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.**

Introduction

The recorded 40% reduction in odds of dying (adjusted for case mix) after major trauma between 1989 and 1994 has been attributed to improvements in hospital care; specifically, implementation of recommendations from the Royal Colleges, increased involvement of senior medical staff, and improved integration of trauma services.[1] Unfortunately, a continuing reduction in mortality, or a change in the process of care has been not been apparent since 1994.[2] Head injury remains an important factor in the cause of death and disability after trauma.[2,3]

Most head injury deaths occur in those presenting in coma (Glasgow coma score less than 9). In the UK, neurosurgeons have the main responsibility for treating such patients. Since 1948, neurosurgical care in the UK has been confined to regional neurosurgical centres, necessitating hospitals without neurosurgical services on site to seek advice for management (including the need for transfer) of severely head injured patients.[4,5] Within US and Canadian trauma systems, most patients with severe head injuries are taken directly to an appropriate trauma centre with neurosurgical facilities on site. However, trauma system coverage is not ubiquitous in Europe or North America, and not all trauma centres offer 24-hour neurosurgical cover.[6–9] This situation suggests that throughout the developed world many patients with severe head injuries are initially managed in facilities without continuous access to neurosurgical care.

Treatment of patients with severe head injury in neurosurgical centres is driven by guidelines. The initial 1984 guidelines recommended treatment based on early identification and intervention for neurosurgical mass lesions (eg, extradural haematoma, subdural haematoma).[10] This approach was justified by a review of a 1980s head injury cohort that suggested a low rate of apparently preventable deaths from severe head injury in patients not transferred to neurosurgical centres.[11] However, contemporary guidelines have recommended that all patients with a severe head injury should be treated in a neurosurgical centre.[3] Despite these updated recommendations, many patients with a severe head injury, particularly those without surgical lesions, are currently not treated in or transferred to a neurosurgical centre.[12,13]

We wished to establish whether case fatality trends were the same in major trauma patients with and without head injury. Our collaboration, which represents the largest trauma registry in Europe, compared the odds of death (adjusted for case mix) in patients with severe head injury managed in neurosurgical centres as opposed to hospitals without neurosurgical services on site, within the context of reporting temporal odds of death trends.

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 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).[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)[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.[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 indicies.[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.[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

	HI complete RTS	HI incomplete RTS	NHI complete RTS	NHI incomplete RTS
Number of patients	13 490	8726	107 282	46 949
Age (years, median, IQR)	34 (20–58)	29 (16–50)	43 (25–64)	43 (23–65)
Male (%, 95% CI)	9905 (73%, 72–74)	6473 (74%, 73–75)	63 031 (58%, 58–59)	25 505 (54%, 53–54)
ISS (median, IQR)	20 (16–27)	25 (16–29)	9 (8–9)	9 (5–9)
Abnormal RTS (95% CI)	58% (57–59)		9% (9)	
Number of deaths (%, 95% CI)	3437 (25%, 24–26);	2732 (31%, 30–32);	2651 (3%, 3);	1319 (3%, 2–3);

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**

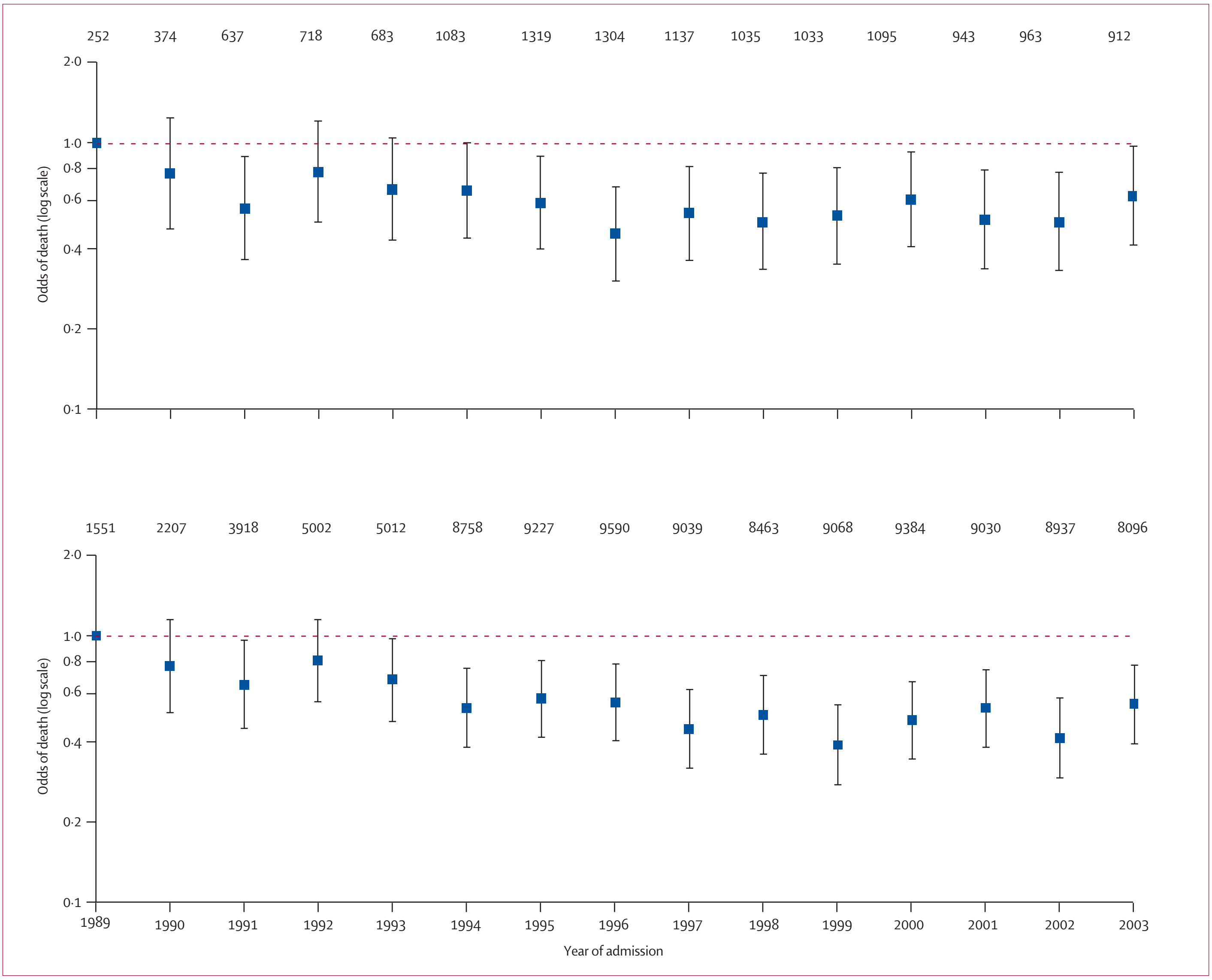

Figure: **Yearly odds of death compared with 1989 baseline adjusted for age, ISS, and RTS**
Upper=patients with head injury (n=13 490). Lower=patients without head injury (n=107 282). Number of patients shown. Vertical bars=95% CI.

(Ws scores) of survivors with severe head injury in both groups.[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.[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.

Role of the funding source
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

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.

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 non-neurosurgical centre were transferred to a neurosurgical centre (table 2). Patients treated in a non-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% (+5% to +8%) for neurosurgical centres and −10% (−9 to −12%) for non-neurosurgical centres.

	All SHI patients n=6921 (age 16–65)	
	Neurosurgical centres	Non–neurosurgical centres
Number of patients	4616	2305
Age (years, median, IQR)	28 (16–48)	34 (20–58)
Male (%, 95% CI)	3448 (75%, 73–76)	1642 (71%, 69–73)
ISS (median, IQR)	25 (18–33)	26 (18–35)
GCS (median, IQR)	3 (3–6)	4 (3–6)
Isolated head injury (95% CI)	2054 (44%, 43–46)	899 (39%, 37–41)
SBP <90 mm Hg (95% CI)	383 (8%, 8–9)	434 (19%, 17–20)
Transferred (95% CI)	2665 (58%, 56–59)	302 (13%, 12–14)
Deaths (95% CI)	1624 (35%, 34–37)	1406 (61%, 59–63)
Isolated, non-surgical SHI n=894 (age 16–65)		
Number of patients	552	342
Age (years, median, IQR)	33 (23–47)	31 (22–46)
ISS (median, IQR)	16 (10–25)	16 (10–25)
GCS (median, IQR)	4 (3–7)	5 (3–7)
SBP <90 mm Hg (%, 95% CI)	21 (4%, 2–5)	29 (9%, 6–12)
Patients transferred (%, 95% CI)	311 (56%, 52–60)	23 (7%, 4–9)
Deaths (%, 95% CI)	142 (26%, 22–29)	118 (34%, 29–40)

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

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

Patients (aged 16–65 years) with an isolated non-surgical head injury treated in a non-neurosurgical centre had a similar median age, Glasgow coma score, and ISS, to those treated in a neurosurgical centre. An 8% (p=0·005) mean increase in mortality was seen in patients treated in a non-neurosurgical centre versus those treated at a neurosurgical centre (table 2), and the adjusted odds of death in patients with complete data treated in a non-neurosurgical centre was 1·92 (1·11–3·30, AROC 0·87) times that of patients in a neurosurgical centre. These findings were again unchanged (2·08 [1·42-3·02]) when a median value for the RTS was inserted for patients with incomplete data to enable their inclusion in the model.

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 neurosurgical 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[19] recruited only 2000 patients with severe 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.[18]

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 ISS[20] 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 UK[21] 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.[1] 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.[22,23] 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.[5,11] Admissions are also driven by the availability of the necessary facilities for neurosurgical intensive care.[5] 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.[25,26]

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.[28,29] Although monitoring of intracranial pressure is possible in non-neurosurgical centres, such facilities are not widely available in the UK.[13] 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.[30] These data are in accordance with our finding that care in a neurosurgical 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 neurosurgical 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

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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, Arrowe Park Hospital Merseyside, Hinchingbrooke Hospital Cambridgeshire, Royal Berkshire Hospital Reading, Trafford General Hospital Manchester, Ashford General Hospital London, 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, Huddersfield 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, Bassetlaw Hospital Nottinghamshire, Ipswich Hospital Suffolk, Royal Hallamshire Hospital Sheffield, University Hospital of Wales Cardiff, Bedford Hospital, James Cook University Hospital Cleveland, Royal Hampshire County Hospital Winchester, University Hospital, Aintree Liverpool, Birmingham Heartlands Hospital, James Paget Hospital Norfolk, Royal Lancaster Infirmary, Walton Centre for Neurology Liverpool, Blackburn Royal Infirmary Lancashire, Jersey General Hospital, Royal Liverpool Childrens Hospital (Alder Hey), Wansbeck General Hospital Northumberland, Blackpool Victoria Hospital, John Coupland Hospital Royal Liverpool University Hospital, Warrington Hospital Cheshire, Booth Hall Children's Hospital Manchester, John Radcliffe Hospital Oxon, Royal London Hospital, Warwick Hospital Warwick, Bradford Royal Infirmary Yorkshire, Kent & Canterbury Hospital, Royal Manchester Children's Hospital Pendlebury, Waterford Regional Hospital Ireland, Bristol Royal Infirmary, Kent & Sussex Hospital, Royal Oldham Hospital, Watford General Hospital Herts, Bromley Hospital Kent, Kettering General Hospital Northamptonshire, Royal Preston Hospital, West Cumberland Hospital Cumbria, Broomfield Hospital Essex, Kings College Hospital London, Royal Shrewsbury Hospital Shropshire, West Middlesex University Hospital, Burnley General Hospital, Kings Mill Hospital Nottinghamshire, Royal Surrey County Hospital, West Wales General Hospital Dyfed, Calderdale Royal Hospital Halifax, Leeds General Infirmary Royal Sussex County Hospital Brighton, Weston General Hospital Avon, Cheltenham General Hospital, Leicester Royal Infirmary, Royal United Hospital Bath, Weymouth & District Hospital Dorset, Chesterfield & Nth Derbyshire Royal Hospital, Leigh Infirmary, Royal Victoria Hospital, Belfast N Ireland, Whipps Cross Hospital London, Chorley District General Hospital, Leighton Hospital Cheshire, Royal Victoria Infirmary, Newcastle Upon Tyne, Whiston Hospital Liverpool, City Hospital Birmingham, Lincoln County Hospital, Sandwell District General Hospital West Midlands, William Harvey Hospital Kent, Colchester General Hospital Essex, Maidstone General Hospital Kent, Scarborough Hospital North Yorkshire, Withington 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, Skegness & District Hospital Lincolnshire, Wrexham Maelor Hospital Clwyd, Craigavon Area Hospital Co Armagh, Nevill Hall Hospital Wales, South Tyneside District Hospital Tyne & Wear, Wycombe Hospital High Bucks, Crawley Hospital West Sussex, Newcastle General Hospital, Southampton General Hospital, Wythenshawe Hospital Manchester, Cumberland 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Middlesex, Pilgrim Hospital Lincs, St Thomas' Hospital London, East Surrey Hospital Redhill Surrey, Pinderfields General Hospital Wakefield, Stepping Hill Hospital Stockport, Eastbourne District General Hospital East Sussex, Pontefract General Infirmary, Stoke Mandeville Hospital Buckinghamshire, Epsom Hospital Surrey, Queen Elizabeth Hospital Kings Lynn, Sunderland Royal Hospital, Fairfield General Hospital Bury, Queen Elizabeth, Queen Mother Hospital Kent, Tameside General Hospital Ashton Under Lyne, Hammersmith Hospital London, Regional Spinal Injuries Unit Southport Merseyside, Taunton & Somerset Hospital, Harrogate District Hospital Yorkshire, Rochdale Infirmary Lancashire, The Horton Hospital Oxfordshire.

References

1 Lecky F, Woodford M, Yates DW. Trends in trauma care in England and Wales 1989–97. UK Trauma Audit and Research Network. *Lancet* 2000; **355:** 1771–75

2 Lecky FE, Woodford M, Bouamra O, Yates DW. Lack of change in trauma care in England and Wales since 1994. *Emerg Med J* 2002; **19:** 520–23

3 Royal College of Surgeons. Report of the working party on the management of patients with head injury. London, UK: The College, 1999.

4 Cairns HWB, Jefferson G, Dott N. Notes on the neurosurgical needs of the population and the training of the neurosurgeon. Report from the planning committee of the Society of British neurological surgeons 1945–1947. Manchester UK: Hotspur Press, 1947.

5 Crimmins DW, Palmer JD. Snapshot view of emergency neurosurgical head injury care in Great Britain and Ireland. *J Neurol Neurosurg Psychiatry* 2000; **68:** 8–13.

6 Hesdorffer DC, Ghajar J, Iacono L. Predictors of compliance with the evidence-based guidelines for traumatic brain injury care: a survey of United States trauma centers. *J Trauma* 2002; **52:** 1202–09.

7 MacKenzie EJ. Review of evidence regarding trauma system effectiveness resulting from panel studies. *J Trauma* 1999; **47:** S34–S41.

8 Sampalis JS, Lavoie A, Boukas S, et al. Trauma center designation : initial impact on trauma-related mortality. *J Trauma* 1995; **39:** 232–37.

9 Sherman HF, Landry VL, Jones LM. Should Level I trauma centers be rated NC-17? *J Trauma* 2001; **50:** 784–91.

10 Guidelines for initial management after head injury in adults. Suggestions from a group of neurosurgeons. *Br Med J (Clin Res Ed)* 1984; **288:** 983–85.

11 Gentleman D, Jennett B, MacMillan R. Death in hospital after head injury without transfer to a neurosurgical unit: who, when, and why? *Injury* 1992; **23:** 471–74.

12 Matta B, Menon D. Severe head injury in the United Kingdom and Ireland: a survey of practice and implications for management. *Crit Care Med* 1996; **24:** 1743–48.

13 McKeating EG, Andrews PJ, Tocher JI, Menon DK. The intensive care of severe head injury: a survey of non-neurosurgical centres in the United Kingdom. *Br J Neurosurg* 1998; **12:** 7–14.

14 Champion HR, Sacco WJ, Copes WS, Gann DS, Gennarelli TA, Flanagan ME. A revision of the Trauma Score. *J Trauma* 1989; **29:** 623–29

15 Committee on Injury Scaling, Association for the advancement of automotive medicine. The Abbreviated injury scale 1990 revision. Des Plaines, Illinois: 1990.

16 Baker SP, O'Neill B. The injury severity score : an update. *J Trauma* 1976; **16:** 882–85.

17 Hollis S, Yates DW, Woodford M, Foster P. Standardized comparison of performance indicators in trauma: a new approach to case-mix variation. *J Trauma* 1995; **38:** 763–6

18 'Agostino Jr RB. Propensity score methods for bias reduction in the comparison of a treatment to a non-randomized control group. *Stat Med* 1998; **17:** 2265–81.

19 CRASH Trial Collaborators. Effect of intravenous corticosteroids on death within 14 days in 10 008 adults with clinically significant head injury (MRC CRASH trial): randomised placebo-controlled trial. *Lancet* 2004; **364:** 1321–28.

20 The Brain Trauma Foundation. The American Association of Neurological Surgeons. The Joint Section on Neurotrauma and Critical Care. Trauma systems. *J Neurotrauma* 2000; **17:** 457–62.

21 The Trauma Audit and Research Network. Ps/04. http://www.tarn.ac.uk/resources/modelsummary.htm

22 Adekoya N, Thurman DJ, White DD, Webb KW. Surveillance for traumatic brain injury deaths—United States, 1989–1998. *MMWR Surveill Summ* 2002; **51:** 1–14.

23 Gennarelli TA, Champion HR, Sacco WJ, Copes WS, Alves WM. Mortality of patients with head injury and extracranial injury treated in trauma centers. *J Trauma* 1989; **29:** 1193–201.

24 Narayan RK, Michel ME, Ansell B, et al. Clinical trials in head injury. *J Neurotrauma* 2002; **19:** 503–57.

25 Patel HC, Menon DK, Tebbs S, Hawker R, Hutchinson PJ, Kirkpatrick PJ. Specialist neurocritical care and outcome from head injury. *Intensive Care Med* 2002; **28:** 547–53.

26 Stocchetti N, Rossi S, Buzzi F, Mattioli C, Paparella A, Colombo A. Intracranial hypertension in head injury: management and results. *Intensive Care Med* 1999; **25:** 371–76.

27 Marshall LF, Gautille T, Klauber MR, et al. The outcome of severe closed head injury. *J Neurosurg* 1991; **75:** S28–S36.

28 Piek J. Decompressive surgery in the treatment of traumatic brain injury. *Curr Opin Crit Care* 2002; **8:** 134–38.

29 Whitfield PC, Patel H, Hutchinson PJ, et al. Bifrontal decompressive craniectomy in the management of posttraumatic intracranial hypertension. *Br J Neurosurg* 2001; **15:** 500–07.

30 Nathens AB, Jurkovich GJ, Maier RV, et al. Relationship between trauma center volume and outcomes. *JAMA* 2001; **285:** 1164–71