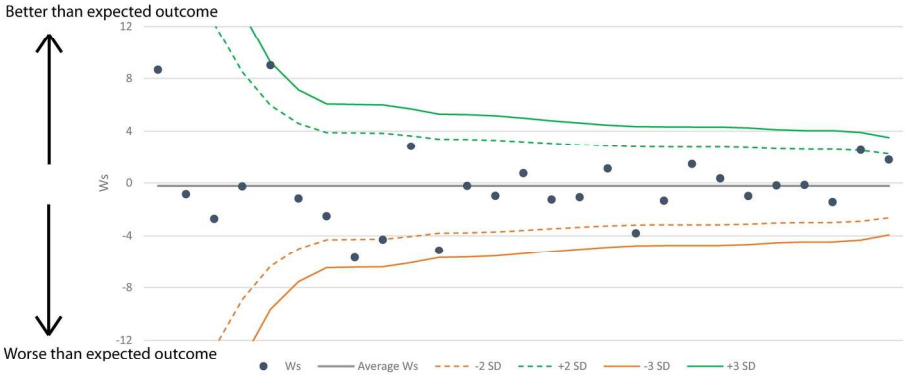
Figures 2. Proportion of patients with TBI by age and mechanism of injury.

190x142mm (300 x 300 DPI)



Figures 3. Proportion of patients with severe TBI (TBI in combination with GCS < 9) by age and mechanism of injury.

106x124mm (300 x 300 DPI)



190x142mm (300 x 300 DPI)

Appendix

The Ps14^{n} model is a modification of the Ps14 model as described by Bouamra in 2015 with the addition of pupil reactivity. It has been derived from 39451 patients recorded in the TARN database with head injuries of AIS 3 or greater severity admitted to hospital between 2012 and 2015. Table 1 describes the characteristics of these patients and table 2 contains the regression coefficients of which the prediction model is formed.

The model is shown to have good discriminant power (AuROC 0.882, 95% CI 0.878 to 0.887). The calibration of the model was assessed using the Brier score, this shows how close predictions are to the actual outcome. Its value varies between 0 (perfect) and 0.25 (useless), the model shows a value of 0.086. The value for the HL-statistic (Hosper & Lemeshow chi^{2}(8)) is 19.51, P-value 0.0124 (as the p-value is <0.05 the model failed the goodness-of-fit test but this is expected with the HL-test as it is too sensitive to large sample sizes). Figure 1 shows a graphical assessment of calibration using 200 bootstrap simulations and shows an almost perfect calibration: the observed and expected are aligned to the 45^{o} line.

Table 1. Characteristics of the patients

n	39451
Age	
Median (IQR)	62.6 (35.8 - 81.4)
ISS	
Median (IQR)	24 (16 - 26)
GCS	
Median (IQR)	14 (11 - 15)
Gender	
Female	13927 (35.3%)
Male	25524 (64.7%)
Comorbidity	
No comorbidity	19776 (50.1%)
1 - 5	10617 (26.9%)
6 - 10	3417 (8.7%)
> 10	1585 (4.0%)
Not recorded	4056 (10.3%)
Mortality	16.0%

Table 2. Coefficients of the model

Variables	Regression Coefficients	p-value	Odds ratio 95% CI	
$(10/ISS)^2$ - 0.1920	3.3294	<0.0001	22.9	33.8
$(10/ISS)^2$*$\log_e$(ISS/10)-0.1584	8.2092	<0.0001	1719.9	7785.4
GCS				
GCS =3	-3.0652	<0.0001	0.04	0.05
GCS 4 -5	-2.6485	<0.0001	0.06	0.08
GCS 6 -8	-1.8352	<0.0001	0.14	0.18
GCS 9 -12	-1.3348	<0.0001	0.23	0.30
GCS 13 - 14	-0.4704	<0.0001	0.57	0.69
GCS 15 (reference)	0.0000		1	1
Intubated	-2.5212	<0.0001	0.06	0.11
Charlson Index				
0 (reference)	0.0000		1	1
1 - 5	-0.4593	<0.0001	0.58	0.69
6 - 10	-0.7754	<0.0001	0.41	0.52
>10	-1.1841	<0.0001	0.26	0.36
Not recorded	-0.6575	<0.0001	0.46	0.58
Age				
0 - 5	-0.0236	0.92	0.63	1.51
6 - 10	0.5668	0.07	0.95	3.25
11 - 15	0.0356	0.87	0.67	1.60
16 - 44 (reference)	0.0000		1	1
45 - 54	-0.5065	<0.0001	0.51	0.72
55 - 64	-1.0091	<0.0001	0.31	0.44
65 - 75	-1.6125	<0.0001	0.17	0.23
>75	-2.7684	<0.0001	0.05	0.07
Gender				
Male (reference)	0.0000		1	1
Female	-0.0216	0.84	0.79	1.21
Age by gender interaction				
0 - 5 & Female	-0.1968	0.55	0.43	1.58
6 - 10 & Female	-0.3357	0.55	0.24	2.14
11 - 15 & Female	0.8354	0.11	0.83	6.49
45 - 54 & Female	-0.2911	0.11	0.52	1.07
55 - 64 & Female	0.2989	0.09	0.95	1.92
65 - 75 & Female	-0.0281	0.85	0.73	1.30
>75 & Female	0.1084	0.36	0.89	1.40
Pupil reactivity				
Both reactive (reference)	0.0000		1	1
Abnormal (both reactive)	-0.4383	<0.0001	0.57	0.73
Abnormal (1 reactive)	-0.5325	<0.0001	0.50	0.69
Neither reactive	-2.0874	<0.0001	0.11	0.14
Constant	4.9208	<0.0001	119.10	157.59

Figure 1: Model Calibration

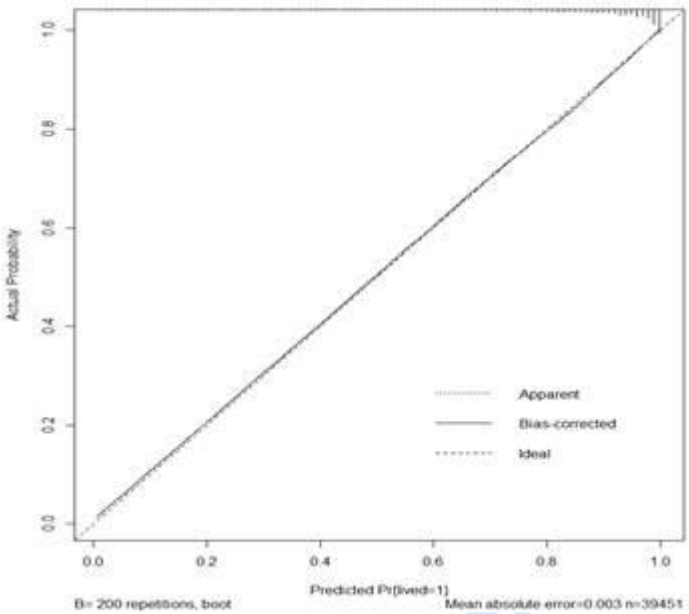


Table 3: Hours to arrival at neurosurgical centre stratified by age

Hours to arrival at neurocentre	Age									
	0 - 10	10 - 20	20 - 30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90	90+
0 - 4	50 (31.8%)	434 (60.5%)	748 (60.1%)	543 (55.9%)	550 (49.5%)	603 (50.2%)	591 (49.5%)	604 (44.7%)	799 (51.4%)	293 (58.8%)
4 - 12	6 (3.8%)	8 (1.1%)	25 (2%)	6 (0.6%)	28 (2.5%)	31 (2.6%)	27 (2.3%)	19 (1.4%)	39 (2.5%)	8 (1.6%)
12 - 24	31 (19.7%)	112 (15.6%)	162 (13%)	132 (13.6%)	159 (14.3%)	190 (15.8%)	165 (13.8%)	155 (11.5%)	125 (8%)	47 (9.4%)
24 - 48	11 (7%)	19 (2.6%)	35 (2.8%)	35 (3.6%)	41 (3.7%)	56 (4.7%)	46 (3.8%)	51 (3.8%)	43 (2.8%)	9 (1.8%)
48 - 72	1 (0.6%)	7 (1%)	8 (0.6%)	8 (0.8%)	10 (0.9%)	11 (0.9%)	9 (0.8%)	9 (0.7%)	14 (0.9%)	2 (0.4%)
72+	6 (3.8%)	6 (0.8%)	13 (1%)	10 (1%)	28 (2.5%)	28 (2.3%)	34 (2.8%)	53 (3.9%)	94 (6.1%)	27 (5.4%)
Unknown	52 (33.1%)	131 (18.3%)	254 (20.4%)	237 (24.4%)	294 (26.5%)	283 (23.5%)	323 (27%)	459 (34%)	439 (28.3%)	112 (22.5%)

Table 4: Rate of complications by age and transfer status

Age	n	Complications	% with complications
0-10	211	35	16.6%
10-20	863	100	11.6%
20-30	1523	184	12.1%
30-40	1206	189	15.7%
40-50	1443	197	13.7%
50-60	1620	271	16.7%
60-70	1760	277	15.7%
70-80	2380	395	16.6%
80-90	3508	613	17.5%
90+	1305	221	16.9%
Total	**15819**	**2482**	**15.7%**

Age	n	Complications	% with complications
No transfer	10893	1611	14.8%
Transfer	4926	871	17.7%
Total	**15819**	**2482**	**15.7%**

Table 5: Mortality stratified by GCS and Head AIS

TBI severity	n	Mortality			Predicted mortality %
		n	%	95% CI	
Mild TBI	9285	730	7.9%	7.3% - 8.4%	8.6%
Moderate TBI	790	178	22.5%	19.6% - 25.4%	23.6%
Severe TBI	3228	1304	40.4%	38.7% - 42.1%	36.1%
GCS not recorded	629	98	15.6%	12.7% - 18.4%	12.4%
Total	**13932**	**2310**	**16.6%**	**16% - 17.2%**	**16.0%**

AIS TBI severity	n	Mortality			Predicted mortality %
		n	%	95% CI	
3	2480	155	6.3%	5.3% - 7.2%	5.9%
4	5828	475	8.2%	7.4% - 8.9%	9.6%
5	5614	1671	29.8%	28.6% - 31%	26.9%
6	10	9	90.0%	71.4% - 100%	68.0%
Total	**13932**	**2310**	**16.6%**	**16% - 17.2%**	**16.0%**

Outcome	n	Outcome at discharge	Outcome at 30 days
Alive	11622	9642	1980
Dead	2310	2310	0
Total	**13932**	**11952**	**1980**

BMJ Open

Traumatic Brain Injury in England and Wales: prospective audit of epidemiology, complications and standardised mortality

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2016-012197.R2
Article Type:	Research
Date Submitted by the Author:	22-Jul-2016
Complete List of Authors:	Lawrence, Thomas; Trauma Audit & Research Network, Helmy, Adel; University of Cambridge, Division of Neurosurgery, Department of Clinical Neurosciences Bouamra, Omar; Trauma Audit & Research Network, Woodford, Maralynn; Trauma Audit and Research Network, Lecky, Fiona; University of Sheffield/ Salford Royal Hospitals NHS Trust, Emergency Medicine; Trauma Audit and Research Network, Institute of Population Health Hutchinson, Peter; University of Cambridge, Clinical Neurosciences
Primary Subject Heading:	Surgery
Secondary Subject Heading:	Emergency medicine, Health policy, Intensive care
Keywords:	Neurological injury < NEUROLOGY, NEUROSURGERY, ACCIDENT & EMERGENCY MEDICINE, TRAUMA MANAGEMENT, Organisation of health services < HEALTH SERVICES ADMINISTRATION & MANAGEMENT

Traumatic Brain Injury in England and Wales: prospective audit of epidemiology, complications and standardised mortality

Lawrence T*[1], Helmy A*[2,3], O Bouamra[1], Woodford M[1], Lecky F[4], Hutchinson PJ[2,3]

* Joint First Authors

1. Trauma Audit and Research Network, Manchester Medical Academic Health Sciences Centre, Institute of Population Health, University of Manchester, 3rd Floor, The Mayo Building, Salford Royal Hospital, Salford M6 8HD
2. Division of Neurosurgery, Department of Clinical Neuroscience, University of Cambridge, Box 167, Cambridge Biomedical Campus, Cambridge, CB2 0QQ
3. Department of Neurosurgery, Addenbrooke's Hospital, Cambridge, CB2 0QQ
4. Centre for Urgent and Emergency care Research (CURE), Health Services Research Section, School of Health and Related Research (ScHARR), University of Sheffield, Regents Court, 30 Regent Street, Sheffield, S1 4DA

Corresponding Author:

Mr Adel Helmy

University Lecturer in Neurosurgery

Division of Neurosurgery

Department of Clinical Neuroscience

University of Cambridge

Box 167

Cambridge Biomedical Campus

Cambridge

CB2 0QQ

Abstract

Objectives: To provide a comprehensive assessment of the management of Traumatic Brain Injury relating to epidemiology, complications and standardised mortality across specialist units.

Design: The Trauma Audit and Research Network collects data prospectively on patients suffering trauma across England and Wales. We analysed all data collected on Traumatic Brain Injury patients between April 2014 and June 2015.

Setting: Data was collected on patients presenting to emergency departments across 187 hospitals including 26 with specialist neurosurgical services, incorporating factors previously identified in the $Ps14^{n}$ multivariate TBI outcome prediction model. The frequency and timing of secondary transfer to neurosurgical centres was assessed.

Results: We identified 15820 patients with TBI presenting to neurosurgical centres directly (6258), transferred from a district hospital to a neurosurgical centre (3682) and remaining in a district general hospital (5880). The commonest mechanisms of injury were falls in the elderly and road traffic collisions in the young, which were more likely to present in coma. In severe TBI (GCS≤8), the median time from admission to imaging with CT scan is 0.5 hours. Median time to craniotomy from admission is 2.6 hours and median time to ICP monitoring is 3 hours. The most frequently documented complication of severe TBI is bronchopneumonia in 5% of patients. Risk adjusted W scores derived from the $Ps14^{n}$ model indicate that no neurosurgical unit fell outside the 3 standard deviation limits on a funnel plot.

Conclusions: We provide the first comprehensive report of the management of TBI in England and Wales, including data from all neurosurgical units. This data provides transparency and suggests equity of access to high quality TBI management provided in England and Wales.

Article Summary: Strengths and Limitations of the Study

-The use of registry data from all specialist units and a large number of hospitals allows a comprehensive assessment of the management of TBI in England and Wales.

-data from a large number of patients provides robust statistical analyses.

-data is limited by the pre-specified categories within the TARN dataset.

-key parameters such as GCS are collected at a single time point at admission that may not reflect the complexity of confounding factors such as resuscitation state.

Introduction

Traumatic Brain Injury (TBI) is a major cause of mortality and morbidity. In England and Wales approximately 1.4 million patients per year attend hospital following head injury and it is the most common cause of death under the age of 40 years[1]. Over the past 30 years advances in management including the introduction of Advanced Trauma Life Support[2], NICE guidelines[1], and protocol driven therapy have improved outcome[3] and reduced mortality[4]. More recently Regional Trauma Networks have been implemented in England and Wales. It is recognised, however, that major gains are still needed in terms of increasing our understanding of the pathophysiology of this heterogeneous condition and defining and optimising individual treatment strategies. The largest existing TBI datasets in the literature are from the CRASH[5] study, approximately 10,000 patients within a randomised control study of corticosteroids, and IMPACT[6], a collated dataset of approximately 9,800 patients from 8 randomised and 3 observational studies.

The UK national neurosurgical society, The Society of British Neurological Surgeons (SBNS), has established the Neurosurgical National Audit Programme (NNAP)[7], the first comprehensive national audit of both emergency and elective activity in an acute surgical specialty with a complex case-mix, as a mechanism for driving quality improvement and maintaining high standards of clinical governance. Hospital and Consultant Surgeon level data has been collected and the first year of data relating to elective activity was published on the 1st December 2014. The management of TBI differs from other aspects of neurosurgical care, in that it is heavily reliant on multi-disciplinary care, including Emergency Medicine, Neurointensive Care, Neurosurgery and Rehabilitation Medicine. In this way, surgeon specific data is less useful and the aggregate performance of a whole unit is more indicative of the quality of care that is delivered. For this reason, the SBNS and the Trauma Audit and Research Network (TARN) have collaborated in order to produce detailed data on the management of several aspects of TBI management across Engalnd and Wales in over 15000 patients.

The objective of this study was to undertake an audit of Traumatic Brain Injury in England and Wales during a 15 month epoch (April 2014 – June 2015) specifically to define the demography, mechanism of injury, arrival mode, to characterise transfers and direct admissions to Neurosurgical Units, length of stay, self-reported complications and outcome in terms of mortality. We specifically sought to ascertain compliance with NICE guidance and variation in mortality according to neurosurgical centre.

Materials and Methods

The information shown in this report is derived from the TARN registry, a prospective, observational registry of hospitalised major trauma patients in England & Wales. TARN has Health Research Authority (PIAGG Section 20) approval to conduct research on anonymised data. There was no patient involvement in the design or implementation of the study other than the oversight presented by the patient and public representatives on the TARN Board. Patients of all ages are eligible for entry to the TARN database if they suffer injuries leading to a hospital stay resulting in any of: 3 or more days in hospital, admission to intensive or high dependency care, inter-hospital transfer or death from injury. Patients aged over 65 years old with an isolated neck of femur fracture or those with isolated closed limb fractures are excluded. Those that died at the incident scene and were not transported to hospital are not eligible. Currently the TARN database contains information on over 69000 eligible major trauma patients admitted to hospitals in England and Wales over the period of the study (April 2014 – June 2015). Each patient's injuries are centrally coded and scored reproducibly by TARN co-ordination centre staff using the Abbreviated Injury Scale (AIS) Dictionary[8] – each injury attracts a threat to life severity code between 1(minimal) to 6(maximal /incompatible with life). Of these 15820 suffered a TBI (defined as an AIS 3 or greater injury to the head). Severe TBI was defined as an initial (i.e. at the time the patient was admitted and assessed in the emergency department) Glasgow Coma Score (GCS) of 8 or less in combination with an AIS 3 or greater traumatic brain injury, moderate and mild TBI were defined as GCS 9 – 13 and GCS 14 – 15 respectively. GCS is a composite score incorporating three categorical variables: best eye opening (E), verbal (V) and motor (M) scores and is, *de facto,* the most widely used stratification metric for TBI patients. Simple cross tabulations and percentages were used to describe the study demography, injury mechanisms and features of the care pathway (endotracheal intubation, imaging with CT scan, transfer to a neurosurgical centre, surgical interventions and in-hospital complications) by severity of TBI for the whole study sample. Bias was avoided by collecting data on all available patients.

The following analysis focuses on these 15820 patients. Some analyses use subsets of this cohort; patients admitted directly from the scene of injury and those admitted to a neurosurgical centre. As a result of relatively small numbers of patients treated exclusively at sites without neurosurgery, these are not included in the risk adjusted outcome analysis, this group is further filtered to only include patients whose outcome is recorded on the TARN database.

Outcome, measured as mortality is considered by using a derivation of the Ps14 multivariate logistic regression model[9] ($Ps14^n$). The $Ps14^n$ model calculates a probability of survival for each patient based on their age, gender, initial GCS, injury severity score (ISS) and any pre-existing medical conditions. The $Ps14^n$ model adds pupillary reactivity due to its prognostic importance in head injury[6 10]. The $Ps14^n$ model was generated using 33715 cases admitted between 2010 and 2013 (inclusive) following head injury. Missing GCS and pupil reactivity values were imputed and patients with missing pre-existing medical condition data were categorised as such. The model was internally validated using bootstrap simulation. Details of the model, including coefficients and calibration information can be found in the supplementary information.

In order to compare mortality across different centres the predicted survival rate at 30 days or discharge (whichever is earliest), derived from the probability of survival values assigned to patients admitted to a given institution is subtracted from the observed survival rate at 30 days or discharge to generate a 'W' score. This is then risk standardised (Ws) to allow direct comparison between units by compensating for variations in admission patterns[11]. A positive Ws score therefore indicates a better than expected rate of survival. The same outcome assessment for mortality, i.e. discharge or 30 day mortality, whichever is earliest, is used in the data within the supplementary data.

Results

Figure 1 provides a summary flow chart of the numbers of patients in each cohort of the study audit, namely: those admitted directly to a neurosurgical centre (n=6358), those with a secondary admission (via a district general hospital, n=3682) to a neurosurgical centre and those not admitted to a neurosurgical centre (n=5880).

Demographics and Mechanism of Injury

For all TBI severities there is a unimodal age distribution with a peak in those aged between 80 and 90 and this cohort represents more than 1 in 5 of those recorded as suffering from a TBI (Figure 2). For those with severe TBI there is a smaller peak between age 20 and 30 representing just over 15% of cases (Figure 3). Younger patients are more likely to be injured as a result of road traffic collisions and assaults while with

increasing age there is a concurrent increase in the proportion of patients injured following falls under 2m. Of those patients with a documented admission GCS (n=15080), the cohort is dominated by mild TBI (68%), with 26% with a severe TBI and only 6% with moderate TBI (Table 1).

Transfer to Hospital and Airway Management

Table 1 summarises data on hospital transfers and airway management stratified by severity of injury of TBI. The most common mode of transport to hospital is ambulance (74% overall). 7% of patients are recorded as being transported by helicopter, although, in patients with severe TBI this increases to 19%. Direct admission to a neurosurgical centre from the scene of injury occurred in approximately 40% of patients overall and over 60% of patients with severe TBI. This proportion was lower for moderate and mild TBI patients (41% and 33%) but significant proportions were subsequently transferred (20%, 22% respectively).

Table 1. Hospital Transfer, Airway Management and Length of Stay

Category	Group	Severe TBI n (%)	Moderate TBI n (%)	Mild TBI n (%)	GCS Not recorded n (%)	*Total n (%)*
Total number of patients		3915	899	10266	742	15822
Mode of arrival (direct admissions, n = 13824)	Ambulance	2504 (71.6%)	662 (83.8%)	6951 (76.6%)	51 (11.1%)	10168 (73.5%)
	Car	3 (0.1%)	1 (0.1%)	65 (0.7%)	7 (1.5%)	76 (0.5%)
	Helicopter	660 (18.9%)	27 (3.4%)	309 (3.4%)	0 (0%)	996 (7.2%)
	Other	1 (0%)	1 (0.1%)	38 (0.4%)	1 (0.2%)	41 (0.3%)
	Unknown	329 (9.4%)	99 (12.5%)	1714 (18.9%)	402 (87.2%)	2544 (18.4%)
Transfer status (all patients), n = 15820	Direct admission to neurocentre	2353 (60.1%)	365 (40.6%)	3374 (32.9%)	167 (22.5%)	6259 (39.6%)
	Transfer into neurocentre	945 (24.1%)	181 (20.1%)	2298 (22.4%)	259 (34.9%)	3683 (23.3%)
	No neurocentre visit	617 (15.8%)	353 (39.3%)	4594 (44.7%)	316 (42.6%)	5880 (37.2%)
Hours to arrival at neurocentre (n = 9940)	0 - 4	2225 (67.5%)	303 (55.5%)	2621 (46.2%)	46 (10.8%)	5195 (52.3%)
	4 - 12	438 (13.3%)	64 (11.7%)	733 (12.9%)	19 (4.5%)	1254 (12.6%)
	12 - 24	57 (1.7%)	21 (3.8%)	252 (4.4%)	8 (1.9%)	338 (3.4%)
	24 - 48	32 (1%)	9 (1.6%)	147 (2.6%)	6 (1.4%)	194 (2%)
	48 - 72	3 (0.1%)	1 (0.2%)	73 (1.3%)	1 (0.2%)	78 (0.8%)
	72+	23 (0.7%)	13 (2.4%)	249 (4.4%)	16 (3.8%)	301 (3%)
	Unknown	520 (15.8%)	135 (24.7%)	1597 (28.2%)	330 (77.5%)	2582 (26%)

Median length of stay (days) (IQR) n = 15820		12 (3 - 33)	11 (5 - 24)	9 (5 - 18)	10 (5 - 21)	9 (4 - 21)
Intubation location (direct admissions, n = 13824)	Pre-hospital	765 (21.9%)	0 (0%)	0 (0%)	0 (0%)	765 (5.5%)
	ED	2236 (63.9%)	0 (0%)	0 (0%)	0 (0%)	2236 (16.2%)
	Critical Care	142 (4.1%)	71 (9%)	257 (2.8%)	21 (4.6%)	491 (3.6%)
	Ward	0 (0%)	0 (0%)	4 (0%)	2 (0.4%)	6 (0%)
	Not intubated	354 (10.1%)	719 (91%)	8815 (97.1%)	438 (95%)	10326 (74.7%)

Over 80% of severe TBI patients were admitted to a neurosurgical centre within 12 hours of injury with 68% within 4 hours. 86% of patients presenting with a severe TBI had definitive airway management (defined as endotracheal intubation, tracheostomy or cricothyroidotomy) pre-hospital or in the emergency department. Definitive airway management was rarely required for patients with less severe injuries.

Time to Intervention

Table 2 summarises the data on the time intervals from injury and admission to investigation and intervention. In those patients admitted directly from the scene of injury with a GCS ≤ 8, a median of 0.5 hours was taken to image with CT scan. Median time from arrival to imaging was 0.9 hours for moderate TBI and 1.7 hours for mild injuries. The median time taken from admission to craniotomy was 2.6 hours for severe TBI and 8.6 hours for moderate TBI. If the time to craniotomy, in severe TBI, is calculated from the time of the incident this increases to 4 hours for direct transfers to a neurosurgical centre and 7.3 hours for those who required a secondary transfer. Median time to ICP monitoring following admission to a neurosurgical centre was 3.1 hours following severe TBI. Smaller numbers of mild or moderate TBI patients required craniotomy (3.1% and 2.7% respectively) or ICP monitoring (0.7% and 2.1% respectively) and in general this was performed within 24 hours of arriving in hospital.

Table 2. Median time to CT scanning, Craniotomy and ICP monitoring from hospital arrival / incident†.

† Hospital arrival time is recorded in almost 100% of cases; incident time is recorded in approximately 75% of cases. Intervals measured from incident time include patients that are transferred between hospitals; those measured from arrival time only include patients admitted directly from the scene of injury.

* n values relate to the number of observations in each cohort. For example 3307 patients with a severe TBI underwent CT scanning and have their arrival and CT scan dates and times recorded.

TBI severity	Measured from	Category	n	Median hours	IQR lower bound	IQR upper bound
Severe TBI	Arrival time	CT	3307	0.5	0.3	0.8
		Craniotomy	457	2.6	1.6	10.1
		ICP monitoring	411	3.1	1.8	7.4
	Incident time	CT	3565	2.0	1.5	3.2
		Craniotomy (direct)	423	4.0	2.9	17.2
		Craniotomy (transfer)	262	7.3	5.3	19.0
		ICP monitoring	571	5.8	3.5	11.3
Moderate TBI	Arrival time	CT	766	0.9	0.5	1.9
		Craniotomy	45	8.6	2.8	47.9
		ICP monitoring	16	8.4	2.7	47.9
	Incident time	CT	751	2.5	1.8	5.5
		Craniotomy (direct)	42	15.8	5.3	65.8
		Craniotomy (transfer)	24	38.3	9.7	226.0
		ICP monitoring	19	8.6	6.1	48.8
Mild TBI	Arrival time	CT	8740	1.7	0.7	3.3
		Craniotomy	218	19.2	6.6	97.3
		ICP monitoring	41	11.6	5.8	28.6
	Incident time	CT	8173	3.7	2.3	8.6
		Craniotomy (direct)	170	21.4	7.4	119.2
		Craniotomy (transfer)	320	53.2	16.3	240.6
		ICP monitoring	69	18.3	8.4	38.0
GCS not recorded	Arrival time	CT	367	3.5	1.4	16.5
		Craniotomy	14	15.4	8.5	36.8
		ICP monitoring	2	10.1	0.0	0.0
	Incident time	CT	202	8.5	2.4	36.6
		Craniotomy (direct)	4	189.1	0.0	0.0
		Craniotomy (transfer)	19	40.0	12.4	560.3
		ICP monitoring	7	11.3	10.0	11.7

Complications in Hospital

Table 3 summarises the documented complications following TBI. Overall, over 19% of patients are recorded as suffering a complication, and in the severe TBI cohort this incidence increases to almost 30%. There is a wide range of complications; the most frequent in the severe TBI cohort were bronchopneumonia (4.9%), in-hospital seizure (2.9%), sepsis (3.1%) and pleural effusion (2%). These were also the most common complications in the cohort as a whole.

Table 3. Inpatient Complications Stratified by Severity of Injury

Complication	Severe TBI	Moderate TBI	Mild TBI	GCS not recorded	Total
Aspiration	63 (1.5%)	8 (0.9%)	48 (0.5%)	5 (0.6%)	124 (0.8%)
Bronchopneumonia	203 (4.9%)	32 (3.4%)	209 (2%)	17 (2.2%)	461 (2.8%)
Pleural Effusion	84 (2%)	9 (1%)	68 (0.7%)	12 (1.6%)	173 (1.1%)
Seizure In Hospital	119 (2.9%)	22 (2.4%)	141 (1.4%)	15 (1.9%)	297 (1.8%)
Sepsis	129 (3.1%)	9 (1%)	107 (1%)	13 (1.7%)	258 (1.6%)
Other	624 (15%)	106 (11.4%)	836 (8%)	88 (11.4%)	1654 (10.1%)
Not complications recorded	**2944 (70.7%)**	**744 (80%)**	**9027 (86.5%)**	**623 (80.6%)**	**13338 (81.8%)**

Risk adjusted Outcomes at Neurosurgical Units

Figure 4 shows a funnel plot[12] of the risk adjusted W scores derived using the Ps14^n model (Ws^n) for each unit on the y-axis against a precision (1 / standard error) based rank on the x-axis. A positive Ws^n indicates that a site is performing better than the model predicts, a negative value indicates worse performance. The 'funnel' refers to the 2 and 3 standard deviation (SD) lines, plotted around the mean Ws that narrow as the precision increases. All units are within the 3 SD lines and most units fall within the 2 SD lines; 4 units are outside the -2 SD line and 2 units are above the +2 line. The Ws^n value for a given site, relative to the position of the SD lines indicates if their performance significantly differs from that of their peers.

Discussion

This audit incorporates prospectively collected data on a large number of patients, including from every neurosurgical unit in England and Wales, and provides the most comprehensive and up to date report of outcomes following TBI in England and Wales.

Demographics and Mechanism of Injury

The cohort of patients in the TARN database mimics data from other large TBI databases and the demographics and mechanism of injury closely mirror those from other series of TBI patients in the developed world [13-15]. The most common injuries are those in elderly people following trips and falls while in younger patients the most common causes are road traffic collisions and assault and these are more likely to present as severe TBI. We have provided a breakdown of delay to transfer to neurosurgical centre and complication rates by 10 year age bracket in the supplementary information. This demonstrates that despite comparable transfer times between adult groups, there are a smaller number of children aged 0-10 years transferred within 4 hours (32%) as compared to adult age brackets (range 45-61%). This does not lead to an increased frequency of complications and we speculate that this is due to specialised transfer team involvement for young children (Children's Acute Transfer Service, CATS). Interestingly, only 6% of TBI patients fall into the moderate (GCS 9-13) category calling into question whether the current GCS thresholds for severity accurately reflect the underlying condition: intuitively, one might expect that more severe injuries are increasingly rare. Other epidemiological studies in high-income countries reinforce this pattern of falls as a common aetiology in elderly patients[15].

Transfer to hospital

While the majority of patients are transported to hospital by land ambulance, there is an increasing use of helicopter ambulance for those patients with severe TBI. These patients are increasingly being transported directly to Major Trauma Centres (MTCs) as part of the NHS plan to centralise the management of complex trauma. The choice of mode of transport to hospital and choice of local hospital versus a neurosurgical or MTC is a complex one. Factors such as the physiological stability of a patient on scene and the geography of local emergency services dictates individualisation of decision making and it is difficult to mandate transport of a group of patients to a given location. A recent publication from the TARN registry[16] found no association between the duration of the pre-hospital interval and deteriorating physiological parameters. We did not find a difference in complication rate between these two cohorts (see supplementary information). There are also challenges with the reliable identification of TBI in the prehospital environment and current strategies suffer from significant under and over triage rates making secondary transfer into neurosurgery a necessary pathway for some TBI patients[17]. However, in patients with severe TBI, who are

likely to survive and require treatment, we would expect transfer to a neurosurgical centre once physiological stability has been achieved[18]. This is supported by NICE guidance – in our series 84% of severe TBI patients received neuroscience care, suggesting reasonable adherence. For mild and moderate TBI, an individual decision is required as to the need and rapidity of transfer to a neurosurgical centre. In a resource-limited environment however, an efficient use of specialist beds necessitates some degree of triage at local centres before transfer to a specialist centre.

Time to Intervention

The median and upper quartile time to CT is within the one hour from ED arrival target defined by the NICE head injury guidelines[18] for patients at high risk of TBI requiring neurosurgery (GCS<13 = moderate/severe TBI), NICE recommends CT brain scan for GCS 15 patients with additional risk factors but not high risk, within 8 hours of injury. Mild TBI patients with GCS 13-14 on arrival at hospital should have CT within an hour if the GCS does not reach 15 within 2 hours of injury. Sequential ED GCS readings are not well recorded on TARN but Table 2 suggests that this NICE recommendation also has reasonable adherence. The Brain Trauma Foundation surgical guidelines[19] recommend that acute intracranial haemorrhages are treated as quickly as possible in those patients presenting in coma. The evidence for rapid treatment by craniotomy is strongest in those presenting with a fixed, dilated pupil[20]. In this regard, our data show direct transfer to a neurosurgical centre facilitates more rapid surgery and as such we support current ambulance service trauma triage guidelines that direct primary transportation from scene to a neurosurgical centre for patients with a unilateral fixed, dilated pupil in the context of severe TBI and a patent airway[17]. Consideration should also be given to establishing guidelines for direct transfer of other TBI patients from the scene to Neurosurgical Units, notwithstanding the difficulty in accurate identification of patients in the pre-hospital setting, and refining referral mechanisms from district hospitals / trauma units to major trauma centres with neurosurgical capability. Any guidelines must reflect the low requirement for craniotomy and ICP monitoring in mild (3.1% and 0.7%) and moderate (2.7% and 2.1%) TBI, such that in the majority of these patients expedited transfer to a neurosurgical centre may be unnecessary.

Complications and Risk adjusted outcomes at Neurosurgical Units

Patients with TBI are susceptible to a wide range of complications as evidenced by the reported complications. Respiratory complications predominate as would be expected in critically ill patients with a reduced conscious state or those in an intensive care environment. The analysis shows that 5 units lie outside of the 2 standard deviation (SD) control limits, however they and all other units are within the 3 SD limits. A single centre is close to the positive 3 SD limit, but this is one of the units with lower precision where we expect to see larger variation from the mean. As such these data suggest that there are no outlying units in terms of risk adjusted mortality in neurosurgical care for patients suffering TBI in England & Wales. Further studies are required to address the quality of survival in terms of outcome beyond mortality. On the basis of the funnel plot, it appears that there is a slight excess of units falling below the expected standardised mortality ratio (worse than expected outcome). This is most likely due to the expected (average) value being skewed upwards by the two centres with low precision and very high Ws^n scores. In addition, a significant proportion of the centres below the expected value are those with lower precision, the higher precision units on the right side of the plot are more evenly balanced.

Study Limitations

Although this audit is comprehensive, there are certain limitations to using aggregate data of this type. Firstly, as with many studies that utilise GCS, we have used a composite score rather than the individual components, despite each component of the GCS being on a categorical scale. This is partly addressed by the validation of this approach by the IMPACT model[21 22]. Secondly, there is some variability in the reporting of GCS, such that 'first' GCS is sometimes used interchangeably with 'post-resuscitation' GCS[22]. Thirdly, we have not addressed the decision making with regards to transfer of patients from peripheral to neurosurgical centres, and the possibility of regional variation. This could potentially have an effect on TBI survival rates in specialist centres if there is a variation in transfer criteria, particularly for older patients who may have poorer prognosis[23]. Lastly there is some variability in patient recruitment into the TARN database, over the time period of the study neuroscience centres recruited almost 100% of relevant patients, outside of these hospitals however the average is roughly 65%. Nevertheless, we hope by compiling data on more than 15,000 patients, we are able to provide robust data on TBI management in England and Wales.

Conclusion

This report provides the first England and Wales audit of its type with a large number of patients that is commensurate with the largest cohorts of patients currently published in TBI, namely the CRASH and IMPACT studies. This provides a robust baseline for further comparisons of outcomes in a transparent and reproducible fashion. The data we present confirms that England and Wales trauma management broadly meets the NICE guidelines and achieves a consistent standard across all regions and neurosurgical units. The NICE guidelines are broad and rightly err on the side of caution in the necessity for CT imaging and discussion with specialist centres[18]. Specifically, they are for the management of Head Injury, rather than Traumatic Brain Injury, and the recommendations address CT imaging and appropriate transfer to neurosurgical centres, rather than ICP monitoring and the need for craniotomy, although this is a possibility in the future. The need for these guidelines to be used in a range of ED settings necessitates this approach, although data presented here highlights that neurosurgical intervention is rarely required for those presenting with mild or moderate TBI. The increasing need for public engagement with regards to surgical outcomes, and the related political imperative to provide this within the NHS will become the *status quo*.

Footnotes

The sponsor has had no role in the design or conduct of this study.

Contributors: FL and PJH conceived of the study and have provided detailed review of the results. AH and TL have written the manuscript. TL, OB and MW have carried out the statistical analysis.

Funding: AH is supported by the University of Cambridge, UK and Medical Research Council/ Royal College of Surgeons of England Clinical Research Training Fellowship (Grant no. G0802251). P.J.H.is supported by National Institute for Health Research Professorship, Academy of Medical Sciences/Health Foundation Senior Surgical Scientist Fellowship and the National Institute for Health Research Biomedical Research Centre, Cambridge.

Competing interests: All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: financial support as described above; no other financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Data sharing: no additional data available.

Transparency declaration: The lead authors (FL, PJH) affirm that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained

References

1. Head Injury: Triage, Assessment, Investigation and Early Management of Head Injury in Children, Young People and Adults. National Institute for Health and Care Excellence (UK) 2014.
2. Advanced Trauma Life Support (ATLS): the Ninth Edition. American College of Surgeons 2012.
3. Patel HC, Menon DK, Tebbs S, et al. Specialist neurocritical care and outcome from head injury. Intensive care medicine 2002;**28**(5):547-53.
4. Stein SC, Georgoff P, Meghan S, et al. Relationship of aggressive monitoring and treatment to improved outcomes in severe traumatic brain injury. J Neurosurg 2010;**112**(5):1105-12.
5. Collaborators MCT, Perel P, Arango M, et al. Predicting outcome after traumatic brain injury: practical prognostic models based on large cohort of international patients. BMJ 2008;**336**(7641):425-9.
6. Murray GD, Butcher I, McHugh GS, et al. Multivariable prognostic analysis in traumatic brain injury: results from the IMPACT study. Journal of neurotrauma 2007;**24**(2):329-37.
7. Neurosurgical National Audit Programme 2014 [Available from: http://www.hed.nhs.uk/SBNS/.
8. Abbreviated Injury Scale (AIS) 2014 [Available from: http://www.aaam.org/about-ais.html.
9. Bouamra O, Jacques R, Edwards A, et al. Prediction modelling for trauma using comorbidity and 'true'30-day outcome. Emergency Medicine Journal 2015:emermed-2015-205176.
10. Marmarou A, Lu J, Butcher I, et al. Prognostic value of the Glasgow Coma Scale and pupil reactivity in traumatic brain injury assessed pre-hospital and on enrollment: an IMPACT analysis. Journal of neurotrauma 2007;**24**(2):270-80.
11. Hollis S, Yates D, Woodford M, et al. Standardized comparison of performance indicators in trauma: a new approach to case-mix variation. Journal of Trauma and Acute Care Surgery 1995;**38**(5):763-66.
12. Spiegelhalter DJ. Funnel plots for comparing institutional performance. Stat Med 2005;**24**(8):1185-202.
13. Peeters W, van den Brande R, Polinder S, et al. Epidemiology of traumatic brain injury in Europe. Acta neurochirurgica 2015;**157**(10):1683-96.
14. Maas AI, Murray GD, Roozenbeek B, et al. Advancing care for traumatic brain injury: findings from the IMPACT studies and perspectives on future research. The Lancet Neurology 2013;**12**(12):1200-10.
15. Walder B, Haller G, Rebetez MM, et al. Severe traumatic brain injury in a high-income country: an epidemiological study. J Neurotrauma 2013;**30**(23):1934-42.
16. Fuller G, Lawrence T, Woodford M, et al. Emergency medical services interval and mortality in significant head injury: a retrospective cohort study. European Journal of Emergency Medicine 2015;**22**(1):42-48.
17. Lecky F, Russell W, Fuller G, et al. The Head Injury Transportation Straight to Neurosurgery (HITS-NS) randomised trial: a feasibility study. Health Technol Assess 2016;**20**(1).
18. NICE. Triage, assessment, investigation and early management of head injury in children, young people and adults 2014 [Available from: http://www.nice.org.uk/guidance/cg176/evidence.
19. Guidelines for the management of severe traumatic brain injury 2007 [Available from: https://www.braintrauma.org/.
20. Clusmann H, Schaller C, Schramm J. Fixed and dilated pupils after trauma, stroke, and previous intracranial surgery: management and outcome. J Neurol Neurosurg Psychiatry 2001;**71**(2):175-81.
21. Marmarou A, Lu J, Butcher I, et al. Prognostic value of the Glasgow Coma Scale and pupil reactivity in traumatic brain injury assessed pre-hospital and on enrollment: an IMPACT analysis. J Neurotrauma 2007;**24**(2):270-80.
22. Reith FC, Van den Brande R, Synnot A, et al. The reliability of the Glasgow Coma Scale: a systematic review. Intensive Care Med 2016;**42**(1):3-15.
23. Kirkman MA, Jenks T, Bouamra O, et al. Increased mortality associated with cerebral contusions following trauma in the elderly: bad patients or bad management? J Neurotrauma 2013;**30**(16):1385-90.

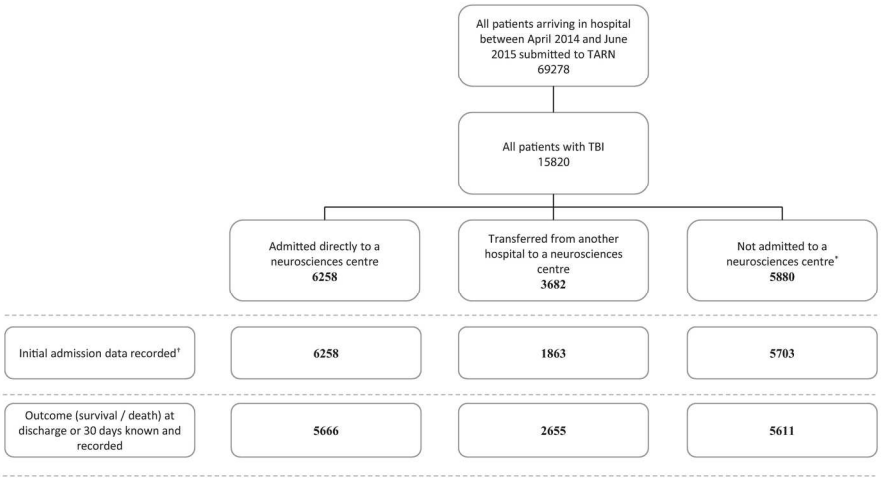
Figure Legends

Figure 1. Flow chart delineating the derivation of the TBI cohort studied.

Figure 2. Proportion of all TBI patients by age and mechanism of injury.

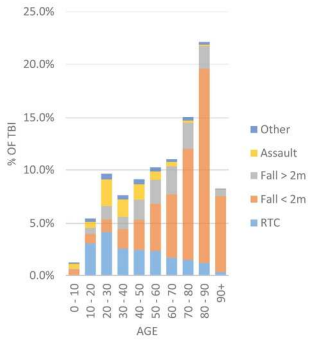
Figure 3. Proportion of patients with severe TBI (TBI in combination with GCS ≤ 8) by age and mechanism of injury.

Figure 4. Funnel plot showing the Wsn for neurosurgical units in England & Wales between April 2014 and June 2015.



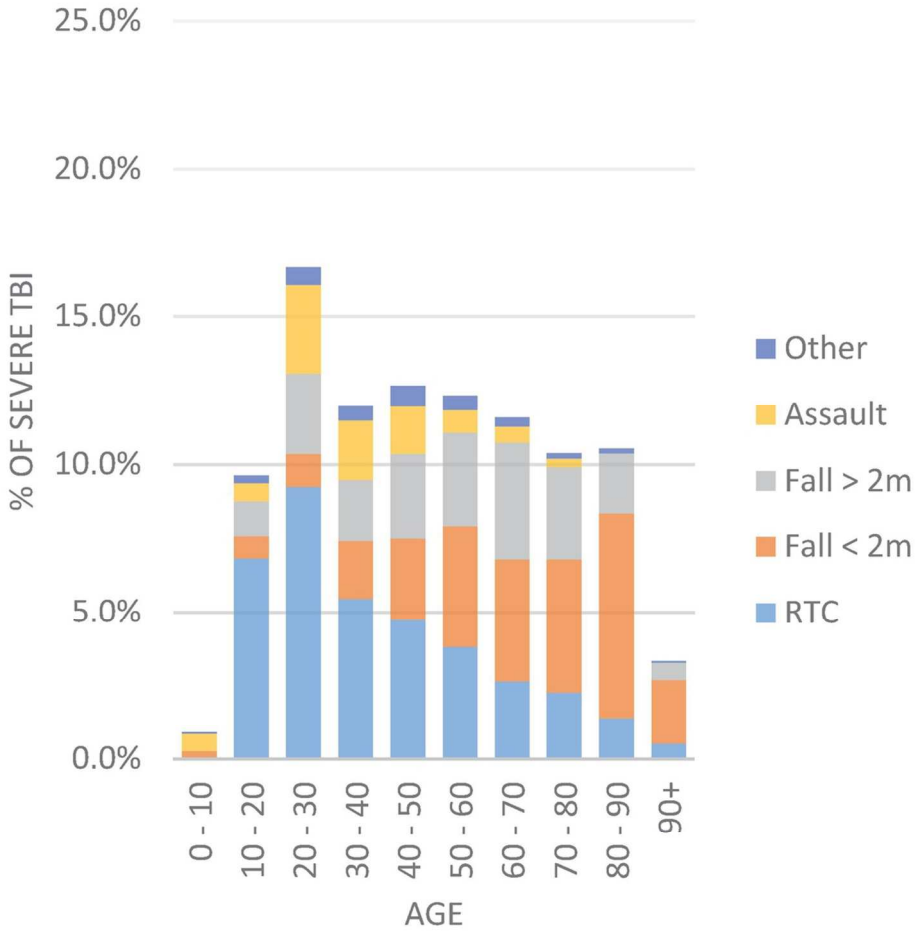
* Patients initially admitted to and treated entirely at hospitals without neuroscience care
† Data from the scene of injury and initial hospital admitted to is recorded on TARN

190x142mm (300 x 300 DPI)



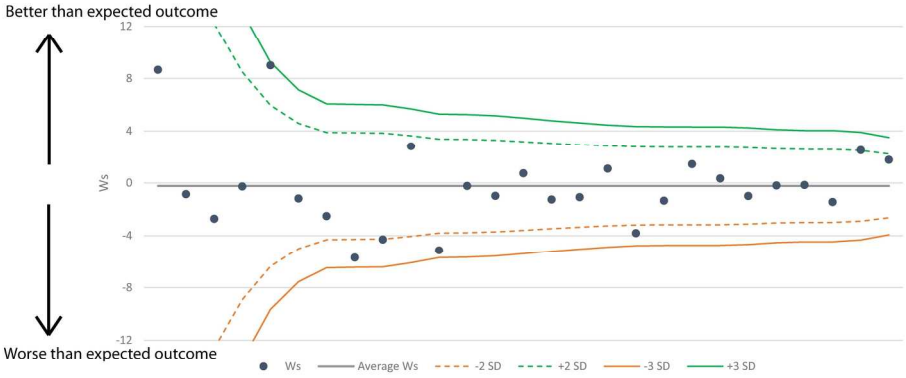
Figures 2. Proportion of patients with TBI by age and mechanism of injury.

190x142mm (300 x 300 DPI)



Figures 3. Proportion of patients with severe TBI (TBI in combination with GCS < 9) by age and mechanism of injury.

106x124mm (300 x 300 DPI)



190x142mm (300 x 300 DPI)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract **prospective audit as per title**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found **structured abstract in place**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported **In text**
Objectives	3	State specific objectives, including any prespecified hypotheses **In text**
Methods		
Study design	4	Present key elements of study design early in the paper **In text**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **In text**
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *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 **In text**
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case **In text**
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable **In text**
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 **In text**
Bias	9	Describe any efforts to address potential sources of bias **Not applicable, registry study**
Study size	10	Explain how the study size was arrived at **Not applicable, registry study**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable,

		describe which groupings were chosen and why **Not applicable**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding **In text**
		(*b*) Describe any methods used to examine subgroups and interactions **Not applicable**
		(*c*) Explain how missing data were addressed **Not applicable**
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *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 **Not Applicable**

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 **In table**
		(b) Give reasons for non-participation at each stage **Not Applicable**
		(c) Consider use of a flow diagram **Not applicable**
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders **In text**
		(b) Indicate number of participants with missing data for each variable of interest **Not applicable**
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		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 **In text**
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
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period **In text**
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **In text and supplementary data**
Discussion		
Key results	18	Summarise key results with reference to study objectives **In text**
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 **In text**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **In text**
Generalisability	21	Discuss the generalisability (external validity) of the study results **In text**
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 **In text**

*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.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

Appendix

The Ps14^{n} model is a modification of the Ps14 model as described by Bouamra in 2015 with the addition of pupil reactivity. It has been derived from 39451 patients recorded in the TARN database with head injuries of AIS 3 or greater severity admitted to hospital between 2012 and 2015. Table 1 describes the characteristics of these patients and table 2 contains the regression coefficients of which the prediction model is formed.

The model is shown to have good discriminant power (AuROC 0.882, 95% CI 0.878 to 0.887). The calibration of the model was assessed using the Brier score, this shows how close predictions are to the actual outcome. Its value varies between 0 (perfect) and 0.25 (useless), the model shows a value of 0.086. The value for the HL-statistic (Hosper & Lemeshow chi^{2}(8)) is 19.51, P-value 0.0124 (as the p-value is <0.05 the model failed the goodness-of-fit test but this is expected with the HL-test as it is too sensitive to large sample sizes). Figure 1 shows a graphical assessment of calibration using 200 bootstrap simulations and shows an almost perfect calibration: the observed and expected are aligned to the 45^{o} line.

Table 1. Characteristics of the patients

n	39451
Age	
Median (IQR)	62.6 (35.8 - 81.4)
ISS	
Median (IQR)	24 (16 - 26)
GCS	
Median (IQR)	14 (11 - 15)
Gender	
Female	13927 (35.3%)
Male	25524 (64.7%)
Comorbidity	
No comorbidity	19776 (50.1%)
1 - 5	10617 (26.9%)
6 - 10	3417 (8.7%)
> 10	1585 (4.0%)
Not recorded	4056 (10.3%)
Mortality	16.0%

Table 2. Coefficients of the model

Variables	Regression Coefficients	p-value	Odds ratio 95% CI	
$(10/ISS)^2$ - 0.1920	3.3294	<0.0001	22.9	33.8
$(10/ISS)^2$*$\log_e$(ISS/10)-0.1584	8.2092	<0.0001	1719.9	7785.4
GCS				
GCS =3	-3.0652	<0.0001	0.04	0.05
GCS 4 -5	-2.6485	<0.0001	0.06	0.08
GCS 6 -8	-1.8352	<0.0001	0.14	0.18
GCS 9 -12	-1.3348	<0.0001	0.23	0.30
GCS 13 - 14	-0.4704	<0.0001	0.57	0.69
GCS 15 (reference)	0.0000		1	1
Intubated	-2.5212	<0.0001	0.06	0.11
Charlson Index				
0 (reference)	0.0000		1	1
1 - 5	-0.4593	<0.0001	0.58	0.69
6 - 10	-0.7754	<0.0001	0.41	0.52
>10	-1.1841	<0.0001	0.26	0.36
Not recorded	-0.6575	<0.0001	0.46	0.58
Age				
0 - 5	-0.0236	0.92	0.63	1.51
6 - 10	0.5668	0.07	0.95	3.25
11 - 15	0.0356	0.87	0.67	1.60
16 - 44 (reference)	0.0000		1	1
45 - 54	-0.5065	<0.0001	0.51	0.72
55 - 64	-1.0091	<0.0001	0.31	0.44
65 - 75	-1.6125	<0.0001	0.17	0.23
>75	-2.7684	<0.0001	0.05	0.07
Gender				
Male (reference)	0.0000		1	1
Female	-0.0216	0.84	0.79	1.21
Age by gender interaction				
0 - 5 & Female	-0.1968	0.55	0.43	1.58
6 - 10 & Female	-0.3357	0.55	0.24	2.14
11 - 15 & Female	0.8354	0.11	0.83	6.49
45 - 54 & Female	-0.2911	0.11	0.52	1.07
55 - 64 & Female	0.2989	0.09	0.95	1.92
65 - 75 & Female	-0.0281	0.85	0.73	1.30
>75 & Female	0.1084	0.36	0.89	1.40
Pupil reactivity				
Both reactive (reference)	0.0000		1	1
Abnormal (both reactive)	-0.4383	<0.0001	0.57	0.73
Abnormal (1 reactive)	-0.5325	<0.0001	0.50	0.69
Neither reactive	-2.0874	<0.0001	0.11	0.14
Constant	4.9208	<0.0001	119.10	157.59

Figure 1: Model Calibration

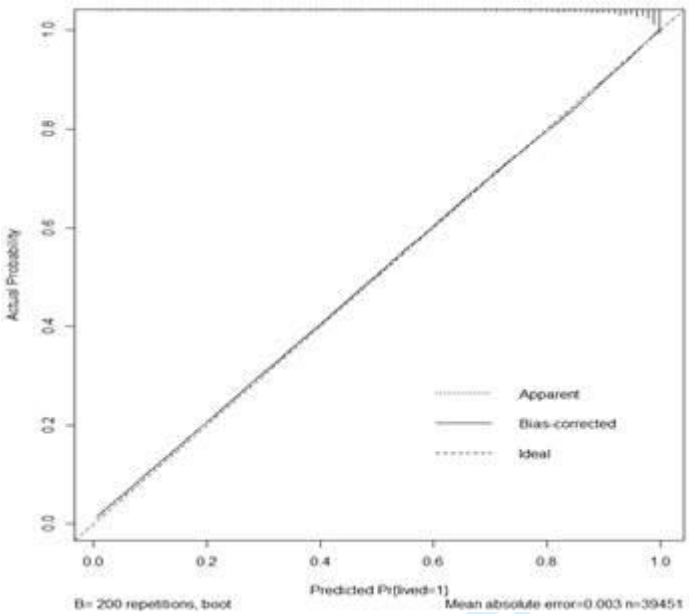


Table 3: Hours to arrival at neurosurgical centre stratified by age

Hours to arrival at neurocentre	Age									
	0 - 10	**10 - 20**	**20 - 30**	**30 - 40**	**40 - 50**	**50 - 60**	**60 - 70**	**70 - 80**	**80 - 90**	**90+**
0 - 4	50 (31.8%)	434 (60.5%)	748 (60.1%)	543 (55.9%)	550 (49.5%)	603 (50.2%)	591 (49.5%)	604 (44.7%)	799 (51.4%)	293 (58.8%)
4 - 12	6 (3.8%)	8 (1.1%)	25 (2%)	6 (0.6%)	28 (2.5%)	31 (2.6%)	27 (2.3%)	19 (1.4%)	39 (2.5%)	8 (1.6%)
12 - 24	31 (19.7%)	112 (15.6%)	162 (13%)	132 (13.6%)	159 (14.3%)	190 (15.8%)	165 (13.8%)	155 (11.5%)	125 (8%)	47 (9.4%)
24 - 48	11 (7%)	19 (2.6%)	35 (2.8%)	35 (3.6%)	41 (3.7%)	56 (4.7%)	46 (3.8%)	51 (3.8%)	43 (2.8%)	9 (1.8%)
48 - 72	1 (0.6%)	7 (1%)	8 (0.6%)	8 (0.8%)	10 (0.9%)	11 (0.9%)	9 (0.8%)	9 (0.7%)	14 (0.9%)	2 (0.4%)
72+	6 (3.8%)	6 (0.8%)	13 (1%)	10 (1%)	28 (2.5%)	28 (2.3%)	34 (2.8%)	53 (3.9%)	94 (6.1%)	27 (5.4%)
Unknown	52 (33.1%)	131 (18.3%)	254 (20.4%)	237 (24.4%)	294 (26.5%)	283 (23.5%)	323 (27%)	459 (34%)	439 (28.3%)	112 (22.5%)

Table 4: Rate of complications by age and transfer status

Age	n	Complications	% with complications
0-10	211	35	16.6%
10-20	863	100	11.6%
20-30	1523	184	12.1%
30-40	1206	189	15.7%
40-50	1443	197	13.7%
50-60	1620	271	16.7%
60-70	1760	277	15.7%
70-80	2380	395	16.6%
80-90	3508	613	17.5%
90+	1305	221	16.9%
Total	**15819**	**2482**	**15.7%**

Age	n	Complications	% with complications
No transfer	10893	1611	14.8%
Transfer	4926	871	17.7%
Total	**15819**	**2482**	**15.7%**

Table 5: Mortality stratified by GCS and Head AIS

TBI severity	n	Mortality			Predicted mortality %
		n	%	95% CI	
Mild TBI	9285	730	7.9%	7.3% - 8.4%	8.6%
Moderate TBI	790	178	22.5%	19.6% - 25.4%	23.6%
Severe TBI	3228	1304	40.4%	38.7% - 42.1%	36.1%*
GCS not recorded	629	98	15.6%	12.7% - 18.4%	12.4%
Total	**13932**	**2310**	**16.6%**	**16% - 17.2%**	**16.0%**

AIS TBI severity	n	Mortality			Predicted mortality %
		n	%	95% CI	
3	2480	155	6.3%	5.3% - 7.2%	5.9%
4	5828	475	8.2%	7.4% - 8.9%	9.6%
5	5614	1671	29.8%	28.6% - 31%	26.9%
6	10	9	90.0%	71.4% - 100%	68.0%
Total	**13932**	**2310**	**16.6%**	**16% - 17.2%**	**16.0%**

Outcome	n	Outcome at discharge	Outcome at 30 days
Alive	11622	9642	1980
Dead	2310	2310	0
Total	**13932**	**11952**	**1980**

*Although in this cohort of severe TBI patients predicted mortality differs from actual mortality, the model is not specifically calibrated by the severity subsets. Overall, mortality across all patients ('total' row) matches the predicted mortality from the PS14^{n} model.

Table 6: Complication rate stratified by location of transfer

Transfer status	n	Complications	% with complications
No transfer	10893	1611	14.8%
Transfer	4926	871	17.7%
Total	**15819**	**2482**	**15.7%**