British Journal of Anaesthesia **113** (2): 286–94 (2014)
doi:10.1093/bja/aeu242

BJA

Trauma scoring systems and databases

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Editor's key points

- Physiological variables such as arterial pressure are unreliable for the diagnosis of injury severity.
- There is a strong association between Glasgow coma score and outcome.
- Clinicians should be aware that triage tools and decision rules have varying sensitivity and specificity.
- Trauma registry data allow tracking of the performance of individual hospitals and of trauma systems.

This review considers current trauma scoring systems and databases and their relevance to improving patient care. Single physiological measures such as systolic arterial pressure have limited ability to diagnose severe trauma by reflecting raised intracranial pressure, or significant haemorrhage. The Glasgow coma score has the greatest prognostic value in head-injured and other trauma patients. Trauma triage tools and imaging decision rules—using combinations of physiological cut-off measures with mechanism of injury and other categorical variables—bring both increased sophistication and increased complexity. It is important for clinicians and managers to be aware of the diagnostic properties (over- and under-triage rates) of any triage tool or decision rule used in their trauma system. Trauma registries are able to collate definitive injury descriptors and use survival prediction models to guide trauma system governance, through individual patient review and case-mix-adjusted benchmarking of hospital and network performance with robust outlier identification. Interrupted time series allow observation in the changes in care processes and outcomes at national level, which can feed back into clinical quality-based commissioning of healthcare. Registry data are also a valuable resource for trauma epidemiological and comparative effectiveness research studies.

Keywords: clinical governance; epidemiology; medical audit; wounds and injuries

Physiological scoring systems

The Glasgow coma scale and score

It is hard to believe that 2014 marks the 40th anniversary of the Glasgow coma scale.[1] At its inception, the creators, Sir Graham Teasdale and Mr Brian Jennet, reflected upon the confusion that characterized the assessment of patients with a head injury or other acute brain insult in the early 1970s. A lack of standardized assessment impaired communication between clinicians and with nursing staff. The consequences were delayed detection of clinically important changes and avoidable mortality and morbidity.

The landmark Glasgow coma scale publication in the *Lancet* in 1974 avoided the problem of trying to define 'comatose', 'stuporose' obtunded, etc.—which meant different things to different people and brought the problem back to first principles, which is defining responsiveness. In the first publication of the Glasgow coma scale, responsiveness is defined by best eye opening, verbal, and motor responses. There was no numbering in this first publication of the Glasgow coma scale, but as the scale is ordinal, it allowed a graphical representation of change over time—which is crucial when assessing the trauma patient.[1]

As the science of clinometrics grew, it became too much of a temptation to put numbers to the various graduations of the Glasgow coma scale; it was also recognized later on that there were different levels of flexion and so the original 14 gradations on the scale became 15 each with a numerical score (eye opening 1–4, verbal response 1–5, motor response 1–6). This gave a potential range of the Glasgow coma scale of between 3—equivalent to unresponsive in all domains—and 15—equivalent of being fully responsive in all domains. From the outset, the Glasgow coma scale was felt to have large degree of face validity for assessing severity and prognosis in traumatic brain injury (TBI). Probably, the best validation of its ability to do this was provided by the first CRASH Trial conducted worldwide between 1998 and 2002.

This trial was a simple randomized trial of steroids in TBI. Ten thousand patients with suspected TBI and a Glasgow coma score (GCS) of <15 in over 100 centres worldwide were recruited. Within the CRASH cohort, the GCS (3–14) was shown to have an almost linear relationship with 14 day mortality.[2]

The same study also showed an almost linear relationship in the likelihood of a good recovery after injury (as defined by the Glasgow outcome scale)[3] at 6 months with $<10\%$ of patients with a GCS of 4 having a good recovery compared with 70% of patients with a GCS of 14 (I. Roberts, personal communication). There is no doubt about the central place of the GCS in assessing the likelihood of TBI and overall prognosis in trauma patients.

The Advanced Trauma Life Support shock classification

Other than TBI, the major killer after injury is death from undetected internal haemorrhage, this is addressed by a shock table within the Advanced Trauma Life Support (ATLS) manual.[4] The table in the ATLS manual is unreferenced and in 2007, investigators from the UK tried to reproduce that Shock Table using data on patients with an injury severity score (ISS) of >15 (indicating the presence of life-threatening injuries) submitted to the largest European Trauma Registry, The Trauma Audit and Research Network (TARN).[4 5]

It was not possible to reproduce the ATLS shock table from the TARN data (Table 1).[5] Increasing heart rate, as a marker of shock, was associated with increasing severity of injury, reduced age, and increasing mortality. However, changes in other physiological variables with increasing severity of shock did not follow the pattern described by the ATLS manual. There were no significant differences in the median systolic arterial pressure or median respiratory rate between the four shock classifications indicated by heart rate. GCS changed more markedly between the groups, but this sample did contain a high prevalence of patients with TBI.

A further study from TARN indicated that injured children tend to be hypertensive compared with their age-adjusted resting norms regardless of the severity of injury.[6] This suggests that reduced systolic arterial pressure, particularly in the young, is only a late indicator of haemorrhage. There is an extensive animal model literature demonstrating that in blunt trauma (the predominant mode of trauma in the western world), nociception attenuates the cardiovascular response to haemorrhage, postponing decompensation up to the point where almost 40% of the blood volume is lost.[7] The ability of abnormal values of single physiological measures to diagnose severe trauma is hence limited with GCS probably performing best.[8]

The revised trauma score

Historically, within Emergency Medicine Systems, the physiological responses of an injured patient have been assessed by the revised trauma score (RTS). The physiological parameters that make up the RTS are respiratory rate, systolic arterial pressure, and GCS. The RTS was developed after statistical analysis of a large North American database to determine the most predictive independent outcome variables.[9] The selection of variables was influenced by their ease of measurement and clinical opinion led to the exclusion of capillary refill and respiratory expansion from the score. In practice, the RTS is a complex calculation combining coded measurements of the three physiological values to obtain a value out of 12. However, latterly, the superiority of GCS compared with other predictors has been recognized[8 9]—adjustment for this adds excessive complexity to clinical scoring—consequently, the RTS has become less widely used in clinical practice.

The RTS is still used in North American Trauma Registries where the coded value for each variable is multiplied by a weighting factor derived from regression analysis, with GCS having much the strongest weighting. After injury, the patient's physiological response is constantly changing, but for the purposes of injury scoring by convention, the first measurements, when the patient arrives at hospital, are used.[9]

Trauma triage tools

Trauma triage tools use a combination of single physiological variables with diagnostic 'cut-offs'; combined with categorical variables based on the mechanism of injury, for example, flags for high-energy trauma such as high-speed road traffic collision or ejection from vehicle. Some trauma triage tools also include variables which describe obvious anatomical injuries such as an obvious flail chest or obvious sucking chest wound[10] or an additional filter for older patients. Most trauma triage tools are used in the pre-hospital environment to identify which patients should bypass the nearest emergency department and be taken to a major trauma centre and to generate pre-alert or standby calls for a trauma team. They can also be used for triage to resuscitation areas and to trigger calling the trauma team on arrival at the emergency

Table 1 Attempt to reproduce ATLS shock table using TARN data on severely injured patients 1989–2007.[5] [Shock classifications are defined 1–4 by presenting heart rate as per the ATLS manual;[4] the median and inter-quartile ranges (IQR) of other presenting physiological recordings are shown for patients in each shock category]

Shock category	1	2	3	4
Heart rate (beats min^{-1})	≤100	101–120	121–140	>140
Number of patients	19383	4615	1924	839
Median age (IQR)	41 (27–61)	36 (24–56)	33 (23–50)	32 (22–47)
Median ISS (IQR)	24 (17–26)	25 (18–33)	26 (21–35)	27 (22–35)
% Dead	20.0 (19.4–20.5)	25.6 (24.4–26.9)	33.6 (31.5–35.7)	39.7 (36.4–43)
Median systolic BP (IQR)	133 (118–150)	132 (110–152)	129 (100–150)	130 (100–152)
Median respiratory rate (bpm) (IQR)	19 (16–24)	20 (18–28)	24 (18–30)	25 (18–33)
Median GCS (IQR)	14 (8–15)	14 (7–15)	12 (5–15)	9 (4–15)

Table 2 Sensitivity, specificity, and over- and under-triage rates of current NHS England paediatric trauma triage rules for severe injury. (Severe injury is defined as ISS>15 present in 230 out of 701 injured children with complete pre-hospital data submitted to the Trauma Audit and Research Network from 2007 to 2011)[10]

Triage tool	*n*	ISS>15	Sensitivity (%)	Specificity (%)	Under-triage (%); 1-sensitivity	Over-triage (%); 1-specificity
East Midlands	701	230	97	17	3	83
London			96	28	4	72
North West			93	20	7	80
Northern			91	23	9	77
SW London and Surrey			88	41	12	59
Wessex			77	47	23	53
Paediatric trauma score			39	93	61	7
Paediatric trauma tape	283	94	36	84	63	16

department if the team has not been pre-alerted. Many triage tools are in existence, reflecting the paucity of good evidence as to their accuracy.[10] The problems with these tools are demonstrated by recent evaluation of paediatric triage tools using of the TARN database. All the current paediatric triage tools suffered from significant rates of either under- or over-triage when applied to identify patients with an ISS over 15—a consequence of either a lack of sensitivity or specificity (Table 2).[10] Trauma triage in its present form is therefore an inexact science reflecting the occult nature of blunt injuries which often do not become apparent until after imaging.

Trauma clinical decision rules for imaging

Trauma clinical decision rules for imaging such as those in the NICE head injury guidelines are used to identify which patients need rapid CT scanning for detection of injury on arrival at the emergency department. An example of such a rule, the latest version of indications for urgent and less urgent CT head scanning in adult head injury patients arriving at the emergency department, from the UK National Institute for Care and Excellence (NICE), is shown in Figure 1.[11]

Like the trauma triage tools, the NICE clinical decision rule uses a variety of physiological cut-offs, mechanism of injury variables, an age variable, and some findings on examination to describe indications for urgent CT. Unlike trauma triage tools, this imaging decision rule is able to build in the luxury of a detailed neurological examination which is often beyond the range of competencies of pre-hospital personnel. The rule also includes time sequence information for seizures, vomiting, and change in the GCS. Not surprisingly, this imaging clinical decision rule has been widely shown to have high sensitivity for picking up TBI requiring neurosurgery or admission for observation.[11 12] With optimal sensitivity and a specificity of 40–60%, the rule eliminates the need for CT in a significant proportion of emergency department head injury attenders. However, large numbers of normal CT scans are still conducted—probably about 10 for every CT brain scan that picks up a detectable abnormality.[12] This is not ideal in overcrowded emergency departments and admission units.

In summary, single physiological measures have limited ability to diagnose severe trauma by reflecting raised intracranial pressure or significant haemorrhage. The GCS has the greatest prognostic value in head-injured and other trauma patients. Trauma triage tools and imaging decision rules using combinations of physiological cut-off measures with mechanism of injury and other categorical variables bring both increased sophistication and increased complexity. It is important for clinicians and managers to be aware of the diagnostic properties (over- and under-triage rates) of any triage tool or decision rule used in their service.

Trauma registries

Trauma registries are an example of clinical databases that have been used to improve the quality of clinical care and conduct research. They have been an expanding phenomenon from North America to Europe and thence across the world over the last 20 yr. They are characterized by systematic continuous collection of trauma data using specified clinical inclusion criteria. They overcome the problems of trying to identify serious trauma using triage tools and decision rules as they use post-imaging injury descriptors (but hence of course are not useable as early triage tools). These injury descriptors are usually the abbreviated injury scale (AIS) or the International Classification of Diseases (ICD). Trauma registries also contain variables describing the care pathway from scene to discharge from acute care and outcome data—usually mortality at discharge but sometimes longer term disability. They are anonymized, secure, and data input is usually separate from routine hospital coding.

Registries are usually funded by participating hospitals or government contracts and their purpose is to improve care by benchmarking and research. Registries have been established with the understanding that the continuous comprehensive data collection with reliable case ascertainment (requiring precise injury diagnoses) is often absent in routine hospital discharge coding and is needed to improve real world care. Across different health economies, there is inequity in trauma management, with variation in provision and variation in patient outcomes. An important objective of the collection and feedback of registry data is to reduce such variation. A recent publication describes European Trauma Registries that are able to share data and have agreed a common list of

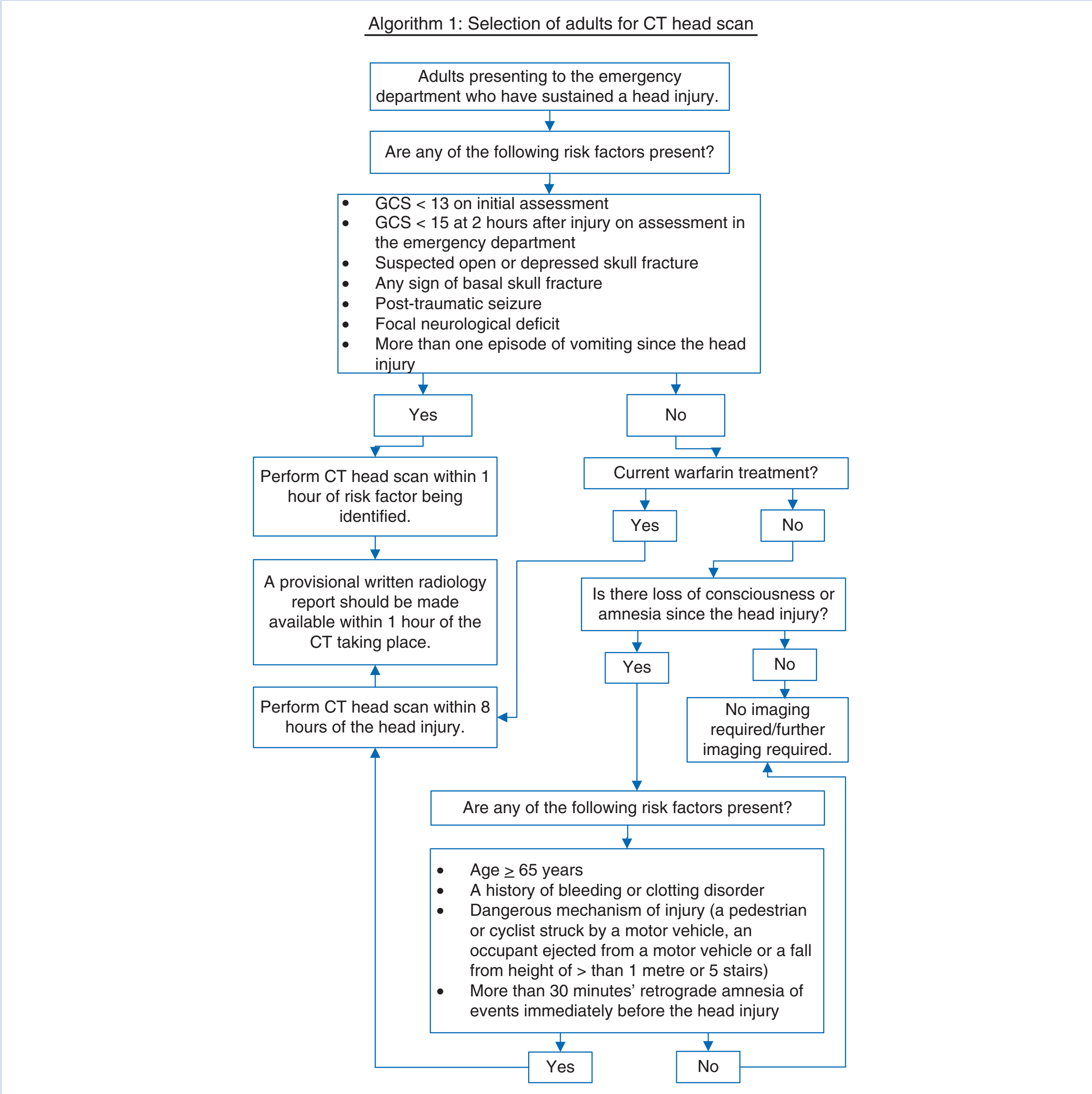

Fig 1 2014 NICE clinical decision rule for CT head scan in head injury patients.[11] Copyright held by NCGC.

40 variables for analysing the quality of trauma care. These variables either describe presenting host factors (age, gender, co-morbidity, physiology, injury descriptors), care (times to key interventions, skill of operators), and outcome (commonly survival to discharge)—the Utstein trauma template.[13]

Describing the threat to life from specific injuries within trauma registries

In general the AIS is felt to be a superior way of describing the threat to life from anatomical injuries when compared with the international classification of disease as it describes severity and anatomical location of each injury. Each injury is scored with a severity code between 1 and 6.

There are more than 2000 injuries listed in the 2005 AIS dictionary, which is in its fifth edition, with a 2008 update.[14] Intervals between the scores are not always consistent—for example, the difference between AIS3 and AIS4 is not necessarily that same as that between AIS1 and AIS2—hence, the severity scale is ordinal, not interval.[14] (Copies of the booklet are available from www.aaam.org.) Tables 3 and 4 give indicative AIS scores for individual injuries and describe how these

Table 3 Examples of injuries scored by the AIS (AIS 2008)[14]

Injury	Score
Shoulder pain (no injury specified)	0
Wrist sprain	1 (minor)
Closed undisplaced tibial fracture	2 (moderate)
Basal skull fracture	3 (serious)
Intimal tear of the thoracic aorta	4 (severe)
Complex liver laceration	5 (critical)
Laceration of the brain stem	6 (incompatible with life)

Table 4 Deriving the ISS[15]

To obtain this

- Use the AIS 2008 dictionary to score every injury
- Identify the highest AIS score in each of the following six areas of the body:
  - (i) Head and neck
  - (ii) Face
  - (iii) Chest and thoracic spine
  - (iv) Abdomen, lumbar spine, and pelvic contents
  - (v) Bony pelvis and limbs
  - (vi) Body surface
- Add together the squares of the highest scores in three different body areas
- Example road traffic collision victim with subdural haematoma, splenic laceration, two rib fractures, and fracture right femur; AIS severity scores are allocated in four body regions, head and neck=4, chest and thoracic spine=2, abdomen=4, limbs=3. As only the three most severely injured body regions count $ISS=4^2+4^2+3^2=41$
- By convention, a patient with an AIS6 in one body region is given an ISS of 75
- ISS is non-linear and the mathematical method creates pronounced variation in the frequency of different scores; 9 and 16 are common, 14 and 22 unusual, 7 and 15 impossible hence the scale is ordinal[15]

are amalgamated to give the ISS which summarizes each patient's overall anatomical severity of injury.[15]

Trauma system governance using registry data: outcome prediction for individual patients and hospitals

The TARN was established in 1989 first as an off-shoot of the US major trauma outcome study and then becoming the UK major trauma outcome study, funded by a grant from central government. In 2014, it has membership from 100% of trauma receiving hospitals in NHS England and 100% in Wales, almost all of the Republic of Ireland and some hospitals in continental Europe. Its stakeholders on the Board and Executive represent patients, clinical trauma specialities, and health service researchers and commissioners. As a National Clinical Audit, it is independent of the Department of Health. The patient inclusion criteria have remained consistent since 1989 and

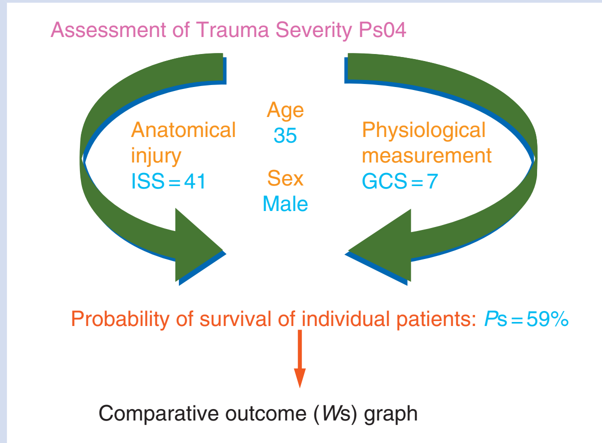

Fig 2 From ISS to individual patients' survival probability; an example of a calculation using the TARN outcome prediction model.[8] ISS, injury severity score; TARN, Trauma and Audit Research Network; *Ws*, *W* score.

include injured patients arriving at hospital alive of all ages where at least one of the following events subsequently occurs: death during admission, admission to critical care, transfer for specialist care, or admission for >72 h. Patients over 65 with isolated neck of femur or pubic ramus fractures are excluded as are all simple isolated closed limb and facial injuries (other than to the femoral shaft) and isolated spinal strains.

Imaging, necropsy, and operation reports are submitted to TARN to derive the AIS codes for each injury and the ISS. An example of an ISS allocated to a multiply injured patient is given in Table 4.

The ISS is combined with the patient's age, gender, and GCS on arrival to give an individual patient probability of survival using a logistic regression model.[8] In Figure 2, we see how this is done for the patient with multiple injuries who is a 35-yr-old male who arrived with a Glasgow coma scale of 7. On average within TARN, which contains data of more than 400 000 major trauma patients, six out of 10 of these patients (with similar age, gender, ISS, and GCS) would survive. This does not imply that if this patient died, it is due to poor care as on average 40% of similar patients will die, so individual patients should not be automatically classified as 'unexpected' deaths or survivors using this calculation. However, if a patient dies with higher survival probabilities (>75%), or lives with a low survival probability, it is worth examining the case at an audit meeting to see if there are lessons to learn. On clinical review, it may be obvious that other factors which are currently not used in the TARN outcome prediction model, such as co-morbidity, made the outcome inevitable.

This calculation of survival probability or '*Ps*' allows all the individual survival probabilities for TARN eligible patients presenting to each hospital over a given time period to be summed. This then gives the expected rate of survival for all patients treated, which is then subtracted from the observed or actual rate of survival. The figure derived is called the standardized *W* score (*W*s) which is equivalent to the observed minus the expected survival rate for TARN eligible patients for the time period specified.[8]

Figure 3 shows a comparative outcome analysis produced by TARN for its participating hospitals over the period 2008–2011 in a caterpillar plot format. The *W*s (observed − expected survival rate) score is on the *Y*-axis and each individual hospital is plotted on the *X*-axis with error bars for 95% confidence intervals. It is unsurprising that most of the hospitals are clustered around the 0% difference between observed and expected survival. However, it can be shown from the green dot on the left of the figure that the top 10% of hospitals produce 3% more survivors than expected and the bottom 10% of hospitals produce 1% more deaths than would be expected. As the actual mortality in the database is only 7%, this represents a difference in performance of 50% between the top and the bottom hospitals over the time period.

This display of hospital performance can be misused. It will be seen that in general, the 95% confidence intervals for hospitals overlap, that is, individual hospitals are not significantly different from each other. However, what hospitals have tended to do in the past is to count their position from the top right of the graph. A more reflective way of comparing hospital performance is to use a funnel plot (Fig. 4). On the funnel plot, the *Y*-axis is again the standardized *W* score. Each hospital is represented by a single point on the plot. The *X*-axis reflects the precision of (inverse of the standard error) the *W* score. The 95% and 97.5% confidence intervals for the *W* score are shown in the graph. As would be expected, most hospitals lie within the 95% confidence limits. Hospitals between the 95% and 97.5% confidence limits at the top are of the graph may be considered to be performing better than expected in terms of observed minus expected trauma survival rate (*W*s). The converse applies to hospitals between the lower limits. Hospitals outside these limits are considered to be outliers and are scrutinized every 3 months at TARN. The initial focus for this scrutiny is data quality and the length of time an outlying hospital has been outside the limits.

Identification of outliers is vital for protecting patients. TARN recently identified an outlier with 8% less survivors that expected using the methods described above. This outlying status persisted for more than a year and TARN was able to work with the UK Healthcare Commission (events predated the UK Care Quality Commission) to scrutinize the data from the hospital. This revealed the root cause of poor survival to be a lack of neurointensive care beds in the local neuroscience centre leading to a very low rate of accepting severe head injury patients from the outlying general hospital under scrutiny. Additional neuroscience beds have been opened in the neuroscience centre, which has resulted in better rates of transfer and improved outcomes in the general hospital such that it is no longer an outlier.

Using registry data to measure trauma system performance over time

The performance of groups of hospitals and individual units can be tracked over time using—expected survival rates or '*W* scores'. Hence, TARN is monitoring the progress of the new NHS England trauma systems in delivering better care. Within these systems, patients with complex or severe injuries

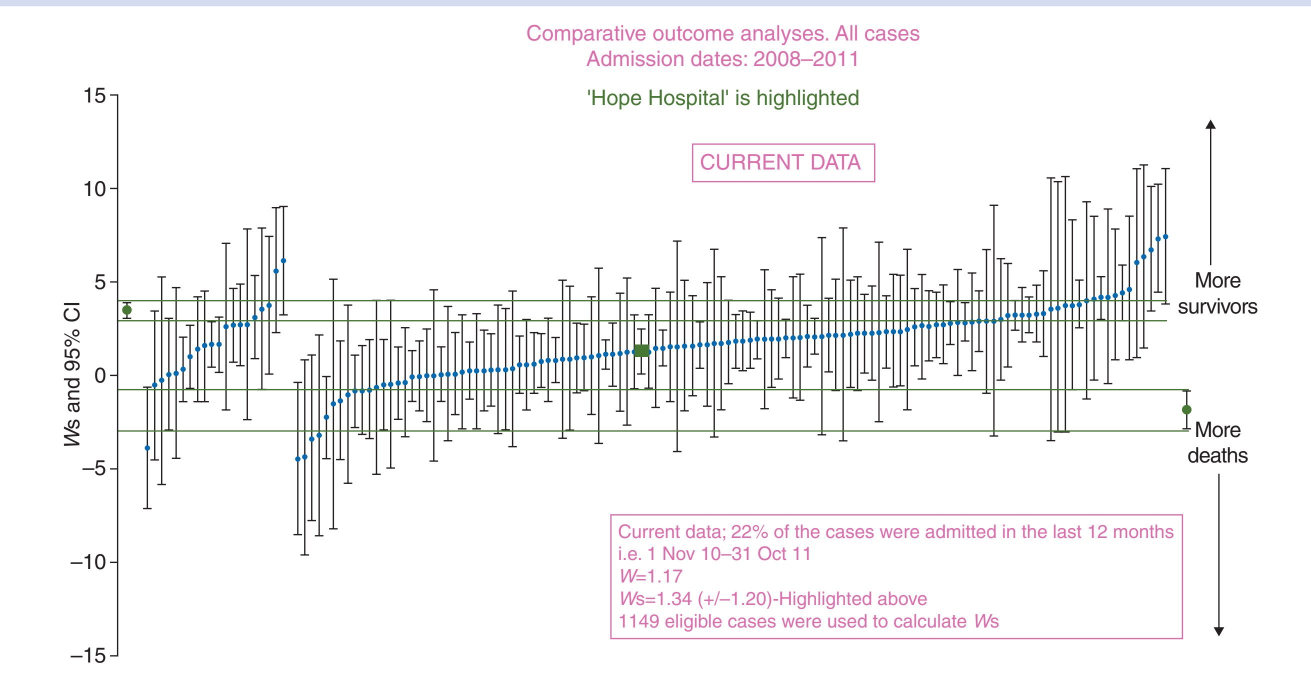

Fig 3 Example of hospital observed − expected mortality rates using caterpillar plot from the TARN. (The first author's hospital is highlighted in an excerpt from the TARN 'Hope Hospital quarterly report 2008–2011'.)

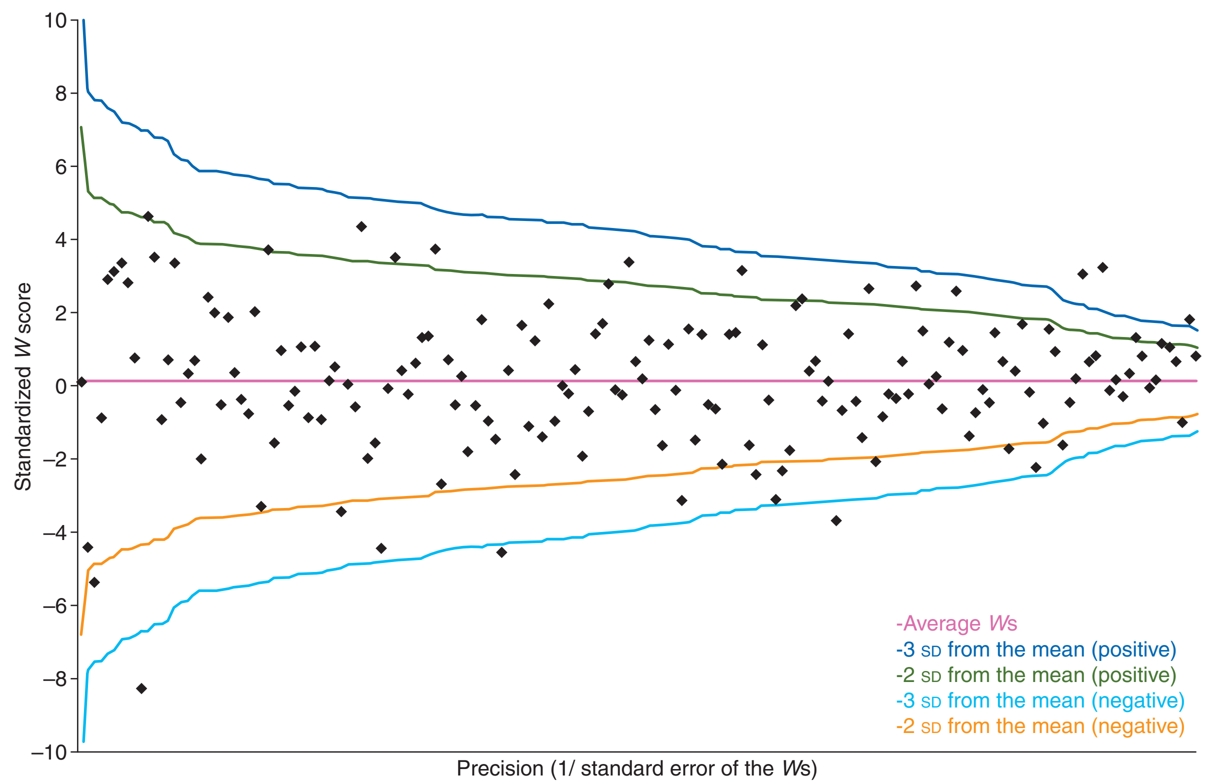

Fig 4 Comparing hospital observed − expected mortality rates using funnel plots—from TARN.

are more likely to receive the prompt resuscitation, diagnosis, and specialist management they require—along with rehabilitation prescriptions. In Figure 5, all groups show an improvement with the introduction of the new networks. The significantly poorer performance of the Greater Manchester trauma network compared with the rest of the country in 11/12 [Greater Manchester *Ws* −1% (95% CI −0.05% to −2% *vs* Rest of England *Ws* +0.3% (95% CI 0.5–0.1%)] has diminished to no significant difference in 12/13 [Greater Manchester *Ws* 0.5% (95% CI 1.6% to −0.2%) *vs* Rest of England 95% CI 1.3% (95% CI 1.5–1%)].

The rigour of analyses such as these is subject to data quality both in terms of the completeness and accuracy of the key variables submitted whether or not all eligible trauma cases have been submitted from each hospital. TARN uses hospital episode statistics to judge the latter. All the individual hospital performance analyses are publicly available on the TARN website and updated every 3 months with a guide to quality of data (https://www.tarn.ac.uk/Content.aspx?ca=15).

Using registry data for research to improve patient outcomes and influence NICE guidance

In 2003, TARN carried out analyses of trends over time which indicated no improvement in the odds of death compared with a 1989 baseline over the 1994–2003 time period when the odds of death were adjusted for any year on year variation in case mix in terms of age, gender, ISS, and RTS. The lack of improvement was even more marked for patients with significant head injury or TBI defined as TBI on CT scan and/or base of the skull, open, or depressed skull fracture; even though the TBI group represented younger more severely injured patients, who often required transfer. These significant skull and brain injuries were only present in 20% of registry patients but were responsible for two-thirds of deaths with a mortality rate that was a factor of 10 greater than patients without TBI.

The reasons for this lack of improvement were explored in a 2005 *Lancet* publication by Patel and colleagues[16] who identified a major survival disadvantage when patients with the most severe form of TBI (presenting with a GCS <9 or intubated on arrival at hospital) were not transferred into neuroscience care. The odds of death were double those of patients who were brought to a neuroscience centre at the outset, or who were secondarily transferred there irrespective of whether neurosurgery for intracranial haematomas, contusions, or to manage complex skull fractures was required. This example illustrates the use of the TARN database for comparative effectiveness research, using adjustment for confounding to identify effective care where trials are not possible.[16] As this publication became disseminated and was reinforced by guidance from the National Institute of Health and Clinical Excellence in 2007, the proportion of severe TBI managed outside of

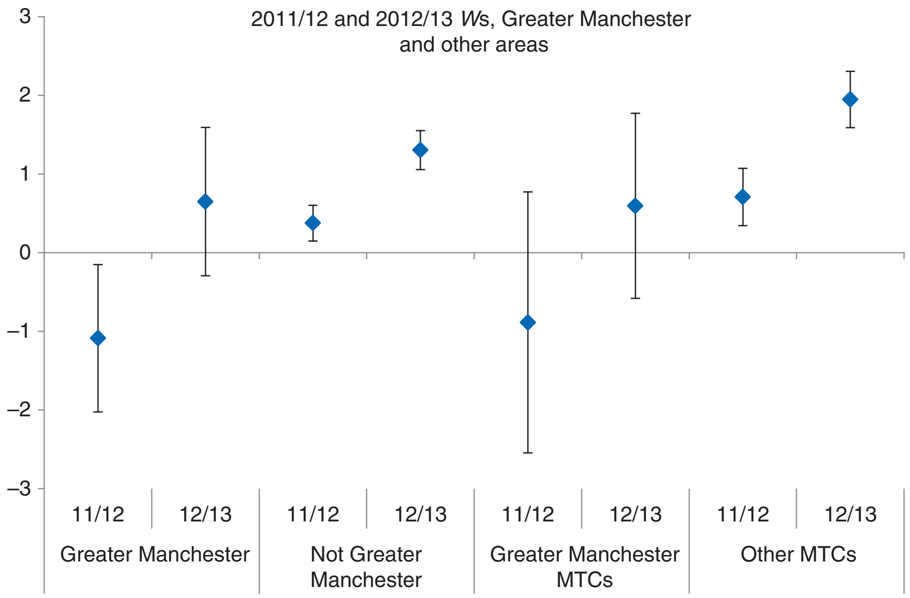

Fig 5 Time series comparisons of network and major trauma centre observed–expected mortality rates from TARN before and after trauma system configuration. [Observed– expected survival rates on the *Y*-axis for the financial year before (11/12) and after (12/13) the introduction of the new trauma networks in NHS England. Hospitals have been grouped into the Greater Manchester trauma network—far left, other trauma networks—centre left, Greater Manchester major trauma centres (MTCs)—centre right, and other MTCs—far right.]

neuroscience centres decreased from 33% to 19% over the 2003–9 time period with a halving in case fatality.[17] Trauma registries in other countries have had similar impact. The 2001–6 introduction of Victorian State Trauma System was also shown to have achieved 50% improvements in case-mix-adjusted survival using similar methodology to that described in Figure 5.[18] The German Trauma Registry has used similar case-mix adjustment to indicate the benefits of whole body CT scanning.[19]

Trauma registries: summary

In England and Wales, TARN is well established and is seen as a leader in the current international expansion of trauma registries.[20] Trauma registries are able to collate definitive injury descriptors and use survival prediction models to guide trauma system governance, through individual patient review and case-mix-adjusted benchmarking of hospital and network performance with robust outlier identification. Interrupted time series allow observation in the changes in care processes and outcomes at national level, which can feed back into clinical quality-based commissioning of healthcare.

The excellent case ascertainment often not present in routine hospital coding allows research on important subgroups of patients such as those with TBI which can lead to changes in care, guidelines, and observed improved survival. It is important that there is a robust system in place to ensure that all these observations are adjusted for important confounders and interpretation of data quality.

Declaration of interest

None declared.

Funding

No specific funding was received for the preparation of this manuscript. The Trauma Audit and Research Network (TARN) supports part salaries of FL and TC and wholly that of MW, OB and AE. TARN is funded by its member NHS and European hospitals by annual subscriptions.

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Handling editor: S. J. Howell