Selecting children for head CT following head injury

A Kemp,1 E Nickerson,1 L Trefan,1 R Houston,2 P Hyde,3 G Pearson,4 R Edwards,5 RC Parslow,6 I Maconochie7

ABSTRACT
Objective Indicators for head CT scan defined by the 2007 National Institute for Health and Care Excellence (NICE) guidelines were analysed to identify CT uptake, influential variables and yield.
Design Cross-sectional study.
Setting Hospital inpatient units: England, Wales, Northern Ireland and the Channel Islands.
Patients Children (<15 years) admitted to hospital for more than 4 h following a head injury (September 2009 to February 2010).
Interventions CT scan.
Main outcome measures Number of children who had CT, extent to which NICE guidelines were followed and diagnostic yield.
Results Data on 5700 children were returned by 90% of eligible hospitals, 84% of whom were admitted to a general hospital. CT scans were performed on 30.4% of children (1734), with a higher diagnostic yield in infants (<1-year-old) than older children.
Conclusion Compliance with guidelines and diagnostic yield was variable across age groups, the type of hospital and region where children were admitted. With this pattern of clinical practice the risks of both missing intracranial injury and overuse of CT are considerable.

INTRODUCTION
Every year an estimated 400 000 children younger than 15 years attend the emergency department with head injury and 35 000 children are admitted to hospital (International Classification of Diseases, Revision 10:S00-02, S06-09) in England. Although the majority of these head injuries are minor, an estimated 5% of those who are admitted to hospital sustain intracranial injuries (ICIs)1,2. Early head CT has high diagnostic specificity for ICI1 and there are several clinical decision rules to determine which children should be imaged.3,4 The Children’s Head Injury Algorithm for the Recognition of Important Clinical Events (CHALICE)5 underpins the National Institute for Health and Care Excellence (NICE) Head Injury Guidelines 2007 (figure 1) (updated in 2014) which aims to identify clinically important brain injury to ensure early intervention while allowing those at low risk to be discharged without investigation, avoiding unnecessary exposure to radiation and cost to the healthcare service.

In 2009, as part of the child health confidential enquiry programme, the Centre for Maternal and Child Enquiries (CMACE) was commissioned by the Department of Health and the funding bodies of Wales, Northern Ireland, the Channel Isles and the Isle of Man to review morbidity and mortality in children admitted to hospital with head injury, to review the effect of early management on outcomes and to identify avoidable factors associated with adverse outcomes. The aim of this analysis was to explore the extent to which children with head injury were investigated with head CT, to identify factors that influenced the rate of CT uptake and yield and to compare practice against the NICE clinical guidelines.

METHODS
Data for this cross-sectional study of children younger than 15 years who were admitted for more than 4 h with a head injury were collected from 90% of hospitals in England, Wales, Northern Ireland and the Channel Islands from September 2009 to February 2010. Children who received any treatment or observation in a hospital inpatient area were included, whereas those with superficial or facial injuries were excluded.

Data were collected using proformas (see online supplementary appendix 1) completed by a...
designated local coordinator and collected monthly from each participating hospital. Data fields that were less than 75% complete were excluded from the analysis.

Data recorded included demographics, clinical information, type and healthcare region of the admitting hospital. Hospitals were categorised according to the specialist facilities offered and the designation of major trauma centres introduced in April 2012: General Hospital (GH); Children’s Hospital with paediatric intensive care unit (PICU); Adult Major Trauma Centre; Adult and Children’s Major Trauma Centre and Children’s Major Trauma Centre.8 Descriptions of injury mechanisms were coded as listed in table 1 and cases of suspected physical abuse were documented. The level of consciousness was recorded according to the Glasgow Coma Scale (GCS)9 reported in the emergency department. When GCS was missing, Alert, Voice, Pain, Unresponsive (AVPU) scores10 were often available. These data were combined to create four categories, ‘GCS=15/Alert’, ‘GCS=13–14’, ‘GCS=9–12/responsive to voice’ and ‘GCS≤8/response to pain or unresponsive’, based on an equivalence study by Mackay et al.11

ICI and/or skull fracture sustained were documented from radiology reports. CT results were grouped into four categories: normal; ICI (injury to the brain or surrounding extra-axial structures, with or without skull fractures) or depressed fracture; simple skull fracture (a linear non-depressed fracture with no

| Mechanism of injury | Total | Proportion who had CT (n) | Median age (years) | CT result ; CT scans that were abnormal (%) (n) |
|---------------------|-------|--------------------------|--------------------|-----------------------------------------------|
|                     |       | (range)                  |                    | Missing (n) | Normal | ICI and/or # | Simple # | Other  |
| Assault             | 118   | 33.9% (40)               | 13 (0–14.9)        | 8          | 45% (18) | 25% (10) | 5% (2)   | 5% (2)  |
| Cycling             | 267   | 43.8% (117)              | 11.5 (8.0–14.8)    | 9          | 70% (82) | 17.1% (20) | 4.3% (5) | 0.9% (1) |
| Fall from <1 m or <5 stairs | 1822 | 22% (402)               | 2.1 (0–14.9)       | 40         | 65.7% (264) | 11.2% (45) | 10.7% (43) | 2.5% (10) |
| Fall from >1 m or >5 stairs | 994  | 30.3% (301)             | 2.1 (0–14.8)       | 22         | 62.1% (187) | 18.6% (56) | 9% (27)   | 3% (9)  |
| Fall, height unknown | 673  | 30.2% (204)             | 4.2 (0.1–14.9)     | 21         | 65.7% (134) | 11.8% (24) | 10.3% (21) | 2% (4)   |
| MVA (not pedestrian)| 88    | 54.5% (48)              | 6.5 (0–14.9)       | 2          | 56.3% (27) | 31% (15)  | 4.2% (2)   | 4.2% (2) |
| MVA: struck by car (child cyclist) | 35  | 51.4% (18)              | 12.2 (1–14.9)      | 0          | 44.4% (6)  | 33.3% (6)  | 22.2% (4) | 0 |
| MVA: struck by car (child pedestrian) | 273 | 55.8% (158)             | 11.3 (0–14.9)      | 22         | 49.4% (78) | 23.4% (37) | 8.9% (14) | 4.4% (7) |
| Impact injuries     | 684   | 25.4% (174)             | 3.7 (0.1–14.8)     | 15         | 72.4% (126) | 10.3% (18) | 6.9% (12) | 1.7% (3) |
| Other recreational  | 150   | 39.3% (59)              | 8.7 (6.4–14.9)     | 5          | 61% (36)  | 15.3% (9)  | 11.9% (7) | 3.4% (2) |
| Sport               | 358   | 44.4% (159)             | 12.4 (0–14.9)      | 10         | 79.2% (126) | 8.8% (14)  | 3.1% (5)   | 2.5% (4) |
| Not known           | 112   | 52% (54)                | 1.4 (0–14.7)       | 6          | 43.4% (23) | 28.3% (15) | 11.1% (6) | 7.5% (4) |
| Total               | 5574  | 31.1% (1734)            |                     | 160        | 64% (1109) | 15.5% (269) | 8.5% (148) | 2.8% (48) |

A total of 126 cases were excluded as it was not known if CT scan was performed. ICI, intracranial injury; MVA, motor vehicle accident.

NICE recommendations for when to request a CT immediately if < 16 years
- Witnessed loss of consciousness lasting > 5 minutes
- Amnesia (antegrade or retrograde) lasting > 5 minutes
- Abnormal drowsiness
- Three or more discrete episodes of vomiting
- Clinical suspicion of non-accidental injury
- Post-traumatic seizure but no history of epilepsy
- Age > 1 year: GCS < 14 on assessment in the emergency department
- Age < 1 year: GCS (paediatric) < 15 on assessment in the emergency department
- Suspicion of open or depressed skull injury or tense fontanelle
- Any sign of basal skull fracture
- Focal neurological deficit
- Age < 1 year: presence of bruise, swelling or laceration > 5cm on head
- Dangerous mechanism of injury (high-speed road traffic accident either as pedestrian, cyclist or vehicle occupant, fall from > 3m, high-speed injury from a projectile or an object)
underlying ICI) and ‘other’ (incidental findings (eg, subarachnoid cysts, congenital anomalies)).

Data analysis

The proportion of children (with 95% CIs) with each of the following four NICE guideline indicators who had a CT scan is described: GCS of <15 for those <1 year, and of <14 for those >1 year of age, loss of consciousness, suspicion of non-accidental injury (NAI), dangerous mechanism of injury (motor vehicle accident (MVA), high fall). The extent to which individual indicators were predictors of abnormal CT was calculated. Children were identified who had at least one of these indicators and the observed:expected ratios (based on the 2007 NICE guidance) of CT were plotted on funnel plots according to the age of the child, hospital type and Health Commissioning Board for England and the regions of Wales and Northern Ireland. The time to CT scan, the duration of admission and the number of eligible for CT, only 50% (35/70) had the investigation, of whom 72% (95% CI 55% to 84%) (25/35) were abnormal. Of infants who had a GCS of 15/Alert, 20.7% (181/876) had CT and 53% (95% CI 46% to 60%) (96/181) had an abnormality recorded. For children older than 1 year, a total of 293 children had a GCS <14 (or AVPU of V, P or U), 77% (225/293) had a CT and 47% (95% CI 41% to 54%) (106/225) had an abnormality detected; for children with a GCS of 14–15 or ‘Alert’, 30% (1170/3922) had a CT and the positive yield was 23% (95% CI 20% to 25%) (264/1170).

RESULTS

A total of 5700 children were included in the study (median age 49 months) (figure 2). Peak prevalence was in infants younger than 1 year. The majority of children 84% (4768) were admitted to a GH, 3.4% of children (191) to a hospital equivalent to a children’s major trauma centre, 7.3% of children (417) to an Adult and Children’s Major Trauma Centre, 3.3% of children (160) to a hospital designated an Adult Major Trauma Centre and 3.3% of children (164) to a Children’s Hospital with PICU.

Overall 30% (1734) of the children had a head CT. This was performed at a median time of 1.5 h (range 0–35.8 h) after the first clinical assessment in the emergency department, 33% (297) were done within an hour. The time to CT scan was shorter in those with GCS of <15 (median time: GCS 15–100 min, GCS 13–14=69 min, GCS 9–12=72 min, GCS ≤8=65 min). All except 10 of the 385 children who were transferred to a second hospital had a CT scan in the first hospital. Two-thirds (64% (1109/1734)) of CT scans were reported as normal, 15% (269) had ICI or depressed fracture, 8.5% (148) a simple fracture and 2.8% (48) had other findings (results were missing 9% (160)).

The proportion of children who had a CT scan varied by mechanism of injury and was greatest for children who had experienced a MVA. These children were most likely to have an abnormality on CT scan (table 1). Children who had low falls were least likely to have a CT or an abnormal CT (table 1).

Child abuse was suspected in 256 cases; 48% (122) had a CT scan, 36% (44/122) of whom had ICI or depressed fracture and 15% (18/122) had a simple skull fracture. The majority of these children (82% (36/44)) were aged <1 year.

The GCS/AVPU score was recorded in the emergency department for 5168 children (91%) (GCS in 4182 children and AVPU in 986 children). Tables 2 and 3 confirm that the majority, 79% of children (4522) had a ‘GCS of 15/Alert’. CT scan was more likely to be performed in older children and in children with a greater level of impaired consciousness (table 2). Of the 70 infants (<1 year) who had a GCS of <15/Alert and were eligible for CT, only 50% (35/70) had the investigation, of whom 72% (95% CI 55% to 84%) (25/35) were abnormal. Of infants who had a ‘GCS of 15/Alert’, 20.7% (181/876) had CT and 53% (95% CI 46% to 60%) (96/181) had an abnormality recorded. For children older than 1 year, a total of 293 children had a GCS <14 (or AVPU of V, P or U), 77% (225/293) had a CT and 47% (95% CI 41% to 54%) (106/225) had an abnormality detected; for children with a GCS of 14–15 or ‘Alert’, 30% (1170/3922) had a CT and the positive yield was 23% (95% CI 20% to 25%) (264/1170).

Table 2

| Age (years) | GCS<15 | 1–4 | 5–9 | 10–14 | Missing age | Total |
|-------------|--------|-----|-----|-------|-------------|-------|
| GCS<15 AVPU='U' or 'P' | 13/18 (72%) | 25/38 (66%) | 15/16 (94%) | 37/39 (95%) | 0 | 90/111 (80%) |
| GCS 9–12 AVPU='V' | 6/13 (46%) | 26/42 (62%) | 28/34 (82%) | 42/52 (81%) | 1/1 | 103/142 (72%) |
| GCS 13–14 | 16/39 (41%) | 39/93 (42%) | 64/87 (74%) | 139/174 (80%) | 0 | 258/393 (66%) |
| GCS=15 AVPU=A | 181/876 (20.7%) | 316/1652 (19%) | 261/891 (29%) | 403/1096 (37%) | 2/7 | 1163/4522 (26%) |
| GCS/AVPU not recorded in the notes | 39/147 (26.5%) | 29/217 (13.4%) | 18/82 (22%) | 34/86 (39.5%) | 0 | 120/532 (22.6%) |
| Total | 255/1059 (23%) (21–26) | 435/2042 (21%) (20–23) | 386/1110 (35%) (32–37.6) | 655/1447 (45%) (42.7–47.8) | 3/8 | 1734/5700 (30.4%) |

AVPU, Alert, Voice, Pain, Unresponsive; GCS, Glasgow Coma Scale.
Loss of consciousness at the time of the incident was recorded in 18% of children (1018/5700); however, the duration was not recorded. Of these children, 47% (474/1018) had a CT scan, 37% (177/474) were abnormal, 37% (66/177) had ICI or a depressed fracture, 39% (70/177) a simple fracture, 7.9% (14/177) had other findings and 15% (27/177) had abnormal findings but details were not recorded.

At least one of the following four indicators (NICE guidelines) for a CT scan was present in 2437 children; GCS <15 and/or cases or severe neuroimaging; NICE guidelines were therefore not followed in the children who did not have a CT at their first attendance (6.5% (259/ 3966)) than those who did (0.3% (6/1734)) (OR 20 (95% CI 6.3% to 259/ 3966)). The mortality rate among those who died at the scene of incident or while in the emergency department prior to having a CT. The mortality rate among those who had a CT scan was 7.5% (13/1734).

In total, 4.6% of the children (265) were readmitted within 72 h of their first presentation for the same head injury (median age 5 years). Of these, six had a CT scan on first admission, all were normal apart from one child who had a facial fracture, four of the six children were scanned with no change to the findings. Ninety children (34%) had a CT scan for the first time on their second admission, 34% (32/ 396) were abnormal (six simple fractures, 21 ICI with or without a skull fracture or depressed fractures, five had other findings). There was no significant difference between the age distribution of these cases and the overall dataset. The re-attendance rate was significantly greater for those children who did not have a CT at their first attendance (6.5% (259/ 3966)) than those who did (0.3% (6/1734)) (OR 20 (95% CI 8.9 to 45)).

**DISCUSSION**

One-third of children admitted to hospital with head injury had a CT scan, 15.5% of whom had traumatic brain injury or depressed fracture. However, 60% of children who had at least one of four NICE guideline indicators did not have any neuroimaging; NICE guidelines were therefore not followed in the majority of cases. CT scan rates were particularly low in children younger than 3 years and those admitted to GHS. The latter showed a strong regional variation.

This is the largest national dataset to evaluate adherence to NICE head injury guidelines for neuroimaging. The study has several limitations. Data were collected from multiple centres. However, the same proforma was used in all centres and data were extracted at each centre by a dedicated local coordinator to ensure a standardised approach. The data collection only included a proportion of the indicators for a CT scan cited in NICE guidelines 2007 and we were unable to analyse how seizures, amnesia, more than three discrete episodes of vomiting, focal neurology or facial bruising influenced CT scan rates.

There were missing data and data inconsistencies that had to be accounted for. The main data fields analysed were more than 90% complete and unlikely to affect the statistical significance of the results provided. The population within this study was confined to hospital admissions of more than 4 h duration. It must be appreciated that this population represents a proportion

**Clinical pathways and outcomes**

Children who had normal CT findings spent significantly longer periods (mean: 23.9 h (SD = 37.6 h)) in hospital under observation than those who did not have CT (mean 14.7 h (SD = 29.2 h)) (p≤0.05). Children with ICI or depressed fracture spent a mean of 88.5 h (SD 120.9 h) in hospital; those with a simple fracture spent 45.2 h (SD 40.6 h) and those with other findings spent 63.5 h (SD 142.6 h). About 1% (57) of children were admitted for treatment to neurosurgery units. Twenty-four children died (0.4%). Fourteen deaths were from MVAs, 11 died at the scene of incident or while in the emergency department prior to having a CT. The mortality rate among those who had a CT scan was 7.5% (13/1734).

In total, 4.6% of the children (265) were readmitted within 72 h of their first presentation for the same head injury (median age 5 years). Of these, six had a CT scan on first admission, all were normal apart from one child who had a facial fracture, four of the six children were scanned with no change to the findings. Ninety children (34%) had a CT scan for the first time on their second admission, 34% (32/ 396) were abnormal (six simple fractures, 21 ICI with or without a skull fracture or depressed fractures, five had other findings). There was no significant difference between the age distribution of these cases and the overall dataset. The re-attendance rate was significantly greater for those children who did not have a CT at their first attendance (6.5% (259/ 3966)) than those who did (0.3% (6/1734)) (OR 20 (95% CI 8.9 to 45)).
A balanced against injury severity that triggered investigation and those who had CT than in those who did not, this must be an argument within their study. While the mortality rate was greater in this study represented a subset (admissions >4 h) of the population. Hospitals. (C) Health Commissioning Board or health region for the General Hospitals.

The overall CT rate was higher than that proposed by Dunning et al when they developed the CHALICE rule (2000–2002). They and others predicted that a CT rate of around 14% would be required to pick up 98% of clinically significant head injuries. Comparison of CT rates between studies is difficult due to the variation of study population inclusion criteria, age ranges, injury severity and the point along the clinical pathway where data were collected. CT rates quoted varied from 12.8% to 38%. The higher CT rate in older than younger children was consistent with a US study of children with mild head injury and may be influenced by the ease of assessing the GCS, the higher prevalence of ‘dangerous mechanisms of injury’ or because performing a CT scan is technically easier.

While improved compliance for adult head CT has been demonstrated following the introduction of NICE guidelines, a reluctance to adhere to the NICE recommendations for children has been identified. Data collected in 2008 showed that 68.7% of children in one teaching hospital and 77.1% in a busy district GH with indicators for a head CT did not have one. The low compliance with NICE guidelines in young children (<3 years) would be consistent with a preference to admit these children to hospital for a period of observation rather than perform CT. It is possible that clinicians were reluctant to risk exposing very young children to cranial irradiation. Recent research estimates ‘one excess case of leukaemia and one excess brain tumour per 10 000 patients’ within 10 years of having a CT for a child aged <10 years and a lifetime excess risk of cancer of one cancer per 1000 head CT scans for children younger than 5 years (one cancer per 2000 scans for exposure at age 15 years). These risks will always influence clinical decisions but must be balanced against the immediate benefits and diagnostic accuracy of CT when assessing a child with potentially serious head injury.

While there was a low uptake of CT in the youngest children, there was a significantly higher yield of cranial and ICI abnormalities than the older children, particularly among infants. It could be argued that the potential to miss cranial and ICI abnormalities in this young age group is high. However, the counterargument is that the practice of clinical assessment and observation when balanced against the risks of sedation or radiation dosage associated with CT in these young children is more appropriate and a greater proportion of the correct children are receiving a CT scan.

For the older age group, CT is potentially overused. A considerable number of CTs were performed in children older than a year with a GCS of 14–15 with a yield of ICI or depressed fracture little more than 10%. This pattern of CT suggests that a modification of NICE guidelines in this age group could ensure that the right children are investigated and the number of children receiving unnecessary CT scans is reduced. It is possible that this will happen once the changes in NICE head injury guidelines 2014 are embedded in clinical practice where loss of consciousness and dangerous mechanism of injury must be present together or in association with at least one other feature before CT is indicated.

The 2007 NICE guidelines recommend immediate CT scan if one of the listed recommendations was present (figure 1) and while an explicit time scale was not given in 2007 guidelines for children, it is assumed that the adult standard applies and CT
should be done within an hour. These data show that this standard was not being met in the majority of cases. The 2014 guidelines\(^7\) have stratified clinical indicators to identify high-risk children where a CT scan should take place within the hour and has the potential to improve uptake.

These data confirm that when children had a CT the diagnostic yield for ICI was as high as 72% for infants with GCS of <15 and 47% for older children with a GCS of <14. However, the debate continues as to when children with mild impairment (GCS of 13–15) should have a CT. Many of the clinical decision rules are designed to inform this specific decision, for example, PECARN and CATCH.\(^4\)\(^,\)\(^5\) A recent validation study of 1009 cases showed that PECARN had the greatest sensitivity and identified 100% of the 21 cases of traumatic brain injury in children presenting mild head injury; CHALICE missed cases having a sensitivity of 84% and a specificity of 85% for the same sample.\(^2\) However, definitive answers to these questions may be provided from the Paediatric Research in Emergency Departments International Collaborative research network ongoing prospective trial.\(^2\)\(^,\)\(^2\)

The low CT scan rate in GHS may reflect paediatric anaesthetic cover, a reluctance to sedate children for imaging, limited out-of-hours access to CT imaging or lack of paediatric emergency medicine expertise, poorer training and thus poorer adherence to national clinical guidelines. Recent studies have shown substantial variation in the use of CT scan across different hospital settings.\(^1\)\(^5\)\(^,\)\(^2\)\(^3\)

In summary, we have shown that compliance with the NICE 2007 head injury guidelines was variable and generally poor. The more recent 2014 guidelines include a second tier of indicators which permit a 4 h observation followed by CT if the child deteriorates; this stratified approach is potentially more complicated to apply but is supported by the data we present. It is important that the implementation and effect of the revised guidelines are studied so that children and children with head injury benefit fully from an evidence-based approach to their care.

**Twitter** Follow Richard Edwards at @paedneurosurg

**Acknowledgements** This project/audit was commissioned by the Healthcare Quality Improvement Partnership as part of the National Clinical Audit and Patient Outcomes Programme (NCAPOP). This is one of a series of forthcoming publications using the study data. Additional members of the original CMACE Head Injury External advisory group: Professor Robert Tasker, Paediatrics, University of Cambridge; Dr Rosemary Arthur, Consultant Paediatric Radiologist, Leeds (British Society Paediatric Radiology); Dr Fiona Lecky, Research Director TARN, Senior Lecturer, Honorary Consultant Emergency Medicine, Manchester; Dr Fiona Moore, Medical Director London Ambulance Service; Dr Kevin Morris, Director PICU Birmingham Children’s Hospital; Lisa Turan, Chief Executive Child Brain Injury Trust; Girkamal Virdi, Assistant Head of Clinical and Audit Research, London Ambulance Service and Mark Woolcock, Emergency Medical Practitioner and Emergency Specialist Service, South Western Ambulance Service, NHS Foundation Trust.

**Contributors** EN: Undertook the data analysis and wrote the first drafts of the paper. LT: Undertook the statistical analysis. RH: Designed the original data collection tools, supervised data collection, cleaning and data entry of the data collected within the original confidential enquiry of head injury (CMACE); GP: Director of the CMACE confidential enquiry and supervised the design and running of the project and has been involved in editing this manuscript. RE, PH, IM, RCP: Members of the project Independent Advisory Board and gave advice and editorial supervision at regular intervals during the study analysis. AK: principal investigator on the data analysis, coordinated the study writing, checked and edited the manuscript, agreed the concept and methodology of this particular analysis.

**Funding** Health Quality Improvement Partnership.

**Competing interests** IM is supported by the National Institute for Health Research (NIHR) Biomedical Research Centre based at Imperial College Healthcare NHS Trust and Imperial College London.

**Ethics approval** Central Manchester Research Ethics Committee prior to the study and updated in July 2012 (Ref 09/H1008/74).

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Open Access** This is an Open Access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/

**REFERENCES**

1. Health and Social Care Information Centre. Hospital Episode Statistics, Admitted Patient Care, England—2012–13. Diagnosis. 2013. http://www.hsic.gov.uk/catalogue/ PUB03666/hospital-episode-stats-aug-2012-13-tables.xls (accessed 20 Feb 2015).

2. Marlow R, Mytton J, Maconochie IK, et al. Trends in admission and death rates due to paediatric head injury in England, 2000–2011. Arch Dis Child 2015;100:1136–40.

3. Pickering A, Harnan S, Fitzgerald P, et al. Clinical decision rules for children with minor head injury: a systematic review. Arch Dis Child 2011;96:414–21.

4. Kuppermann N, Holmes JF, Dayan P, et al. Identification of children at very low risk of clinically important neurologic injury after head trauma: a prospective cohort study. Lancet 2009;374:1160–70.

5. Osmond MH, Klassen TP, Wells GA, et al. CATCH: a clinical decision rule for the use of computed tomography in children with minor head injury. CMAJ 2010;182:341–8.

6. Dunning J, Daly JP, Lomas JP, et al. Derivation of the children’s head injury algorithm for the prediction of important clinical events decision rule for head injury in children. Arch Dis Child 2006;91:885–91.

7. National Institute for Health and Clinical Excellence (NICE). Head injury: Triage, assessment, investigation and early management of head injury in children, young people and adults. 2014. http://www.nice.org.uk/guidance/cg176 (accessed 20 Feb 2015).

8. National Health Service (NHS). Major trauma centres. 2012. http://www.nhs.uk/NHSEngland/AboutNHSservices/Emergencyandurgentcare/services/Documents/2012-map-of-major-trauma-centres-2012.pdf (accessed 20 Feb 2015).

9. Teasdale G, Jennett B. Assessment of coma and impaired consciousness. A practical scale. Lancet 1974;304:81–4.

10. McNarry AF, Goldthri DR. Single bedside assessment of level of consciousness: comparison of two simple assessment scales with the Glasgow Coma scale. Anaesthesia 2004;59:347–9.

11. Mackay CA, Burke DP, Burke JA, et al. Association between the assessment of conscious level using the AVPU system and the Glasgow coma scale. Prehospital Immediate Care 2000;4:17–19.

12. Elliot RR, Sola Gutiérrez Y, Harrison R, et al. Cautious observation or blanket scanning? An investigation into paediatric attendances to an emergency department after head injury. Injury 2011;42:896–9.

13. Ghosh R, Docherty E, Schickerling S, et al. Application of the 2007 NICE guidelines in the management of paediatric minor head injuries in a UK emergency department. Emerg Med J 2012;29:197–200.

14. Lyttle MD, Cheek JA, Blackburn C, et al. Applicability of the CATCH, CHALICE and PECARN paediatric head injury clinical decision rules: pilot data from a single Australian centre. Emerg Med J 2013;30:790–4.

15. Mannix R, Bourgeois FT, Schutzman SA, et al. Neuroimaging for pediatric head trauma: do patient and hospital characteristics influence who gets imaged? Acad Emerg Med 2010;17:694–700.

16. Mannix R, Meehan WP, Monetteau MC, et al. Computed tomography for minor head injury: variation and trends in major United States pediatric emergency departments. J Pediatr 2010;156:99–106.

17. Mooney JS, Yates A, Sellar L, et al. Emergency head injury imaging: implementing NICE 2007 in a tertiary neurosciences centre and a busy district general hospital. Emerg Med J 2011;28:778–82.

18. Pearce MS, Salotti JA, Little MP, et al. Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. Lancet 2012;380:499–505.

19. Berrington de González A, Mahesh M, Kim KP, et al. Projected cancer risks from computed tomographic scans performed in the United States in 2007. Arch Intern Med 2009;169:2071–7.

20. Stanley RM, Hoyle JDJ, Dayan PS, et al. Emergency department practice variation in computed tomography use for children with minor blunt head trauma. J Pediatr 2014;165:1201–6.e2.

21. Easter JS, Baikis K, Dhalwala I, et al. Comparison of PECARN, CATCH, and CHALICE rules for children with minor head injury: a prospective cohort study. Ann Emerg Med 2014;64:145–52.

22. Bahl FE, Lyttle MD, Bressan S, et al. A prospective observational study to assess the diagnostic accuracy of clinical decision rules for children presenting to emergency departments after head injuries (protocol): the Australasian Paediatric Head Injury Rules Study (APHIRS). BMC Pediatrics 2014;14:1–10.

23. Marin JR, Weaver MD, Barnato AE, et al. Variation in emergency department head computed tomography use for pediatric head trauma. Acad Emerg Med 2014;21:987–95.