Child Protection Evidence
Systematic review on Head and Spinal Injuries

Published: August 2019

While the format of each review has been revised to fit the style of the College and amalgamated into a comprehensive document, the content remains unchanged until reviewed and new evidence is identified and added to the evidence-base. Updated content will be indicated on individual review pages.

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Summary

This systematic review evaluates the scientific literature on abusive and non-abusive head and spinal injury published up until **June 2018** and reflects the findings of eligible studies. The review aims to answer five clinical questions:

1. What neuroradiological investigations are indicated to identify abusive head trauma (AHT) in children?
2. What are the distinguishing clinical features of abusive head trauma in children?
3. What neuroradiological features distinguish abusive from non-abusive head trauma (nAHT)?
4. Can you date inflicted intracranial injuries in children neuroradiologically?
5. What are the clinical and radiological characteristics of spinal injury in abusive head trauma?

Fifteen new high-quality studies published between 2014 and June 2018 met the inclusion criteria and have been included in this systematic review with new evidence added to each clinical question.[1-15] Three studies included useful information regarding the identification of occult abusive head trauma (AHT)[4,15] and a study that explored whether children with 'acute/chronic subdural haemorrhage (SDH)' represent repeated trauma or rebleeding[16] are summarised in the useful reference section.

Six new studies addressed clinical question one, regarding the neuroradiological investigations that are indicated to identify AHT. The advent of more studies using MRI has expanded the ability to identify and interpret parenchymal lesions. Three studies provided data that compared computerised tomography (CT) and Magnetic resonance imaging (MRI) findings.[5,7,9] Two studies explored the findings of advanced MRI techniques that can characterise the nature and extent of parenchymal lesions in comparison to standard MRI in children with AHT[13,17] and one study assessed the utility of high-resolution coronal susceptibility-weighted imaging (SWI) in depicting bridging vein thrombosis and the rupture of bridging veins.[14]

The second question, 'what are the distinguishing clinical features of abusive head trauma in children' only included data from three new studies.[3,7,10] Eight studies were added that described the neuroradiological features that distinguish abusive from non-abusive head trauma,[1,2,5,6,9,10,18,17] and enabled an update of the meta-analyses.

Limited new evidence was available when assessing the dating of intracranial injuries from AHT neuroradiologically, one systematic review was added which assessed the dating of subdural hematomas found on CT and MRI scans.[12]

The clinical and radiological characteristics of spinal injuries in AHT were investigated in four new studies.[1,2,8,19]

Key evidence findings:

Question 1 'What neuroradiological investigations are indicated to identify abusive head trauma in children?

Widely accepted clinical guidelines used as part of best practice promote a computerised tomography scan (CT) as the preferred first line imaging technique in acutely ill children with suspected AHT in all children less than one year of age when physical abuse is suspected.

- Evidence shows that if the initial CT is abnormal, magnetic resonance imaging (MRI) has the capacity to identify further intracranial lesions, particularly parenchymal lesions.
- Studies describe a number of children with AHT who have a normal initial CT scan, but abnormalities were identified on MRI.
- Advanced MRI techniques have the ability to further delineate the extent and regions of parenchymal damage in terms of abnormal; parenchymal diffusion, cerebral blood flow, haemorrhage. These features can help to inform the full extent of brain injury and the prognosis.
- Cranial ultrasound is not an effective diagnostic investigation, whilst it can identify some features, it will miss 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.

Question 2: What are the distinguishing clinical features of abusive head trauma in children?

- Certain features (retinal haemorrhage, apnoea) correlate strongly with AHT rather than non-abusive head trauma (nAHT) in children less than three years of age.
- Other features such as seizures, rib and long-bone fractures show a positive association with AHT that failed to reach statistical significance (once missing data had been accounted for).
- Skull fractures and bruising to the head and neck were more strongly associated with nAHT but this association failed to reach statistical significance.

Question 3: What neuroradiological features distinguish abusive from non-abusive head trauma?

- Subdural haemorrhages (SDH) are statistically significantly associated with AHT, subarachnoid haemorrhages are equally prevalent in AHT and nAHT and extradural haemorrhages are statistically significantly associated with nAHT.

- Subdural haemorrhages in AHT are significantly more likely to be multiple, occur in the interhemispheric fissure, over the convexities, in the posterior fossa and be bilateral than SDHs in nAHT.
- Multiple SDH identified on CT scans of different attenuations and those of low attenuation are more commonly seen in AHT than nAHT. Those of mixed attenuation (different attenuation seen in the same SDH) have been reported in both AHT and nAHT.
- Cerebral oedema, hypoxic ischaemia, diffuse axonal injury and closed head injury were statistically significantly associated with AHT as compared with nAHT.

Question 4: Can you date inflicted intracranial injuries in children neuroradiologically?

- The time scale of the different appearances of subdural haemorrhages as they resolve, vary and overlap mean that CT or MRI findings cannot be used to accurately date SDH.

  Question 5: What are the clinical and radiological characteristics of spinal injury in abuse head trauma?
- There is a significant association between spinal injury found on MRI and AHT, particularly in the cervical region. The prevalence of spinal injury in AHT ranges from 13%-78%.
- There is growing evidence of an association between ligamentous injury and soft tissue injury to the cervical spine and AHT.
- Spinal subdural haemorrhages reported in AHT were associated with intracranial SDH. (there is debate as to whether this relates to redistribution of intracranial SDH).
- These findings would support consideration of a guideline to include spinal MRI in the assessment of children with AHT to include Short TI Inversion Recovery (STIR) sequences.

Question 5: What are the clinical and radiological characteristics of spinal injury in abusive head trauma?

- There is a significant association between spinal injury found on MRI and abusive head trauma, particularly in the cervical region. The prevalence of spinal injury in AHT ranges from 13%-78%.
- There is growing evidence of an association between ligamentous injury and soft tissue injury to the cervical spine and AHT.
- Spinal subdural haemorrhages reported in AHT were associated with intracranial SDH (*there is debate as to whether relates to redistribution of intracranial SDH*).
- These findings would support consideration of a guideline to include spinal MRI in the assessment of children with AHT to include STIR sequences.

Background

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.[20] AHT remains the most common form of fatal child abuse and multiple studies show that it predominantly affects infants. This review has used the term AHT to include cases of inflicted head injury where there is intra cranial injury. Cases of skull fracture alone have not been included, as this is addressed in the skeletal fractures section of Child Protection Evidence.

It is recognised that a number of children with AHT may have this diagnosis missed when they first come into contact with child health practitioners.[21] Current controversies exist around clinicians' ability to confidently diagnose AHT; we hope that this review explains the strength of evidence that one can rely on in this regard.

This systematic review evaluates the scientific literature on abusive and non-abusive neurological and spinal injuries in children published up until **June 2018** and reflects the findings of eligible studies. The review aims to answer the five clinical questions:

1. What neuroradiological investigations are indicated to identify abusive central neurological system injury in children?
2. What are the distinguishing clinical features of abusive head trauma in children?
3. What neuroradiological features distinguish abusive from non-abusive head trauma?
4. Can you date inflicted intracranial injuries in children neuroradiologically?
5. What are the clinical and radiological characteristics of spinal injuries in abusive head trauma?

Methodology

A comprehensive 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 (please note that due to improving quality of publications over the time scale of this programme of work, the study types included and ranking of abuse criteria may have changed from the original criteria for certain questions). The first review was completed in 2010 and has been updated regularly. This report includes the most recent update 2014-2018.

Potentially relevant studies underwent full text screening and critical appraisal. To ensure consistency, a ranking system was used to indicate the level of confidence that abuse had taken place (Appendix 1).

Findings of clinical question 1

What neuroradiological investigations are indicated to identify abusive head trauma in children?

Abusive head trauma is associated with high morbidity and mortality in children.[22-24] AHT includes a variety of features such as extra-axial haemorrhages with or without parenchymal lesions (e.g. cerebral oedema, lacerations, hypoxic ischaemic injury or cerebral contusion).[25] 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 anaesthesia or sedation for MRI. The Royal College of Radiology guidelines[26] reassure that a head CT is said to be equivalent to 18 months of background radiation, that radiologists adhere to the ALARA principal (As low as is Reasonably Achievable) and that radiation doses from CT are reducing over time as the imaging techniques are upgraded and the process becomes quicker. Imaging decisions need to weigh the risk of missing significant injury, radiation dosage and the need for sedation/general anaesthesia for magnetic resonance imaging (MRI) in young children.[27]

Computerised tomography (CT)

In an acutely ill child, CT is the preferred imaging technique, due to its widespread availability and ability to identify and localise acute extra-axial bleeding. Current published clinical guidelines in the UK recommend a CT scan as the first investigation and should be undertaken in all children less than one year old with suspected physical abuse.[26] NICE guidance recommends a CT scan in children with a head injury when non accidental injury is suspected.[28] This systematic review aims to address the value of neuroimaging modalities in addition to the initial CT scan.

1.1 Magnetic resonance imaging

When investigating cases of suspected AHT, does magnetic resonance imaging add information in children with abnormal computerised tomography scans?

Eleven studies including children aged 0-4 years addressed this issue.[5,7,9,29-36] In children with an abnormal brain CT, at least 20.5% (95% CI: 15.3 – 26.9) would have additional abnormalities detected by MRI.[30-33] One of the studies[31] had a lower rate of additional findings which may be due to the 'heightened scrutiny by the imaging readers' of CT images.

A study of 0-21 year olds (65.7% less than five years of age) with traumatic brain injury (TBI), compared the agreement of findings between early CT and MRI scans within two weeks (median delay one day), (sagittal T1 Axial T1/T2/fluid, attenuated inversion recovery, DWI/gradient echo and coronal T2).[5] There were 37 patients with AHT in the study population and 68 accidental cases. The level of agreement between CT and MRI in AHT cases was worse than in nAHT cases (extra parenchymal findings Kappa score 0.23 vs 0.71: intra parenchymal Kappa 0.27 vs 0.52). In AHT cases MRI identified more lesions than CT.[5]

Additional findings seen on MRI

Eight studies confirmed that further subdural haemorrhages (SDHs) not seen on the initial CT were seen on MRI.[5,29,30,32-36] These SDHs were found in occipital, posterior fossa, subtemporal, subfrontal, convexity and interhemispheric locations.[29,30,32-36] Two studies identified the same numbers of subdural haemorrhages on CT and MRI.[7,31] MRI gave additional information about the signal intensity of the SDHs.[29-31,33]

Additional SAHs could be seen on MRI that had been missed on the initial CT.[29,32,35] However in 4/16 children MRI missed SAHs seen on CT.[36]

Seven studies confirmed that additional parenchymal lesions can be seen on MRI that are not seen on CT.[5,9,29-33] Buttram et al[5] identified parenchymal lesions in 16/37 children on MRI compared to 4/37 on CT scanning (p=0.03). [5] Palifka showed that only half (9/18) cases of AHT with parenchymal lacerations seen on MRI were suspected on non-contrast CT.[9] Cerebral contusions were identified more clearly on MRI than on CT.[36] MRI demonstrated cranial shearing injury that was not apparent on CT.[32,33,36] MRI identified additional features that included diffuse axonal injury and ischemia.[31]

When investigating cases of suspected AHT, does magnetic resonance imaging add information in children with normal initial computerised tomography scans?

Six studies identified lesions on MRI in children with normal initial CT scan.[4,5,19 ,29,34,36] Of eight children with normal CT undergoing MRI, subdural collections, cortical contusion and shearing injury were shown on MRI.[29,34,36] Buttram et al reported three cases of AHT with normal CT where lesions were identified on MRI.[5] Jacob et al reported restricted parenchymal diffusion in one of seven children with normal CT who also had MRI.[19] (*Of note Jacob et al describe three of eight children with normal cranial CT who had evidence of cervical -spine injury on MRI and injuries consistent with physical abuse, of these one had restricted parenchymal diffusion on MRI and two had normal MRI*).

In Boehnke et al's study of 714 children less than two years old investigated for suspected physical abuse but with normal neurological status at presentation, there were 100 children who underwent both CT and MRI of whom five (5%) had head trauma diagnosed on MRI that was not evident on CT.[4] MRI findings included ischemia, subdural hematoma or intraparenchymal haemorrhage.

1.2 Advanced MRI techniques

When investigating cases of suspected AHT, do diffusion weighted/advanced MRI techniques add information to standard magnetic resonance imaging?

There were eight studies which included children aged 0-36 months that addressed this issue.[7,14,17,37-41]

Diffusion weighted imaging (DWI)

Diffusion weighted imaging (DWI) demonstrated additional findings that were not apparent on conventional magnetic resonance imaging (MRI),[38-41] such as more extensive brain injury.[41] DWI with apparent diffusion coefficient (ADC) mapping allowed better delineation of the extent of white matter injury.[41] The severity of injury on DWI correlated with prognosis.[41]

DWI identified restricted diffusion of cortical and subcortical areas.[38-40] Diffuse cortical infarction and early subacute phase hypoxic ischaemic encephalopathy (HIE) shown on DWI, were found to correlate with later poor prognosis.[38-40]

Susceptibility-weighted MR

Susceptibility-weighted MR imaging demonstrated brain micro-haemorrhages and intra-parenchymal brain micro-haemorrhages in cases of AHT that were significantly more common amongst children with poorer outcome than those with good outcome, predictive accuracy of poor outcome was 92.5%.[37]

Low resolution axial susceptibility weighted imaging (SWI) identified 11/17 of the children as having possible thrombosis of the bridging veins. However, only 4/11 (36%) had findings consistent with bridging vein thrombosis on high resolution coronal SWI. Where axial images showed the "Tadpole sign", this was not found to be a predictor of bridging vein thrombosis on coronal SWI (odds ratio = 0.3 [0.02, 5.01], p=0.538). Coronal SWI identified irregularities in the walls of the bridging veins that was statistically significantly associated with SDH. Disruption of the normal anatomy of bridging veins further supports the traumatic nature of AHT.[14]

Diffusion Tensor imaging (DTI)

One study supported the role of MRI with diffusion tensor imaging (DTI) to identify white matter micro-structural abnormalities in children with AHT.[7] Data from 17 children (between three months and three years of age) found reduced axial diffusivity (AD) (consistent with axonal injury) in white matter regions in the AHT children compared with the 34 age matched controls, namely children undergoing MRI for other clinical reasons e.g. possible seizure activity or meningitis. The AHT 'severe outcome' group had significantly higher incidences of diffuse oedema on CT group than the 'mild/moderate outcome' group (p=0.04) but no significant differences were found in the incidence of subdural haemorrhage on CT or MRI between these two outcome groups. The AHT 'severe outcome' group had lower axial diffusivity compared with the AHT 'mild/moderate outcome' group or compared to control infants.[7] AHT cases had significantly reduced AD in regions associated with neuro cognition and executive functioning including auditory and visual systems when compared with the control cohort. The study advocated DTI as a possible technique with therapeutic and prognostic implications.

Arterial Spin Labelling (ASL)

A study of Arterial Spin Labelling (ASL) perfusion imaging measured cerebral blood flow in 12 children less than two years of age with SDH (six with AHT and six with nAHT), and 21 controls who had a normal conventional MRI undertaken in the course of investigation of structural abnormalities or medical conditions.[17] This small study identified a higher proportion of cases with brain perfusion abnormalities on MRI in five (83%) of six with AHT compared to one (17%) in the nAHT group. In the AHT group two had hyperperfusion, two had hypoperfusion and one had both hypo- and hyperperfusion, the nAHT case had hypoperfusion. The four patients with hypoperfused lesions had a poor outcome, two died and one experienced hemiparesis, all in the AHT group. The study suggests that these findings may be associated with axonal injury in AHT and that ASL may be used to monitor the clinical conditions of patients, to asses prognosis.

1.3 High resolution ultrasound scans

What is the value of high-resolution ultrasound scans?

There are no large-scale studies of the utilisation of ultrasound scanning of the head in children with suspected AHT. Three case series studies including 21 children aged between 0-12 months with AHT addressed this issue.[42-44]

Ultrasound scans (USS) found SDHs and staging (ageing the lesion) was possible in 15/20 SDHs identified and also echogenic cortical oedema in five patients; this was visible on CT or MRI.[42] Ultrasound scans also found SDHs and contusional tears[43] and cerebral oedema.[44]

However, USS missed two posterior cranial fossa SDHs and three basal cistern subarachnoid haemorrhages (SAHs) that were visible on CT or MRI.[42] Ultrasound scans also missed SAH,[44] skull fractures and characterisation and ageing of SDHs.[43]

1.4 Key evidence statements

Clinical guidelines promote a computerised tomography scan (CT) as the preferred imaging technique in acutely ill children with suspected AHT and in all children less than one year of age when physical abuse is suspected.

- If the initial CT is abnormal magnetic resonance imaging (MRI) has the capacity to identify further intracranial lesions, particularly parenchymal lesions.
- Studies describe a number of children with AHT who have a normal initial CT scan, but abnormalities identified on MRI.
- Advanced MRI techniques have the ability to further delineate the extent and regions of parenchymal damage in terms of abnormal; parenchymal diffusion, cerebral blood flow, haemorrhage. These features can help to inform the full extent of brain injury and inform prognosis.
- Cranial ultrasound is not an effective diagnostic investigation whilst it can identify some features, it will miss 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.

1.5 Research implications

- Further research to identify the value of magnetic resonance imaging as a first line investigation, to inform prognosis and management of children with AHT would be of value.

- Further studies or a systematic review to determine the positive diagnostic yield of head CT in all children less than one year of age with suspected abuse and whether there are specific clinical indicators to inform the validity of this recommendation would be of value.

1.6 Limitations of review findings

- Limited 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 studies evaluating MRI/DWI at standard time intervals after initial CT scan.

Findings of clinical question 2

What are the distinguishing clinical features of abusive head trauma in children with intracranial injury?

Abusive head trauma may present in a variety of ways, from overt neurological symptoms to mild irritability or co-existent physical injuries.[21,45] Symptoms and signs of AHT can be subtle especially in babies and it is well documented that children with AHT may be missed on initial presentation.[21,46] We systematically reviewed the literature to identify key clinical indicators of AHT versus nAHT.

There were 18 studies included that addressed the demographic features of children with AHT.[1,29-43,44 ,47] Children were aged less than three years in 14 studies [1,29,30,32-39,41,43,47] and 0-16 years in three studies.[31,40,42] Children with AHT were younger than those with nAHT.[33,36,37,43] Overall boys sustained more intracranial injuries than girls but there was no statistically significant difference between AHT and nAHT.[29-31,35-38,42,43,47]

The influence of ethnicity and socio-economic group were reported in three studies. Ethnicity showed no significant difference between groups.[29,42,47] AHT was found to be more common in the lower socio-economic groups, in two out of the three studies addressing this issue.[29,38,42] 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

Three studies addressed the association between apnoea and AHT, apnoea was variably defined between studies and was not always recorded.[25,48,49] In a child less than three years of age with intracranial injury and apnoea, a meta-analysis showed that the positive predictive value for abusive head trauma was 93% (95% confidence interval (CI) 73%-99%) and odds ratio of 17.1 (95%CI 5 – 58, p<0.001).[25,48,49]

2.2 Retinal findings

In the original Systematic review, 13 studies addressed the association between retinal findings and AHT.[33,48-59] Not all children in the comparison groups (nAHT) were examined for retinal haemorrhage and a conservative approach was taken to account for this within a meta-analysis[60] that showed that in children less than three years old with intracranial injury and retinal findings, the positive predictive value for AHT was 71% (95% CI 48%-87%) and odds ratio 3.5 (95% CI 1.1 -11.3, p=0.03).[33,48-59] This meta-analysis was based on the presence or absence of retinal findings without details of the retinal findings.

Further studies included in the most recent update documented the prevalence of RH in AHT vs nAHT, Bhardwaj confirmed that 2% (2/86) of nAHT cases had RH in comparison to 78% (14/18) of AHT cases.[3] Baerg reported retinal findings in 48% (25/52) AHT but in none of 21 cases of nAHT.[1]

2.3 Rib fracture

Eight studies addressed the association between rib fractures and AHT, full skeletal surveys were not performed in all cases of suspected AHT and even less so in cases of nAHT, whilst rib fractures were infrequently recorded but predominant in AHT.[33,49,51,53,54,57,58,61]

In a child with intracranial injury and rib fracture, the meta-analysis[60] showed that the positive predictive value for AHT was 73% (95% confidence interval (CI) 50%-88%) and odds ratio of 3.0 (95%CI 0.7 – 12.8).[33,49,51,53,54,57,58,61] A combination of rib fractures and intracranial injury is associated with AHT, however the odds ratio did not reach statistical significance (this may be due to the small numbers of rib fractures recorded and the imputation strategy used to account for the fact that not all cases of nAHT had skeletal survey).

2.4 Long bone fracture

Eight studies addressed the association between long bone fractures and AHT. In a child with intracranial injury and long bone fracture the positive predictive value for AHT was 59% (95% confidence interval (CI) 48%-69%) and odds ratio 1.7 (95%CI 0.8 – 3.6).[33,49,51,53,54,57,58,61] A combination of long bone fractures (including metaphyseal fractures) and intracranial injury is associated with AHT, however the odds ratio did not reach statistical significance (this may be due to the small numbers of long bone fractures recorded and the imputation strategy used to account for the fact that not all cases of nAHT had skeletal survey).

2.5 Seizure

Eight studies addressed the association between seizures and AHT, seizures were infrequently recorded and only had a weak association with abusive head trauma (AHT).[48-54,58] In a child less than three years of age with intracranial injury and seizure the meta-analysis[60] showed that the positive predictive value for AHT was 66% (95% confidence interval (CI) 45% – 82%) and odds ratio 2.9 (95%CI 0.7 – 11.7).[48-54,58] Seizures and intracranial injury were associated with AHT, however the odds ratio did not reach statistical significance (this may be due to the small number of cases with seizures recorded).

The character and number of seizures was not recorded in all studies. It may be important to look at this in more detail.

2.6 Bruising to the head and/or neck

Three studies addressed the association between head or neck bruising and AHT.[30,48,62] Bruising was the least recorded item across the studies, giving very weak statistical influence.[60] In a child aged less than three years with intracranial injury and bruising to the head and/or neck, the meta-analysis showed that the positive predictive value for abusive head trauma was 37% (95% confidence interval (CI) 3% – 91%) and odds ratio 0.8 (95%CI 0.07 – 9.4) showing that head and neck bruising was not a significant indicator of AHT over nAHT.[60]

2.7 Skull fracture

Skull fracture is associated with non-abusive head trauma.[10,11,33,49-51,53,54,56,58,61,62] In the meta-analysis[60] a child aged less than three years with intracranial injury and skull fracture the positive predictive value for AHT was 44% (95% confidence interval (CI) 22%-68%) and odds ratio for AHT was 0.8 (95%CI 0.3-2.3) showing that a skull fracture was not a significant indicator of AHT over nAHT.[33,49-51,53,54,56,58,61] The most recently added studies confirmed these findings: Roach et al identified skull fractures in 53% (378/716) nAHT and 23% (121/533) AHT in children under two years old with traumatic brain injury giving an odds ratio for AHT of 0.26 (95% CI 0.2-0.37).[18] Pontarelli et al showed that skull fractures were more common after falls in infants less than 12 months of age with intra cranial injury (ICI) than in AHT 42% (11/26) vs. 36% (7/19) OR 0.8 (0.2-2.7).[10]

Clinical Decision Rules

Recursive partitioning, a statistical method for performing multivariable analysis, was used on a large dataset of children aged less than three years old that identified variables that may assist in “screening out” children where abusive head trauma is unlikely.[63]

Individual patient data from six comparative studies of children less than three years old with intracranial injury were analysed to determine the association between AHT and combinations of apnoea; retinal haemorrhage; rib, skull, and long-bone fractures; seizures; and head and/or neck bruising. An aggregate analysis of data from these studies provides estimates of predictive values and odds ratios for AHT from 64 different combinations of features.[64]

Results from a further systematic review

In addition to figures quoted from the meta-analysis undertaken from the initial systematic review and meta-analysis published in 2009, Piteau et al published a similar review in 2013, their definition of head trauma included children with skull fracture as well as cases of intracranial injury.[65] A similar list of included studies to those listed above met their inclusion criteria and search (1950-2010). Analysing high quality studies, the authors identified 'retinal hemorrhage(s), skull fracture(s) plus intracranial injury, metaphyseal fracture(s), long bone fracture(s), rib fracture(s), seizure(s), apnoea, were significantly associated with AHT. Isolated skull fracture(s) were significantly associated with nAHT and head and neck bruising, any bruising, and vomiting were not significantly associated with either type of trauma. The authors undertook a sensitivity analysis for skeletal fractures and retinal findings to account for the potential lack of skeletal survey or ophthalmology examination in nAHT cases. While retinal hemorrhages remained significantly associated with AHT, long bone and rib fractures did not, and there were no studies examining metaphyseal fractures to include in the analysis.[65]

With the exception of a strong association between skull fractures and ICI with AHT, these findings are similar to those described above. It is likely that the strong association between skull fracture and ICI is influenced by the wider population included in the review which would include more children within the nAHT group (children with skull fracture alone).

2.8 Key evidence statements

- Certain features (retinal haemorrhage, apnoea) appear to correlate strongly with AHT rather than nAHT in children less than three years of age.
- Other features such as seizures, rib and long-bone fractures show a positive association with AHT that failed to reach statistical significance.
- Skull fractures and bruising to the head and neck were more strongly associated with nAHT but this association failed to reach statistical significance.

2.9 Research implications

- Few studies have been conducted over the last 10 years that address the clinical features associated with AHT. Large-scale studies evaluating multiple variables and how they combine to inform a diagnosis of AHT would enhance this field.

- Further studies addressing the history offered in AHT versus nAHT may assist in distinguishing these two conditions.

2.10 Limitations of review findings

- Neither apnoea nor seizure type/duration were consistently defined, limiting the value of this item.
- The AHT population varied between studies (some ascertaining all children with subdural haemorrhage and others all children with brain injury), which may influence results.
- Not all children with nAHT had full radiological or ophthalmology examination that potentially biased results, albeit this was taken into consideration within the meta analytic analysis.

Findings of clinical question 3

What neuroradiological features distinguish abusive from non-abusive head trauma?

Good-quality studies are included in this meta-analysis which make an important contribution to our understanding of the neuroradiological findings that help when determining the likelihood of AHT.

Neuroimaging is undertaken in infants where AHT is suspected. The neuroimaging must be interpreted carefully, in the context of the historical and clinical features, giving due consideration to the differential causes of intracranial injury in infancy e.g. accidental 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.

A total of 33 studies were included.[1,3,5,6,9,10,17,18,22,30,40,45,48-50,57-59,61-63,66-77] All studies included an initial head CT, many with additional MRI, with the exception of two studies which relied solely upon MRI.[17,,45] Where possible data were added to the meta analyses cited below.

3.1 Extra-axial haemorrhages

There are 20 included studies that described details of extra-axial haemorrhages.[2,3,5,6,18,22,48-50,59,61-63,66,67,69,70,72,73,77]

Subdural haemorrhage (SDH)

The prevalence of SDH in children with AHT and nAHT was reported in 18 studies.[1,3,5,6,18,22,48-50,59,61-63,69,70,72,73,75] All studies confirmed that SDH was statistically significantly associated with AHT.

Meta-analysis using a random effects model gave an overall odds ratio (OR) of 8.75 (95% confidence interval 7.37 – 10.39, p<0.0001; I^2 = 0%;) for SDH in AHT.

Subarachnoid haemorrhage (SAH)

There were 13 studies[3,18,48-50,62,63,66,67,69,72,75,77] that described SAH which was equally prevalent in AHT and nAHT. The overall OR for AHT was 1.39 (95% CI 0.83 – 2.33, p=0.21; I^2 = 78%;).

Extradural Haemorrhage (EDH)

Extradural haemorrhage was reported in 14 studies[5,18,22,48-50,61-63,67,69,73,75,77] and confirmed a statistically significant association between EDH and nAHT. The overall OR for EDH and AHT was 0.16 (95% CI 0.11 – 0.22, p<0.0001; I^2= 0%).

3.2 Pattern of subdural haemorrhages

Interhemispheric haemorrhages

Meta-analysis of seven studies[30,63,67,69-71,77] showed that interhemispheric haemorrhages were significantly associated with abusive head trauma (AHT), with an odds ratio (OR) of 8.03 (95% CI 5.58 – 11.56, p<0.00001;I^2 = 0%;).

Multiple subdural haemorrhages

There were only two studies[30,67] that looked at children with multiple extra-axial haemorrhages, both demonstrating a strong association with AHT and an overall OR of 6.01 (95% CI 2.52 – 14.35, p<0.0001;I^2=0%;).

Subdural haemorrhage (SDH) over the convexities

Meta-analysis of three studies[30,67,77] gave an overall OR for convexity SDH and AHT of 4.93 (95% CI 1.25 – 19.42, p=0.02; I^2=75%).

Infra-tentorial/posterior fossa haemorrhages

Infra-tentorial/posterior fossa haemorrhages were associated with AHT; meta-analysis of three studies[30,67,70] gave an overall OR for AHT of 2.55 (95% CI 1.06 – 6.13, p=0.047; I^2=0%).

Bilateral haemorrhages

A meta-analysis of five studies[3,58,63,67,71] showed that bilateral subdurals are significantly associated with AHT (OR 4.92, 95% CI 1.68 – 14.46, p=0.004; I^2=80%).

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.[30,62,68,71,77] Low attenuation haemorrhages were more commonly seen in AHT than in nAHT.[62,67,68,70,71,77]

Two studies reported SDH of mixed attenuation (different attenuation in the same SDH). Tung et al[74] stated they were seen significantly more often in AHT than in nAHT and Vinchon[76] noted that they were equally prevalent in both conditions.

Complex subdural haemorrhages

In a study comparing neuroimaging findings in children less than four years old with AHT versus nAHT,[6] SDHs were classified as complex if bilateral, differing internal densities on CT or signal intensities on MR or a neo-membrane web and simple if unilateral of homogenous signal intensity.

AHT was associated with complex subdural haematoma (81% (13/16) vs 29% (10/35), p=0.0007).[6] Simple subdural hematomas were absent in all 16 cases of AHT but present in 20% (7/35) cases of nAHT (p=0.08).

3.3 Cerebral lesions

The advent of more studies reporting MRI findings is expanding knowledge regarding cerebral lesions (lesions within the brain itself).

Cerebral oedema

A meta-analysis of eight studies[3,30,49,67,68,71,73,77] showed that cerebral oedema was significantly associated with AHT OR 2.56, (95% CI: 1.42.-4.61,p=0.02; I^2=60%).

Intra-Parenchymal haemorrhage

Nine studies [45,48,49,62,63,66,67,69,77] described intra-parenchymal injury; however, there was no statistically significant association with AHT: OR 1.3, (95% CI 0.57-2.97, = $I^2$75%; p=0.53).

Diffuse axonal injury

Nine studies[5,6,18,30,45,63,67,70,75] addressed shear injury or diffuse axonal injury, enabling a meta-analysis to be performed for the first time giving OR for AHT of 2.18, (95% CI 1.22-3.91, I^2=24%;p=0.008).

Parenchymal Laceration

A recently included study of 165 children with head injury who had non contrast CT and MRI found that parenchymal brain lacerations were identified by MRI in 18 (13.1%) of the 137 cases of AHT, while none (0%) were detected in the 28 patients with moderate to severe accidental injury (mean GCS=5.9), representing a statistically significant difference (P=0.045) in the risk of brain laceration between the groups. Parenchymal brain lacerations had a specificity and positive predictive values of 100% for AHT.[9] Associated parenchymal injuries included contusions (4/18), shear (7/18) and ischaemic injury (7/18). Most lacerations were in the subcortical white matter and present in various locations with frontal lobe lacerations predominating. Only half (9/18) had lacerations suspected on non-contrast CT.[9]

Hypoxic ischaemic injury

Ten studies addressed hypoxic ischemic injury (HII).[5,6,40,45,49,63,73,75,78,79] Ichord et al stated that HII was predominantly bilateral and generalised in 9/22 cases of AHT, compared to 1/30 cases of nAHT.[45] The overall OR for HII in association with AHT from the ten studies was 4.06 (95% CI 2.60-6.32; p=0.00001; I^2=22%).

Perfusion Abnormalities

Wong et al used advanced MR techniques (Arterial spin-labeling perfusion imaging) in a small group of children (six AHT and six nAHT) and showed that 5/6 AHT cases had perfusion abnormality scores compared with 1/6 with nAHT. Of the five AHT cases two had hyperperfused lesions, two had hypoperfused lesions and one case had both hyper- and hypoperfused lesions. The three AHT cases with hypoperfused lesions had poor outcomes.[17]

Closed head injury

The prevalence of closed head injury, i.e. intracranial injury in the absence of skull fracture was described in 16 studies.[3,10,18,45,49,58,61-63,66,68,69,71,73,75,77] The meta-analysis showed a very significant association with AHT, OR 4.34 (95% CI 3.22-5.84;p<0.00001; I^2=50%).

Other Systematic Review

Piteau et al identified very similar results within their systematic review for SDH, EDH, SAH, Cerebral oedema and ischaemia, however they did not identify a statistically significant association between diffuse axonal injury and AHT.[65] The findings in our systematic review for DAI have only reached significance following the addition of the most recently published studies.

3.4 Key evidence statements

- Subdural haemorrhages are statistically significantly associated with AHT, subarachnoid haemorrhages are equally prevalent in AHT and nAHT and extradural haemorrhages are statistically significantly associated with nAHT.
- Subdural haemorrhages in AHT are significantly more likely to be 'complex', multiple, occur in the interhemispheric fissure, over the convexities, in the posterior fossa and be bilateral than SDHs in nAHT.
- Multiple SDH identified on CT scans of different attenuations and those of low attenuation are more commonly seen in AHT than nAHT. Those of mixed attenuation (different attenuation seen in the same SDH) have been reported in both AHT and nAHT.
- Cerebral oedema, hypoxic ischaemia, diffuse axonal injury and closed head injury were statistically significantly associated with AHT as compared with nAHT.

3.5 Limitations of review findings

This systematic review is valuable as it includes several similar studies that all draw upon populations of children less than three years of age.[25] The limitations include variation in composition of AHT 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?

Four studies addressed this issue, concluding that as of yet, the age of intra cranial injury could not be accurately assessed on MRI or CT.[12,47,76,80] One cross sectional study demonstrates that there is a considerable variation among radiologists regarding the age determination of subdural hematomas. The study surveyed 172 radiologist's confidence and ability to age subdural haemorrhages in four cases of AHT from CT and four from MRI images. In this study, 51 of 172 radiologists surveyed replied with regard to their confidence in dating subdural haemorrhages in abusive head trauma.[80] The percentage that reported that it was possible to estimate the age of the four CT cases varied from 58-83% – in 2/4 of cases the known age of the SDH fell within the range given by the participants. In the four cases with MRI, the level of confidence reporting the age was 63-90% – in 2/4 cases the estimated age was correct.

A systematic review (SR) of dating SDH on CT or MRI in an all age population included 25 studies, of which 10 addressed children with SDH. The SR examined changes in signal intensity (MRI) or density (CT) of SDH by time interval between trauma and neuroimaging based upon the hypothesis that SDH follows a progression from hyperdense through isodense to hypodense as the SDH resolves. The review looked at the timing post trauma that each appearance of SDH was recorded.[12] The SR was rigorously conducted but limited to a small number of studies of moderate quality, high levels of heterogeneity and lack of clarity as to how the time intervals between trauma and neuroimaging were calculated. However, a specific analysis was undertaken for the child related data, giving the following findings that have relevance to the assessment of children with AHT with an SDH.

A pooled analysis of 339 cases included 148 children (all except three cases were less than three years old) and showed that in children hypodense, isodense, hyperdense or mixed density were seen after a median time interval of two days and there was no significant difference between these time intervals and these did not differ between AHT and nAHT. By contrast in adults the results were very different and cannot therefore be extrapolated to children; hypo, iso and hyperdense appeared significantly later than in children and in adults hyperdense and mixed density appeared on CT (or different intensities on MRI) significantly earlier that isodense and hypodense.

Two studies previously included in our review[47,76] were included in the systematic review described above. Vinchon et al found consistent time related modifications of MRI signal in the sediment within mixed density SDHs on T1-weighted and FLAIR sequences.[76] They set out a schematic of temporal evolution of CT and MRI findings and propose a method to develop a time scale for dating traumatic events but advocate that a large study is needed.[76]

Bradford et al outlined the serial changes over time of SDH appearances and parenchymal hypodensities on CT and MRI from the time of known injury in 43 cases of AHT.[47] Whilst the authors claim that their data provides a framework on which AHT intracranial injuries can be broadly timed, they urge caution against using imaging findings alone to do so.[47]

These findings confirm that the time intervals of the different appearances of SDH are broad and overlapping in children and cannot be relied upon to age SDH and secondly findings in adults differ significantly to that in children and thus adult findings cannot be extrapolated to children.[12]

4.1 Key evidence statements

- CT or MRI findings cannot be used to accurately date SDH.

4.2 Limitations of review findings

The systematic review included above[12] (identified that studies were of variable quality, few set out to directly address the question of aging but gave time scales for appearance changes of

SDH on neuroimaging, the actual date of trauma was difficult to capture, there were few studies that described changes on MRI.

4.3 Research implications

- With rapidly advancing neuroimaging techniques, there is a need for larger scale studies of clinical cases to determine the accuracy of dating by radiologists (however there are significant methodological and ethical issues surrounding serial imaging that would be required, studies must rely upon the pooling of images that are undertaken for clinical reasons).

Spinal Injury in Abusive Head Trauma

The first systematic review in this series explored the scientific literature about spinal injury in child abuse.[81] Scientific literature was limited to a series of case reports and small case studies, since that time the evidence base has expanded and attention has turned to the **recognition of spinal injury co-existing with AHT**.

This review aims to characterise spinal injury in children with AHT and its associated radiological features.

Findings of clinical question 5: What are the clinical and radiological characteristics of spinal injuries in AHT?

The initial systematic review of spinal injury in physical abuse[81] was limited to individual case studies and small case series amongst which we identified a handful of cases of AHT with co-existing spinal injury, most of which were to the cervical spine.[82-86] Whilst spinal fractures are relatively uncommon in physical abuse, in 2013 Barber et al identified AHT in 10/14 children with spinal fractures on skeletal survey.[87]

Over the past 10 years larger studies using MRI, in particular using STIR sequence (Short-TI Inversion Recovery) to null the signal from fat have identified and described the association between spinal injuries and AHT.[1,2,19,88-92]

Spinal subdural haemorrhage

Koumellis analysed head and spinal MRI (T1-T2 sagittal imaging and axial T1 and T2 images where appropriate) on 18 children with AHT and identified occult spinal subdural collections in 8/18 (44%).[92] All eight cases were associated with subdural haematomas in the supratentorial and infratentorial compartment. In six cases the spinal subdurals were large extending from the sacrum to the cervical spine in two cases, up to the thoracic spine in three cases, and up to the upper lumbar spine in one. Two were small, one tracking along the posterior aspect of the cervical spine, and a similar one in the thoracolumbar region.

Choudhary conducted a case-control study of 67 AHT cases versus 70 non-AHT cases.[88] Of 67 cases of AHT 31 had spinal subdural haemorrhage (SDH). All cases had intracranial supratentorial and posterior fossa, subdural haematoma including 15 small intracranial SDH and 16 moderate SDH. The majority of the spinal SDH was along the posterior dura although some were circumferential, and some were exclusively anterior. Only 1/70 nAHT had spinal subdural – this child had substantial posterior fossa injuries including displaced comminuted occipital bone fracture and cerebellar contusions. Of the 70 accidental cases, 22 had small intracranial subdural haemorrhages, one of whom had the spinal subdural haemorrhage.

Spinal cord and ligamentous injuries

Two case-control studies of children with AHT versus nAHT addressed the correlation between intra-cranial and spinal injury on MRI.[78,79] Kadom identified cervical spinal injury (most of which were ligamentous in 27/74 children included in the study) but found no significant difference between cervical spine injuries and AHT (confirmed or suspected) and nAHT.[79] Choudhary identified that cervical spine ligamentous injuries were significantly more common on MRI (including STIR sequence) in AHT and found a strong association between cervical ligamentous injury and cerebral ischaemia in children with AHT.[89]

Knox et al identified that of 29 children, less than two years old with spinal injuries, 11 (38%) were injured as a result of physical abuse (in the nAHT cases 11 were MVCs, four pedestrian motor vehicle incidents and three were falls).[8] All 11 AHT cases were younger than two years, 8/11 had c-spine injuries and 7/8 cases had associated intracranial injury. Injuries were most common at the atlanto-occipital junction or atlanto-axial spine in 7/8 cases. MRI demonstrated that ligamentous injury was the most common injury type (8/11, 73%).[8]

In their prospective study (with children less than three years old) Baerg et al compared the pattern of cervical spine injury between 52 of the children with AHT (witnessed or admitted: 17/52 were shaken) and 21 accidental head trauma (Motor vehicle related 10, falls 11). MRI (*T1,T2 and STIR sequence*) identified a C-spine injury in 7/52 (13%) AHT cases and 3/21 (14%) accidental cases.[1] C-spine injury in AHT cases included atlanto-occipital dislocation (1), cord injury and epidural haematoma (2), cord haematoma (1), vertebral artery shear (1), ligamentous injury (2) and in the three accidental cases; atlanto-occipital dislocation (1), cord injury and epidural haematoma (1) and cord haematoma (1). The stated mechanism of those with AHT and c-spine injury was shaking and for the accident group was MVA/pedestrian injury, no c-spine injury was seen after accidental falls. The seven children with a c-spine injury were significantly more likely to have been shaken (p=0.01), have a lower GCS at presentation (p=0.01), brain infarction at 48 hrs on MRI (p=0.04), and profound neurodisability (vegetative state) from hypoxic-ischemic brain injury (p=0.01), when compared to the 45 with AHT without a c-spine injury.[1]

A cohort study by the same group of authors explored the same group of AHT cases (with one further case added). The study included 53 children less than three years old with AHT. The authors identified a prevalence of c spinal injury of 15.1% (8/53). They compared the eight cases of AHT who had c-spine injury[1] (ligamentous injury (2), vertebral artery shear injury (1), atlantooccipital dissociation (1), cord injury with cord epidural hematoma (2) and an isolated cord epidural hematoma (2)) with the 45 cases that did not. There was a significantly higher incidence of lower Glasgow coma score (GCS) (p=0.01), retinal haemorrhages (p=0.02), shaking mechanism (p=0.04), brain infarcts (p=0.01), hypoxic/ischemic injury (p=0.01), stroke (p<0.01) and multiple findings (p=0.01) on brain neuroimaging in those with cervical-spine injury when compared to those without cervical spinal injury.[2] The authors recommended DWI MRI of the cervical spine when investigating children with suspected AHT.

Jacob et al. analysed 85 children less than five years of age (82 cases had a diagnosis of AHT) who were admitted to hospital with physical abuse. Cervical MRI (*sagittal STIR images, sagittal T1Wis axial T2W1s and axial T2 gradient-echo*) performed as well as cranial neuroimaging in these children.[19] C-spine injury was identified in 61/85 (69%) of cases, 60/61 had ligamentous injury, the most common were cervical interspinous (65%), upper thoracic interspinous (46%) and nuchal (39%) with no transverse, anterior or posterior longitudinal ligament injury. Abnormal capsular fluid (atlanto occipital atlanto axial) was present in 32%, cervical/thoracic subdural haemorrhage in 18% (always associated with intracranial SDH), epidural fluid 10%, cord haemorrhage in 5%. Cervical spinal injury on MRI was significantly associated with parenchymal restricted diffusion on cranial MR. Three of eight children with normal cranial CT had evidence of c-spine injury and injuries consistent with physical abuse (of these one had restricted parenchymal diffusion on MRI and two had normal MRI).[19]

5.1. Key evidence statements

- There is a significant association between spinal injury found on MRI and abusive head trauma, particularly in the cervical region. The prevalence of spinal injury in AHT ranges from 13%-78%.

- There is growing evidence of an association between ligamentous injury and soft tissue injury to the cervical spine and AHT.

- Spinal subdural haemorrhages reported in AHT were associated with intracranial SDH (*there is debate as to whether relates to redistribution of intracranial SDH*).

- These findings would support consideration of a guideline to include spinal MRI in the assessment of children with AHT to include STIR sequences.

5.2. Limitations of review findings

- With increasing use of MRI, more injuries are being detected, however the imaging sequences selected by authors vary from one study to another.

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: What neuroradiological investigations are indicated to identify abusive head trauma in children?

- Proton and phosphorus magnetic resonance spectroscopy (MRS) may have a role in identifying metabolic abnormalities[93,94] The use of apparent diffusion coefficient on MRI may be of value in predicting poor long term neurodevelopmental outcome.[95]

- Standards for radiological investigations of suspected non-accidental injury Royal College of Radiology – November 2018.[96]

- Two new studies[4,15] together with two older studies[97,98] describe the prevalence of occult head injury in children with suspected physical abuse and contribute to the decision as to whether CT scan is indicated in all children less than one year of age with suspected physical abuse.

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

- 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).[99-101]

- 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.[102]

- The importance of identifying children with minor abusive injuries (sentinel injuries) to prevent further severe injury, including AHT, has been highlighted.[21,103] There is increasing interest in the identification of a clinical decision rule or screening investigations which may indicate which children have sustained intracranial injury/AHT.[104]

- There is ongoing debate as to the significance of pre-existing macrocephaly amongst infants who present with intracranial injury.[105]
- There is a welcome expansion of the literature relating to long term outcomes in children who sustain AHT.[106]
- Work continues to identify the biomechanics underlying shaking as a cause of intracranial injury.[107,108] In addition studies of the biomechanics of falls are an important contribution to our understanding of AHT.[109,110]
- Publications relating to perpetrator admissions may provide insight into the mechanism of injury in AHT.[111]

Clinical question 3: What neuroradiological features distinguish abusive from non-abusive head trauma?

- 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 abuse.[112]
- Asymptomatic intra-cranial haemorrhage has been described in newborns undergoing MRI imaging. Supratentorial subdural haemorrhage 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 months.[113]
- From the basis that there is controversy as to whether acute (high density) SDH associated with chronic SDH (low density) results from trauma or re bleed, one study examined the differences in clinical presentation between young children diagnosed with AHT with acute SDH (n=291) and acute/chronic SDH (n=92). The study concluded that the clinical presentation of these two groups of children did not differ suggesting that the acute SDH in children with acute and chronic SDH is a result of new trauma rather than a rebleed. Within the study there were eight children with asymptomatic macrocephaly and acute/chronic SDH, the acute and chronic SDH was co-located. The authors suggest that in these circumstances the acute SDH may occur spontaneously or after minor trauma.[16]

Clinical question 4: Can you date inflicted intracranial injuries in children neuroradiologically?

There were no recommended resources for clinical question 4.

Clinical question 5: What are the clinical and radiological characteristics of spinal injury in abusive head trauma?

- Study of accidental spinal injury confirming that upper cervical injury is commoner in younger children with thoraco-lumbar injuries becoming more common with increasing age.[114]

- One post-mortem study demonstrated that 70% of children with abusive head trauma had pathological cervical cord injuries.[115]

- In another, a three and a half-year-old child was found dead with complete fracture dislocation through L2-L3 intervertebral disc with completely disrupted anterior longitudinal ligament, haematomas in para-spinal muscles, and extradural haematoma around caudal spinal cord. This was associated with traumatic transection of the abdominal aorta.[116]

- Study describing the correlation between radiology and histopathology of vertebral fractures in fatal cases of child abuse.[117]

- Infants who may present with features suggestive of physical abuse including spinal injury should have differential diagnoses (e.g. Menkes disease) considered.[118]

- Optimal radiological techniques are essential for the identification of spinal injury in children; currently MRI would appear to be the imaging technique of choice to identify relevant soft tissue injuries.[79,119-121]

- Physiological anomaly a coronal cleft may be present in the vertebral body in infants in the first year of life. They are predominantly in the lumber-spine but may be mistaken for a compression fracture.[122]

- Biomechanical studies have explored the failure properties of cervical spine ligaments[123] and the pattern of histological injury following shaking in animal studies.[108]

Related publications

Publications arising from neurological injuries review (these were the first systematic reviews published prior to the more recent updates)

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 children in whom inflicted brain injury (iBI) is suspected? A systematic review. Clinical Radiology. 2009;64(5):473-483

Maguire SM, Pickerd N, Farewell D, Mann MK, Tempest V, Kemp AM. Which clinical features distinguish inflicted from non-inflicted brain injury? A systematic review. Archives of Disease in Childhood. 2009;94(11):860-867

Kemp AM, Jaspan T, Griffiths J, Stoodley N, Mann MK, Tempest V, Maguire SA. Neuroimaging: what neuroradiological features distinguish abusive from non-abusive head trauma? A systematic review. Archives of Disease in Childhood. 2011;96(12):1103-1112

Kemp AM. Abusive head trauma: recognition and the essential investigation. Archives of Disease in Childhood - Education and Practice. 2011;96(6):202-208

Kemp A, Joshi A, Mann M, Tempest V, Liu A, Holden S, Maguire S. What are the clinical and radiological characteristics of spinal injuries from physical abuse: a systematic review. Archives of Disease in Childhood. 2010;95(5):355 -360 [Pubmed]

Part primary study deriving from neurological injuries review

Maguire SA, Kemp AM, Lumb RC, Farewell DM. Estimating the probability of abusive head trauma: A pooled analysis. Pediatrics. 2011;128(3):e550-e564

Comment: Reading R. Estimating the probability of abusive head trauma: a pooled analysis. Child: Care, Health and Development. 2011;37(6):897-898

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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.

Prior to the 2018 update, 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 and those that met our inclusion criteria were reviewed. For the 2018 update studies were managed using Endnote and only data included in English language papers or with an English language abstract were accessed for relevancy. No contact was made with authors in this update.

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).[124] We also used a selection of systematic review advisory articles to develop our critical appraisal forms.[125-129] 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.

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, and this was supported by a dedicated electronic critical appraisal module.

Question 5 aims to characterise abusive spinal injury and its associated radiological features. Since both musculoskeletal and spinal cord injuries are included, studies before 2013 were identified and reviewed during our fractures and neurological injury systematic reviews. Therefore, prior to 2013 we have used both the fractures and neurological injury methodology and tools.

In October 2013 we combined terms from both the fractures and neurological injuries search strategies in order to create a separate search strategy specific to spinal injuries.

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:
    - intra-parenchymal haemorrhage
    - diffuse axonal injury
    - hypoxic ischaemic injury
    - cerebral contusion cerebral oedema

We defined the term “abusive head trauma” (AHT) as:

- intracranial injury caused by inflicted injury

We defined the term “non-abusive head trauma” (nAHT) as:

- intracranial injury as a consequence of 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.

Neurological injuries

Clinical question 1: What neuroradiological investigations are indicated to identify abusive central neurological system injury in children?

Inclusion	Exclusion
Children from birth to their 18th birthday	Consensus statements or personal practice studies
Systematic reviews /Comparative and non-comparative studies	Studies addressing exclusively post-mortem neuro-pathological findings
Children with confirmed or suspected abuse (rank 1-5)	Studies with mixed adult and child data, where the children's data cannot be extracted
All language studies	Significantly methodologically flawed studies
	Studies that only addressed head injury where there was no intracranial abnormality
Children who are alive at presentation	
Relevant clinical data given	

Clinical questions 2 and 3:

What are the clinical features that distinguish AHT from nAHT?

What Neuroradiological features distinguish abusive from non-abusive head trauma?

Inclusion	Exclusion
Children from birth to their 18th birthday	Consensus statements or personal practice studies
Systematic reviews/observational comparative study (cross-sectional/case-control/case series/longitudinal cohort)	Non-comparative studies, consensus statements or personal practice studies
Ranking of abuse 1 or 2 for AHT	Studies with low surety of diagnosis of abusive injury (rank 3-5 abuse)
All language studies	Studies with mixed adult and child data, where the children's data cannot be extracted
	Significantly methodologically flawed studies
	Studies that only addressed head injury where there was no intracranial abnormality

Clinical question 4: Can you date inflicted intracranial injuries in children neuroradiologically?

Inclusion	Exclusion
Children aged 0 years up to 18th birthday	Studies about complications, management or prognosis of AHT / nAHT
Systematic reviews/observational comparative study (cross-sectional/case-control/case series/longitudinal cohort)	Non-comparative studies, consensus statements or personal practice studies
Children with AHT	Studies addressing exclusively post-mortem neuro-pathological findings
Ranking of abuse 1 or 2 for AHT	Studies with mixed adult and child data, where the children's data cannot be extracted
nAHT: non-abusive aetiology confirmed	Methodologically flawed studies (e.g significant bias, where AHT was not adequately confirmed or where inadequate clinical details were given)

Children who were alive at presentation	Studies that only addressed head injury where there was no intracranial abnormality
All language studies	Studies with low surety of diagnosis of abusive injury (rank 3-5 abuse)
Relevant clinical details given for each group	

Spinal injuries in AHT

Inclusion and exclusion criteria for the spinal review update 2018 are as above (neurological injuries).

Inclusion	Exclusion
Systematic reviews/observational comparative study (cross-sectional/case-control/case series/longitudinal cohort)	Personal practice, Case studies, conference abstracts
English and non-English papers	Management of fractures papers
Ranking Abuse (1 or 2)	Papers where the population included adults and children
Confirmation of non abusive trauma (comparative studies)	Studies of non-abusive data only

Ranking of abuse

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

Ranking of evidence by study type

Ranking of evidence by study type	
T_1	Randomised controlled trial (RCT)
T_2	Controlled trial (CT)
T_3	Controlled before-and-after intervention study (CBA)
O_1	Cohort study/longitudinal study
O_2	Case-control study
O_3	Cross-sectional
O_4	Study using qualitative methods only
O_5	Case series
O_6	Case study
D_1	Diagnostic study
X	Formal consensus or other professional (expert) opinion (automatic exclusion)

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 review published in 2009 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.[130]

Since not all children underwent both examinations, there remained 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.

A narrative description of the findings of studies added to the review thereafter is provided, as many individual studies described the findings of advanced MRI techniques.

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. In the systematic review published in 2010[60] we used an extremely conservative imputation strategy to allow for this[131] 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[132], 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)).

Thereafter, we have provided a narrative description of data published in studies identified within the updated literature searches.

Question 3: What neuroradiological features distinguish abusive from non-abusive head trauma?

Included studies had the advantage that cases all had neuroimaging and we were able to conduct a meta-analysis of the data grouped according to primary items of interest. We used Odds ratios as a measure of effect with 95% confidence intervals. Data were pooled using a random effects model to allow for inter and intra study variance and to give a more conservative estimate of effect. RevMan was used to present data in Forest Plots. We have been able to update these meta analyses with sequential updates of the systematic reviews.

Data for questions 4 and 5 are presented in a narrative synthesis.

Search strategy

The below tables present the search terms used in the 2018 Medline database search for neurological and spinal injuries, truncation and wildcard characters were adapted to the different databases where necessary.

Neurological injuries

1. CHILD/ 2. (paediatric or pediatric or neonate*).af. 3. (child: or infant: or toddler: or babies or baby).af. 4. or/1-3 5. ((non-accidental or nonaccidental) adj3 (trauma or injur:)).af. 6. ((non-abusive or nonabusive) adj3 (injur: or trauma)).af. 7. (non-accidental: and injur:).af. 8. soft tissue injur:.af. 9. physical abuse.af.	55. spinal subdural.tw. 56. cervical.af. 57. exp Spinal Cord Injuries/ 58. Spinal Injuries/ 59. spinal cord trauma.af. 60. Spinal Cord Compression/ 61. Cervical Vertebrae/ 62. hyperflexion injur*.af. 63. hyperextension injur*.af. 64. or/23-6365. Fractur*.af. 66. exp Fractures, Comminuted/ 67. exp Fractures, Bone/

10. ((inflicted or noninflicted or non-inflicted) adj3 (brain injur: or cerebral injur: or head injur:)).af. 11. (inflicted traumatic head injur: or inflicted traumatic brain injur:).af. 12. (maltreat* or shaking).af. 13. (AHT or Abusive Head Trauma).af. 14. (or/5-13) and 4 15. (child abuse or child maltreatment or child protection).af. 16. (battered child or shaken baby or battered baby).af. 17. (battered infant or shaken infant).af. 18. (Shak: Baby Syndrome or shak: impact syndrome).af. 19. Caffey-Kempe syndrome.af. 20. *"Child Abuse"/di [Diagnosis] 21. or/15-20 22. 14 or 21 23. extracranial CNS injur*.af. 24. Craniocerebral Trauma/ 25. cervical spine injur:.af. 26. cervical spine neuropathology.af. 27. diffuse axonal injur:.af. 28. extracranial CNS injur:.af. 29. (extradural haematoma or hematoma).af. 30. extradural haemorrhage.af. 31. exp Neck Injuries/ 32. neck injur*.af. 33. (parenchymal contusion or laceration).af. 34. spinal cord injur:.af. 35. (subdural haematoma or hemotoma).af. 36. (subarachnoid hematoma or subarachnoid haematoma).af. 37. (subdural haemorrhage or subdural hemorrhage).af. 38. whiplash impact syndrome.af. 39. whiplash injur:.af. 40. whiplash shaken infant.af. 41. infarction.af. 42. (hypoxic-ischemic injur: or hypoxic-ischaemic injur:).af. 43. (contusion: or contusional tear).af. 44. (hematoma or haematoma).af. 45. laceration:.af. 46. shearing injur:.af. 47. traumatic effusion:.af. 48. sciwora.mp. 49. spinal cord injury without radiologic abnormality.af. 50. thoracic lumbar sacral.af. 51. leptomeningeal cyst.af. 52. (Extradural haemorrhag: or extradural hemorrhag: or extradural spinal haemorrhag: or extradural spinal hemorrhag:).af. 53. (intraparenchymal hemorrhag: or intraparenchymal haemorrhag:).af.	68. exp Fractures, Compression/ 69. hangmans fractur*.af. 70. Cervicomedullary injur*.af. 71. (Atlanto-Axial Joint adj3 injur*).af. 72. (fracture dislocation or crush fractur*).af. 73. (or/65-72) and 64 74. (Spinal adj5 fract*).af. 75. (Cervical adj5 fract*).af. 76. (thoracic adj5 fract*).af. 77. (lumbosacral adj5 fract*).af. 78. (thoraco-lumbar adj5 fract*).af. 79. (sacral adj5 fract*).af. 80. (lumbar adj5 fract*).af. 81. or/74-80 82. 73 or 81 83. skeletal survey.mp. 84. ((paediatric or pediatric) adj3 radiolog:).mp. 85. ((paediatric or pediatric) adj3 nuclear medicine).mp. 86. Scintigraphy.mp. 87. (bone scan or X rays).mp. 88. isotope bone scan:.mp. 89. (MRI or magnetic resonance imaging).af. 90. exp Tomography, X-Ray Computed/ 91. (CT or CAT scan*).af. 92. diagnostic imaging.af. 93. (neuroradiology or neuroimaging or neuro-imaging).af. 94. (radiological imag* or neurologic* imag*).af. 95. diffusion weighted imaging.af. 96. *"Diffusion Magnetic Resonance Imaging"/ 97. (plain films or ultrasound scan* or 3D reconstruction).af. 98. exp Ultrasonography/ 99. (Susceptibility Weighted Imaging or SWI).tw. 100. neuro* radiology.af. 101. neuro* examination*.af. 102. or/83-101 103. healing.mp. 104. (timing adj3 healing).mp. 105. ((dating or date or pattern*) adj3 fractur*).mp. 106. (ag: adj3 fractur*).mp. 107. (ag* adj3 fractur*).mp. 108. ((dating or date or pattern* or age or aging) adj3 fractur*).mp. 109. (aging adj3 fracture).mp. 110. exp Aging/ 111. exp Time Factors/ 112. or/103-111 113. 102 or 112 114. 22 and 82 and 113 115. limit 114 to yr="20

54. diffuse axonal injur*.tw.	

Spinal Injuries

1. CHILD/ 2. (paediatric or pediatric or neonate*).af. 3. (child: or infant: or toddler: or babies or baby).af. 4. or/1-3 5. ((non-accidental or nonaccidental) adj3 (trauma or injur:)).af. 6. ((non-abusive or nonabusive) adj3 (injur: or trauma)).af. 7. (non-accidental: and injur:).af. 8. soft tissue injur:.af. 9. physical abuse.af. 10. ((inflicted or noninflicted or non-inflicted) adj3 (brain injur: or cerebral injur: or head injur:)).af. 11. (inflicted traumatic head injur: or inflicted traumatic brain injur:).af. 12. (maltreat* or shaking).af. 13. (AHT or Abusive Head Trauma).af. 14. (or/5-13) and 4 15. (child abuse or child maltreatment or child protection).af. 16. (battered child or shaken baby or battered baby).af. 17. (battered infant or shaken infant).af. 18. (Shak: Baby Syndrome or shak: impact syndrome).af. 19. Caffey-Kempe syndrome.af. 20. *"Child Abuse"/di [Diagnosis] 21. or/15-20 22. 14 or 21 23. extracranial CNS injur*.af. 24. Craniocerebral Trauma/ 25. cervical spine injur:.af. 26. cervical spine neuropathology.af. 27. diffuse axonal injur:.af. 28. extracranial CNS injur:.af. 29. (extradural haematoma or hematoma).af. 30. extradural haemorrhage.af. 31. exp Neck Injuries/ 32. neck injur*.af. 33. (parenchymal contusion or laceration).af. 34. spinal cord injur:.af. 35. (subdural haematoma or hemotoma).af. 36. (subarachnoid hematoma or subarachnoid haematoma).af. 37. (subdural haemorrhage or subdural hemorrhage).af. 38. whiplash impact syndrome.af. 39. whiplash injur:.af. 40. whiplash shaken infant.af. 41. infarction.af. 42. (hypoxic-ischemic injur: or hypoxic-ischaemic injur:).af.	55. spinal subdural.tw. 56. cervical.af. 57. exp Spinal Cord Injuries/ 58. Spinal Injuries/ 59. spinal cord trauma.af. 60. Spinal Cord Compression/ 61. Cervical Vertebrae/ 62. hyperflexion injur*.af. 63. hyperextension injur*.af. 64. or/23-6365. Fractur*.af. 66. exp Fractures, Comminuted/ 67. exp Fractures, Bone/ 68. exp Fractures, Compression/ 69. hangmans fractur*.af. 70. Cervicomedullary injur*.af. 71. (Atlanto-Axial Joint adj3 injur*).af. 72. (fracture dislocation or crush fractur*).af. 73. (or/65-72) and 64 74. (Spinal adj5 fract*).af. 75. (Cervical adj5 fract*).af. 76. (thoracic adj5 fract*).af. 77. (lumbosacral adj5 fract*).af. 78. (thoraco-lumbar adj5 fract*).af. 79. (sacral adj5 fract*).af. 80. (lumbar adj5 fract*).af. 81. or/74-80 82. 73 or 81 83. skeletal survey.mp. 84. ((paediatric or pediatric) adj3 radiolog:).mp. 85. ((paediatric or pediatric) adj3 nuclear medicine).mp. 86. Scintigraphy.mp. 87. (bone scan or X rays).mp. 88. isotope bone scan:.mp. 89. (MRI or magnetic resonance imaging).af. 90. exp Tomography, X-Ray Computed/ 91. (CT or CAT scan*).af. 92. diagnostic imaging.af. 93. (neuroradiology or neuroimaging or neuro-imaging).af. 94. (radiological imag* or neurologic* imag*).af. 95. diffusion weighted imaging.af. 96. *"Diffusion Magnetic Resonance Imaging"/ 97. (plain films or ultrasound scan* or 3D reconstruction).af. 98. exp Ultrasonography/ 99. (Susceptibility Weighted Imaging or SWI).tw. 100. neuro* radiology.af. 101. neuro* examination*.af. 102. or/83-101 103. healing.mp. 104. (timing adj3 healing).mp.

43. (contusion: or contusional tear).af. 44. (hematoma or haematoma).af. 45. laceration:.af. 46. shearing injur:.af. 47. traumatic effusion:.af. 48. sciwora.mp. 49. spinal cord injury without radiologic abnormality.af. 50. thoracic lumbar sacral.af. 51. leptomeningeal cyst.af. 52. (Extradural haemorrhag: or extradural hemorrhag: or extradural spinal haemorrhag: or extradural spinal hemorrhag:).af. 53. (intraparenchymal hemorrhag: or intraparenchymal haemorrhag:).af. 54. diffuse axonal injur*.tw.	105. ((dating or date or pattern*) adj3 fractur*).mp. 106. (ag: adj3 fractur*).mp. 107. (ag* adj3 fractur*).mp. 108. ((dating or date or pattern* or age or aging) adj3 fractur*).mp. 109. (aging adj3 fracture).mp. 110. exp Aging/ 111. exp Time Factors/ 112. or/103-111 113. 102 or 112 114. 22 and 82 and 113 115. limit 114 to yr="20

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

Neurological injuries

Databases	Time period searched
ASSIA (Applied Social Sciences Index and Abstracts)	1970 – 2014
Child Data	1970 – 2009†
CINAHL (Cumulative Index to Nursing and Allied Health Literature)	1970 – 2014
Cochrane Central Register of Controlled Trials	1996 – 2014
Cochrane database of Systematic Reviews	2014-2018
EMBASE	1970 – 2018
MEDLINE	1970 – 2018
MEDLINE In-Process and Other Non-Indexed Citations	2006 – 2018
Open SIGLE (System for Information on Grey Literature in Europe)	1980 – 2005*
Scopus	1970 – 2018
Social Care Online	1970 – 2018
TRIP Database	1997 – 2008**
Web of Knowledge – ISI Proceedings	1990 – 2014
Web of Knowledge – ISI Science Citation Index	1970 – 2014
Web of Knowledge – ISI Social Science Citation Index	1970 – 2014
Journals 'hand searched'	**Time period searched**
Child Abuse and Neglect	1977 – 2014
Child Abuse Review	1992 – 2014
Websites searched	**Date accessed**
Child Brain Injury Trust (CBIT)	12.08.2014
International Society for Prevention of Child Abuse and Neglect (ISPCAN)	12.08.2014
Child Information Welfare Gateway	12.08.2014
Google Scholar	12.08.2014
National Center on Shaken Baby Syndrome	12.08.2014

Spinal Injuries

Databases	Time period searched
ASSIA (Applied Social Sciences Index and Abstracts)	2010-2014
Child Data	N/A
CINAHL (Cumulative Index to Nursing and Allied Health Literature)	2010-2014
Cochrane Central Register of Controlled Trials	2010-2014
Cochrane database of Systematic Reviews	2014-2018
EMBASE	2010-2018
MEDLINE	2010-2018
MEDLINE In-Process and Other Non-Indexed Citations	2010-2018
Open SIGLE (System for Information on Grey Literature in Europe)	N/A
Pubmed e-publications	2018
Scopus	2010-2018
Social Care online (previously Caredata)	2010-2018
Trip Plus	N/A
Web of Knowledge – ISI Proceedings	2010-2014
Web of Knowledge – ISI Science Citation Index	2010-2014
Web of Knowledge – ISI Social Science Citation Index	2010-2014
Journals 'hand searched'	**Time period searched**
Child Abuse and Neglect	2010-2014
Child Abuse Review	2010-2014
Websites searched	**Date accessed**
The Alberta Research Centre for Health Evidence (ARCHE)	12 Nov 2014
Child Welfare Information Gateway (formerly National Clearinghouse on Child Abuse and Neglect)	12 Nov 2014
Google Scholar	Nov

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. These first two stages were carried out by a systematic reviewer at the RCPCH and a clinical expert. 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).