



# Radiation Exposure in Imaging of Suspected Child Abuse: Benefits versus Risks

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Recent articles on child abuse in this journal discussed the value of ordering a skeletal survey in children age 24-36 months and the need for a computed tomography (CT) of the head in children less than 2 years with an isolated single nonmetaphyseal long bone fracture.<sup>1-3</sup> The benefits of these and other imaging studies are not merely in the number of positive tests. Negative results can be extremely important. However, both radiography and CT use ionizing radiation (X-rays). Determining the risks of radiation exposure from medical imaging is not straight forward. Radiation doses vary considerably depending on the modality, the type of study, the number of images, and the techniques used. Understanding the ability of an imaging examination (ie, CT vs magnetic resonance [MR] imaging) to accurately identify the pathology is crucial in test selection.

## Basic Principles

1. Imaging tests should be ordered based on the history and physical examination and a well thought out differential diagnosis.
2. Clinical imaging guidelines serve as the foundation of what to begin with. Guidelines usually start with the less invasive test that has a high sensitivity and reasonable specificity. Follow-up imaging (problem solving tests) should be ordered based on the individual patient's unanswered clinical and imaging questions.
3. The risks for any imaging test include (if applicable) the effects of ionizing radiation and complications of sedation or general anesthesia.<sup>4</sup> Importantly, consideration must be given to the risks of not doing the test and missing a diagnosis.
4. Children are more sensitive to the effects of radiation exposure.<sup>5,6</sup> Therefore, the as low as reasonably achievable (ALARA) principle dose of radiation, while obtaining diagnostic images, must be adhered to by the ordering physician in test selection and by the imager through protocol design and in supervision of technical staff in performing the examination.
5. All imaging facilities are not the same.<sup>7,8</sup> Pediatric centers use standard protocols that have been determined by national guidelines and concern for radiation.<sup>9</sup> Imaging at pediatric-focused facilities with

access to subspecialty consultation on what images to acquire in any nonroutine cases adds greatly to the appropriate care of children.

6. "Image Gently" ([www.imagegently.org](http://www.imagegently.org)) is a source of information about ionizing radiation awareness for parents and healthcare practitioner. The Alliance for Radiation Safety in Pediatric Imaging was formed in 2007 and consists of 84 leading medical societies, agencies, and regulatory groups. This alliance created "Image Gently" to "impact patient care and change practice through an educational and awareness campaign."<sup>10</sup> The means of achieving diagnostic images at a properly managed radiation dose is a sentinel concept of the campaign. This focus, together with emphasis on proper medical indications for doing an imaging examination (meeting appropriateness criteria), form the cornerstones of intelligent test selection.

The ALARA acronym is used to denote properly managed radiation dose by the "Image Gently" campaign. The original use of ALARA was limited to ionizing radiation received by healthcare workers (occupational exposure).

## Risks of Exposure to Ionizing Radiation

All modes of imaging within diagnostic radiology departments subject the patient to penetrating beams of energy carried by radio waves (MR), mechanical waves (ultrasound),  $\gamma$ -rays (nuclear medicine), or X-rays. The radio waves and mechanical waves of MR and ultrasound, at the energy levels used in diagnostic tests, are believed to be risk free. However, the X- and  $\gamma$ -rays are forms of ionizing radiation; these rays ionize tissue molecules as they travel through the body, which if concentrated, can lead to biological damage. As the X or  $\gamma$  radiation beam deposits energy in the superficial layers of the patient's tissues, less energy is carried by the beam resulting in less dose to tissues at a greater depth in the body relative to the entrance plane of the beam (attenuation). This explains why one must designate where

ALARA	As low as reasonably achievable
CT	Computed tomography
MR	Magnetic resonance

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any specified dose is located—skin entrance, midline, exit plane, or specific organ location.

## Radiation Metrics

A basic understanding of radiation dose metrics<sup>5,6,11</sup> is necessary to aid the discussion of the implications of ionizing radiation in imaging. Absorbed dose indicates that energy is deposited microscopically in the tissue of the body as X- or  $\gamma$ -rays pass through. Absorbed doses are typically not measured; they are estimated from measurements of the amount of radiation arriving at the entrance skin plane of the patient (air Kerma). The unit of the absorbed dose is the gray (Gy) or milliGy (mGy). Historically, absorbed dose was expressed in rads or mrad (1 mGy = 100 mrad).

Ionizing radiation dose may also be expressed as equivalent dose. Equivalent dose is used to report occupational radiation doses. For all diagnostic tests conducted in radiology, which use X- or  $\gamma$ -ray, the absorbed dose and equivalent dose (typically at the entrance plane of the patient's body) are equal. However, unlike absorbed dose, the unit of equivalent dose is the Sievert (Sv). The equivalent dose is usually expressed in milliSieverts (mSv). The historical unit is the rem (100 rem = 1 Sv).

Ionizing radiation dose is sometimes expressed as effective dose, which must not be confused with equivalent dose, even though both dose indices use the same units, Sv or mSv. Effective dose is a dose to the whole body and defined only for a population, and equivalent dose is a dose to a subset of the whole body of an individual patient. When a dose is expressed in Sieverts, one must carefully identify which dose index is being used—effective or equivalent. If an effective dose is assumed to be an equivalent dose, the dose to directly irradiated organs and their potential risk will be significantly underestimated (by a factor more than 10).

It is good to use a reference point to understand metrics. For background radiation the effective dose is approximately 0.01 mSv per day and 3-3.5 mSv per year.<sup>11</sup> Radiation doses from diagnostic studies vary from modality to modality and type of examination from 0.03 mGy to over 50 mGy (Table). Most of the absorbed doses in the Table are expressed as a range because the skin dose to the patient varies by thickness of body part irradiated and length of the path of the X-ray through the body.

## Inherent Risks from Medical Radiation Doses

Effects from radiation exposure may be either deterministic (tissue reactions) or stochastic.<sup>11</sup> Deterministic effects (tissue reactions) have a threshold below which the effect does not occur. Once the threshold is crossed, the severity of the injury is typically proportional to the radiation dose. These include cataracts, skin burns, epilation, and more serious forms of skin damage. The doses required to cause skin burns are over 2 Gy, substantially greater than the doses incurred in most diagnostic tests.

**Table.** Relative radiation dose of some common examinations in a 2-year-old child

Examination	Dose range (mGy)	Where measured
Chest 1 view	0.03-0.08	Skin entrance
Abdomen 1 view	0.2-0.3	Skin entrance
Humerus 1 view	0.08	Skin entrance
Femur 1 view	0.12	Skin entrance
Spine thoracolumbar frontal view	0.34	Skin entrance
Head CT, standard <sup>†</sup>	20-25	Skin entrance*
Head CT, reduced dose for skull <sup>‡</sup>	4-5	Skin entrance*
Abdominal CT	4-8	Skin entrance*

3D, 3-dimensional; CTDIvol, CT dose index volume.

\*Skin dose is approximately 10% greater than the dose reported as CTDIvol. The CTDIvol is the dose reported on the scanner and is measured by a phantom simulating the center portion of the body region scanned.

†The first head CT technique is for evaluation of the brain and is a higher radiation dose procedure. It is not a helical scan but individual axial slices.

‡The second head CT technique is a lower radiation dose helical scan designed only for bone detail and requiring much less radiation. This is a volumetric or 3D-examination. When using the higher radiation dose head CT technique, images can also be reconstructed with 3D volume rendering to evaluate the skull with no additional radiation exposure.

Stochastic effects, carcinogenesis, occur randomly by chance. Energy transferred to a cell (absorbed dose) may alter the cell's DNA and cause mutations. The number of cells with mutations increase progressively from present to future generations over 10-30 years at which time malignancy may manifest. The National Council on Radiation Protection and Measurements tried but failed in 2 extensive studies (1993 and 2001) to identify a threshold below which no carcinogenic effect occurred.<sup>12,13</sup> This is modeled by the linear no-threshold concept of radiation safety.

Children are more vulnerable to carcinogenic effects of radiation than adults because of their higher cell duplication rates and their longer expected life span. It is well documented that the younger the age at the radiation exposure, the higher the risk of inducing cancer.<sup>5</sup>

The risk of tissue effects is cumulative. A patch of skin that has previously received large radiation doses will suffer a deterministic injury during a current procedure at a current dose less than 2 Gy. Stochastic effects, unlike tissue effects, are not cumulative. The risk to a patient from an 11th CT examination is identical to the risk of the patient's first 1st CT examination. A clinically justified additional radiation study should never be denied or discouraged because of the patient's radiation exposure history.

The scientific/medical community does not agree on the risk of cancer from radiation doses because of CT scans. Clinical studies with large cohorts of patients followed for over 40 years have suggested that a small individual risk of cancer exists from diagnostic imaging studies using ionizing radiation.<sup>5,14-17</sup> Theoretical extrapolations of additional malignancies because of increased radiation risk have ranged from 1/1000 in 2001 to 1/10 000 more recently because of dose reductions during CT.<sup>18</sup> However, a large clinical study published in 2015, for the first time identified that 32% of identified cancers during a 4- year follow-up period occurred in patients with cancer-predisposing factors other than ionizing radiation.<sup>19</sup> This study suggests that overestimates of risk may have occurred in previous studies because of

reverse causation and confounding bias that was not eliminated in the earlier analyses.<sup>19</sup>

The proposed largest individual risks of malignancy above are still extremely small. However, 80 million CTs performed in the US per year (2010), approximately 10% on children, suggest a public health concern.<sup>20,21</sup> Many of the CT examinations on children (up to 85%) are performed in nonpediatric-focused institutions where management of radiation doses may be less diligent than in pediatric focused facilities.<sup>7,8</sup>

## Skeletal Surveys and Radiation Dose

The radiation dose of radiographs is typically calculated at the skin entrance, not at the midline of the body as is done in CT (CT dose index). Although the distribution of dose from CT of the abdomen of a small child is relatively uniform in the transverse plane of the body, the delivered dose during radiography decreases dramatically at depth from the entrance plane as previously described. The improved contrast of a CT examination occurs in part because less scatter radiation is produced compared with radiography. The entrance skin doses for the CT examinations are more than 2 orders of magnitude greater than those of the single radiographs listed (Table).

The radiation dose of a skeletal survey varies by the age of the patient and the total number of images and many other factors such as exposure metrics, equipment used, and collimation. Using the American College of Radiology/Society for Pediatric Radiology guidelines, there are 21 standard exposures or images per skeletal survey.<sup>22,23</sup> The largest average dose to any organ of the body based on the skin entrance doses listed in the Table is less than 0.5 mGy. The entrance skin doses associated with each exposure of a skeletal survey cannot be added to estimate patient risk.

There are few studies relating diagnostic radiography (rather than CT) and the development of malignancy.<sup>16</sup> Most notable are studies showing later development of breast cancer in adolescent girls who had multiple radiographs of the spine for scoliosis in the 1920s to the 1970s.<sup>14,15,17</sup> An excess relative risk of breast cancer of 2.86 was found in girls in whom the radiographs were performed from front to back (anterior to posterior positioning); the breasts received the full dose of radiation. However, there has been a significant reduction of entrance dose during radiography in the last 50-70 years (increased technical efficiency). Posterior to anterior positioning has also reduced breast dose to less than 1/10th of the previous anterior to posterior positioning. These factors have reduced the overall breast dose on current studies to 5% or less of its historic value.

The relative radiation dose for head CT is approximately 250 times higher than radiography (Table). Done properly, in an infant less than 2 years old at our institutions, the radiation dose of a head CT is approximately 15-20 mGy. A recent national survey reported a mean dose in children's hospitals of 22 mGy, whereas the overall dose was higher when considering all hospitals with a mean of 27 mGy.<sup>24</sup>

This radiation dose must be considered when deciding between CT and MR for central nervous system imaging. When a child presents with acute symptoms, CT of the cervical spine is usually obtained in conjunction with head imaging. When properly indicated in the acute presentation, the radiation dose from CT of the head, cervical spine, abdomen, and pelvis is firmly justified. Routine inclusion of CT of the chest is dubious.<sup>25</sup> In the absence of clinical findings suggesting possible intra-abdominal injury, CT of the abdomen and pelvis is low yield and should be avoided.<sup>26,27</sup>

## Risks of Not Obtaining the Imaging Test

Twenty to 25% of fracture cases in children less than 12 months old and 6%-7% of fracture cases in children 13-23 months old are caused by physical abuse.<sup>28</sup> Furthermore, 27.5% of abused children less than 12 months old have a previous sentinel injury not diagnosed as abuse.<sup>29</sup> Jenny<sup>30</sup> reported that in 31.2% (54 patients) of children less than 3 years old with abusive head trauma, the diagnosis of abuse had been previously missed: 27.8% of these were reinjured; 40.7% of these experienced medical complications related to missed diagnosis; and 9% died.

Because the risk (consequences) of not correctly and expeditiously diagnosing a case of child abuse in an infant is so high, the clinician needs only a few clues to justify ordering a skeletal survey. However, when there are no clues and the yield is small (as in toddlers older than 24 months with a single extremity fracture), the very small risks of radiation exposure may exceed the benefits. At times, the benefits of an additional positive or negative finding may be very important in the legal arena, particularly now in era of those who deny the existence of child abuse.<sup>31-33</sup>

## Guidelines for Skeletal Survey

Two recent papers<sup>34,35</sup> have discussed the appropriate indications in ordering of a skeletal survey particularly in young children with fractures. These guidelines are important to avoid excess examinations and radiation in children. However, any fracture can be caused by abuse and clinical judgment concerning abuse is the most important determining factor regarding obtaining imaging.

## Sensitivity and Specificity of Imaging Regarding the Findings of Fractures in Child Abuse

The most used imaging is the radiographic skeletal survey. The skeletal survey is the most sensitive and specific, least invasive, and easily available test for long bone fractures. The most frequent site of fractures in child abuse is the ribs, and in the most acute stage, rib fractures may be easily missed on the skeletal survey.<sup>36,37</sup>

CT is probably more sensitive and specific for rib fractures but is generally only used for problem solving with limited

range of exposure. Lower images on cervical spine CT examinations and upper images on abdominal CT examinations, when obtained for clinical reasons, should be carefully evaluated for rib fracture. Although nuclear medicine bone scan has a high sensitivity for rib fractures, it has a relatively high radiation dose and poor sensitivity for other fractures (ie, skull fractures, metaphyseal fractures). Nonetheless, bone scans may occasionally be performed explicitly for the detection of rib fractures when an immediate answer is required.<sup>38</sup>

### Problem Solving Imaging

When on a skeletal survey, there are multiple rib fractures of differing ages with metaphyseal long bone fractures, it is of little additional diagnostic value to detect 1 or more additional fractures. However, when no fractures are found or when uncertainty exists about a possible fracture in a child in which there is a strong clinical suspicion for abuse, additional imaging is indicated. Each patient is different, and imaging must be tailored to the individual situation and to the clinical question to be answered. There are several approaches:

1. Limited repeat skeletal survey performed at 14–21 days.<sup>39–43</sup> This entails a second exposure with slightly less total radiation dose than the first survey. Suspicious and higher yield areas (ie, ribs, extremities) are included. Most would exclude the skull, spine, pelvis, hands, and feet. Additional views of a troublesome extremity may be added, including a contralateral comparison. Repeat skeletal survey, though it may yield new fractures (10%) should not be done if there is no diagnostic, medical, or forensic reason to do so.
2. Perform a nuclear bone scan (with optimal pinhole images) now to see if any rib fractures have been missed. Such studies should only be performed at pediatric centers with experience in pediatric nuclear medicine. One research group has suggested that an 18F-fluorodeoxyglucose positron emission tomography (PET) scan be used.<sup>44</sup>
3. Rarely, a limited CT of the chest is performed for a questionable rib abnormality.<sup>45,46</sup>

### Head CT in a Child Less than 24 Months Old in Whom There Is a Suspicion for Abuse

It is obvious that head CT should be obtained immediately for a child with symptomatic head trauma as the first imaging test. However, in the asymptomatic child less than 24 months, imaging is not emergent. We are looking for clues of subtle hemorrhage, old as well as new parenchymal injury, and for evidence of venous thrombosis, all of which are less well shown on CT than MR.<sup>47–53</sup>

The American College of Radiology/Society for Pediatric Radiology practice parameters and technical standards state

that “MR (imaging) avoids the radiation of CT and is particularly good choice in the nonemergent setting to image these high risk children without overt neurologic signs or symptoms.”<sup>22</sup> Because there is more information from an MR, we believe this is the preferred test in the asymptomatic patients, access and timing being appropriate to the acuity of the individual patient.

### Analysis of the Recent Articles on Imaging in Suspected Child Abuse

Wilson et al<sup>3</sup> investigated the use of head CT in children with a single nonmetaphyseal extremity fracture. They conclude that “clinicians should consider obtaining CT in those who are younger than 12 months of age, have proximal extremity fractures, or who have previous evaluations for nonaccidental trauma.” The results of this study are difficult to interpret because of the small number of patients with positive findings and the unclear effect of the CT findings on medical and forensic outcome. By the authors’ definition, none of the patients had “clinically significant head injury.” It could be argued that all 3 patients classified by the authors as “high” abuse suspicion did not have isolated extremity fractures—each had pertinent medical history suggestive of prior abuse. One of the 3 also had retinal hemorrhages noted in the emergency department. A fourth patient, classified as “low” abuse suspicion by the authors, had left temporal swelling at presentation. Clearly, history and physical examination findings (besides those related to the extremity fracture) are important and aid the clinician in deciding whether further evaluation for abuse is warranted. If one excludes the aforementioned 4 cases from the study of Wilson et al,<sup>3</sup> we are left with 1 child with a “tiny” subarachnoid hemorrhage of no clinical significance. This is not a strong argument for performing head CT in infant with a truly “isolated” single nonmetaphyseal extremity fracture.

The children studied by Wilson et al<sup>3</sup> did not have acute neurologic symptoms. Simply put, MR is a better study to perform when looking for subtle findings of prior traumatic injury.<sup>47–57</sup> In our pediatric institutions, the standard of care is to perform head MR rather than head CT in evaluating the neurologically asymptomatic patient for suspected abuse.

Lindberg et al<sup>1</sup> have shown that skeletal survey findings in the 24- to 36-month-old age group have a higher yield (10.3%) than commonly recognized. This is compelling. Clearly, there is a clinical selection bias as the overall rate of imaging is less in this age group than in younger patients. One must consider that findings in the 24- to 36-month-old age group are less specific for child abuse than in infants. The forensic and clinical value of the skeletal surveys is probably less in these older children. Some fractures (ie, skull and classic metaphyseal fractures) are less common in the 24- to 36-month-old group leading the authors to suggest that a limited skeletal survey might be considered. However, it is interesting to note that fractures at “other” sites (clavicle, spine, scapula, mandible, pelvis, and sternum) were more common, suggesting that mechanisms of physical abuse are

different and that surveys need to be tailored for this age group. Further study of this age group is necessary to define the optimal age-specific skeletal survey protocol.

## Discussion

The risks and benefits of imaging in suspected child abuse is an incalculable equation. The risk of missing child abuse can have devastating consequences for the patient. The risk of additional imaging, namely skeletal survey and head CT, is extremely small, but not negligible and is impossible to compute for an individual patient. When does the risk of missing child abuse trump the risk of additional radiation dose from imaging?

The studies by Wilson et al<sup>3</sup> and Lindberg et al<sup>1</sup> both remind us that medicine is an art. The astute clinician must consider all of the information available about the child, must understand the utility, risks, and benefits of imaging, and must decide what to do. ■

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## References

- Lindberg DM, Berger RP, Reynolds MS, Alwan RM, Harper NS. Examining Siblings To Recognize Abuse I. Yield of skeletal survey by age in children referred to abuse specialists. *J Pediatr* 2014;164:1268-73.e1.
- Pekarsky AR, Botash AS. Skeletal surveys and head computed tomographies in the evaluation of child abuse: refining practice patterns. *J Pediatr* 2014;164:1250-2.
- Wilson PM, Chua M, Care M, Greiner MV, Keshin B, Bennett B. Utility of head computed tomography in children with a single extremity fracture. *J Pediatr* 2014;164:1274-9.
- Olsen EA, Brambrink AM. Anesthesia for the young child undergoing ambulatory procedures: current concerns regarding harm to the developing brain. *Curr Opin Anaesthesiol* 2013;26:677-84.
- Hall EJ. Introduction to session I: helical CT and cancer risk. *Pediatr Radiol* 2002;32:225-7.
- Slovic TL (ed.). Conference on the ALARA (as low as reasonably achievable) concept in pediatric CT: intelligent dose reduction. *Pediatr Radiol* 2002;32:217-317.
- Calvert C, Strauss KJ, Mooney DP. Variation in computed tomography radiation dose in community hospitals. *J Pediatr Surg* 2012;47:1167-9.
- Nosek AE, Hartin CW Jr, Bass KD, Glick PL, Caty MG, Dayton MT, et al. Are facilities following best practices of pediatric abdominal CT scans? *J Surg Res* 2013;181:11-5.
- Goske MJ, Strauss KJ, Coombs LP, Mandel KE, Towbin AJ, Larson DB, et al. Diagnostic reference ranges for pediatric abdominal CT. *Radiology* 2013;268:208-18.
- Goske MJ, Applegate KE, Boylan J, Butler PF, Callahan MJ, Coley BD, et al. The Image Gently campaign: working together to change practice. *AJR Am J Roentgenol* 2008;190:273-4.
- Slovic TL, Frush DP. Biologic effects of radiation on children. In: Kliegman RM, Behrman RE, St Jeme J, eds. *Nelson textbook of pediatrics*. 20th ed., Chapter 718. St. Louis, MO: Saunders; 2016. p. 3416-22.
- NCRP. Limitation of exposure to ionizing radiation. Bethesda, Maryland: National Council on Radiation Protection and Measurements; 1993.
- NCRP. Evaluation of the linear-nonthreshold dose-response model for ionizing radiation. Bethesda, Maryland: National Council on Radiation Protection and Measurements; 2001.
- Doody MM, Lonstein JE, Stovall M, Hacker DG, Luckyanov N, Land CE. Breast cancer mortality after diagnostic radiography: findings from the U.S. Scoliosis Cohort Study. *Spine (Phila Pa 1976)* 2000;25:2052-63.
- Hoffman DA, Lonstein JE, Morin MM, Visscher W, Harris BS III, Boice JD Jr. Breast cancer in women with scoliosis exposed to multiple diagnostic x rays. *J Natl Cancer Inst* 1989;81:1307-12.
- Linet MS, Slovic TL, Miller DL, Kleinerman R, Lee C, Rajaraman P, et al. Cancer risks associated with external radiation from diagnostic imaging procedures. *CA Cancer J Clin* 2012;62:75-100.
- Ronckers CM, Land CE, Miller JS, Stovall M, Lonstein JE, Doody MM. Cancer mortality among women frequently exposed to radiographic examinations for spinal disorders. *Radiat Res* 2010;174:83-90.
- Brenner D, Elliston C, Hall E, Berdon W. Estimated risks of radiation-induced fatal cancer from pediatric CT. *AJR Am J Roentgenol* 2001;176:289-96.
- Journy N, Rehel JL, Ducou Le Pointe H, Lee C, Brisse H, Chateau JF, et al. Are the studies on cancer risk from CT scans biased by indication? Elements of answer from a large-scale cohort study in France. *Br J Cancer* 2015;112:185-93.
- Brenner DJ. What we know and what we don't know about cancer risks associated with radiation doses from radiological imaging. *Br J Radiol* 2014;87:20130629.
- Slovic TL. Boots on the ground: how to influence your local radiology departments to use appropriate CT dose. *Pediatr Radiol* 2014;44(Suppl 3):492-4.
- American College of Radiology. ACR Appropriateness Criteria. Suspected Physical Abuse - Child, <http://www.acr.org/~media/300CC40D9D3E4E498BD77074AF814C68.pdf>; 2012. Accessed August 24, 2015.
- American College of Radiology. ACR-SPR Practice parameter for skeletal surveys in children (Resolution 39\*). Reston, VA: American College of Radiology; 2014. p. 1-6. Amended 2014.
- Kanal KM, Graves JM, Vavilala MS, Applegate KE, Jarvik JG, Rivara FP. Variation in CT pediatric head examination radiation dose: results from a national survey. *AJR Am J Roentgenol* 2015;204:W293-301.
- Patel RP, Hernanz-Schulman M, Hilmes MA, Yu C, Ray J, Kan JH. Pediatric chest CT after trauma: impact on surgical and clinical management. *Pediatr Radiol* 2010;40:1246-53.
- Hilmes MA, Hernanz-Schulman M, Greeley CS, Piercey LM, Yu C, Kan JH. CT identification of abdominal injuries in abused pre-school-age children. *Pediatr Radiol* 2011;41:643-51.
- Trout AT, Strouse PJ, Mohr BA, Khalatbari S, Myles JD. Abdominal and pelvic CT in cases of suspected abuse: can clinical and laboratory findings guide its use? *Pediatr Radiol* 2011;41:92-8.
- Wood JN, Feudtner C, Medina SP, Luan X, Localio R, Rubin DM. Variation in occult injury screening for children with suspected abuse in selected US children's hospitals. *Pediatrics* 2012;130:853-60.
- Sheets LK, Leach ME, Koszewski IJ, Lessmeier AM, Nugent M, Simpson P. Sentinel injuries in infants evaluated for child physical abuse. *Pediatrics* 2013;131:701-7.
- Jenny C, Hymel KP, Ritzen A, Reinert SE, Hay TC. Analysis of missed cases of abusive head trauma. *JAMA* 1999;281:621-6.
- Block RW. Child abuse—controversies and imposters. *Curr Probl Pediatr* 1999;29:249-72.
- Slovic TL, Strouse PJ, Coley BD, Rigsby CK. The creation of non-disease: an assault on the diagnosis of child abuse. *Pediatr Radiol* 2012;42:903-5.
- Strouse PJ. 'Keller & Barnes' after 5 years—still inadmissible as evidence. *Pediatr Radiol* 2013;43:1424.

34. Flaherty EG, Perez-Rossello JM, Levine MA, Hennrikus WL, American Academy of Pediatrics Committee on Child Abuse and Neglect, Section on Radiology, American Academy of Pediatrics, Section on Endocrinology, American Academy of Pediatrics, Section on Orthopaedics, American Academy of Pediatrics, Society for Pediatric Radiology. Evaluating children with fractures for child physical abuse. *Pediatrics* 2014;133:e477-89.
35. Wood JN, Fakeye O, Feudtner C, Mondestin V, Localio R, Rubin DM. Development of guidelines for skeletal survey in young children with fractures. *Pediatrics* 2014;134:45-53.
36. Barsness KA, Cha ES, Bensard DD, Calkins CM, Partrick DA, Karrer FM, et al. The positive predictive value of rib fractures as an indicator of non-accidental trauma in children. *J Trauma* 2003;54:1107-10.
37. Ingram JD, Connell J, Hay TC, Strain JD, Mackenzie T. Oblique radiographs of the chest in nonaccidental trauma. *Emerg Radiol* 2000;7:42-6.
38. Conway JJ, Collins M, Tanz RR, Radkowski MA, Anandappa E, Hernandez R, et al. The role of bone scintigraphy in detecting child abuse. *Semin Nucl Med* 1993;23:321-33.
39. Harlan SR, Nixon GW, Campbell KA, Hansen K, Prince JS. Follow-up skeletal surveys for nonaccidental trauma: can a more limited survey be performed? *Pediatr Radiol* 2009;39:962-8.
40. Harper NS, Eddleman S, Lindberg DM, Ex SI. The utility of follow-up skeletal surveys in child abuse. *Pediatrics* 2013;131:e672-8.
41. Singh R, Squires J, Fromkin JB, Berger RP. Assessing the use of follow-up skeletal surveys in children with suspected physical abuse. *J Trauma Acute Care Surg* 2012;73:972-6.
42. Sonik A, Stein-Wexler R, Rogers KK, Coulter KP, Wootton-Gorges SL. Follow-up skeletal surveys for suspected non-accidental trauma: can a more limited survey be performed without compromising diagnostic information? *Child Abuse Negl* 2010;34:804-6.
43. Hansen KK, Keeshin BR, Flaherty E, Newton A, Passmore S, Prince J, et al. Sensitivity of the limited view follow-up skeletal survey. *Pediatrics* 2014;134:242-8.
44. Drubach LA, Johnston PR, Newton AW, Perez-Rossello JM, Grant FD, Kleinman PK. Skeletal trauma in child abuse: detection with 18F-NaF PET. *Radiology* 2010;255:173-81.
45. Hong TS, Reyes JA, Moineddin R, Chiasson DA, Berdon WE, Babyn PS. Value of postmortem thoracic CT over radiography in imaging of pediatric rib fractures. *Pediatr Radiol* 2011;41:736-48.
46. Proisy M, Marchand AJ, Loget P, Bouvet R, Roussey M, Pele F, et al. Whole-body post-mortem computed tomography compared with autopsy in the investigation of unexpected death in infants and children. *Eur Radiol* 2013;23:1711-9.
47. Colbert CA, Holshouser BA, Aaen GS, Sheridan C, Oyoyo U, Kido D, et al. Value of cerebral microhemorrhages detected with susceptibility-weighted MR Imaging for prediction of long-term outcome in children with nonaccidental trauma. *Radiology* 2010;256:898-905.
48. Datta S, Stoodley N, Jayawant S, Renowden S, Kemp A. Neuroradiological aspects of subdural haemorrhages. *Arch Dis Child* 2005;90:947-51.
49. Foerster BR, Petrou M, Lin D, Thurnher MM, Carlson MD, Strouse PJ, et al. Neuroimaging evaluation of non-accidental head trauma with correlation to clinical outcomes: a review of 57 cases. *J Pediatr* 2009;154:573-7.
50. Ghahreman A, Bhasin V, Chaseling R, Andrews B, Lang EW. Nonaccidental head injuries in children: a Sydney experience. *J Neurosurg* 2005;103:213-8.
51. Kadom N, Khademian Z, Vezina G, Shalaby-Rana E, Rice A, Hinds T. Usefulness of MRI detection of cervical spine and brain injuries in the evaluation of abusive head trauma. *Pediatr Radiol* 2014;44:839-48.
52. Kemp AM, Rajaram S, Mann M, Tempest V, Farewell D, Gawne-Cain ML, et al. What neuroimaging should be performed in children in whom inflicted brain injury (iBI) is suspected? A systematic review. *Clin Radiol* 2009;64:473-83.
53. Vazquez E, Delgado I, Sánchez-Montañez A, Fábregas A, Cano P, Martín N. Imaging abusive head trauma: why both computed tomography and magnetic resonance imaging? *Pediatr Radiol* 2014;44 Suppl 4:589-603.
54. Altinok D, Saleem S, Zhang Z, Markman L, Smith W. MR imaging findings of retinal hemorrhage in a case of nonaccidental trauma. *Pediatr Radiol* 2009;39:290-2.
55. Choudhary AK, Bradford RK, Dias MS, Moore GJ, Boal DK. Spinal subdural hemorrhage in abusive head trauma: a retrospective study. *Radiology* 2012;262:216-23.
56. Choudhary AK, Ishak R, Zacharia TT, Dias MS. Imaging of spinal injury in abusive head trauma: a retrospective study. *Pediatr Radiol* 2014;44:1130-40.
57. Demaerel P. MR imaging in inflicted brain injury. *Magn Reson Imaging Clin N Am* 2012;20:35-44.