Article published online: 2024-07-29

CT in pediatric trauma patients

CT-Diagnostik bei Kindern und Jugendlichen im Schockraum

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Keywords

children, injuries, infants, injuries, CT, trauma

received 10.1.2024
accepted after revision 5.5.2024
published online 2024

Bibliography

Fortschr Röntgenstr
DOI 10.1055/a-2341-7559
ISSN 1438-9029
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Georg Thieme Verlag KG, Rüdigerstraße 14, 70469 Stuttgart, Germany

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Deutsche Version unter: https://doi.org/10.1055/a-2341-7559.

ABSTRACT

Background The decision as to whether to perform a computed tomography (CT) examination in severe pediatric trauma poses a challenge. The therapeutic benefit of computed tomography in injured children is lower compared to adults, while the potential negative effects of ionizing radiation may be higher. Thus, the threshold for CT should be higher. Centers that less frequently treat pediatric cases tend to conduct more whole-body CT examinations than dedicated pediatric trauma centers, indicating a clinical overestimation of injury severity with subsequently unnecessary imaging due to inexperience. On the other hand, a CT scan that is not performed but is actually necessary can also have negative consequences if an injury is detected with a delay. An injured child presents a challenging situation for all involved healthcare providers, and thus requires a structured approach to decision-making.

Methods Selective literature review of the benefits and risks of CT in injured children, as well as indications for whole-body and region-specific CT imaging.

Results and Conclusion This article provides an overview of current guidelines, recent insight into radiation protection and the benefits of CT in injured children, and evidence-based decision criteria for choosing the appropriate modality based on the mechanism of injury and the affected body region.

Key Points

- Whole-body CT has less of an influence on treatment decisions and mortality in severely injured children than in adults.
- For radiation protection reasons, the indication should be determined more conservatively in children than in adult trauma patients.
- The indication for CT should ideally be determined separately for each region of the body.
- Ultrasound and MRI are a good alternative for the primary diagnostic workup in many situations.

Citation Format

- Appelhaus S, Schönberg SO, Weis M. CT in pediatric trauma patients. Fortschr Röntgenstr 2024; DOI 10.1055/a-2341-7559

ZUSAMMENFASSUNG

Hintergrund Die Entscheidung, ob eine Computertomografie in der Situation eines Kinderschockraums durchgeführt werden soll, stellt eine Herausforderung dar – Der therapeutische Nutzen der Computertomografie (CT) bei verletzten Kindern ist im Vergleich zu Erwachsenen niedriger, die negativen Auswirkungen ionisierender Strahlung aber potenziell höher, entsprechend sollte die Indikation strenger gestellt werden. In Zentren, die seltener Kinder versorgen, werden häufiger Ganzkörper-CT-Untersuchungen durchgeführt als in dezidierten pädiatrischen Traumazentren, was auf eine klinische Überschätzung der Verletzungsschwere mit konsekutiver Überdiagnostik aus Unsicherheit hindeutet. Andererseits kann eine nicht durchgeführte, aber eigentlich notwendige CT ebenso zu negativen Folgen führen, wenn eine Verletzung hierdurch zu spät erkannt wird. Ein verletztes Kind stellt eine besondere Belastungssituation für alle beteiligten Behandelnden dar, sodass es eines möglichst strukturierten Vorgehens in der Entscheidungsfindung bedarf.

Methode Selektive Literaturübersicht zu Nutzen und Risiken der CT bei verletzten Kindern sowie Indikationen zur Ganzkörper- und Körperregionszentrierten CT-Diagnostik.

Ergebnisse und Schlussfolgerung Diese Arbeit gibt einen Überblick über die gültigen Leitlinien, aktuelle Erkenntnisse

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zu Strahlenschutz und Nutzen der CT bei verletzten Kindern und evidenzbasierte Entscheidungskriterien für die Wahl der richtigen Modalität in Abhängigkeit von Verletzungsmechanismus und betroffener Körperregion.

Kernaussagen

- Die Ganzkörper-CT schwerverletzter Kinder hat weniger Auswirkungen auf Behandlungsentscheidungen und Mortalität als bei Erwachsenen.
- Aus Strahlenschutzgründen sollte die Indikation strenger als bei verunfallten Erwachsenen gestellt werden.
- Die Indikation zum CT sollte möglichst für jede Körperregion einzeln gestellt werden.
- Sonografie und MRT sind in vielen Situationen eine gute alternative Primärdiagnostik.

Prompt completion of a whole-body CT examination is a fundamental part of trauma room care for polytrauma patients in Germany [1]. In light of the risks that ionizing radiation poses for young patients, pediatric surgeons and radiologists need to determine and review the indication for CT on a conservative basis. A severe mechanism of injury alone is not sufficient to indicate whole-body CT. A preceding careful clinical examination and ultrasound examination based on eFAST or FAST ((extended) Focused Assessment with Sonography in Trauma) and thus experience treating children are required. Compared to dedicated pediatric trauma centers, general trauma centers are 1.8 times more likely to perform whole-body CT, which highlights the fact that a lack of routine and experience treating injured children can result in unnecessary diagnostic testing [2]. Even in pediatric trauma centers, injuries are found in only 1/3 of cases [3]. The majority of patients examined in this way are treated conservatively and an indication for surgery is typically determined on the basis of symptoms and not imaging. Therefore, CT does not have any direct therapeutic consequences in these cases [4]. So when should whole-body CT be performed and when can it be omitted?

For general radiologists, who usually do not have experience performing clinical examinations of children, this decision can only be made on an interdisciplinary basis in coordination with the entire trauma team. At the same time, a potentially severely injured child represents a particularly stressful situation for treating physicians and requires quick decisions. With the goal of providing radiologists with decision support in such situations, this article addresses the advantages and disadvantages of whole-body CT in children and the determination of the indication based on the relevant guidelines and recently published clinical decision criteria for selecting the correct diagnostic workup, with suggestions for protocol selection, special injury patterns, and typical pitfalls.

How important is radiation protection in children?

Whether a single diagnostic dose of X-ray radiation increases cancer risk in general and to a greater extent in children is controversial. The linear no threshold (LNT) model which provides the foundation for most federal regulations is based on the assumption that the increase in cancer rates seen in Hiroshima and Nagasaki after the atomic bombing can be extrapolated linearly to lower radiation doses. In contrast, the hormesis effect hypothesizes that low doses of ionizing radiation activate the DNA repair mechanisms and could thus even have positive effects [5]. Therefore, it is unclear whether a single CT examination actually presents a real health risk [6]. Calculations based on the LNT model estimate a lifetime incidence of up to one additional case of cancer per 500 abdominal CT examinations or 1000 head CT examination after exposure during childhood. However, these calculations are based in some cases on significantly higher effective dose values than used in modern devices [7]. The actual disease rate is difficult to determine due to the very low incidence of oncological diseases in children and young adults, the rare use of ionizing radiation in childhood and adolescence, and the long observation periods. Therefore, most published studies are retrospective registry studies with heterogeneous results. Multiple studies observed an elevated risk for brain tumors or leukemia after head CT examinations but the average dose values were higher than generally accepted today [8, 9, 10]. A recently published study could not establish an increase in risk from a single CT examination. A greater risk was only seen in the case of 4 or more CT examinations, especially in young patients <6 years old [11]. However, an initial evaluation of the large European EPI-CT study was also able to show an increased risk for brain tumors even in the case of low radiation doses with a corresponding linear increase in risk at higher doses, which is supported by the LNT model. Based on the calculations of the authors, approx. one additional brain tumor per 10,000 head CT examinations occurred within 5–15 years of exposure [12]. Due to the ambiguity of the available data, there is consensus among most professional societies that the indication especially for multiple CT examinations in young patients should be reviewed critically. At the same time, the individual risk posed by a single CT examination in children is probably very low so that parents can be reassured regarding any concerns they may have about radiation. A clinically necessary CT examination should never be skipped.

Dose reduction in pediatric CT examinations

If a CT examination is performed in a child, the radiologist is responsible for selecting the correct protocol, ensuring that the examination is performed correctly in accordance with the guidelines of the German Medical Association on quality assurance, and for applying all available dose reduction methods like iterative reconstructions, tube voltage reduction, increased pitch factor, and device-specific automatic exposure control with dynamic tube

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current modulation – with constant adjustment of the image quality. The German Commission on Radiological Protection recommends the use of radiation protection particularly for the eyes and thyroid, and in children also for the mammary gland as applicable. Alternatively, many devices also have sectional tube current modulation with a reduction of the direct organ dose [13]. However, particularly in the field of emergency diagnostics, its use should not delay the examination. Many of the CT scanners currently available for emergency diagnostic workup also allow reduction of the tube voltage, which is associated with a dose reduction and can also improve the ability to delimit the contrast bolus by approaching the k-edge of iodine [14]. Therefore, particularly in slender/small children, the tube voltage should be reduced, depending on the device as low as 70 keV. Moreover, additional filters – e. g., tin filters – are now widely available and can contribute to a significant dose reduction especially in non-contrast examinations [15]. Furthermore, dual-energy protocols can reduce the number of contrast phases by generating virtual non-contrast or monoenergetic reconstructions [16]. The photon counting technology that was recently introduced on the market provides even further possibilities. By registering individual photons including their energy in the detector, virtual monoenergetic images can be subsequently generated even without the use of a dual energy scan – with simultaneously high detector efficiency and a lack of electronic noise in the signal since only the photon signal is included in the reconstruction [17]. New deep learning-based algorithms promise a further dose reduction with consistent image quality for the future [18].

Questionable benefit of whole-body CT in injured children

The main advantages of whole-body CT are the very high sensitivity and specificity for detecting relevant injuries, the fact that it is largely examiner-independent, and the fast implementation in the acute situation. Therefore, it has become established as the modality of first choice when diagnosing polytrauma patients. The positive effect of whole-body CT on morbidity and mortality in adult trauma care is well established [1, 19]. However, similar studies including children could not detect any positive effect of whole-body CT on survival [20, 21]. The authors attribute the results to the more frequent occurrence of isolated head injuries without torso trauma and to the more rare occurrence of trauma to the bones of the chest and pelvis, for which the greatest benefit of whole-body CT is assumed. At the same time, sonographic examination of the abdominal organs in children is often easier for anatomical reasons. Therefore, in an article recently published in the Deutsches Ärzteblatt, Berger et al. recommend very conservative determination of the indication for whole-body CT and prefer in most cases a combination of thorough and possibly repeat sonographic examination and an organ-centered diagnostic workup (e. g. isolated head CT) depending on the clinical examination and the injury mechanism [21]. A further alternative, if available, is whole-body MRI with abbreviated protocols adapted to the acute situation [22]. As a rule, the risk of an injury not being diagnosed or being diagnosed too late (delayed diagnosis of injury, DDI) should always be taken into consideration and a necessary CT examination should never be withheld from an injured child.

▶ **Table 1** Indications for whole-body CT based on the currently valid S2K guidelines "pediatric polytrauma care" [20].

Changes in vital signs	Injury pattern
Loss of consciousness, intubation as a result of the trauma	Pediatric polytrauma
GCS ≤ 13 due to trauma	Suspicion of blunt chest or abdominal trauma
Oxygen saturation < 90 %	Paralysis or suspicion of severe spinal injury
Changes in breathing rate	Unstable pelvis
Signs of shock (be sure to use age-based reference values)	At least 2 long bone fractures
	Signs of severe injury (e. g., fracture with severe soft-tissue injury, amputation)

Indication determination and modality selection

In the current S2k guidelines on pediatric polytrauma care, whole-body CT continues to play an important role since, for example, the indication is broad in the case of "suspicion of blunt chest or abdominal trauma". In contrast, the British guidelines, for example, generally advise against whole-body CT in patients < 16 years and require the indication to be separately determined for each body region [23]. All indications for whole-body CT according to the German S2k guidelines are listed in ▶ **Table 1** [24].

As a rule, according to the guidelines for both children and adults, the indication for whole-body CT should be determined on the basis of the clinical examination and not just depending on the trauma mechanism. Whole-body CT requires a suspected diagnosis of polytrauma even after the primary survey (clinical examination, vital signs, FAST ultrasound), i. e., an injury or a combination of injuries that could be life-threatening alone or in combination [1, 24].

If a decision against whole-body CT is made on this basis, a targeted diagnostic workup can be performed based on the clinical findings. To prevent unnecessary diagnostic testing and radiation exposure, there are different clinical decision criteria for identifying patients with a very low risk of a relevant injury. The criteria of the "Pediatric Emergency Care Applied Research Network" (PECARN), which were developed in large multicenter studies in North America, are probably the most well known.

Head

The "PECARN rules" are the most established criteria for the indication for head CT. They have been externally validated many times, see ▶ **Fig. 1** [25]. In the German health care system, inpatient monitoring of uncertain cases is a good alternative to initial head CT so that the indication can be determined on a more con-

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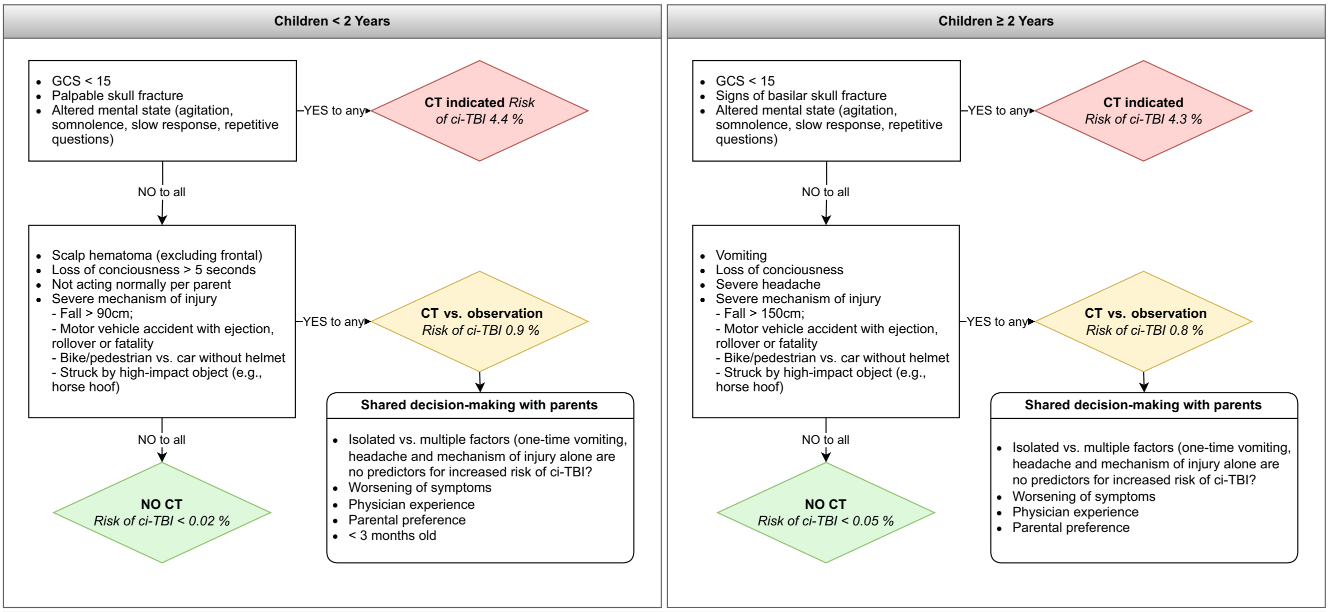

▶ **Fig. 1** PECARN criteria for determining the indication for head CT in mild head trauma [21]; ci-TBI: clinically important traumatic brain injury.

servative basis. Due to the higher sensitivity for most injuries and the lack of radiation, magnetic resonance imaging (MRI), if available, is also a suitable alternative for initial imaging in stable patients or for follow-up in the case of increasing or persistent symptoms. In newborns and infants with an open fontanel, ultrasound of the head is also possible but should not delay cross-sectional imaging when indicated [26].

Spine

The existing clinical decision criteria for diagnostic imaging of spine and torso injuries in children are unfortunately less established. The “NEXUS” criteria for identifying injuries to the cervical spine that are widely used for adults could not be sufficiently validated in children [27]. The PECARN criteria listed in ▶ **Table 2** have a high sensitivity of 98 %. However, with strict application, the percentage of patients to be examined could increase [28, 29]. CT is rarely needed on an isolated basis but rather is typically performed as part of an indicated head CT examination or whole-body CT examination. To clarify unclear isolated spinal injuries, MRI is more sensitive, especially for ligament and intraspinal injuries. Many guidelines continue to recommend acquiring X-ray images on two planes as the basic diagnostic workup, but MRI is also being increasingly used for radiation-free primary diagnosis as in our hospital [30].

Chest

Multiple studies have examined the added benefit of CT compared to conventional chest X-ray in children. Hemothorax, pneumothorax, pneumomediastinum, and rib injuries can also be visualized with high sensitivity on conventional X-ray. Injuries additionally seen on CT only change the clinical management in exceptional cases. The most important indication for chest CT is a suspected aortic injury. This is typically only seen in the case of high speed

▶ **Table 2** PECARN criteria for cervical spine and abdomen. If all criteria are met, X-ray (cervical spine) and cross-sectional imaging (abdomen) are usually not needed [25, 31].

Cervical spine	▪ No impaired consciousness ▪ No focal-neurological deficit ▪ No torticollis ▪ No neck pain ▪ No severe torso injury ▪ No fall injury ▪ No high-speed traffic accident ▪ No predisposing preexisting disease (e. g. Down syndrome, disease of the musculoskeletal system)
Abdomen	▪ No visible abdominal wall trauma, no seat belt sign ▪ GCS > 13 ▪ No muscle guarding ▪ No chest wall trauma ▪ No abdominal pain ▪ Normal breathing ▪ No vomiting

trauma and is rarely an isolated occurrence so that whole-body CT is usually indicated in these highly rare cases [32, 33, 34, 35, 36]. Due to the higher heart rate of pediatric patients compared to adults, significant pulsation artifacts can occur particularly in the ascending aorta and can complicate detection of an aortic dissection. Consequently, an ECG-triggered examination or an examination with a high pitch factor (flash mode) should be considered [31, 37]. Retrospective studies were able to show that clinically relevant isolated chest injuries are very rare [38, 39]. Therefore, isolated chest CT should only be performed in exceptional cases during diagnostic workup in the trauma room. Conventional X-ray is typically sufficient in the case of suspected chest trauma without polytrauma. Ultrasound is also a suitable radiation-free al-

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ternative, particularly for the detection of pleural effusion. However, the sensitivity with respect to pneumothorax is heterogeneous in the literature. In the majority of published studies, ultrasound tends to have slightly better sensitivity in adults than X-ray. This has not yet been able to be confirmed in children [40, 41]. In groups with heterogeneous ultrasound training, very low sensitivities of only 16.8 % have been described in some cases. Therefore, routine use requires prior examiner training in the trauma room or it cannot be performed at all times [42].

Abdomen

The PECARN criteria for identifying children with a very low risk of therapeutically relevant intraabdominal injury are listed in ▶ **Table 2**. If none of these criteria are met, the risk of overlooking an injury requiring intervention is 0.1 %. The greatest risk is in the case of visible trauma to the abdominal wall, a seat belt sign, or decreased GCS (5.4 %), which are strong indicators for abdominal CT [43]. By introducing these structured criteria in the diagnostic workflow, Leeper et al. were able to show a significant reduction in the number of CT examinations being performed. Therapeutically relevant, higher grade organ injuries were still detected, while the number of diagnosed, low grade injuries decreased [44]. Abdominal ultrasound can be used as an alternative diagnostic method. However, particularly for FAST ultrasound performed prior to CT, the sensitivity for the detection of intraabdominal injuries in children is low (between 27.8 % and 56.5 %) compared to CT [45, 46]. In the case of repeat examination by an experienced examiner combined with clinical examination result, the sensitivity can increase to 87 % [47]. When ultrasound contrast agent (CEUS – contrast-enhanced ultrasound) is used, the sensitivity increases to 85–100 %. Moreover, a lack of perfusion and active bleeding can be visualized [48]. Unfortunately, properly trained examiners are not available around the clock in many hospitals.

Extremities

Extremity injuries are usually examined by acquiring X-ray images on 2 planes. If the first plane shows an indication for surgery, this is usually sufficient so that the patient can be spared additional pain due to positioning [24]. When performing whole-body CT, fractures of the upper extremities, which are usually secured to the upper body in the case of pain, can also be visualized on CT and correspondingly reconstructed. Examination of the lower extremities is indicated particularly in complex joint fractures and is associated with low additional radiation exposure so that it can be performed following whole-body CT to avoid a time delay due to repositioning and the acquisition of additional X-ray images.

Preclinical care – selecting a suitable trauma center

As stated above, the number of CT examinations depends on the hospital's level of experience with pediatric emergencies. Therefore, a decision should be made preclinically as to whether the child needs to be transported to a pediatric trauma center. In the future, telemedicine concepts as already used, for example, for stroke assessment can provide support for selecting a suitable hospital [49]. Using a tablet at the accident location, it is possible to digitally transfer data to the trauma center (e. g., NIDAmobile, medDV) so that important information can be provided in advance particularly in adult medicine. Rogers et al. were able to show the advantage of telemedicine techniques for emergency care by exchanging information between the trauma center and the community hospital [50]. Pediatric emergency care appears to be a particularly useful area of application since telemedicine support could have a significant benefit due to the rarity of pediatric trauma [51]. Dayal et al. were able to show an improvement in the condition of transferred children after the introduction of telemedicine consultations [52]. Therefore, Universitätsmedizin Mannheim is working on implementing telemedicine concepts in pediatric emergency care.

Implementation: Examination protocols

The current guidelines recommend a non-contrast head CT examination in children and adolescents < 15 years in whom whole-body CT is to be performed, followed by a monophasic examination from the base of the skull to the pelvis in a venous contrast phase, alternatively with administration of a split contrast bolus [24]. The contrast bolus is split and is administered with a time delay based on the patient's weight, 45–65 seconds and 15–25 seconds before image acquisition [53]. The authors describe improved simultaneous contrast enhancement of arteries and parenchymatous organs in a single-phase examination. The same is true for an isolated CT examination of the abdomen [47].

The protocol can be supplemented by CT venography of the head if non-contrast CT examination shows fractures in contact with the venous sinuses. In the case of injuries to the urinary tract, a further examination in the excretion phase is usually indicated [24]. In individual cases, biphasic (arterial and venous) imaging can be indicated in the case of suspicion of active bleeding [54]. In the case of an isolated head CT examination, some authors recommend including the cervical spine up to C3 since upper cervical spine injuries are most common in small children [30].

Depending on the selected protocol, the contrast dose is typically 1.5–2 ml/kg body weight when using hyperosmolar contrast agents. Depending on the pump system that is used, IV access, and the child's weight, manual injection may be needed. Use of a 3-way valve system for the contrast agent and a saline solution for flushing is recommended here to avoid time delays due to syringe changes. In the case of small-lumen access, the contrast agent can be diluted 1:1 with a saline solution to lower the viscosity. The location with the lowest radiation exposure for the examiner is directly next to the gantry. However, it is typically possible to leave the room due to the delay in monophasic examinations [55].

Typical injury patterns and pitfalls

The typical injury patterns in children are age-dependent, partly due to anatomical characteristics and partly due to a difference in activities. In small children, falls are the dominant injury pattern. Since the head is large in proportion to the rest of the body,

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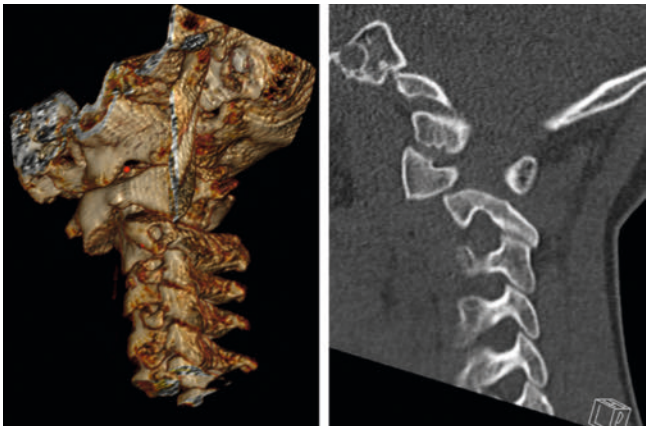
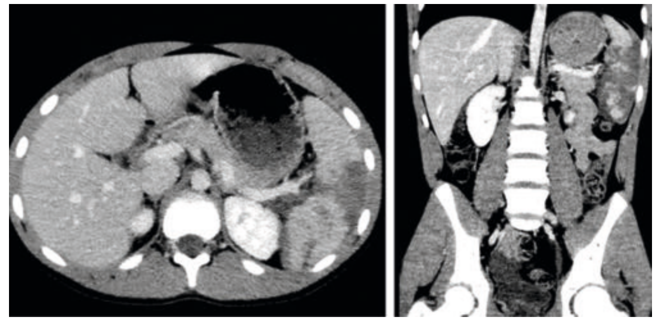
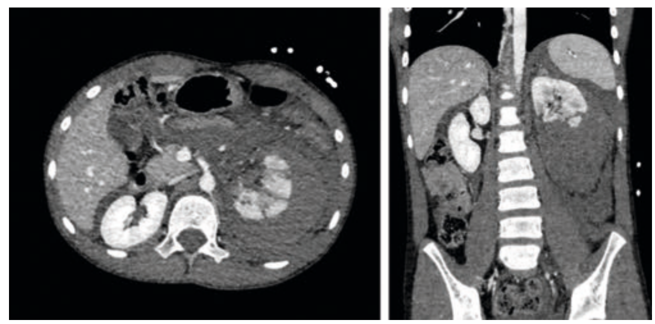


▶ **Fig. 2** Atlanto-axial dislocation in a 10-year-old boy. Clearly visible dislocation without fracture on 3 D MIP (left) and incongruence between the C1 and C2 vertebrae at the level of the facet joint (right).



▶ **Fig. 3** Grade IV spleen trauma in a 12-year-old boy. The injury could be successfully treated conservatively.



▶ **Fig. 4** 4-year-old patient with grade IV renal laceration with extensive retroperitoneal hematoma and tear of the lower pole of the kidney after trauma to the flank region resulting from a fall, secondary finding of partially visualized grade II splenic laceration. After placement of a ureteral stent, the patient could be successfully treated conservatively.

head injuries are most common. With increasing age, activities involving sports and road traffic increase and the incidence of body injuries increases. The presence of head and chest injuries is associated with greater mortality [38, 39, 56].

Bones and ligaments in children have greater elasticity so that fractures of the axial skeleton are rarer compared to adults. Isolated ligament lesions without an unstable fracture are more common, are often not or only indirectly visible on CT, and require primary or additional MRI examination. Particularly in small children, the majority of detected injuries occur in the upper cervical spine due to the large size of the head in proportion to the body and the consequently higher center of gravity. Atlanto-occipital and atlanto-axial dislocation injuries are a typical example of injuries that occur in young children but are rarely seen in adults, see ▶ **Fig. 2** [30, 57].

Thoracic injuries are typically not an isolated occurrence. However, in the case of polytrauma, they are associated with increased mortality [38]. Due to the increased elasticity of bone in children, organ injuries without rib fracture are not uncommon, e. g., lung contusions and lesions of the upper abdominal organs. Injuries to the liver, spleen, and kidneys can be treated conservatively more often in children than in adults. ▶ **Fig. 3** and ▶ **Fig. 4** show an example of dramatic image findings that were able to be treated without surgery. In this connection, a precise evaluation regarding active bleeding on CT angiography is important since the detection of active extravasation into the peritoneum is a strong predictor of the failure of conservative management. This must be communicated accordingly especially in the case of spleen lacerations, which are almost always treated conservatively in children [54]. The second most injured organ after the upper abdominal organs is the bowel. This injury is more common in children than adults [58]. Another critical injury is renal artery dissection, which must be ruled out with duplex sonography if contrast-enhanced CT is not performed.

Especially infants and toddlers under the age of 3 years can be victims of child abuse. However, the parents often provide a different medical history. Suspicious findings requiring further clarification include subdural hematoma and upper cervical spine injuries without corresponding trauma, dorsal rib fractures, sternum fractures, spinous process fractures, metaphyseal apophyseal fractures of the extremities (bucket handle fracture due to shaking of the extremities), and general presumably repeat injuries. In the case of all pediatric trauma patients and particularly in the case of injury patterns not corresponding to the injury mechanism, a non-accidental injury should always be considered as a differential diagnosis and further workup in interdisciplinary child protection teams should be performed as needed [59, 60]. A typical presentation in the trauma room is an infant with lethargy. A non-contrast head CT scan and ultrasound examination of the chest and abdomen are typically initially sufficient for diagnosis in the case of corresponding suspicion.

Conclusion

It is essential for radiologists participating in the care of injured children to be familiar with pediatric characteristics in order to determine the indication for imaging and select, perform, and interpret imaging methods. Whole-body CT is only one possibility for the diagnostic workup and should only be used after careful consideration due to children's increased sensitivity to radiation and the often lower treatment relevance in children. The indication

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for CT is typically determined separately for each region of the body and on an interdisciplinary basis, ideally at a pediatric trauma center. If the situation allows, ultrasound and MRI are often suitable radiation-free alternatives for imaging injured children.

Conflict of Interest

The authors declare that they have no conflict of interest.

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