Table of contents

Summary .................................................................................................................................................. 4

Methodology ......................................................................................................................................... 5

Findings of clinical question 1 .............................................................................................................. 5
  1.1 Magnetic resonance imaging ...................................................................................................... 6
  1.2 Diffusion weighted/susceptibility weighted imaging ................................................................. 7
  1.3 High resolution ultrasound scans .............................................................................................. 7
  1.4 Neuroimaging ............................................................................................................................ 8
  1.5 Implications for practice .............................................................................................................. 8
  1.6 Research implications ................................................................................................................ 9
  1.7 Limitations of review findings .................................................................................................. 9

Findings of clinical question 2 .............................................................................................................. 9
  2.1 Apnoea ........................................................................................................................................ 10
  2.2 Retinal haemorrhage ................................................................................................................ 10
  2.3 Rib fracture ................................................................................................................................ 10
  2.4 Long bone fracture ................................................................................................................... 10
  2.5 Seizure ................................................................................................................................:::::: 11
  2.6 Bruising to the head and / or neck ............................................................................................ 11
  2.7 Skull fracture ............................................................................................................................. 11
  2.8 Implications for practice ............................................................................................................ 11
  2.9 Research implications ................................................................................................................. 12
  2.10 Limitations of review findings ................................................................................................ 12

Findings of clinical question 3 .............................................................................................................. 12
  3.1 Extra-axial haemorrhages .......................................................................................................... 13
  3.2 Pattern of subdural haemorrhages ............................................................................................ 14
  3.3 Further intracranial lesions ....................................................................................................... 15
  3.4 Implications for practice ............................................................................................................ 16
  3.5 Research implications ................................................................................................................. 16
  3.6 Limitations of review findings .................................................................................................. 16

Findings of clinical question 4 .............................................................................................................. 16
  4.1 Implications for practice ............................................................................................................ 17
  4.2 Limitations of review findings .................................................................................................. 17
  4.3 Research implications ................................................................................................................. 17

Other useful resources .......................................................................................................................... 17
  Clinical question 1 ........................................................................................................................... 17
  Clinical question 2 ........................................................................................................................... 17
Clinical question 3................................................................. 18
Clinical question 4................................................................. 18

Related publications ............................................................ 18

References ............................................................................. 20

Appendix 1 - Methodology ...................................................... 27
  Inclusion criteria.................................................................... 28
  Ranking of abuse.................................................................... 29
  Search strategy ...................................................................... 31
  Pre-review screening and critical appraisal............................. 34
Summary

Abusive head trauma (AHT) is the term the American Academy of Paediatrics recommends that paediatricians use when describing an inflicted injury to the head and its contents. AHT remains the commonest form of fatal child abuse and predominantly affects infants. While there has been a large body of literature relating to spinal injuries, no new studies have been included addressing the neuroradiological or clinical features of abusive head trauma within the past year. One study addressing the ability of neuroradiologists to date subdural haemorrhages has been included.

It is well recognised that a number of children with AHT may have this diagnosis missed when they first come into contact with child health practitioners.

Current controversies exist around clinicians’ ability to confidently diagnose AHT; we hope this review highlights the strength of evidence that one can rely on in this regard.

New high quality studies have also enabled us to update the original meta-analysis of the Neuroradiological features that distinguish abusive from non-abusive head trauma.

This systematic review evaluates the scientific literature on abusive and non-abusive neurological injuries in children published up until August 2014 and reflects the findings of eligible studies. The review aims to answer four clinical questions:

- What neuroradiological investigations are indicated to identify abusive central neurological system injury in children?
- What are the distinguishing clinical features of abusive head trauma in children?
- What neuroradiological features distinguish abusive from non-abusive head trauma?
- Can you date inflicted intracranial injuries in children neuroradiologically?

Key findings:

- In an acutely ill child, a computerised tomography scan (CT) is the preferred imaging technique
- If the CT is abnormal or there are ongoing clinical concerns, magnetic resonance imaging (MRI) with diffusion weighted imaging (DWI) should be performed since it has the capacity to identify further features and identify intracranial changes
- Ultrasound scanning should never be used as a diagnostic investigation since, whilst it found some features, it missed many others
- It is vital that all children with suspected AHT have their eyes examined thoroughly by an ophthalmologist (dilated pupils and indirect fundoscopy) for the presence of retinal haemorrhage
- Skeletal survey including oblique views of the ribs should be performed in all children less than two years of age with suspected AHT
- Certain features (retinal haemorrhage, apnoea) appear to correlate strongly with AHT rather than non-abusive head trauma in children less than three years of age

**Background**

This systematic review evaluates the scientific literature on abusive and non-abusive neurological injuries in children published up until August 2014 and reflects the findings of eligible studies. The review aims to answer four clinical questions:

- What neuroradiological investigations are indicated to identify abusive central neurological system injury in children?
- What are the distinguishing clinical features of abusive head trauma in children?
- What neuroradiological features distinguish abusive from non-abusive head trauma?
- Can you date inflicted intracranial injuries in children neuroradiologically?

**Methodology**

A literature search was performed using a number of databases for all original articles and conference abstracts published since 1970. Supplementary search techniques were used to identify further relevant references. See Appendix 1 for full methodology including search strategy and inclusion criteria.

Potentially relevant studies underwent full text screening and critical appraisal. To ensure consistency, ranking was used to indicate the level of confidence that abuse had taken place and also for study types.

**Findings of clinical question 1**

*What neuroradiological investigations are indicated to identify abusive central neurological system injury in children?*

Abusive head trauma (AHT) is associated with a high morbidity and mortality in children\(^5\)\(^7\). AHT includes a variety of features such as extra-axial haemorrhages with or without cerebral oedema, hypoxic ischaemic injury or cerebral contusion\(^8\). The identification of these injuries influences both clinical management and subsequent child protection procedures.

Neuroimaging is essential to identify these injuries; however, concerns have been expressed about the radiation dosage associated with computerised tomography (CT) scanning and the
need for sedation/general anaesthesia (GA) for magnetic resonance imaging (MRI) in young children. This review aims to identify the optimal investigation strategy when central neurological system (CNS) injury is suspected.

1.1 Magnetic resonance imaging

Is there any value in performing magnetic resonance imaging in children with abnormal computerised tomography scans?

Of 374 studies reviewed from the international literature, eight articles addressed this issue. The age ranged from 0-4 years. Four studies were suitable for statistical analysis. 120/175 underwent additional MRI.

In children with an abnormal brain CT, at least 20.5% (95% CI: 15.3 – 26.9) would have additional abnormalities detected by MRI. It is notable that the most recent study had a lower rate of additional findings which may be due to the lower threshold for conducting MRI in children with suspected AHT.

Additional findings

Further subdural haemorrhages (SDHs) not seen on the initial CT were the commonest additional finding. A recent study did not identify additional SDH, subarachnoid haemorrhages (SAHs) or parenchymal haemorrhage but did note diffuse axonal injury and ischemia, as noted previously. These SDHs were found in occipital, posterior fossa, subtemporal, subfrontal, convexity and interhemispheric locations.

Additional SAHs could be seen on MRI that had been missed on the initial CT. In 4/16 children MRI missed SAHs seen on CT. Cerebral contusions were identified more clearly on MRI than on CT. MRI also gave additional information about the signal intensity of the SDHs. It demonstrated cranial shearing injury that was not apparent on CT.

MRI was superior to CT at detecting parenchymal haemorrhages and also contributed to the dating of SDHs.

What is the value of magnetic resonance imaging in children with normal initial computerised tomography scans?

Of 374 studies reviewed from the international literature, three articles addressed this issue:

- Age: ranging from 0-4 years
- Total data: eight children
- Study limitations
- Details on the standard of original reporting were not provided
• It is unclear where children were living / placed between computerised tomography (CT) scan and magnetic resonance imaging (MRI)
• Analysis of included studies\textsuperscript{14,15,17}
• Of eight children with normal CT undergoing MRI, MRI showed:
  o subdural collections
  o cortical contusion
  o shearing injury

1.2 Diffusion weighted/susceptibility weighted imaging

Is there any value in performing diffusion weighted/susceptibility weighted imaging in addition to standard magnetic resonance imaging?

• Of 374 studies reviewed from the international literature, five articles addressed this issue
• Age: ranging from 0-22 months
• Analysis of included studies
• Diffusion weighted imaging (DWI) demonstrated additional findings that were not apparent on conventional magnetic resonance imaging (MRI)\textsuperscript{18-21}
• DWI revealed more extensive brain injury\textsuperscript{21}
• DWI with apparent diffusion coefficient (ADC) mapping allowed better delineation of the extent of white matter injury\textsuperscript{21}
• The severity of injury on DWI correlated with prognosis\textsuperscript{21}
• DWI identified restricted diffusion of cortical and subcortical areas in addition to subdural haemorrhage\textsuperscript{18-20}
• Diffuse cortical infarction and early subacute phase hypoxic ischaemic encephalopathy (HIE) shown on DWI\textsuperscript{18-20}
• These were found to correlate with later poor prognosis\textsuperscript{18-20}
• Susceptibility-weighted MR imaging demonstrated brain micro-haemorrhages and intraparenchymal brain micro-haemorrhages which were significantly more common amongst children with poorer outcome than those with good outcome, predictive accuracy of 92.5%. N.B the SW-images may have been confounded by previous undocumented trauma or induced foci of germinal matrix haemorrhage\textsuperscript{22}

1.3 High resolution ultrasound scans

What is the value of high resolution ultrasound scans?

• Of 374 studies reviewed from the international literature, three articles addressed this issue
• Age: ranging from 0-12 months
• Total data: 21 children
• Ultrasound scans (USS) found (also visible on computerised tomography scan (CT) or magnetic resonance imaging (MRI))
  o subdural haemorrhages (SDHs) and staging (aging the lesion) was possible in 15/20 SDHs identified
  o echogenic cortical oedema in 5 patients
• USS missed (visible on CT or MRI):
  o two posterior cranial fossa SDHs
  o three basal cistern subarachnoid haemorrhages (SAHs)
• USS found:
  o SDHs and contusional tears
• USS missed:
  o skull fractures
  o characterisation and ageing of SDHs
• USS found:
  o cerebral oedema
• USS missed:
  o SAH

1.4 Neuroimaging

• Of 374 studies reviewed from the international literature, one study addressed this issue
• Age: ranging from 0-24 months
• Total data: 105 children
  o All children underwent CT scanning and 49 underwent MRI
  o 97 children had subdural haemorrhages and 52 had parenchymal hypodensities
  o The study details the timetable of changes on each imaging modality, providing a framework for dating of injuries

1.5 Implications for practice

• In an acutely ill child, a computerised tomography scan (CT) is the preferred imaging technique, due to its:
  o widespread availability
  o ability to identify and localise acute extra-axial bleeding
• If the CT is abnormal or there are ongoing clinical concerns, magnetic resonance imaging (MRI) with diffusion weighted imaging (DWI) should be performed since it has the capacity to identify further features and identify intracranial changes. Centres experienced in magnetic resonance scanning are increasingly offering MRI as first line investigation
Ultrasound scanning should never be used as a diagnostic investigation since, whilst it found some features, it missed many others. High resolution ultrasound scans (USS) may have some advantage as a secondary investigation in experienced hands to monitor or follow the development of a lesion already identified on CT or MRI disorders.

1.6 Research implications

- Further research to identify the value of late magnetic resonance imaging in the prognosis and management of these children would be of value
- Studies to determine the positive yield of computerised tomography scanning in all children less than one year of age with suspected abuse would be of value

1.7 Limitations of review findings

- Inadequate data on the value of magnetic resonance imaging (MRI)/diffusion weighted imaging (DWI) in children with a normal initial computerised tomography (CT) scan
- Lack of prospective study evaluating MRI/DWI at standard time interval after initial CT scan

Findings of clinical question 2
What are the distinguishing clinical features of abusive head trauma in children?

Abusive head trauma (AHT) is the commonest cause of death in physical abuse. It may present in a variety of ways, from overt neurological symptoms to mild irritability or co-existent physical. It is well documented that many children with AHT may be missed on initial presentation. We systematically reviewed the literature to identify key clinical indicators of AHT versus non-abusive head trauma.

- Of 374 studies reviewed from the international literature, 16 articles addressed this issue.
- Age:
  - Less than three years in 13 studies
  - 0-16 years in three studies
  - Children with AHT were younger than those with nAHT
- Gender:
  - Boys sustained more intracranial injuries than girls but there was no difference between AHT and nAHT
- Influence of ethnicity and socio-economic group:
  - Three studies addressed ethnicity and found no significant difference between groups
o AHT was found to be more common in the lower socio-economic groups, in two out of
the three studies addressing this issue.14,18,23
o No study addressed the diagnosis of AHT in disabled children

We analysed the data to determine the odds ratio and positive predictive value for abusive
head trauma for each of the following features.

2.1 Apnoea

• Infrequently recorded2,29,30
• In a child less than three years of age with intracranial injury and apnoea, the positive
predictive value for abusive head trauma is 93% (95% confidence interval (CI) 73%-99%) and
odds ratio of 17.1 (95%CI 5 – 58, p<0.001)2,29,30
• Apnoea was variably defined between studies2,29,30

2.2 Retinal haemorrhage

• Not all children were examined for this feature2,13,29,31-40
• In a child aged less than three years with intracranial injury and retinal haemorrhage, meta-
analysis 41 showed that the positive predictive value for abusive head trauma is 71% (95%
confidence interval (CI) 48%-87%) and odds ratio 3.5 (95% CI 1.1 -11.3, p=0.03)2,13,29,31-40
• This meta-analysis is based on the presence or absence of retinal haemorrhage without
details of the retinal findings

2.3 Rib fracture

• Full skeletal surveys were not performed in all cases of suspected abusive head trauma
(AHT)2,13,32,34,35,38,39,42
• Rib fractures were infrequently recorded but predominant in AHT 2,13,32,34,35,38,39,42
• In a child with intracranial injury and rib fracture the meta-analysis (17) showed that the
positive predictive value for AHT is 73% (95% confidence interval (CI) 50%-88%) and odds
ratio of 3 (95%CI 0.7 - 12.8)2,13,32,34,35,38,39,42
• A combination of rib fractures and intracranial injury is associated with AHT, however the
figures do not reach statistical significance (this may be due to the small numbers recorded)

2.4 Long bone fracture

• Full skeletal surveys were not performed in all cases of suspected abusive head trauma
(AHT)2,13,32,34,35,38,39,42 In a child with intracranial injury and long bone fracture the positive
predictive value for AHT is 59% (95% confidence interval (CI) 48%-69%) and odds ratio 1.7
(95%CI 0.8 - 3.6)2,13,32,34,35,38,39,42
• A combination of long bone fractures (including metaphyseal fractures) and intracranial injury is associated with AHT, however the figures do not reach statistical significance (this may be due to the small numbers recorded)

2.5 Seizure

• Seizures were infrequently recorded and only had a weak association with abusive head trauma (AHT).\textsuperscript{2,29,31-35}

• In a child less than three years of age with intracranial injury and seizure the meta-analysis (17) shows that the positive predictive value for AHT is 66% (95% confidence interval (CI) 45% – 82%) and odds ratio 2.9 (95%CI 0.7 – 11.7).\textsuperscript{2,29,31-35}
  \begin{itemize}
  \item Seizures and intracranial injury are associated with AHT, however the figures do not reach statistical significance (this may be due to the small number of cases recorded)
  \item The character and number of seizures was not recorded in all studies. It may be important to look at this in more detail
  \end{itemize}

2.6 Bruising to the head and / or neck

• Least recorded item across the studies, giving very weak statistical influence(1, 3, 10)

• In a child aged less than three years with intracranial injury and bruising to the head and/or neck the positive predictive value for abusive head trauma is 37% (95% confidence interval (CI) 3% – 91%) and odds ratio 0.8 (95%CI 0.07 – 9.4).\textsuperscript{1, 3, 10}

2.7 Skull fracture

• Skull fracture is associated with non-abusive head trauma\textsuperscript{2,13,31,32,34,35,37,39,42}

• In a child aged less than three years with intracranial injury and skull fracture the positive predictive value for abusive head trauma is 44% (95% confidence interval (CI) 22%-68%) and odds ratio 0.8 (95%CI 0.3-2.3).\textsuperscript{2,13,31,32,34,35,37,39,42}

Clinical Decision Rules

• Recursive partitioning was used on a large dataset of children aged less than three years that identified variables that may assist in “screening out” children where abusive head trauma is unlikely\textsuperscript{43}

2.8 Implications for practice

• It is vital that all children with suspected abusive head trauma (AHT) have their eyes examined thoroughly by an ophthalmologist (dilated pupils and indirect fundoscopy) for the presence of retinal haemorrhage
• Skeletal survey including oblique views of the ribs should be performed in all children less than two years of age with suspected AHT
• Certain features (retinal haemorrhage, apnoea) appear to correlate strongly with AHT rather than non-abusive head trauma in children less than three years of age

2.9 Research implications
• Large-scale studies evaluating multiple variables such as detailed retinal findings, seizure detail, apnoea and precise neuroimaging would enhance this field
• Further studies addressing the history offered in abusive head trauma versus non-abusive head trauma may assist in distinguishing these two conditions

2.10 Limitations of review findings
• Not all authors gave details of precise retinal findings, which may be important discriminating features
• Seizure type/duration was not consistently defined, limiting the value of this item
• The abusive head trauma population varied between studies (some ascertaining all children with subdural haemorrhage and others all children with brain injury), which may influence results

Findings of clinical question 3
What neuroradiological features distinguish abusive from non-abusive head trauma?

New high quality studies have enabled us to update the original meta-analysis and in particular they make an important contribution with regard to the significance of bilateral subdural haemorrhages and diffuse axonal injury.

Neuroimaging is undertaken in infants where abusive head trauma (AHT) is suspected. The neuroimaging must be interpreted carefully, in the context of the historical or clinical features, giving due consideration to the differential causes of intracranial injury in infancy e.g. intentional trauma, birth-related injury, bleeding disorders, encephalitis, meningitis, congenital abnormality or metabolic conditions such as glutaric aciduria. This systematic review evaluates the strength of the scientific evidence behind the neuroradiological features that are associated with AHT.

• Of 374 studies reviewed from the international literature, 25 articles addressed this issue (see references for clinical question 3)²,5,10,20,27,29,31,38-40,42-56
• Study designs:
  o 20 cross-sectional²,5,10,20,27,29,31,38-40,42-44,46-48,50-52,56
• 2 case-controls\textsuperscript{45,49}  
• 2 comparative case series\textsuperscript{53,55}  
• 1 prospective cohort\textsuperscript{56}  

• Age:  
  o 21/25 studies focused on age groups under three years of age\textsuperscript{2,5,10,20,27,29,31,38-40,42-44,47,50-56}  
  o Four studies included children aged up to four, five, six and 16 years respectively

• Gender:  
  o Of four studies addressing gender, three found no significant difference\textsuperscript{44,45,54}  
  o One study showed more boys than girls in the abusive head trauma (AHT) group\textsuperscript{52}  

• Neuroimaging:  
  o All studies included an initial computerised tomography scan, many with additional magnetic resonance imaging (MRI), with the exception of Ichord et al\textsuperscript{27} which relied solely upon MRI

\textbf{Influence of ethnicity and socio-economic group}  
• One study addressed ethnicity and found no difference\textsuperscript{52}  
• There was no significant difference in socio-economic group in one Mexican study that explored this\textsuperscript{45}  
• Among the recent studies, one includes a detailed examination of a subset of the data from previous studies\textsuperscript{40,54,55}

\textbf{3.1 Extra-axial haemorrhages}  
• 16 studies described details of extra-axial haemorrhages\textsuperscript{2,5,29,31,40,42-46,48,49,51,52,56} (1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 14, 17, 19, 33, 23, 25)

\textbf{Subdural haemorrhage (SDH)}  
• 13 studies\textsuperscript{2,5,29,31,40,42-44,48,49,51,52,54} compared the prevalence of SDH in abusive head trauma (AHT) and non-abusive head trauma (nAHT)  
• All studies confirmed that SDH was significantly associated with AHT. Meta-analysis using a random effects model gave an overall odds ratio (OR) of 9.18 (95% confidence interval 7.12 – 11.83, I\textsuperscript{2} = 0%; p<0.00001) for SDH in AHT

\textbf{Subarachnoid haemorrhage (SAH)}  
• 11 studies\textsuperscript{2,29,31,43-46,48,51,54,56} described SAH which was equally prevalent in AHT and nAHT. The overall OR for AHT was 1.28 (95% confidence interval 0.67 – 2.44, I\textsuperscript{2} = 77%; p=0.95; p=0.45)
Extradural Haemorrhage (EDH)

- 12 studies confirmed a significant association between EDH and nAHT. The overall OR for EDH and AHT was 0.16 (95% confidence interval 0.10 - 0.25, I^2 = 6%; p<0.00001)

3.2 Pattern of subdural haemorrhages

Interhemispheric haemorrhages

- Meta-analysis of seven studies showed that interhemispheric haemorrhages were significantly associated with abusive head trauma (AHT), with an odds ratio (OR) of 8.03 (95% confidence interval 5.58 - 11.56, I^2 =0%; p<0.0001)

Multiple subdural haemorrhages

- There were only two studies that looked at children with multiple extra-axial haemorrhages, both demonstrating a strong association with AHT and an overall OR of 6.01 (95% confidence interval 2.52 - 14.35, I^2 =0%; p<0.0001)

Subdural haemorrhage (SDH) over the convexities

- Meta-analysis of three studies gave an overall OR for convexity SDH and AHT of 4.93 (95% confidence interval 1.25 - 19.42, I^2 =75%; p=0.02)

Infra-tentorial / posterior fossa haemorrhages

- Infra-tentorial / posterior fossa haemorrhages were associated with AHT; meta-analysis of three studies gave an overall OR for AHT of 2.55 (95% confidence interval 1.06 - 6.13, I^2 =0%; p=0.047)

Bilateral haemorrhages

- A meta-analysis of four studies showed that bilateral subdurs are significantly associated with AHT (OR 3.36, 95% confidence interval 1.10 - 10.27, I^2 =77%; p=0.03)

Attenuation of extra-axial haemorrhages on the initial computerised tomography (CT) scan

- Despite the fact that different studies used different terminology, five studies concluded that multiple SDH of different attenuations were reported on initial CT, predominantly in AHT
- Low attenuation haemorrhages were more commonly seen in AHT than in non-abusive head trauma (nAHT)
• Mixed attenuation – two studies reported SDH of mixed attenuation (different attenuation in the same SDH):
  
• Tung et al\textsuperscript{53} stated they were seen significantly more often in AHT than in nAHT
  
• Vinchon (2004)\textsuperscript{55} noted that they were equally prevalent in both conditions

### 3.3 Further intracranial lesions

#### Cerebral oedema

• A meta-analysis of seven studies\textsuperscript{2,10,46,47,50,52,56} showed that cerebral oedema was significantly associated with abusive head trauma (AHT) (odds ratio (OR) 2.24, 95% confidence interval 1.18-4.26, I\textsuperscript{2}=62%; p=0.01)

#### Intra-Parenchymal injury

• Nine studies\textsuperscript{27,29,43-46,48,54} described intra-parenchymal injury; however, there was no significant association with AHT (OR 1.25, 95% confidence interval 0.58-2.69, I\textsuperscript{2}=73%; p=0.56)
  
• One study noted significantly more parenchymal haemorrhage amongst AHT vs nAHT p<0.001

#### Shear injury and diffuse axonal injury

• Six studies\textsuperscript{10,27,43,46,49,54} addressed shear injury or diffuse axonal injury, enabling a meta-analysis to be performed for the first time (OR 3.19, 95% confidence interval 1.14-8.93, I\textsuperscript{2}=10%; p=0.03)

#### Hypoxic ischaemic injury

• Six studies addressed hypoxic ischemic injury (HII)\textsuperscript{2,20,27,43,52,54}
  
• Ichord et al\textsuperscript{27} was the only study based purely on magnetic resonance imaging (MRI) imaging which has the greatest sensitivity for HII. The study stated that HII was predominantly bilateral and generalised in 9/22 cases of AHT, compared to 1/30 cases of nAHT. The overall OR for HII in association with AHT from the six studies was 4.19 (95% confidence interval 2.65-6.62; p=0.00001)

#### Closed head injury

• 13 studies\textsuperscript{2,27,39,42-45,47,48,50,52,54,56} analysed the prevalence of closed head injury, i.e. intracranial injury in the absence of skull fracture, and an updated meta-analysis showed a very significant association with AHT, OR 4.96 (95% confidence interval 3.44-7.15; p<0.00001)
3.4 Implications for practice

A systematic review has confirmed the positive association of clinical features with abusive head trauma including retinal haemorrhages, apnoea and rib fractures. Careful interpretation of the full clinical picture, together with the neuroradiological findings on computerised tomography scans and early magnetic resonance images should facilitate greater diagnostic confidence.

3.5 Research implications

As magnetic resonance imaging (MRI) techniques and availability improves, this field would benefit from further research around:

- Aging intracranial injuries on MRI
- Prospective studies relating neurological findings to clinical factors of abusive and non-abusive head trauma

3.6 Limitations of review findings

This systematic is valuable as it includes several similar studies that all draw upon populations of children less than three years of age. The limitations include variation in composition of abusive head trauma groups, inclusion criteria and imaging techniques used, together with small study numbers and datasets that support some of the meta-analyses.

Findings of clinical question 4
Can you date inflicted intracranial injuries in children neuroradiologically?

- Of 374 studies, one article addressed this issue
- In this study 51 of 172 radiologists surveyed replied with regard to their confidence of dating subdural haemorrhages in abusive head trauma. The survey utilised 8 paediatric cases with CT or MRI images. The level of confidence in reporting the estimated age of these injuries from CT was 58-83% – in only 2 of 4 cases did the age estimate match with the age known of the injury. In the four cases with MRI, the level of confidence reporting the age was 63-90% – in 2 of 4 cases the estimated age was correct
4.1 Implications for practice

- This single survey of neuroradiologists indicated a wide range of confidence between practitioners, but the age estimates of the subdural haemorrhages by CT or MRI was only accurate in 50% of the cases provide

4.2 Limitations of review findings

- The dating of intracranial injuries from neuroimaging is an important part of the assessment of abusive head trauma
- With rapidly advancing neuroimaging techniques, there is a need for larger scale studies of clinical cases to determine the accuracy of dating by radiologists

4.3 Research implications

- A single study exploring radiologist confidence which evaluated only four cases with CT and four cases with MRI imaging
- Only 30% of the radiologists surveyed responded, and not all of these completed all aspects of the survey

Other useful resources

The review identified a number of interesting findings that were outside of the inclusion criteria. These are as follows:

Clinical question 1

- New techniques such as diffusion tensor imaging (DTI) may have a place in identifying further abnormalities
- Proton and phosphorus magnetic resonance spectroscopy (MRS) may have a role in identifying metabolic abnormalities The use of apparent diffusion coefficient on MRI may be of value in predicting poor long term neurodevelopmental outcome
- Standards for radiological investigations of suspected non-accidental injury – March 2008
- Revision of radiological standards from the American Academy of Pediatrics

Clinical question 2

- Differential diagnoses for the clinical features seen in AHT (e.g. subdural haemorrhage) need to be considered (e.g. glutaric aciduria, coagulopathy, metabolic disorders etc)
• The postulated association between immunisation and neuropathology was explored among 5,545 investigations; 37 underwent post-mortem and there was no association between vaccines administered and lesions found.65
• The importance of identifying children with minor abusive injuries (sentinel injuries) to prevent further severe injury, including abusive head trauma, has been highlighted4,66. There is increasing interest in the identification of a clinical decision rule or screening investigations which may indicate which children have sustained intracranial injury / AHT67
• There is ongoing debate as to the significance of pre-existing macrocephaly amongst infants who present with intracranial injury68
• There is a welcome expansion of the literature relating to long term outcomes in children who sustain AHT69
• Work continues to identify the biomechanics underlying shaking as a cause of intracranial injury. 70,71 In addition studies of the biomechanics of falls are an important contribution to our understanding of AHT72,73
• Publications relating to perpetrator admissions may provide insight into the mechanism of injury in AHT74

Clinical question 3

• Missed physical abuse: of 38 cases of AHT, five had a history of missed diagnosis of AHT, three of which died. There were two cases of missed fractures and one case of missed abuse by shaking. These children presented with fatal abuse75
• Spinal injuries co-exist with abusive head trauma (AHT)76, 29/41 cases with AHT had injuries to the cervical cord, two with cervical spinal injuries alone. Details of soft tissue and spinal cord injuries are given for all cases
• Asymptomatic intra-cranial hemorrhage has been described in newborns undergoing MRI imaging. Supratentorial subdural hemorrhage was noted in 46 / 101 infants, a further 20 infants had infratentorial SDH. All had resolved by three months and most children with SDH’s had normal developmental examinations at 24 months77

Clinical question 4

There were no recommended resources for clinical question 4.

Related publications

Publications arising from neurological injuries review
Kemp AM, Rajaram S, Mann M, Tempest V, Farewell D, Gawne-Cain ML, Jaspan T, Maguire S, Welsh Child Protection Systematic Review Group. What neuroimaging should be performed in

Added to DARE Database - The Database of Abstracts of Reviews of Effects (DARE) is a collection of quality assessed systematic reviews of health care research identified in the biomedical literature from 1994 onwards. For those reviews which meet the CRD quality criteria, structured abstracts are written summarising the content and methods used to conduct the review and offering a commentary on the rigour with which the review was conducted.


**Part primary study deriving from neurological injuries review**


References


61. Standards for radiological investigations of suspected non-accidental injury. Available from https://www.rcr.ac.uk/system/files/publication/field_publication_files/RCPCH_RCR_final_0.pdf (last accessed


78. Centre for Reviews and Dissemination U.o.Y. CRD's Guidance for Undertaking Reviews in Health Care. 2009. [https://www.york.ac.uk/crd/guidance/](https://www.york.ac.uk/crd/guidance/)


Appendix 1 – Methodology

We performed an all-language literature search of original articles, their references and conference abstracts published since 1970. Studies published post-1970 were considered for inclusion, since radiological techniques prior to this would not be relevant to current practice. The initial search strategy was developed across OVID Medline databases using keywords and Medical Subject Headings (MeSH headings) and was modified appropriately to search the remaining bibliographic databases. The search sensitivity was augmented by the use of a range of supplementary ‘snowballing’ techniques including consultation with subject experts and relevant organisations, and hand searching selected websites, non-indexed journals and the references of all full-text articles.

Identified articles, once scanned for duplicates and relevancy, were transferred to a purpose-built Microsoft Access database to coordinate the review and collate critical appraisal data. Where applicable, authors were contacted for primary data and additional information. Translations were obtained, when necessary. Relevant studies were scanned for eligibility by the lead researcher; those that met our inclusion criteria were reviewed.

Standardised data extraction and critical appraisal forms were based on criteria defined by the National Health Service’s Centre for Reviews and Dissemination (CRD).78 We also used a selection of systematic review advisory articles to develop our critical appraisal forms.79-83 Articles were independently reviewed by two reviewers. A third review was undertaken to resolve disagreement between the initial reviewers when determining either the evidence type of the article or whether the study met the inclusion criteria. Decisions related to inclusion and exclusion criteria were guided by Cardiff Child Protection Systematic Reviews, who laid out the basic parameters for selecting the studies.

Our panel of reviewers included paediatricians, paediatric neurologists, neuro-radiologists, ophthalmologists, pathologists, designated and named doctors and specialist nurses in child protection. All reviewers underwent standardised critical appraisal training, based on the CRD critical appraisal standards 3, and this was supported by a dedicated electronic critical appraisal module.

Definition of intracranial injury

We defined the term “intracranial injury” as:

- children with brain injury diagnosed on computerised tomography (CT) scan / magnetic resonance imaging (MRI) with any combination of the following:
  - intracranial haemorrhage
  - extra-axial haemorrhage (subdural, subarachnoid or extradural haemorrhage)
  - intra-cerebral injury:
We defined the term “abusive head trauma” (AHT) as:
- intracranial injury caused by abuse

We defined the term “non-abusive head trauma” (nAHT) as:
- intracranial injury as a consequence of illness or accident (e.g. witnessed falls, motor vehicle collision, etc)

### Inclusion criteria

We included comparative studies of abusive head trauma (AHT) and non-abusive head trauma (nAHT) with consecutive case ascertainment. We included AHT where the rank of abuse was 1 or 2. We looked for confirmation of non-abusive causes (trauma or medical). We excluded from the final analysis studies which included a category where the aetiology was 'indeterminate'. To minimise selection bias and circularity, we did not include any studies where the decision of abuse had relied solely on clinical features.

See evidence sheets and critical appraisal forms for each year’s update.

<table>
<thead>
<tr>
<th>Inclusion</th>
<th>Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children aged 0 years up to 18th birthday</td>
<td>Studies about complications, management or prognosis of AHT / nAHT</td>
</tr>
<tr>
<td>Observational comparative study (cross-sectional / case-control / case series / longitudinal cohort)</td>
<td>Non-comparative studies</td>
</tr>
<tr>
<td>Children with AHT</td>
<td>Consensus statements or personal practice studies</td>
</tr>
<tr>
<td>Ranking of abuse 1 or 2 for AHT</td>
<td>Studies addressing exclusively post-mortem neuro-pathological findings</td>
</tr>
<tr>
<td>nAHT: non-abusive aetiology confirmed</td>
<td>Studies with mixed adult and child data, where the children's data cannot be extracted</td>
</tr>
<tr>
<td>Children who were alive at presentation</td>
<td>Methodologically flawed studies (e.g. significant bias, where AHT was not adequately confirmed or where inadequate clinical details were given)</td>
</tr>
<tr>
<td>All language studies</td>
<td>Studies that only addressed head injury where there was no intracranial abnormality</td>
</tr>
<tr>
<td>Relevant clinical details given for each group</td>
<td>Studies with low surety of diagnosis of abusive injury (rank 3-5 abuse)</td>
</tr>
</tbody>
</table>
Ranking of abuse

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Criteria used to define abuse</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Abuse confirmed at case conference or civil, family or criminal court proceedings or admitted by perpetrator or independently witnessed</td>
</tr>
<tr>
<td>2</td>
<td>Abuse confirmed by stated criteria including multidisciplinary assessment</td>
</tr>
<tr>
<td>3</td>
<td>Abuse defined by stated criteria</td>
</tr>
<tr>
<td>4</td>
<td>Abuse stated but no supporting detail given</td>
</tr>
<tr>
<td>5</td>
<td>Suspected abuse</td>
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</tbody>
</table>

Ranking of evidence by study type

<table>
<thead>
<tr>
<th>Ranking of evidence by study type</th>
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<tbody>
<tr>
<td><strong>T</strong>1</td>
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<td><strong>T</strong>2</td>
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<td><strong>T</strong>3</td>
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<td><strong>O</strong>1</td>
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<tr>
<td><strong>O</strong>2</td>
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<tr>
<td><strong>O</strong>3</td>
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<tr>
<td><strong>O</strong>4</td>
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<tr>
<td><strong>O</strong>5</td>
</tr>
<tr>
<td><strong>O</strong>6</td>
</tr>
<tr>
<td><strong>D</strong>1</td>
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<td><strong>X</strong></td>
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Statistics

Used to answer our question: 1. What neuroradiological investigations are indicated to identify abusive central neurological system injury in children?

The aim of the study was to analyse the relative value of an MRI examination additional to the initial CT examination, and to estimate the proportion of cases in which an additional MRI would provide supplementary information to an initial CT examination.
Since not all children underwent both examinations, there remains the possibility that, had MRI examinations been performed (when they were not), additional information would have been provided. In these cases, a conservative assumption was used. It was assumed that such MRI examinations would have revealed the same information as the CT investigation. The proportion of cases in which an MRI examination provided additional information was computed.

Used to answer our question: 2. What are the distinguishing clinical features of abusive intracranial injury in children?

We analysed the following clinical features:

- Apnoea
- Retinal haemorrhages
- Rib fractures
- Long bone fractures
- Bruising to the head and/or neck
- Seizures
- Skull fractures

The analysis was limited by the items that authors chose to report. Further, even when a feature was commented upon by an author, not all children in each group were examined for the feature in question. We have used an extremely conservative imputation strategy to allow for this. We chose to assume that any missing data (e.g. fundoscopy) in the abusive head trauma (AHT) group would have been negative, had the child been examined. If a data item was missing from the non-abusive head trauma (nAHT) group we assumed it would have been positive, had the child been examined (e.g. rib fractures). Only in the case of skull fractures, a feature whose presence we suspect to be associated with nAHT, was the opposite imputation performed. We believe that this strategy may underestimate the discriminating power of an individual feature, but that this counteracts any circularity in the data collection.

These imputations being given, we then conducted a multilevel logistic regression analysis, allowing not only the prevalence of abuse to vary between studies, but also the odds ratios (OR) for the features in question. By allowing the OR to differ between studies, we again aim to minimise the risk of circularity, where an individual study may have overly relied upon a particular feature in order to arrive at the diagnosis of abuse. For each feature, we report the estimated OR for the feature in discriminating between AHT and nAHT (with a 95% confidence interval (CI)), and a positive predictive value (PPV) the estimated probability of abuse given the presence of this feature in a child with brain injury (with a 95% CI).
Search strategy

The below table presents the search terms used in the 2014 Medline database search for neurological injuries, truncation and wildcard characters were adapted to the different databases where necessary.

<p>| | |</p>
<table>
<thead>
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<tbody>
<tr>
<td>1.</td>
<td>CHILD/</td>
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<td>2.</td>
<td>CHILD, PRESCHOOL/</td>
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<tr>
<td>3.</td>
<td>(child: or infant: or toddler: or babies or baby).af.</td>
</tr>
<tr>
<td>4.</td>
<td>or/1-3</td>
</tr>
<tr>
<td>5.</td>
<td>((non-accidental or nonaccidental) adj3 (trauma or injur:)).af.</td>
</tr>
<tr>
<td>6.</td>
<td>((non-abusive or nonabusive) adj3 (injur: or trauma)).af.</td>
</tr>
<tr>
<td>7.</td>
<td>(non-accidental: and injur:).af.</td>
</tr>
<tr>
<td>8.</td>
<td>soft tissue injur:.af.</td>
</tr>
<tr>
<td>9.</td>
<td>physical abuse.af.</td>
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<tr>
<td>10.</td>
<td>((inflicted or noninflicted or non-inflicted) adj3 (brain injur: or cerebral injur: or head injur:)).af.</td>
</tr>
<tr>
<td>11.</td>
<td>(inflicted traumatic head injur: or inflicted traumatic brain injur:).af.</td>
</tr>
<tr>
<td>12.</td>
<td>(or/5-11) and 4</td>
</tr>
<tr>
<td>13.</td>
<td>(child abuse or child maltreatment or child protection).af.</td>
</tr>
<tr>
<td>14.</td>
<td>(battered child or shaken baby or battered baby).af.</td>
</tr>
<tr>
<td>15.</td>
<td>(battered infant or shaken infant).af.</td>
</tr>
<tr>
<td>17.</td>
<td>Caffey-Kempe syndrome.af.</td>
</tr>
<tr>
<td>18.</td>
<td>**“Child Abuse”/di [Diagnosis]</td>
</tr>
<tr>
<td>19.</td>
<td>infant traumatic stress syndrome.af.</td>
</tr>
<tr>
<td>21.</td>
<td>or/13-20</td>
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<tr>
<td>22.</td>
<td>12 or 21</td>
</tr>
<tr>
<td>23.</td>
<td>abusive head trauma.af.</td>
</tr>
<tr>
<td>61.</td>
<td>(subdural haemorrhage or subdural hemorrhage).af.</td>
</tr>
<tr>
<td>62.</td>
<td>(ventricular haemorrhage or ventricular hemorrhage).af.</td>
</tr>
<tr>
<td>63.</td>
<td>whiplash impact syndrome.af.</td>
</tr>
<tr>
<td>64.</td>
<td>whiplash injur:.af.</td>
</tr>
<tr>
<td>65.</td>
<td>whiplash shaken infant.af.</td>
</tr>
<tr>
<td>66.</td>
<td>infarction.af.</td>
</tr>
<tr>
<td>67.</td>
<td>(hypoxic-ischemic injur: or hypoxic-ischaemic injur:).af.</td>
</tr>
<tr>
<td>68.</td>
<td>(contusion: or contusional tear).af.</td>
</tr>
<tr>
<td>69.</td>
<td>(hematoma or haematoma).af.</td>
</tr>
<tr>
<td>70.</td>
<td>laceration:.af.</td>
</tr>
<tr>
<td>71.</td>
<td>shearing injur:.af.</td>
</tr>
<tr>
<td>72.</td>
<td>traumatic effusion:.af.</td>
</tr>
<tr>
<td>73.</td>
<td>subdural hygroma.af.</td>
</tr>
<tr>
<td>74.</td>
<td>hygroma.af.</td>
</tr>
<tr>
<td>75.</td>
<td>interhemispheric.af.</td>
</tr>
<tr>
<td>76.</td>
<td>parafalcine.af.</td>
</tr>
<tr>
<td>77.</td>
<td>(brain or brainstem).af.</td>
</tr>
<tr>
<td>78.</td>
<td>cerebral.af.</td>
</tr>
<tr>
<td>79.</td>
<td>intraparenchymal.af.</td>
</tr>
<tr>
<td>80.</td>
<td>sciwora.mp.</td>
</tr>
<tr>
<td>81.</td>
<td>spinal cord injury without radiologic abnormality.af.</td>
</tr>
<tr>
<td>82.</td>
<td>cervical lumbar.af.</td>
</tr>
<tr>
<td>83.</td>
<td>thoracic lumbar sacral.af.</td>
</tr>
<tr>
<td>84.</td>
<td>leptomeningeal cyst.af.</td>
</tr>
<tr>
<td>85.</td>
<td>growing skull fracture.af.</td>
</tr>
</tbody>
</table>
24. bleeding into brain.af.
25. blow to the head.af.
26. brain damage.af.
27. (brain haemorrhage: or brain hemorrhage:).af.
28. (brain swelling or cerebral edema).af.
29. cerebral injur:.af.
30. cervical spine injur:.af.
31. cervical spine neuropathology.af.
32. cranial injur:.af.
33. craniocerebral trauma.af.
34. diffuse axonal injur:.af.
35. extracranial CNS injur:.af.
36. extracranial Central Nervous System injur:.af.
37. central nervous system injur:.af.
38. (extradural haematoma or hematoma).af.
39. extradural haemorrhage.af.
40. haemorrhagic retinopathy.af.
41. (head injur: or head trauma).af.
42. impact injur:.af.
43. intracerebral bleeding.af.
44. (intracerebral haemorrhage or intracerebral hemorrhage).af.
45. (intracranial haemorrhage or intracranial hemorrhage).af.
46. intracranial injur:.af.
47. (intraventricular hematoma or intraventricular haematoma).af.
48. (multiple skull fractur: or eggshell fractur:).af.
49. exp Neck Injuries/
50. neck injur*.af.
52. neuropathology.af.
86. (Extradural haemorrhag: or extradural hemorrhag: or extradural spinal haemorrhag: or extradural spinal hemorrhag:).af.
87. laminar necrosis.af.
88. encephalomalacia.af.
89. cerebral atrophy.af.
90. (craniocervical or hydrocephalus).af.
91. encephalopathy.af.
92. (intraparenchymal hemorrhag: or intraparenchymal haemorrhag:).af.
93. (Haemorrhagic retinopathy adj3 retinal haemorrhag:).af.
94. cerebral venous thrombosis.mp.
95. diffuse axonal injur*.tw.
96. spinal subdural.tw.
97. or/23-96
98. Computed tomography.af.
99. (CT or CAT scan:).af.
100. diagnostic imaging.af.
101. (magnetic resonance imaging or MRI).af.
102. neuroradiology.af.
103. neuroimaging.af.
104. plain films.af.
105. radiological imaging.af.
106. X-rays.af.
107. neurologic: imaging.af.
108. diffusion weighted imaging.af.
109. neurologic examination.af.
110. ultrasound scan:.af.
111. (Susceptibility Weighted Imaging or SWI).tw.
112. or/98-111
113. 22 and 97 and 112
114. 22 and 97
53. non-accidental head injur:.af.
54. (parenchymal contusion or laceration).af.
55. (retinal hemorrhage or retinal haemorrhage).af.
56. skull fracture:.af.
57. (spinal cord injury adj3 radiologic abnormality).af.
58. spinal cord injur:.af.
59. (subdural haematoma or hemotoma).af.
60. (subarachnoid hematoma or subarachnoid haematoma).af.

115. 12 and 97
116. 113 or 114 or 115
117. limit 116 to yr="2013 -Current"
118. management.mp.
119. Review.pt.
120. 118 or 119
121. 117 not 120

Fourteen databases were searched together with hand searching of particular journals and websites. A complete list of the resources searched can be found below.

<table>
<thead>
<tr>
<th>Databases</th>
<th>Time period searched</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child Data</td>
<td>1970 – 2009†</td>
</tr>
<tr>
<td>CINAHL (Cumulative Index to Nursing and Allied Health Literature)</td>
<td>1970 – 2014</td>
</tr>
<tr>
<td>Cochrane Central Register of Controlled Trials</td>
<td>1996 – 2014</td>
</tr>
<tr>
<td>EMBASE</td>
<td>1970 – 2014</td>
</tr>
<tr>
<td>MEDLINE</td>
<td>1970 – 2014</td>
</tr>
<tr>
<td>MEDLINE In-Process and Other Non-Indexed Citations</td>
<td>2006 – 2014</td>
</tr>
<tr>
<td>Open SIGLE (System for Information on Grey Literature in Europe)</td>
<td>1980 – 2005*</td>
</tr>
<tr>
<td>Scopus</td>
<td>1970 – 2014</td>
</tr>
<tr>
<td>Social Care Online</td>
<td>1970 – 2014</td>
</tr>
<tr>
<td>TRIP Database</td>
<td>1997 – 2008**</td>
</tr>
<tr>
<td>Web of Knowledge – ISI Science Citation Index</td>
<td>1970 – 2014</td>
</tr>
<tr>
<td>Web of Knowledge – ISI Social Science Citation Index</td>
<td>1970 – 2014</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Journals ‘hand searched’</th>
<th>Time period searched</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child Abuse and Neglect</td>
<td>1977 – 2014</td>
</tr>
</tbody>
</table>
**Pre-review screening and critical appraisal**

Papers found in the database and hand searches underwent three rounds of screening before they were included in this update. The first round was a title screen where papers that obviously did not meet the inclusion criteria were excluded. The second was an abstract screen where papers that did not meet the inclusion criteria based on the information provided in the abstract were excluded. In this round the pre-review screening form was completed for each paper. These first two stages were carried out by clinical experts. Finally a full text screen with a critical appraisal was carried out by members of the clinical expert sub-committee. Critical appraisal forms were completed for each of the papers reviewed at this stage. Examples of the pre-review screening and critical appraisal forms used in previous reviews are available on request ([clinical.standards@rcpch.ac.uk](mailto:clinical.standards@rcpch.ac.uk)).