Trends in head injury outcome from 1989 to 2003 and the effect of neurosurgical care: an observational study

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Background Case fatality rates after all types of blunt injury have not improved since 1994 in England and Wales, possibly because not all patients with severe head injury are treated in a neurosurgical centre. Our aims were to investigate the case fatality trends in major trauma patients with and without head injury, and to establish the effect of neurosurgical care on mortality after severe head injury.

Methods We analysed prospectively collected data from the Trauma Audit and Research Network database for patients presenting between 1989 and 2003. Mortality and odds of death adjusted for case mix were compared for patients with and without head injury, and for those treated in a neurosurgical versus a non-neurosurgical centre.

Findings Patients with head injury (n=22,216) had a ten-fold higher mortality and showed less improvement in the adjusted odds of death since 1989 than did patients without head injury (n=154,231). 2305 (33%) of patients with severe head injury (presenting between 1996 and 2003) were treated only in non-neurosurgical centres; such treatment was associated with a 26% increase in mortality and a 2.15-fold increase (95% CI 1.77–2.60) in the odds of death adjusted for case mix compared with patients treated at a neurosurgical centre.

Interpretation Since 1989 trauma system changes in England and Wales have delivered greater benefit to patients without head injury. Our data lend support to current guidelines, suggesting that treatment in a neurosurgical centre represents an important strategy in the management of severe head injury.

Method

Patients We studied patients injured by blunt trauma between 1989 and 2003 who were treated by participating hospitals in the Trauma Audit and Research Network (TARN=60% of trauma receiving hospitals within England and Wales). TARN includes patients of any age who sustain injury resulting in immediate admission to hospital due to severe head injury.
hospitals for 3 days or longer, subsequent death, intensive or high dependency care, or interhospital transfer. Initial admitting data, including presenting age, Glasgow coma scale, blood pressure, and respiratory rate, were recorded on a standard data sheet by trained coders to calculate the revised trauma score (RTS, which is a measure of physiological derangement).\(^\text{14}\)

Participating hospitals removed all patient identifiers and sent data sheets to the TARN coordination centre at the University of Manchester. Every injury recorded was defined according to the abbreviated injury scale dictionary (AIS)\(^\text{15}\) before the data sheets were scanned into the TARN database. From these data, the injury severity score (ISS, which is a measure of the overall severity of anatomical injury from a combination of every patient’s AIS codes) could be calculated.\(^\text{16}\) Each hospital transfer led to the generation of a separate record, which was attached to the patient’s records from the initial presentation. Outcome in terms of survival or death was based on assessment at discharge or 30 days, whichever was first. Patients over 65 years of age with an isolated fracture of the femoral neck or pubic ramus and those with single uncomplicated limb injuries were prospectively excluded. Patients submitted to TARN but transferred to non-participating hospitals were subsequently excluded from this analysis.

For the temporal analysis, patients with an abnormal CT brain scan and those with a clinical compound/base skull fractures (ie, head injury severity of AIS >2) were identified as head injured patients. All other patients were regarded as not having sustained a significant head injury.

To study the effect of neurosurgical care on outcome, we undertook a later time series, when on-site CT scanning was available in all trauma-receiving hospitals. Therefore, head injured patients presenting between 1996 and 2003 with a Glasgow coma score of less than 9 or those intubated and ventilated on arrival, were defined as the severely head injured group. For this group, overall mortality in patients who received care at a neurosurgical centre (including those who had been transferred) was compared with patients who received all their care in hospitals without neurosurgical facilities on site.

Hospitals with and without neurosurgical facilities were identified from the TARN database. Patients with severe head injuries were further categorised on the basis of whether they had sustained a head injury injury that unequivocally did not need initial operative neurosurgical intervention. The need for such treatment was identified from the AIS code taken from the CT brain scan findings (ie, all AIS 3+ codes apart from those related to contusion, extradural, haematoma, intracerebral haematoma, subdural haematoma). Severe head injury was said to be isolated if there were no extracranial injuries of severity greater than AIS 1.

### Statistical analyses

A logistic regression model was used to calculate the 95% CI for the odds of death in each year (1990–2003), compared with the 1989 baseline for patients with head injury. The odds of death were adjusted for variations in ISS, RTS, and age of patients. These factors were entered as independent variables in the model. ISS and RTS were entered as continuous variables and age as a categorical variable (five bands: <55 years, 55–64 years, 65–74 years, 75–84 years, and >84 years). Patients with incomplete physiological data were included in a repetition of this analysis by allocation of a median RTS identical to that of patients with a similar ISS and known physiological indices.\(^\text{17}\) Linear regression was used to seek a yearly trend in the log odds of death. This process was repeated for patients without head injury.

Within the severely head injured group, we calculated with a logistic regression model the odds of death for patients treated in a non-neurosurgical centre (entered as a binary variable), with age, ISS, and RTS. To overcome bias caused by non-randomisation, we also included each patients’ propensity score as an independent variable in the logistic regression model. The propensity score is the conditional probability for a patient chosen randomly to be treated in a neurosurgical centre given their age, ISS, and RTS, and was calculated by a separate logistic regression analysis.\(^\text{18}\) We also did a subgroup analysis of patients with severe head injury aged 16–65 years who did not need surgery to indicate whether any outcome difference according to treatment centre could be attributed to non-operative care. Similar adjustments (to those previously stated) were made for any missing physiological data. The model enabled calculation of standardised observed–expected rates

<table>
<thead>
<tr>
<th>HI complete RTS</th>
<th>HI incomplete RTS</th>
<th>NHI complete RTS</th>
<th>NHI incomplete RTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>13 490</td>
<td>8726</td>
<td>107 282</td>
</tr>
<tr>
<td>Age (years, median, IQR)</td>
<td>34 (20–58)</td>
<td>29 (16–50)</td>
<td>43 (25–64)</td>
</tr>
<tr>
<td>Male (% 95% CI)</td>
<td>9905 (73%, 72–74)</td>
<td>6473 (74%, 73–75)</td>
<td>63 031 (58%, 58–58)</td>
</tr>
<tr>
<td>ISS (median, IQR)</td>
<td>20 (16–27)</td>
<td>25 (16–29)</td>
<td>9 (8–9)</td>
</tr>
<tr>
<td>Abnormal RTS (95% CI)</td>
<td>58% (57–59)</td>
<td>9% (9)</td>
<td></td>
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<tr>
<td>Number of deaths (%, 95% CI)</td>
<td>3437 (25%, 24–26%)</td>
<td>2732 (31%, 30–32%)</td>
<td>2651 (3%, 3)</td>
</tr>
</tbody>
</table>

HI=head injury, NHI=no head injury, RTS=revised trauma score. IQR=interquartile range. ISS=injury severity score. Complete=physiological data available for patients. Incomplete=RTS could not be calculated because physiological data missing for some patients.

Table 1: Injury, demographic, and mortality data for patients with head injury and without head injury
(Ws scores) of survivors with severe head injury in both groups.\textsuperscript{17} Logistic regression model performance was described in terms of area under the receiver operator curve (AROC).

TARN publishes quarterly Ws scores for all trauma cases to participating hospitals aiding clinical governance.\textsuperscript{2} This benchmarking activity is supported by the Healthcare Commission without specific informed patient consent or ethical approval because no patient identifiers are retained by TARN electronically or on paper. Data for this study came exclusively from the TARN database without author access to patient records and we used the same principles toward patient consent and ethical approval as described for the TARN benchmarking role.

### Results

22 216 patients (13% of 176 447 eligible patients) had a head injury AIS greater than 2. Patients with head injury were on average 9–14 years younger than those without such injury, although age ranges overlapped considerably. Head injured patients were much more likely to be male, have more severe injury, and have higher mortality (table 1) than those without head injury.

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Figure: Yearly odds of death compared with 1989 baseline adjusted for age, ISS, and RTS

Upper=patients with head injury (n=13 490). Lower=patients without head injury (n=107 282). Number of patients shown. Vertical bars=95% CI.

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The sponsor had no role in study design, data collection, data analysis, data interpretation, or the writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.
Patients with head injury constituted less than an eighth of the patients on the database. However, such injuries were present in 6169 (61%) of all deaths, and were associated with a ten-fold increase in mortality compared with patients without head injury.

There was a significant trend in odds of death adjusted for case mix for patients with head injury between 1989 and 2003 (1.5% reduction per year, p=0.008, AROC=0.91) (figure). However, all the actual reduction occurred before 1994, so the trend after 1994 was not significant (p=0.845). A similar but lesser trend was recorded when 8726 additional patients with incomplete RTS were included (0.1% reduction per year between 1989 and 2003, p=0.032, AROC=0.87).

In 2003 the odds of death (case mix adjusted) for patients without head injury was almost half that in 1989 (odds ratio 0.55; 95% CI 0.4–0.78, crude mortality 2.7%) (figure). The trend analysis showed a significant reduction of 2% per year in the odds of death adjusted for case mix (p=0.003, AROC 0.92). Although a 10% reduction by year occurred between 1989 and 1994 (p=0.05), the 1994–2003 trend was not significant (p=0.4). The trend remained significant after 46,949 patients with missing RTS were included (0.4% per year between 1989 and 2003; p=0.01, AROC=0.91).

6921 patients were identified as having had severe head injury between 1996 and 2003. Age, median Glasgow coma score, and ISS were much the same between the two groups (table 2). 53% (2677/4982) of patients presenting to a neurosurgical centre were less likely to have isolated head injury and to have normal blood pressure at first hospital presentation than those in a neurosurgical centre. Mortality was 26% higher than for those treated in neurosurgical centres (p=0.000). An additional 660 severe head injury patients were excluded because of a secondary transfer to non-TARN hospitals and consequent lack of outcome data. Their injury characteristics (median age 33, median ISS 16, median Glasgow coma score 5) were similar to the study group, making this exclusion unlikely to cause selection bias (data not shown).

The case mix adjusted odds of death after injury for patients with severe head injury with complete physiological data who were treated in a non-neurosurgical centre was 2.15 (95% CI 1.77–2.60, AROC=0.87) times that of patients who were treated in a neurosurgical centre. However, slightly fewer than 50% of these patients had a component of the RTS missing (not Glasgow coma score and usually respiratory rate). Imputing a median value for the RTS in such patients did not substantially change the result (2.39 [2.11–2.69, AROC 0.82]).

Ws scores for severe head injury (standardised observed–expected survival rates) were +6% (+1.5% to +8%) for neurological centres and −10% (−9 to −12%) for non-neurosurgical centres.

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<table>
<thead>
<tr>
<th>Number of patients</th>
<th>Neurosurgical centres</th>
<th>Non–neurosurgical centres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years, median, IQR)</td>
<td>28 (16–48)</td>
<td>34 (20–58)</td>
</tr>
<tr>
<td>Male (% 95% CI)</td>
<td>3448 (75%, 73–76)</td>
<td>1642 (73%, 69–73)</td>
</tr>
<tr>
<td>ISS (median, IQR)</td>
<td>25 (18–33)</td>
<td>26 (18–35)</td>
</tr>
<tr>
<td>GCS (median, IQR)</td>
<td>3 (3–6)</td>
<td>4 (3–6)</td>
</tr>
<tr>
<td>Isolated head injury (95% CI)</td>
<td>2054 (44%, 43–46)</td>
<td>899 (39%, 37–41)</td>
</tr>
<tr>
<td>SBP &lt;90 mm Hg (95% CI)</td>
<td>383 (8%, 8–9)</td>
<td>434 (10%, 7–20)</td>
</tr>
<tr>
<td>Transferred (95% CI)</td>
<td>2665 (58%, 56–59)</td>
<td>302 (11%, 12–14)</td>
</tr>
<tr>
<td>Deaths (95% CI)</td>
<td>1624 (35%, 34–37)</td>
<td>1406 (61%, 59–63)</td>
</tr>
</tbody>
</table>

SHI=severe head injury. GCS=Glasgow coma score. SBP=systolic blood pressure.

Table 2: Patient characteristics after severe head injury according to treatment centre

Discussion

In patients presenting with blunt trauma, we observed a ten-fold increased mortality in those who had sustained a head injury (of any severity visible on CT) compared with those who had not. Further, although substantial improvement in the odds of death adjusted for case mix was recorded from 1989 to 2003 in patients without head injury, a less pronounced improvement was seen in those with head injury. For patients with severe head injury, the overall mortality was 44%. This crude mortality was significantly higher (26% p=0.01) in the 33% of patients who were treated in a non-neurosurgical centre than in those who were treated in a neurosurgical centre.

The observational approach used to assess the effect of neurological care could be biased by case selection. In deciding whether to proceed with the analysis, we assessed whether 6000 patients with severe head injury could be randomised to different locations of care. We thought this randomisation process unlikely, since the CRASH trial recruited only 2000 patients with severe

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head injury (Glasgow coma score <9) over 4 years, despite a worldwide recruitment drive. Further, we acknowledge that routinely collected data might be useful for assessment of interventions, provided that they are of sufficient scope and quality, since they are likely to cover the range of conditions that interventions apply to, which is not always the case in randomised clinical trials. TARN has regularly used case-mix analysis to compare the effectiveness of trauma care in single or groups of hospitals across Europe. These differences between neurosurgical and non-neurosurgical outcomes are substantially larger than any previously recorded within TARN. The inclusion of propensity score in our analysis of the benefit of neurosurgical care is a valid method to keep bias to a minimum in this type of study.14

Current practice is such that patients who are not transferred to a neurosurgical centre have injuries deemed incompatible with life, or do not require operative neurosurgical treatment. Therefore, the differences in mortality might indicate good neurosurgical triage, which further justifies current practice, especially since pupillary responses (which help identify patients with non-survivable head injury) were not available. However, in this large study adjustment of case mix with other important prognostic factors such as age, RTS, and ISS20 supplemented by the use of propensity scores, we have shown that care in a non-neurosurgical centre was associated with a two-fold increase in odds of death, suggesting that the mortality data do indicate less than optimum outcomes. That patients with an isolated non-surgical severe head injury treated in a non-neurosurgical centre also had an almost two-fold increase in odds of death adjusted for case mix further suggests that this current neurosurgical triage practice is unsatisfactory.

Our study has some weaknesses, since the physiological data were incomplete in 40% of head injury cases and 30% of other cases. This scarcity of data was most commonly attributable to the absence of presenting respiratory rate recordings. However, the respiratory rate has the lowest weighting within the RTS, and our database modelling has shown it can be ignored within TRISS UK11 without loss of model integrity. Our adjustments for incomplete physiological data have been established in previous publications and have no material effect on the results when they allow all-case inclusion. Notably, the number of neurosurgical centres within TARN (and England and Wales) remained stable over the study period and severe head injury cases transferred out from TARN were similar in injury and demographic characteristics to those studied.

We have shown that only 53% of patients with severe head injury in England and Wales are transferred to receive neurosurgical or neurointensive care. 60% of hospitals receiving trauma patients submit data to TARN. Therefore, the national proportion of patients with severe head injury not treated in a neurosurgical centre might be different from this figure. However, national surveys lend support to the observation that a substantial proportion of patients with severe head injury are treated in units without neurosurgical facilities.12,13 Our odds of death estimate for centres without neurosurgical facilities is probably typical, since our membership comes from all regions of England and Wales, representing district general teaching hospitals and 50% of neurosurgical centres.

International reports of temporal trends have shown an overall reduction in age-adjusted mortality associated with traumatic brain injury, which does not accord with the trends we describe.12,21 However, these previous studies have shown a reduction in mortality secondary to penetrating brain injury, a small increase in mortality from fall-related head injuries, and no change in mortality related to road traffic accidents. This variance probably relates to the fact that our analysis was based on all patients with injury secondary to non-penetrating injury.

The lack of improvement in head injured patients is typified by the apparent overall lack of progress in head injury care, which is suggested by the failure to identify a single therapy to improve outcome despite over 250 randomised controlled trials.24 However, several studies have shown that the institution of packages of specialist neurosurgical or neurocritical care is associated with improved outcomes.25,26

The reason for the reluctance to accept and treat all head injuries in neurosurgical centres is unknown, and might indicate the lack of good quality data for the effect of neurosurgical care. Within Europe, decisions about the transfer of patients are often based on early initial CT scan findings and whether patients have a surgical lesion, and therefore are most likely to benefit from neurosurgical intervention.12,13 Admissions are also driven by the availability of the necessary facilities for neurosurgical intensive care. Therefore, patients with surgical lesions have justifiably been given preference because of the shortage of neurosurgical expertise in non-neurosurgical centres (most of which have intensive care facilities). However, non-surgical head injuries consist of up to 55% of patients with severe head injuries, and patients with non-surgical head injuries similarly have a high mortality to those with surgical lesions.27 Furthermore, contemporary studies have shown that protocol driven therapy based on intracranial pressure and cerebral perfusion targets in the specialist setting can improve outcome after severe head injury, even in patients with non-surgical injuries.27,28

Non-surgical lesions are generally accepted to evolve into those requiring neurosurgical intervention, and increasingly, interventions such as a decompressive craniectomy in patients with non-surgical head injury have been beneficial.29,30 Although monitoring of intracranial pressure is possible in non-neurosurgical
centres, such facilities are not widely available in the UK. There is also evidence that outcome after trauma in comatose patients is better in high volume centres than in those seeing fewer head injury patients, which argues against setting up protocols for monitoring of intracranial pressure in centres that on average treat less than 16 patients per year. These data are in accordance with our finding that care in a neurological centre is important for patients with a non-surgical head injury.

This analysis strongly suggests that improvement of care for patients with severe head injury represents the best strategy for reduction of case fatality in those hospitalised after blunt trauma (which has plateaued since 1994 in England and Wales) and that neurological or neurointensive care intervention is pivotal to such a strategy. The lack of evidence surrounding single neuroprotective interventions makes it unlikely that changes in care for patients with severe head injury in hospitals without neurosurgical services would deliver outcome improvements of the magnitude that could follow significant expansion in neurointensive care facilities. Therefore, in accordance with current guidelines all patients with severe head injury should be transferred to and treated in a setting with 24-hour neurosurgical facilities.

Conflict of interest statement
We declare that we have no conflict of interest

Acknowledgments
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Participating Hospitals since 1989
Addenbrooke’s Hospital Cambridge, Heatherwood & Wexham Park Hospital Slough, Rotherham District General Hospital, The Princess Royal Hospital Shropshire, Airedale General Hospital Yorkshire, Hillingdon Hospital Middlesex, Royal Albert Edward Infirmary Wigan, Torbay Hospital Devon, Arrow Park Hospital Merseyside, Hinchingbrooke Hospital Cambridgeshire, Royal Berkshire Hospital Reading, Trafford General Hospital Manchester, Ashford General Hospital Oxfordshire, Homerton Hospital London, Royal Bolton Hospital Farnworth, University Hospital Lewisham London, Atkinson Morley’s Hospital London, Hope Hospital Salford, Royal Cornwall Hospital Truro, University Hospital of Hartlepool, Barnsley District General Hospital Yorkshire, Hullersfield Royal Infirmary, Royal Devon & Exeter Hospital University Hospital, North Staffordshire, Basildon Hospital Essex, Hull Royal Infirmary North Humberside, Royal Gwent Hospital Newport, University Hospital of North Tees Cleveland, Basildon Hospital, James Cook 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Whiston Hospital Liverpool, City Hospital Birmingham, Lincoln County Hospital, Sandwell District General Hospital West Midlands, Williams Harvey Hospital Kent, Colchester General Hospital Essex, Maidstone General Hospital Kent, Scarborough Hospital North Yorkshire, Whiston Hospital Manchester, Conquest Hospital East Sussex, Manchester Royal Infirmary, Scunthorpe General Hospital South Humberside, Withybush General Hospital Dyfed, Countess of Chester Hospital, Medway Hospital Kent, Selly Oak Hospital Birmingham, Worcester Royal Infirmary, County Hospital Hereford, Milton Keynes Hospital, Sheffield Children’s Hospital, Worthing Hospital West Sussex, Coventry & Warwickshire Hospital, Morriston Hospital Swansea, Sedgefield & District Hospital County Durham, Wrexham Maelor Hospital Celyn, Craigavon Area Hospital Co Armagh, Nevill Hall Hospital Sussex, South Tyneside District Hospital Tyne & Wear, Wycombe Hospital High Bucks, Crawley Hospital West Sussex, Newark General Hospital, Southampton General Hospital, Wythenshawe Hospital Manchester, Cumberland Infirmary Cumbria, Norfolk & Norwich General Hospital, Southend District General Hospital, York District Hospital, Daisy Hill Hospital County Down Northern Ireland, North Manchester General Hospital, Southmead Hospital Bristol, Ysbyty Gwynedd District General Darrent Valley Hospital Kent, North Tyneside General Hospital Tyne & Wear, Southport & Formby District General Hospital, Derbyshire Royal Infirmary, Northampton General Hospital, St Bartholomew’s Hospital London, Deriford Hospital Plymouth, Norwich General Hospital Sheffield, St George’s Hospital London, Dewsbury District Hospital Yorkshire, Northwick Park Hospital Middlesex, St Helier Hospital Surrey, Daire Princess of Wales Children’s Hospital Birmingham, Northampton University Hospital, St James’ University Hospital Leeds, Diana, Princess of Wales Hospital South Humberside, Ormskirk & District Hospital, St Mary’s Hospital London, Doncaster Royal Infirmary, 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References