Curr Radiol Rep (2017) 5:51
DOI 10.1007/s40134-017-0248-2

PEDIATRICS (L AVERILL, SECTION EDITOR)

Pediatric Emergency MRI: What You Need to Know to Make It Through the Night

Ashish K. Parikh[1] · **Chetan C. Shah**[1]

Abstract

Purpose of Review The purpose of this review is to introduce the non-pediatric radiologist to the many common conditions that can be diagnosed via pediatric magnetic resonance imaging (MRI), particularly in the emergency setting.

Recent Findings The vast majority of radiologic examinations in children occurs in non-pediatric facilities, and is interpreted by non-pediatric radiologists. Therefore, it is essential that the non-pediatric radiologist is aware of the current and potential imaging trends occurring in the pediatric setting, largely focused on increased MRI utilization. With advances in MR technology, many MRIs can be performed relatively quickly, eliminating the need for sedation. Because of this, and its lack of ionizing radiation, pediatric MRI has been increasingly relied upon in the emergency setting over the past decade. It is ever more prudent that every radiologist familiarize him or herself with the varying MR studies that can be performed after hours, and the MR appearance of common diagnoses. Our review focuses on the more common conditions diagnosed via MR imaging including appendicitis, other causes of right lower quadrant pain, shunted hydrocephalus, limited sequence brain MR in the acute setting, musculoskeletal infections and spine emergencies.

Summary With the continued advent of faster MRI scanners and avoidance of ionizing radiation, the usage of MRI in the pediatric setting will only increase in the future. We believe that it is important that every radiologist become familiar and comfortable in interpreting the common conditions that can be diagnosed via MRI.

Keywords MRI · Pediatrics · Pediatric radiology · Emergency MRI

Introduction

With the introduction and success of the Image Gently campaign utilizing the principles of ALARA (as low as reasonably achievable), there has been a concerted effort amongst pediatric imaging departments to limit the use of ionizing radiation, the paramount contributor being computed tomography (CT). As an alternative imaging modality, magnetic resonance imaging (MRI) provides exquisite contrast resolution and soft tissue detail, often better than CT, particularly in the brain and spine. With the advent of faster and more ubiquitous MR scanners, an increasing number of MR examinations are now being performed from pediatric emergency departments (ED). Scheinfeld and colleagues have recently examined MR usage in their pediatric ED over a 5-year period, and found an increased number of MR examinations over the 5 years, with the far majority of exams being in the neuroradiology realm [1•]. This coincides with our experience, where MR usage has increased after hours and on weekends. In our institution, the majority of emergent examinations are brain MRIs for neurologic indications, followed by abdominal MRIs for appendicitis. This review will examine after-hours MR imaging of several common pathologies, with a

---

This article is part of the Topical collection on *Pediatrics*.

✉ Ashish K. Parikh
ashishkumar.parikh@nemours.org

Chetan C. Shah
chetan.shah@nemours.org

[1] Nemours Children's Specialty Care, 807 Children's Way, Jacksonville, FL 32207, USA

focus on what the radiologist needs to know in order to survive the night.

Acute Appendicitis

Appendicitis is the most common cause of urgent abdominal surgery in the pediatric population [2•]. Clinical diagnosis of pediatric appendicitis can be challenging, as children can often present with atypical symptoms, rendering imaging a vital asset in diagnosis [3]. Ultrasound (US) is the first-line imaging modality in the evaluation of pediatric appendicitis, due to its lack of ionizing radiation, cost-effectiveness, and efficiency in aiding diagnosis. A number of studies support the utility of US for the diagnosis of appendicitis, including a meta-analysis by Doria et al. that showed a sensitivity of 88% [5]. However, a recent study by Trout et al. demonstrated a meager 67% sensitivity of US in the diagnosis of appendicitis, highlighting the operator-dependent nature of US for this indication [4].

Because of this variability, alternative cross-sectional imaging modalities are often employed after an inconclusive or equivocal US. Contrary to CT, MRI lacks ionizing radiation and employs similar sensitivity and specificity for the diagnosis of appendicitis. A study from 2013 by Herlizcek et al. revealed a sensitivity of 100% for appendicitis on MR examinations performed after an inconclusive US [3]. Further, a systemic review and meta-analysis of 30 studies and 2655 patients, performed by Duke et al. in 2016, showed a 96% sensitivity and specificity for the diagnosis of acute appendicitis by MR [6•].

MR examinations to evaluate for appendicitis employ a limited number of sequences and are typically performed without intravenous contrast or sedation. With total MR table time of approximately 15 min, the use of MRI rather than CT does not significantly delay patient triage [7]. In fact, a recent meta-analysis by Moore et al. demonstrated no significant difference in time to antibiotics, time to appendectomy, or length of stay in patients imaged with MR versus CT for appendicitis [7]. At our institution, T2-weighted single-shot fast spin-echo sequences (SSFSE) with and without fat saturation are performed in the coronal and axial planes of the entire abdomen and pelvis. Axial diffusion-weighted images (DWI) are additionally employed to improve the conspicuity of the appendix. Multiple authors have reported that compared to conventional MR techniques alone, the addition of DWI increases readers' sensitivity and specificity for the diagnosis of acute appendicitis. For example, Bayraktutan et al. demonstrated sensitivity of 92% and specificity of 92% when DWI was included in the protocol, compared to 81 and 82%, respectively, when employing conventional MR techniques alone [8]. Our institution does not employ intravenous contrast during our MR examinations for appendicitis, as we feel that it does not significantly change our diagnosis when compared with T2-weighted sequences alone.

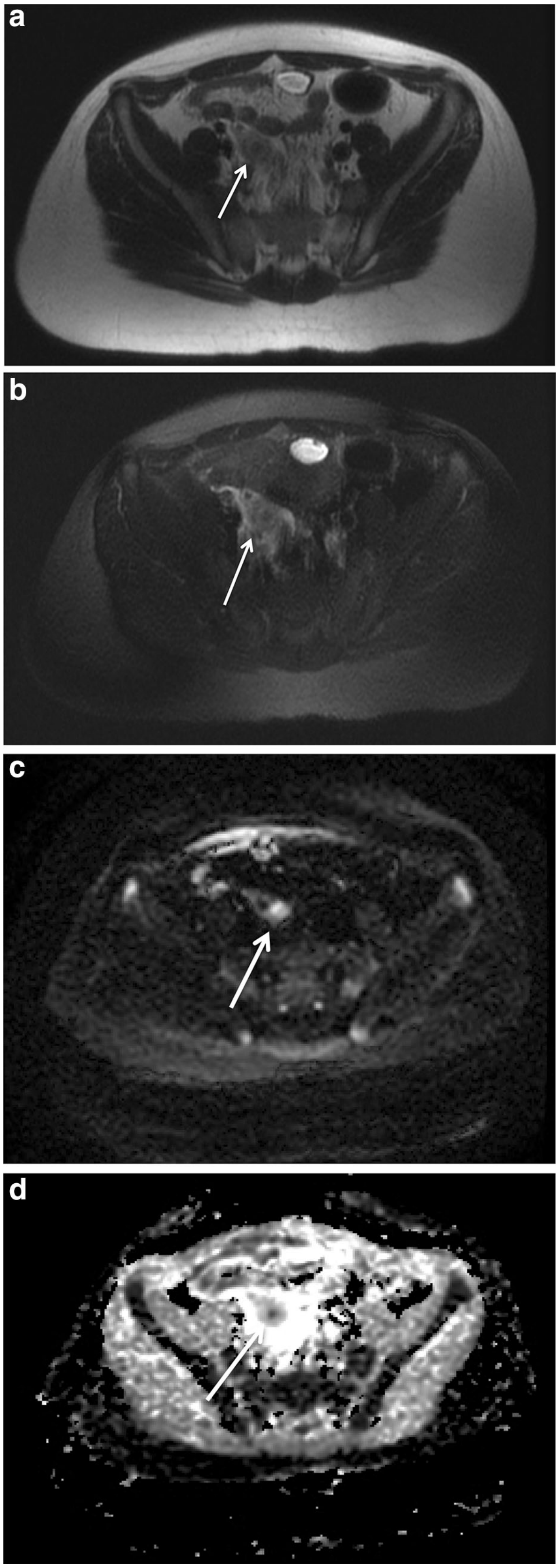
As with other imaging modalities, an enlarged, fluid-filled appendix with periappendiceal inflammation is the hallmark of acute appendicitis on MRI. Due to inherent superior soft tissue resolution, MR reveals inflammatory changes around a dilated appendix exquisitely well (Fig. 1a, b). Further, an inflamed appendix can demonstrate diffusion restriction (Fig. 1c, d). However, diffusion restriction should not be the sole criterion, but rather taken collectively with other findings of acute appendicitis. Non-visualization of the appendix after careful scrutiny, and without right lower quadrant or pelvic inflammation, can be confidently considered a negative study [9].

Alternative Etiologies of Right Lower Abdominal Pain

Due to the increasing utilization of MRI for the assessment of appendicitis, alternative diagnosis as to the etiology of the abdominal pain must be considered [10]. A recent publication by Moore et al. documented alternative diagnoses in at least 19% of children, ranging from common entities such as adnexal pathology to rare disorders such as ataxia telangiectasia [10]. Here we present several of the more commonly encountered conditions that can be diagnosed with emergent abdominal MRI, including adnexal pathology, enteritis and colitis, mesenteric adenitis, and epiploic appendagitis.

As in appendicitis, US is the first-line imaging study in evaluation of adnexal pathology. In fact, right lower quadrant US for appendicitis and pelvic US with Doppler are commonly ordered together at our institution for girls presenting with acute lower abdominal pain. When these studies are inconclusive, abdominal MRI is often obtained. Unlike CT, MRI provides excellent contrast resolution for evaluation of ovarian parenchyma. The most common adnexal pathologies encountered are ovarian cysts, either functional or hemorrhagic, with MR features similar to those seen with US [10].

Unexpected cases of ovarian torsion may also be encountered, particularly in instances when a pelvic ultrasound is not performed. The radiologist must be comfortable in diagnosing an ovarian torsion on MRI, as time is of the essence in this surgical emergency. Similar to US, the affected ovary will be enlarged and edematous, with peripheral follicles (Fig. 2). The majority of cases will be associated with a lead point, such as an enlarged cyst or dermoid, as the cause of the torsion [10].



◀**Fig. 1** Uncomplicated acute appendicitis. **a** Axial T2W image demonstrates the appendix (*arrow*) with surrounding mesenteric stranding, consistent with inflammation and acute appendicitis. **b** Axial T2-weighted image with fat saturation better reveals the increased T2 signal (*arrow*) surrounding the appendix, consistent with appendicitis. **c** Axial diffusion-weighted image showing restricted diffusion (*arrow*) in the appendix. In conjunction with the anatomic findings, this is consistent with acute appendicitis. **d** Axial ADC confirms the diffusion restriction of the appendix (*arrow*)

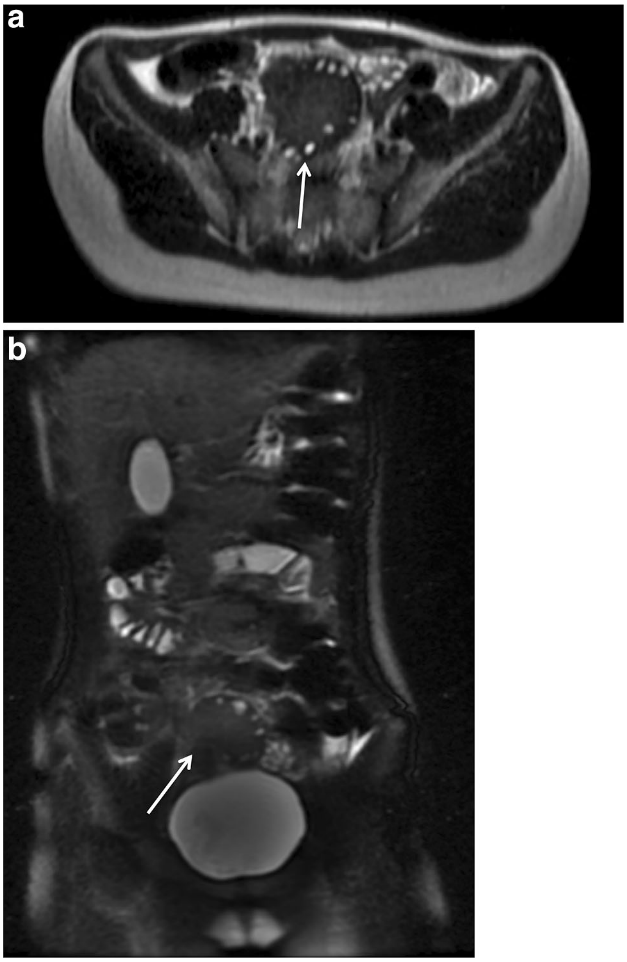


Fig. 2 Case of ovarian torsion diagnosed on a routine appendicitis MRI. **a** Axial T2-weighted image demonstrates an enlarged mass lesion with peripheral cysts/follicles (*arrow*). Scrolling through the images confirms this to be the right ovary, with a normal appearing left ovary. Findings are consistent with ovarian torsion. **b** Coronal T2-weighted image with fat saturation reveals the torsed right ovary (*arrow*), demonstrating peripheralization of ovarian follicles

Similar in frequency to adnexal pathology, acute infectious or inflammatory enteritis or colitis is a commonly encountered alternative diagnosis during a MR examination for acute appendicitis [10]. Bowel thickening, bowel wall edema, and surrounding inflammation in the absence of other etiologies for this inflammation are hallmark features of enteritis or colitis, well depicted with MRI [10]. It should be noted, however, that MRI may not be appropriate for imaging patients with known or suspected inflammatory bowel disease (IBD) in the emergency setting due to exam preparation and exam length that is necessary for an adequate and detailed IBD evaluation. At our institution, MR enterography involves drinking between 900 and 1000 ml of oral contrast 45–60 min prior to examination [11]. With the imaging time of at least 45 min, and additional 45–60 min of preparatory time, this can easily become a 1.5–2 h examination, not ideal for the emergency setting. CT enterography, while employing a similar preparatory time, has a much shorter imaging period (seconds–minutes) and would be the ideal study in an urgent situation.

Mesenteric adenitis is a diagnosis of exclusion, but can be suggested by the absence of a specific cause of the abdominal pain, such as those discussed above, with the presence of localized pain in the region of multiple enlarged lymph nodes (Fig. 3) [10].

Epiploic appendagitis is a mimic of appendicitis, and involves inflammation of the epiploic appendages of the colon. The epiploic appendages are foci of pedunculated adipose tissue, whose function is unknown [12]. Similar to CT, this presents as localized inflammation involving the antimesenteric side of the colon, with the epicenter of inflammation being adipose tissue. This presents as increased T2-weighted signal and fat stranding surrounding a focus of fat, adjacent to the antimesenteric side of the colon. Often, there will be a low-signal-intensity rim on T1- and T2-weighted images, with the central component of the inflammation demonstrating signal characteristics of fat [12]. Further, there can be a central, hypointense, round focus referred to as the “central dot sign” [12]. Occasionally, there can also be a linear focus, analogous to the

Fig. 3 Mesenteric adenitis. Axial diffusion-weighted image reveals hyperintense lymph nodes (*arrow*) in the patient with no other identifiable cause for right lower quadrant (RLQ) pain. These findings can be seen with mesenteric adenitis

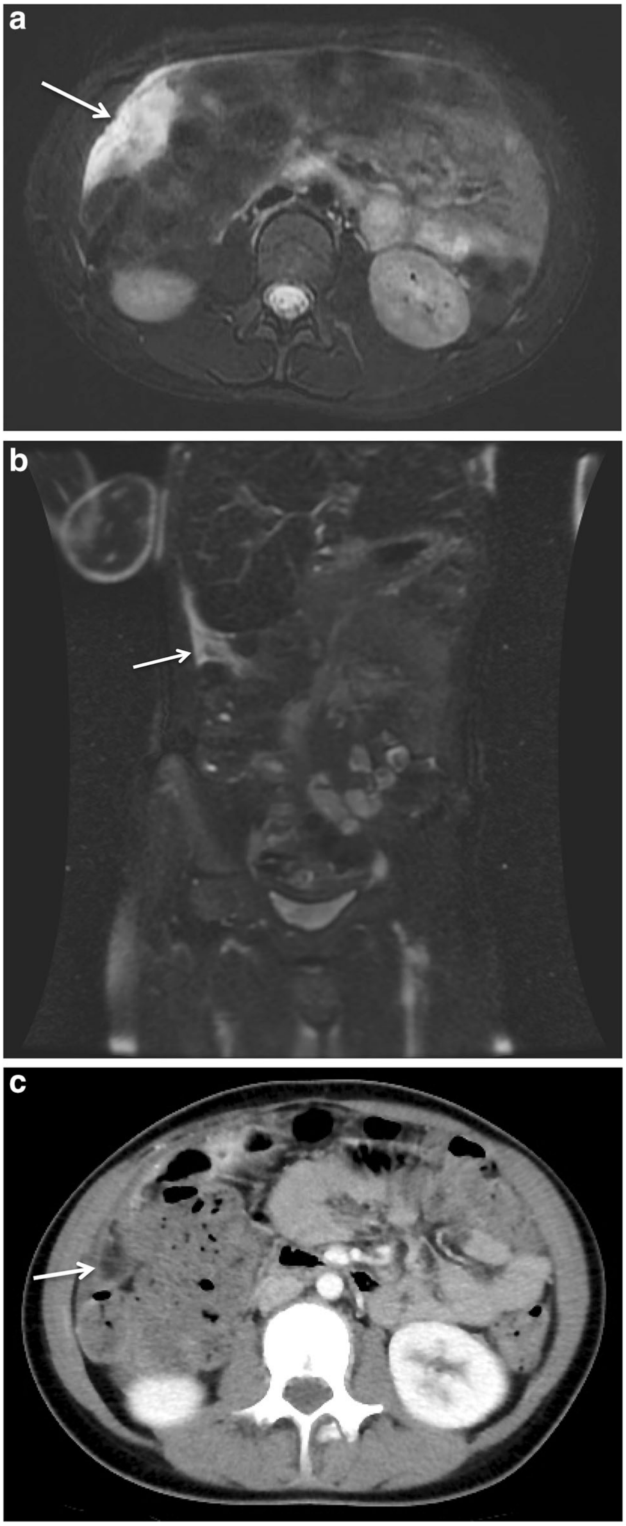


Fig. 4 Omental infarction. **a** Axial T2-weighted image with fat saturation reveals increased signal in the mesentery of the RLQ (*arrow*). The normal appendix was identified (not shown). **b** Coronal T2-weighted image with fat saturation revealing similar findings to **a** (*arrow*). **c** Axial contrast-enhanced CT demonstrating the fatty center, with surrounding stranding of the mesentery in the RLQ (*arrow*). This is consistent with omental infarction

"central dot sign" representing a thrombosed or hemorrhagic vessel [12]. Although helpful, the absence of the "central dot sign" or linear focus does not exclude the diagnosis of epiploic appendagitis. Of note, omental infarction can sometimes appear quite similar to epiploic appendagitis, and cannot always be distinguished (Fig. 4) [12].

Shunted Hydrocephalus

Hydrocephalus is one of the most common pediatric neurological conditions, often treated with shunt catheters [13]. These children undergo many imaging studies in order to evaluate the hydrocephalus, as an indirect measure of shunt catheter functioning [13]. Instead of receiving numerous head CT examinations to assess ventricle size, our institution has implemented a rapid, limited brain MR study in order to avoid ionizing radiation. Our rapid brain MR study for hydrocephalus consists of a single-shot fast spin-echo sequence (SSFSE) in the axial, coronal, and sagittal planes, usually easily acquired in non-sedated children of all ages (Fig. 5). Taking only a few minutes to perform, these exams can be worked into the MRI schedule during busy day-shift hours as well as overnight. In a 2013 study by Niederhauser et al., rapid brain MR examinations for the evaluation of hydrocephalus in children with shunt catheters were effective in evaluating ventricular size, providing a non-ionizing alternative to CT [14]. Reducing the number of head CTs, and thereby decreasing ionization radiation is in keeping with the principles of ALARA. This is a worthwhile goal in the pediatric setting, a population most vulnerable to the effects of ionizing radiation.

Fig. 5 Hydrocephalus in patient with VP shunt catheter. Axial SSFSE image reveals hydrocephalus in this patient with a VP shunt catheter (*arrow*). Notice that the degree of hydrocephalus is easily demonstrated

Limited Sequence Brain MRI (LSMR) in the Acute Setting

An alternative and more accurate assessment of acute intracranial pathology in the emergency setting is a limited sequence brain MRI (LSMR) examination [15]. Often, the initial imaging study of choice in the evaluation of acute intracranial pathologies is a non-contrast head CT. While very efficient, a non-contrast head CT is limited in the assessment of many neurological conditions, including that of acute stroke, brainstem and posterior fossa lesions, demyelinating disease, and diffuse axonal injury [15].

Fig. 6 Osteomyelitis. Sagittal STIR image demonstrates exuberant increased signal in the bone marrow of the distal tibia, and involving the talus, along with increased signal in the surrounding soft tissues (*arrow*); consistent with osteomyelitis. There is a subperiosteal fluid collection as well (*yellow arrow*)

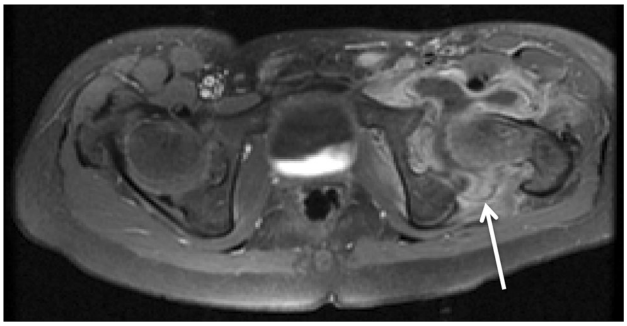


Fig. 7 Septic arthritis. Axial fat-saturated post-contrast image demonstrates synovial thickening and enhancement surrounding the left hip joint (*arrow*), consistent with septic arthritis

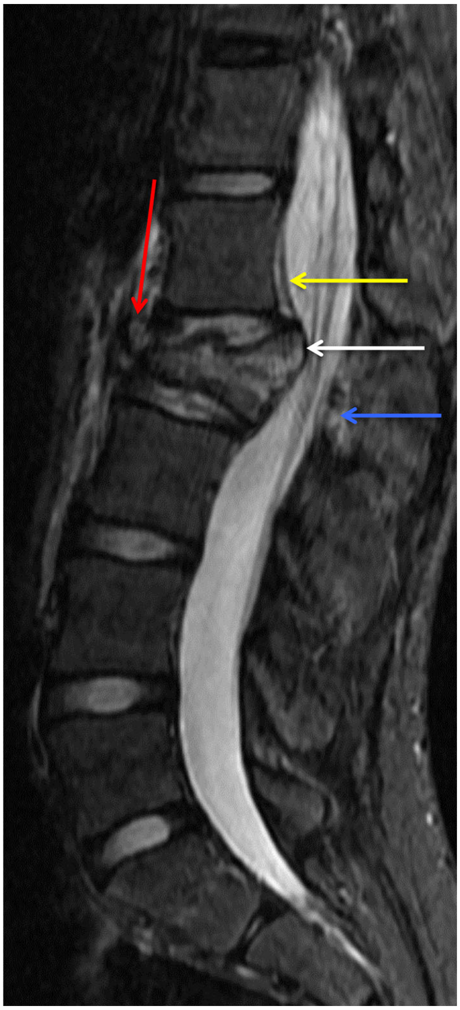


Fig. 8 Ligament injury. STIR sagittal image of the lumbar spine shows a burst fracture of L2 with retropulsed fracture fragment (*white arrow*). Anterior longitudinal ligament is ruptured with a fracture fragment seen displaced anteriorly (*red arrow*). Posterior longitudinal ligament is stretched and uplifted with hemorrhage between it and the vertebral body (*yellow arrow*). Ligamentum flavum is also ruptured (*blue arrow*). L2 vertebral body shows hyperintense STIR signal due to edema

A LSMR can include only a few sequences to increase efficiency and the ability to perform these examinations without sedation. Albers et al. proposed using axial diffusion (b0 and b500 values), apparent diffusion coefficient map, axial fluid-attenuated inversion recovery, and sagittal T1- or T2-weighted images (to assess for midline abnormalities) for their limited brain MR study. Not only could this or other similar LSMR examinations provide quick answers, these LSMR studies may be more accurate than a non-contrast head CT in a variety of situations.

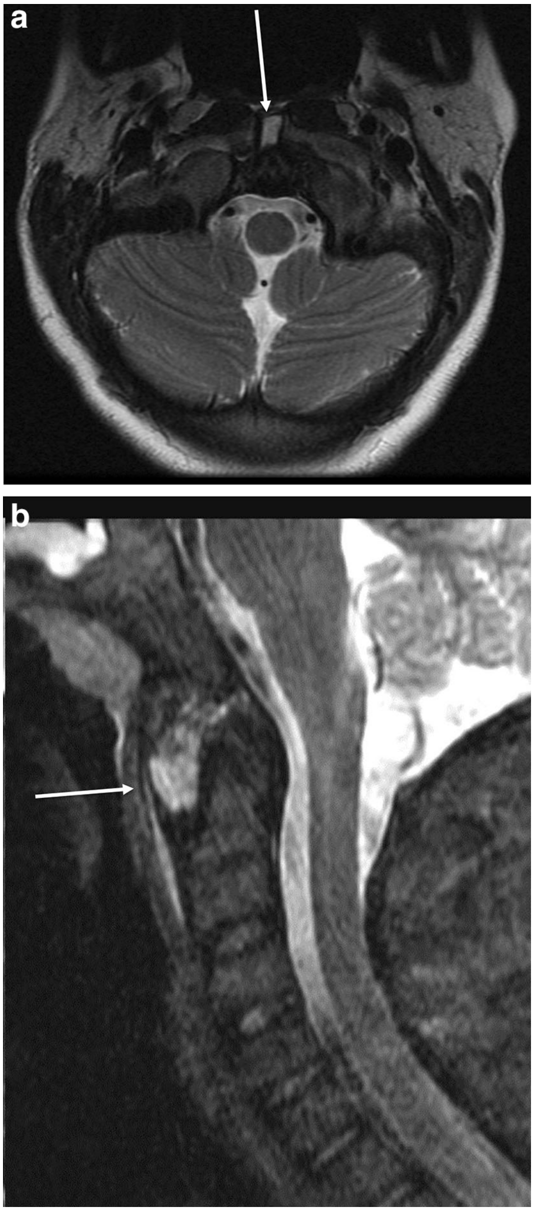


Fig. 9 Craniocervical junction injury. **a** Demonstrates an axial T2 image that reveals distraction injury of anterior arch of C1. There is hemorrhage (*arrow*) between the right and left anterior arch. **b** Sagittal STIR image shows hemorrhagic fluid uplifting the anterior atlanto-occipital membrane (*arrow*)

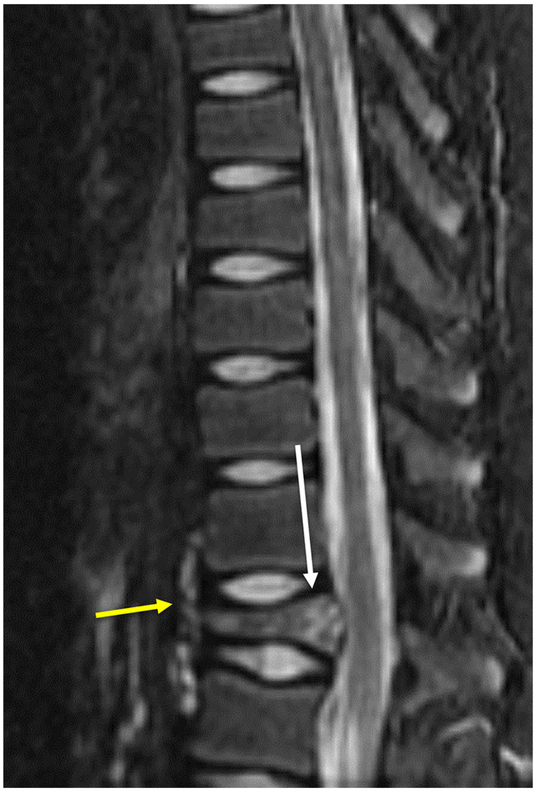


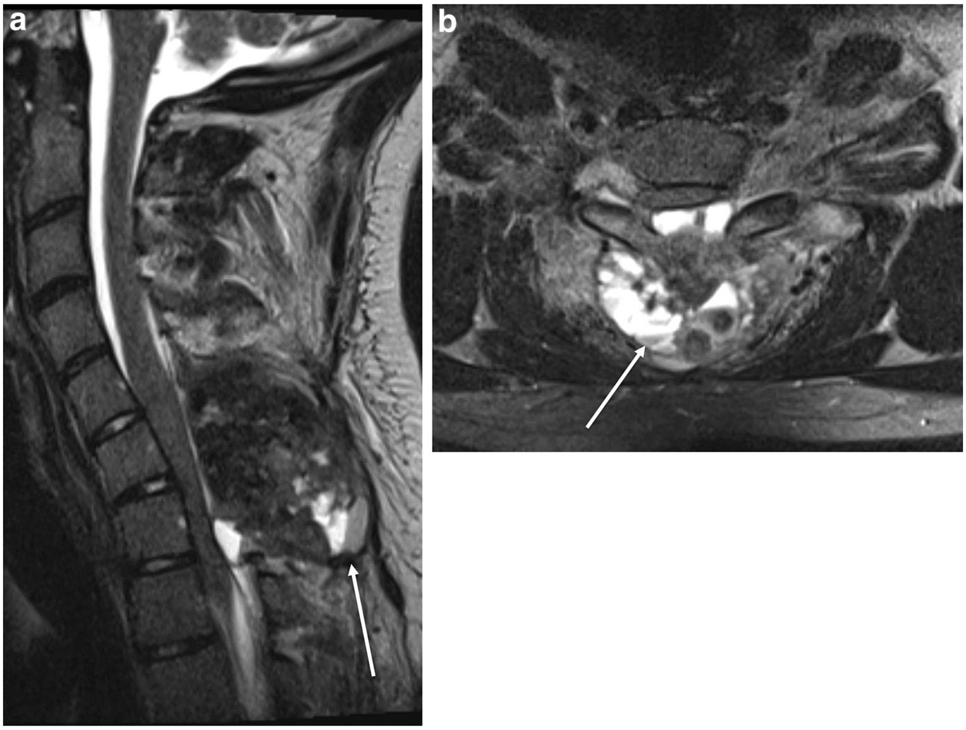
Fig. 10 Cord compression and ligament injury. Sagittal STIR images show compression fracture of T12 (*white arrow*) with posterior part of the vertebral body projecting into the spinal canal causing mild cord compression. There is edema of the vertebral body. Anterior longitudinal ligament is injured (*yellow arrow*). Posterior longitudinal ligament is stretched

This was confirmed by Albers et al. who stated that there was a benefit in LSMR examinations over non-contrast head CTs, in which several conditions such as stroke, cortical dysplasia, posterior fossa malformations, and arteriovenous malformations were discovered [15]. Further, several authors have suggested that a LSMR can effectively assess traumatic brain injury. Roguski et al. revealed that LSMR is as sensitive as CT for traumatic head injury, diffuse axonal injury, and intracranial hemorrhage [16]. This was also supported by Young et al., who found similar detection rates of LSMR to CT for intracranial injury in young children (<6 year old) with acute head trauma [17•].

Musculoskeletal Infection

Although there are a wide array of musculoskeletal conditions that can present in the acute setting, in the pediatric age group the one that is assessed most frequently via MRI is osteomyelitis. Osteomyelitis is an infection of the bone, and can often be associated with surrounding inflammation, and complicated by the presence of soft tissue or bony abscesses [18]. Acute hematogenous osteomyelitis is the most common musculoskeletal infection in children in the United States, often occurring in children younger than 5 years of age [18]. MRI is an invaluable imaging modality in the assessment of osteomyelitis, as it is sensitive to the early changes of osteomyelitis, such as bone marrow

Fig. 11 **a** Bony vertebral mass compressing spinal cord. Sagittal T2-weighted images demonstrate a mass involving the posterior elements of distal cervical vertebrae that has fluid–fluid levels (*arrow*). It has cystic components and projects inside the spinal canal causing cord compression. Histopathology showed osteosarcoma. **b** Bony vertebral mass compressing spinal cord. Axial T2-weighted images demonstrate a mass involving the posterior elements of distal cervical vertebrae that has fluid–fluid levels (*arrow*). It has cystic components and projects inside the spinal canal causing cord compression. Histopathology showed osteosarcoma



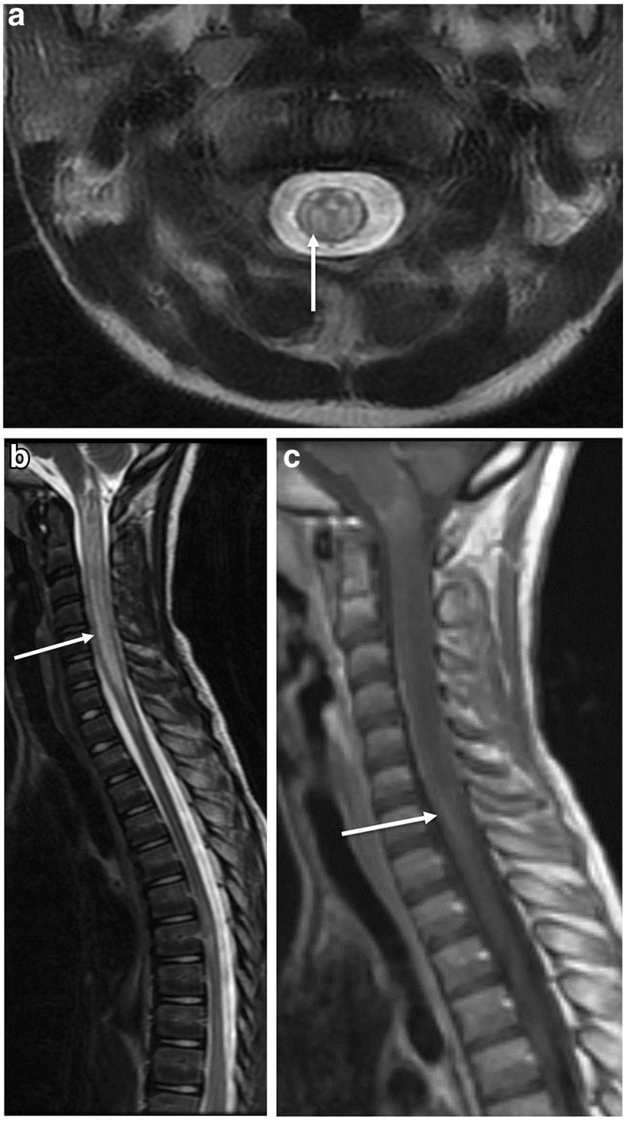


Fig. 12 Neuromyelitis optica. T2-weighted axial (**a**), sagittal (**b**) sequences show hyperintense T2 signal in the spinal cord, most extensive in the cervical spinal cord (*arrow*). Cervical spinal cord appears swollen due to cord edema. Post-contrast T1-weighted (**c**) sequence shows patchy enhancement of cervical spinal cord (*arrow*)

edema (Fig. 6). Fat-saturated T2-weighted or STIR sequences are vital to every osteomyelitis protocol in order to assess for these early changes. Additional features of osteomyelitis include periosteal elevation, subperiosteal fluid collection, and abscess. Many institutions typically utilize contrast administration as it has been shown to increase readers' confidence in the diagnosis of osteomyelitis [19]. Further, contrast administration is vital in cases in which a bone or soft tissue abscess is suspected. However, in the absence of any bone or soft tissue edema on unenhanced images, further administration of contrast is not necessary [19].

Another common condition occurring in children is septic arthritis, considered a surgical emergency. Because radiography may be normal in children with acute septic arthritis, often times these children are imaged with US to assess for the presence of a joint effusion rather than MRI [20•]. However, osteomyelitis and septic arthritis may coexist, and therefore it is prudent to become familiar with the MR imaging appearance of septic arthritis. Septic arthritis presents as a joint effusion, typically with surrounding synovial and deep soft tissue enhancement (Fig. 7).

Spine Emergencies

MRI of the spine is an important diagnostic tool for pediatric spine emergencies in both trauma and non-trauma cases.

Spine MRI for Trauma

While the bony evaluation for fracture is initially accomplished by CT, the evaluation of the spinal cord and ligaments requires MRI. A typical trauma spine MRI protocol includes sagittal and axial T2-weighted, axial gradient, and sagittal STIR images [21]. Sagittal and axial T1-weighted images are also usually performed; however, these sequences do not add much in the acute trauma setting since the required information about the spinal cord, ligaments, and hemorrhage is obtained better using T2-weighted, STIR, and gradient sequences, respectively. Thus, T1-weighted images can be avoided in the interest of time in the trauma setting. Additional coronal STIR images of the cervical spine, though, are helpful to evaluate the ligaments at C1–C2.

Spinal cord injury causes altered signal of the spinal cord on a T2-weighted sequence [22, 23]. Spinal cord edema should not be confused with the Gibbs artifact on sagittal T2-weighted sequences, which appears as a linear hyperintense T2 signal. Corresponding axial T2-weighted images at those levels will show normal signal thereby confirming the artifact seen on the sagittal image.

Ligamentous injury appears as hyperintense signal on a STIR sequence (Fig. 8). It may have associated hemorrhagic fluid adjacent to the ligament, which may be mixed intensity or hyperintense on a T2-weighted image. The anterior longitudinal ligament, posterior longitudinal ligament, and posterior ligament complex are important stabilizers of the spine. If two out of these three ligaments are injured, the spine is at risk for instability.

The craniocervical junction is susceptible to injury in children. The child's disproportionate head size, poor muscle tone, ligamentous laxity, and immature articulations render the craniocervical junction susceptible to injury [24]. Further, it is much more common in children to have soft tissue and ligamentous injury at the craniocervical junction [24]. It is not uncommon to have normal CT examinations, but have an abnormal MRI with nonosseous injury occurring at the craniocervical junction [24].

The craniocervical junction includes the occiput, atlas, axis, and ligaments connecting these bony structures [25]. The apical ligament extends vertically from the tip of the dens to the basion [26]. Alar ligaments extend from the lateral aspect of the tip of the dens to the anteromedial aspect of the occipital condyles. The anterior atlanto-occipital membrane connects the anterior arch of C1 to the anterior margin of the foramen magnum. Injury to this ligament can result in hemorrhage or edema separating the ligament from its normal location (Fig. 9). The tectorial membrane is the superior continuation of the posterior longitudinal ligament that attaches to the posterior aspect of the clivus. The atlanto-dental interval (ADI) is less than 5 mm in children in flexion. Pseudosubluxation can be normally seen in children less than 8 years of age at the C2–C3 or C3–C4 level.

Epidural or intraspinal hemorrhage within the spinal canal is seen best on the gradient sequence. Cerebrospinal fluid flow artifact is seen as hypointense signal on T2-weighted images similar to intraspinal hemorrhage, an artifact especially exaggerated in children. Gradient axial images help distinguish flow artifact from hemorrhage, as hemorrhage will be hypointense, whereas the gradient sequence does not show CSF flow artifact.

Spinal cord compression from intraspinal hemorrhage or a bony fracture fragment is a critical finding and the clinician must be alerted immediately (Fig. 10). Trauma below the level of the conus usually spares the spinal cord.

Spine MRI in Non-Traumatic Pediatric Emergencies

Inflammatory, infectious, and neoplastic lesions can lead to pediatric spine emergencies as well. Acute infarct of the spinal cord in children is uncommon.

A vertebral bony mass may compromise the spinal canal and cause cord compression (Fig. 11) [27]. Epidural mass lesions can also cause spinal cord compression. A

Fig. 13 Acute flaccid myelitis. T2-weighted axial images at cervical (**a**) and thoracic (**b**) level show H-shaped hyperintense T2 signal in the central gray matter of the spinal cord (*arrow*). T2-weighted sagittal image (**c**) shows extensive hyperintense T2 signal in the spinal cord (*arrow*)

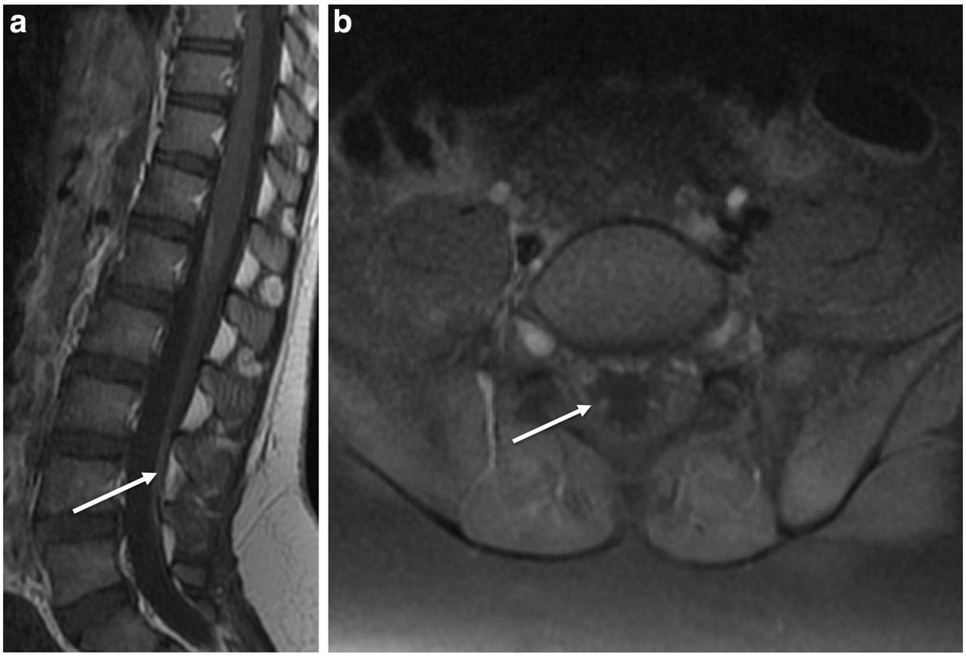


Fig. 14 Guillain–Barré syndrome. Post-contrast sagittal T1-weighted (**a**) and fat-suppressed post-contrast T1-weighted axial (**b**) images of the lumbar spine show enhancing anterior nerve roots (*arrow*) typically seen in Guillain–Barré syndrome

paravertebral mass like neuroblastoma can enter the spinal canal and cause cord compression. Any spinal cord mass may cause weakness or sensory deficits corresponding to the spinal level of the lesion.

Inflammation or infection of the spinal cord causes hyperintense T2 signal within the spinal cord. Transverse myelitis typically involves less than 4 spinal cord segments. Four or more spinal cord segments are involved in neuromyelitis optica (Fig. 12) [28]. This diagnosis requires brain and orbit MRI with and without intravenous contrast to evaluate for optic neuritis and any demyelinating lesions of the brain. When there is central gray matter involvement ("H" shaped hyperintense T2 signal) of the spinal cord that involves more than 4 spinal cord segments, the diagnosis of acute flaccid myelitis should be considered (Fig. 13) [29]. Although it is an uncommon entity, a sudden increase in cases was seen in 2014 and 2016. A number of viruses are associated with acute flaccid myelitis including enteroviruses, West Nile virus, and adenoviruses. Acute disseminated encephalomyelitis (ADEM) typically shows patchy hyperintense T2 signal in the spinal cord and brain. Guillain–Barré syndrome is characterized by ascending paralysis, with contrast-enhanced MRI of the lumbar spine showing enhancing anterior nerve roots at the lumbar levels (Fig. 14) [30]. Close attention to presenting symptoms is necessary since the addition of contrast to the MRI protocol is essential in Guillain–Barré syndrome and a delay in diagnosis and initiation of therapy can affect patient outcomes [31].

Conclusion

MRI is an invaluable imaging modality in assessing acute pediatric conditions from the emergency department. With avoidance of ionizing radiation, this modality is consistent with the principles of ALARA and the Image Gently campaign. Further, many of the conditions discussed above are as effectively or more effectively diagnosed with MRI as compared to CT. With the continued development of faster MR scanners, we believe that the trend of increased MRI utilization throughout the night will continue. Therefore, it is imperative that general radiologists familiarize themselves with the MR appearance of common emergency pediatric conditions.

Acknowledgements The authors would like to thank David Dinan, MD for the opportunity to write this article.

Compliance with Ethical Guidelines

Conflict of Interest Ashish K. Parikh and Chetan C. Shah each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Recently published papers of particular interest have been highlighted as:

- Of importance

1. • Scheinfeld MH, Moon JY, Fagan MJ, Davoudzadeh R, Wang D, Taragin BH (2017) MRI usage in pediatric emergency departments: an analysis of usage and usage trends over 5 years. Pediatr Radiol 47(3):327–32. *Excellent article demonstrating the increasing usage of MR in the pediatric acute setting.*
2. • Dillman JR, Gadepalli S, Sroufe NS, Davenport MS, Smith EA, Chong ST, Mazza MB, Strouse PJ (2016) Equivocal pediatric appendicitis: unenhanced mr imaging protocol for nonsedated children—a clinical effectiveness study. Radiology 279(1):216–225. *Helpful article retrospectively analyzed the efficacy of MR relative to CT in the diagnosis of appendicitis after an equivocal US.*
3. Herliczek TW, Swenson DW, Mayo-Smith WW. Utility of MRI after inconclusive ultrasound in pediatric patients with suspected appendicitis: retrospective review of 60 consecutive patients. AJR. 2013;200(5):969–73.
4. Trout AT, Sanchez R, Ladino-Torres MF, Pai DR, Strouse PJ. A critical evaluation of US for the diagnosis of pediatric acute appendicitis in real-life setting: how can we improve the diagnostic value of sonography? Pediatr Radiol. 2012;42(7):813–23.
5. Doria AS, Moineddin R, Kellenberger CJ, Epelman M, Beyene J, Schuh S, Babyn PS, Dick PT. US or CT for diagnosis of appendicitis in children and adults? A meta-analysis. Radiology. 2006;241(1):83–94.
6. • Duke E, Kalb B, Arif-Tiwari H, Daye JZ, Gilbertson-Dahdal D, Keim SM, Martin DR (2016) A systematic review and meta-analysis of diagnostic performance of MRI for evaluation of acute appendicitis. AJR 206(3):508–517. *Powerful meta-analysis demonstrating the efficacy of MR in diagnosis acute appendicitis.*
7. Moore MM, Kulaylat AN, Hollenbeck CS, Engbrecht BW, Dillman JR, Methratta ST. Magnetic resonance imaging in pediatric appendicitis: a systematic review. Pediatr Radiol. 2016;46(6):928–39.
8. Bayrakutan U, Oral A, Kantarci M, Demir M, Ogul H, Yalcin A, Kaya I, Salman AB, Yigiter M, Okur A. Diagnostic performance of diffusion-weighted MR imaging in detecting acute appendicitis in children: comparison with conventional MRI and surgical findings. J Magn Reson Imaging. 2014;39(6):1518–24.
9. Moore M (2015) Pediatric appendicitis MRI. pedrad.org. http://www.pedrad.org/LinkClick.aspx?fileticket=bbLDzS3oDYI=&portalid=5. Accessed 5 May 2017.
10. Moore MM, Kulaylat AN, Brian JM, Khaku A, Hulse MA, Engbrecht BW, Methratta ST, Boal DK. Alternative diagnoses at paediatric appendicitis MRI. Clin Radiol. 2015;70(8):881–9.
11. Mollard BJ, Smith EA, Dillman JR. Pediatric MR enterography: technique and approach to interpretation—how we do it. Radiology. 2015;274(1):29–43.
12. Boscarelli A, Frediani S, Ceccanti S, Falconi I, Masselli G, Casciani E, Cozzi DA. Magnetic resonance imaging of epiploic appendagitis in children. J Pediatr Surg. 2016;51(12):2123–5.
13. Deflorio RM, Shah CC. Techniques that decrease or eliminate ionizing radiation for evaluation of ventricular shunts in children with hydrocephalus. Semin Ultrasound CT MR. 2014;35(4):365–73.
14. Niederhauser BD, McDonald RJ, Eckel LJ, Keating GF, Broomell EM, Wetien NM, Diehn FE, Schwartz KM, Hunt CH, Welker KM, Kallmes DF. Retrospective review of rapid pediatric brain MR imaging at an academic institution including practice trends and factors affecting scan times. AJNR. 2013;34(9):1836–40.
15. Albers B, Yang Y, Parikh A, Shah C. Feasibility of limited brain MRI for pediatric neurologic symptoms. In: Electronic exhibit. 60th annual society for pediatric radiology meeting, 2017 May 16–20, Vancouver, BC.
16. Roguski M, Morel B, Sweeney M, Talan J, Rideout L, Risenburger RI, Madan N, Hwang S. Magnetic resonance imaging as an alternative to computed tomography in select patients with traumatic brain injury: a retrospective comparison. J Neurosurg Pediatr. 2015;15(5):529–34.
17. • Young JY, Duhaime AC, Caruso PA, Rincon SP (2016) Comparison of non-sedated brain MRI and CT for the detection of acute traumatic injury in children 6 years of age or less. Emerg Radiol 23(4):325–31. *Compares the detection rates of various traumatic injuries amongst CT and MRI.*
18. Pugmire BS, Shailam R, Gee MS. Role of MRI in the diagnosis and treatment of osteomyelitis in pediatric patients. World J Radiol. 2014;6(8):530–7.
19. Averill LW, Hernandez A, Gonzalez L, Pena AH, Jaramillo D. Diagnosis of osteomyelitis in children: utility of fat-suppressed contrast-enhanced MRI. AJR. 2009;192:1232–8.
20. • Monsalve J, Kan JH, Schallert EK, Bissett GS, Zhang W, Rosenfield SB (2015) Septic arthritis in children: frequency of coexisting unsuspected osteomyelitis and implications on imaging work-up and management. AJR 204:1289–95. *Provides examples of the not so uncommon occurrence of coexisting osteomyelitis and septic arthritis, and throws a wrinkle into the common dogma that suspected cases of septic arthritis do not warrant MR imaging.*
21. Rossi A, Martinetti C, Morana G, Severino M, Tortora D. Diagnostic approach to pediatric spine disorders. Magn Reson Imaging Clin N Am. 2016;24(3):621–44.
22. Farrell CA, Hannon M, Lee LK. Pediatric spinal cord injury without radiographic abnormality in the era of advanced imaging. Curr Opin Pediatr. 2017;29(3):286–90.
23. Baerg J, Thirumoorthi A, Vannix R, Taha A, Young A, Zouros A. Cervical spine imaging for young children with inflicted trauma: expanding the injury pattern. J Pediatr Surg. 2017;52(5):816–21.
24. Junewick J. Pediatric Craniocervical Junction Injuries. AJR. 2011;196:1003–10.
25. Smoker WR, Khanna G. Imaging the craniocervical junction. Childs Nerv Syst. 2008;24(10):1123–45.
26. Ross JS, Moore KR, Borg B, Crim J, Shah LM. Diagnostic imaging: spine. 2nd ed. Salt Lake City: Amirsys; 2010.
27. Ravindra VM, Eli IM, Schmidt MH, Brockmeyer DL. Primary osseous tumors of the pediatric spinal column: review of pathology and surgical decision making. Neurosurg Focus. 2016;41(2):E3.
28. Tenembaum S, Chitnis T, Nakashima I, Collongues N, McKeon A, Levy M, Rostasy K. Neuromyelitis optica spectrum disorders in children and adolescents. Neurology. 2016;87(9 Suppl 2):S59–66.
29. Yoder JA, Lloyd M, Zabrocki L, Auten J. Pediatric acute flaccid paralysis: enterovirus D68-associated anterior myelitis. J Emerg Med. 2017;S0736–4679(17):30232–9.
30. Shanbag P, Amirtharaj C, Pathak A. Intravenous immunoglobulins in severe Guillain-Barré syndrome in childhood. Indian J Pediatr. 2003;70(7):541–3.
31. Ye Y, Li SL, Li YJ. Comparison on therapeutic effect of plasma exchange and intravenous immunoglobulin for Guillain-Barré syndrome. Transfus Med. 2015;25(2):79–84.