JAOCR
Official Journal of the American Osteopathic College of Radiology

Aims and Scope
The Journal of the American Osteopathic College of Radiology (JAOCR) is designed to provide practical up-to-date reviews of critical topics in radiology for practicing radiologists and radiology trainees. Each quarterly issue covers a particular radiology subspecialty and is composed of high-quality review articles and case reports that highlight differential diagnoses and important teaching points.

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In this Issue

Brooke S. Lampl, D.O.
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I would like to extend my gratitude to Dr. O’Brien and the JAOCR for the opportunity to serve as guest editor of this pediatric radiology issue of the JAOCR. I have enjoyed working with Dr. O’Brien, my pediatric radiology colleagues, and radiology residents. I involved many of the osteopathic residents from this allopathic program to demonstrate to them our vibrant and active osteopathic radiology community. My hope is that this project will encourage them to pursue more osteopathic opportunities and further contribute to our community.

The review topics are meant to serve not only the general radiologist reading pediatric cases, as in gastrointestinal emergencies, but also to pique interest in exciting and new modalities, such as PET/MRI. Case presentations include a pediatric intracranial mass and pancreatic mass, along with appropriate differential diagnoses and an interesting final diagnosis based on pathologic findings. Finally, the Viewbox cases serve to demonstrate an often-confusing presentation of a common entity and further elucidate the use of PET/MRI in pediatric patients.

I hope that you will enjoy, learn from, and be inspired by this edition of the JAOCR. The further I am in my career, the more I realize how much I have to learn. Pediatric radiology is an amazing field with continued growth, learning, and exploration. My hope is that this issue will inspire you to continue that journey.
Gastrointestinal (GI) symptoms, including vomiting, pain and diarrhea, are common reasons pediatric patients visit the emergency department. Because the clinical picture can be confusing in children, imaging often plays a key role in establishing a list of differential diagnoses. It is the responsibility of the radiologist to assist in defining the clinical picture and guide the physician to the most appropriate imaging modality. In this article, we address some of the more important pediatric GI pathologies that usually result in patients presenting to the emergency department, with a review of the typical clinical presentations and associated imaging findings.

Entities discussed include foreign body ingestion, hypertrophic pyloric stenosis, malrotation and midgut volvulus, duodenal and pancreatic trauma, intussusception, appendicitis, mesenteric adenitis, Meckel diverticulum, and inflammatory bowel disease.

Foreign Bodies
Foreign body ingestion is common in the pediatric population, with most cases occurring in patients ages 6 months to 3 years. Children present with nonspecific symptoms related to the GI or respiratory tract, such as vomiting, gagging, choking, throat pain, or foreign body sensation. Most foreign bodies (80% to 90%) pass spontaneously, but approximately 10% to 20% require endoscopic removal, and approximately 1% necessitate surgical removal.

The first-line imaging study used in the evaluation for foreign body is the conventional radiograph, including frontal and lateral radiographs of the neck, chest and/or abdomen. The location, size, shape and number of foreign bodies should be noted in the radiology report, as this information will help the referring physician to make informed decisions about management. Common ingested radiopaque foreign bodies include coins, magnets and batteries. The lack of visualization of a radiopaque foreign body, however, does not exclude the diagnosis; in such cases with a high clinical suspicion or a witnessed ingestion, subspecialty consultation should be obtained.

Magnification of images or fluoroscopy may aid problem-solving. If the magnets are static on multiple images or demonstrate an intervening gap, the possibility of entrapment should be raised.

A button battery is another radiopaque foreign body that can cause significant adverse effects. The double edge of the button battery or halo helps to distinguish this entity from a coin on the anteroposterior (AP) view (Figure 1). Ingested batteries may cause significant injury due to electrical discharge, necrosis due to pressure, and/or caustic injury from leakage. Complications of button battery ingestion include fistula formation, burns and perforations, which can be life-threatening and require immediate communication to the referring provider.

Hypertrophic Pyloric Stenosis
Infantile hypertrophic pyloric stenosis is a relatively common condition characterized by abnormal thickening of the muscular layer of the pyloric channel secondary to hyperplasia and hypertrophy of the pyloric circular muscle fibers. This leads to failure of the pylorus to relax, which subsequently causes gastric outlet obstruction. Clinically,
Hypertrophic pyloric stenosis should be considered when a previously healthy patient aged 2 weeks to 3 months presents with projectile nonbilious vomiting. Hypertrophic pyloric stenosis is most likely to occur in Caucasian first-born males (male:female predilection of 4:1). Children of mothers with a history of hypertrophic pyloric stenosis have between a 7% (for male) and 20% (for female) risk of developing the condition. Patients with this condition may present with dehydration from repeated vomiting and decreased feeding. On physical examination, the experienced clinician can palpate an olive-sized mass in the right upper quadrant.

Ultrasound is the imaging modality of choice in this setting and demonstrates a hypertrophied muscle, manifested as a thickened hypoechoic layer, with one wall measuring > 3 mm in
thickness, from the linear echogenic mucosal line to the outer edge of the hypoechoic muscle, and longer than 15 to 17 mm in length\(^8\) (Figure 2). The abnormally thickened appearance of the pylorus on ultrasound is often described as the cervix sign on sagittal images and target sign on transverse images. Additionally, the antral nipple sign can be seen at the gastric outlet portion. The patient should be placed right side down so that fluid passing through the pylorus can be observed, and gas from the stomach does not obscure visualization. After initial images are obtained, the patient may be given sugar water or formula while lying on his/her right side to demonstrate the passage of material through the pyloric channel while not over-distending the stomach.

Potential pitfalls in the imaging of pyloric stenosis include pylorospasm, which causes transient pseudo-thickening of the pylorus, and inadvertent imaging of the gastroesophageal junction.
To avoid these problems, it is important to reimage the patient in 10 minutes to determine whether the pyloric muscle has changed. Additionally, attention must be paid to key anatomic landmarks to ensure that the pylorus is being imaged. If the pylorus consistently appears borderline in measurement (2-3 mm) and does not relax, follow-up ultrasound examination should be considered, especially in younger infants (aged < 1 month) and premature infants, as studies have shown a correlation between dimension of the pylorus and patient weight. These findings may represent pyloric stenosis in evolution; therefore, continued follow-up is recommended.

On an upper GI series, pyloric stenosis will present as delayed gastric emptying along with vigorous contractions of the stomach (caterpillar sign). The pylorus appears abnormally elongated with a narrow lumen, resulting in the string sign (Figure 3); this sign may appear duplicated because of puckering of the mucosa (double-track sign). The thickened pylorus also indents the contrast-filled antrum or the base of the duodenal bulb, referred to as the shoulder sign and mushroom sign, and the pyloric entrance may be beak-shaped (beak sign).

The treatment for hypertrophic pyloric stenosis consists of pyloromyotomy. Repeat ultrasound examinations may be performed if the patient persistently vomits; however, the pyloric muscle may remain thickened after successful surgical intervention and may not resolve to normal thickness for up to 5 months.

Malrotation and Midgut Volvulus

Malrotation refers to abnormal fixation of the gut during embryogenesis, leading to a shortened mesenteric pedicle. This abnormality occurs in an estimated 1/500 live births. Malrotation may result in midgut volvulus, which is a surgical emergency that classically presents in the newborn period with bilious emesis. A missed or delayed diagnosis of midgut volvulus can lead to bowel ischemia, necrosis, and even death. Although conventional radiographs may be obtained to evaluate for obstruction, these studies do not exclude the diagnosis of malrotation and midgut volvulus, which are most commonly identified on an upper GI series performed after the patient ingests oral contrast media (nonionic water soluble or barium). On an upper GI series, signs of normal rotation include the second and third portion of the duodenum positioned posteriorly into the retroperitoneum on the lateral view, nearly superimposed on one another, and the duodenal-jejunal junction to the left of the spine at the level of the pylorus.

Malrotation is diagnosed when the second portion of the duodenum is not seen in the posterior location on the lateral view, the duodenum does not cross the midline, and/or the duodenal-jejunal junction is not at the height of the duodenal bulb. Classic findings of malrotation with midgut volvulus include the corkscrew sign, dilation and beaking of the proximal duodenum, or an abrupt termination of contrast (Figure 4A). Emergent surgical intervention with a laparoscopic Ladd’s procedure is indicated when malrotation is diagnosed; delay in diagnosis or treatment may lead to bowel ischemia and/or necrosis.

Ultrasound has been described in the literature as another method for diagnosing malrotation through evaluation of the orientation of the superior mesenteric vessels and the retroperitoneal duodenum. The normal anatomic relationship demonstrates the superior mesenteric vein to the right of the superior mesenteric artery (Figure 5). However, there are variations in anatomy and, although a normal relationship is seen in 91% of patients, the presence of a normal relationship does not exclude malrotation. Likewise, an abnormal orientation does not confirm the diagnosis of malrotation; rather, it warrants further investigation with an upper GI series.
The upper GI series remains the current standard because of its ability to provide a timely and accurate diagnosis.

**Duodenal and Pancreatic Trauma**

Duodenal and pancreatic traumas are rare injuries that can occur in the setting of blunt abdominal trauma. Common and important causes include child abuse, bleeding disorders, and seatbelt or handlebar injuries. The duodenum and pancreas are prone to injury due to their anatomic position anterior to the spine. Clinical signs are nonspecific initially and can often be overshadowed by concurrent solid organ injuries; therefore, the radiologist must be mindful of the mechanism of injury when evaluating trauma patients.

Although the evaluation of duodenal trauma can be made using a variety of imaging modalities, CT is the mainstay of diagnosis. A mixed-attenuation mass at the second or third portion of the duodenum is highly suggestive of duodenal hematoma on CT. The presence of retroperitoneal free gas should alert the radiologist to the possibility of an associated duodenal perforation. Secondary signs may include adjacent retroperitoneal free fluid or hemorrhage. Upper GI exam may indirectly identify extraluminal mass effect or an intraluminal filling defect in the affected portion of the duodenum, and ultrasound may demonstrate a hypoechoic, heterogeneous, avascular mass in this location. MRI often demonstrates a mass of variable signal intensity due to evolving blood products in the region of the duodenum and is generally reserved for problem solving, such as in cases of smaller duodenal hematomas or for evaluating secondary injuries associated with the biliary ducts (Figure 7).

CT is also the preferred modality for evaluating pancreatic trauma, despite its limitations in enhancement pattern for such cases. Trauma CT scans are typically performed in the portal venous phase, whereas optimal pancreatic enhancement occurs approximately 35 to 40 seconds after intravenous contrast administration. Nonetheless, given the lack of sufficient data and the need to evaluate concurrent solid organ injuries, CT in the portal venous phase is still considered the best initial examination for these patients. If the CT scan is suggestive of pancreatic trauma, a follow-up MR/MR cholangiopancreatography examination can be performed to obtain further information. On CT, pancreatic hematomas present as heterogeneous collections between the pancreas and splenic vein with or without peri-pancreatic inflammatory changes. Altered pancreatic parenchymal enhancement may be present and may represent pancreatic contusion. Pancreatic hemorrhage may be identified by active contrast extravasation on CT. Additionally, there may be pancreatic laceration or transection. In these cases, it is important to assess the integrity of the pancreatic duct, as this is paramount in determining prognosis and the need for emergent endoscopic retrograde cholangiopancreatography or surgery.

Pancreatic and duodenal hematomas are most often graded according to the American Association for the Surgery of Trauma scoring system, with hematomas graded from I to V based on the location and the extent of contusion or laceration. This grading system is useful for determining which cases are appropriate for surgical intervention and which can be managed conservatively. (Tables 1 and 2).

**Intussusception**

Intussusception refers to telescoping of one segment of bowel into another, leading to edema and venous congestion within the bowel wall. Ileocolic intussusception is a common...
Pediatric emergency, usually occurring between ages 6 months and 2 years. In this age group, approximately 95% of cases have no pathological lead point, regardless of recurrence. The classic clinical presentation is episodic abdominal pain, currant-jelly stools, and a palpable abdominal mass; however, less typical symptoms can often be confused for more benign etiologies (such as gastroenteritis), delaying diagnosis.

Conventional radiographs in these patients may reveal a small bowel obstruction and/or a paucity of bowel gas in the right hemiabdomen. Occasionally, a soft-tissue mass may be seen within the colon. However, abdominal ultrasound is the diagnostic examination of choice in this setting with a specificity of 100%. On abdominal ultrasound, intussusception has a classic “target” appearance of multiple concentric rings and central mesenteric fat in the transverse plane (Figure 8A) with a typical size of 2.5 to 5 cm. On longitudinal images, intussusception often shows peripheral hypoechoic bowel with central increased echoes, referred to as the “pseudokidney” appearance (Figure 8B). The measurement of the intussusception can assist in differentiating between ileocolic and small bowel-small bowel intussusception; this is an important distinction, as a

<table>
<thead>
<tr>
<th>Grade</th>
<th>Type of injury</th>
<th>Description</th>
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<tbody>
<tr>
<td>1</td>
<td>Hematoma</td>
<td>Single portion of the duodenum</td>
</tr>
<tr>
<td></td>
<td>Laceration</td>
<td>Partial thickness without laceration</td>
</tr>
<tr>
<td>2</td>
<td>Hematoma &gt;1 portion of</td>
<td>50 – 75% disruption of D2</td>
</tr>
<tr>
<td></td>
<td>Laceration</td>
<td>50 – 100% disruption of D1, D3, D4</td>
</tr>
<tr>
<td>3</td>
<td>Laceration</td>
<td>&gt;75% disruption of D2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Involving ampulla or distal CBD</td>
</tr>
<tr>
<td>4</td>
<td>Laceration</td>
<td>Disrupted duodenal pancreatic complex</td>
</tr>
<tr>
<td></td>
<td>Vascular</td>
<td>Devascularization of the duodenum</td>
</tr>
</tbody>
</table>

Table 2. Pancreatic injury: Advance 1 grade for multiple injuries up to grade 3

<table>
<thead>
<tr>
<th>Grade</th>
<th>Type of injury</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hematoma</td>
<td>Contusion without injury to duct</td>
</tr>
<tr>
<td></td>
<td>Laceration</td>
<td>Superficial laceration, no duct injury</td>
</tr>
<tr>
<td>2</td>
<td>Hematoma</td>
<td>Major contusion without duct injury</td>
</tr>
<tr>
<td></td>
<td>Laceration</td>
<td>Major laceration, no duct injury</td>
</tr>
<tr>
<td>3</td>
<td>Laceration</td>
<td>Distal transection or parenchymal injury, no duct</td>
</tr>
<tr>
<td>4</td>
<td>Laceration</td>
<td>Proximal transection or parenchymal injury</td>
</tr>
<tr>
<td></td>
<td></td>
<td>involving ampulla</td>
</tr>
<tr>
<td>5</td>
<td>Laceration</td>
<td>Disruption of pancreatic head</td>
</tr>
</tbody>
</table>

FIGURE 8. Intussusception on ultrasound. Transverse (A) and longitudinal (B) gray-scale US images reveal findings characteristic of intussusception with a target and “pseudokidney” appearance, respectively. Lymph nodes can be seen with the intussusceptum on the transverse image (arrow).
small bowel–small bowel intussusception is smaller, typically self-limiting, and typically does not require intervention. Some ultrasound findings such as intussuscepted lymph nodes (Figure 8A) and interloop fluid may indicate increased difficulty in an attempt at reduction, although these features are not considered contraindications to reduction.25

Once ileocolic intussusception has been diagnosed, the patient should undergo prompt reduction via air or contrast enema to prevent complications such as bowel wall ischemia and/or necrosis, perforation, and shock.25

Nonoperative management is the treatment of choice, with surgery reserved for patients in whom reduction is unsuccessful or for those with contraindications to fluoroscopic reduction (eg, free air, peritonitis, or signs of shock). Intussusception reduction is not without risk, such as is tension pneumoperitoneum secondary to perforation during pneumatic reduction. Therefore, close monitoring by nursing staff and notification of the surgical department are of the utmost importance in this setting.28

An intravenous line should be placed for immediate access in case of an emergency and for the administration of fluids before the procedure. Additionally, the radiologist should have access to a needle for emergent decompression should pneumoperitoneum occur.28

Pneumatic or hydrostatic reduction may be performed to put pressure on the intussusceptum and push it back into its proper anatomic position.25,26

In both procedures, an enema tube is placed and sealed in the patient’s rectum with tape. In pneumatic reduction, air is pumped manually through the tube into the colon, pushing the intussusceptum through the ileocecal valve. A pressure of 120 mm Hg or less should be maintained; if the patient engages in a Valsalva maneuver, the pressure may intermittently increase. When the mass is no longer seen and air enters the distal small bowel, the reduction is considered successful. A postreduction imaging showing the lack of pneumoperitoneum at the end of the procedure is recommended.29

In hydrostatic reduction, water-soluble near-isotonic or iso-osmolar contrast is hung 3 feet above the table and allowed to flow freely into the colon.29 When the intussusceptum reduces, contrast is seen in distal small bowel loops. Advantages of the pneumatic technique include faster reduction, decreased radiation, and air rather than contrast entering the peritoneal cavity in cases of perforation.25,26

Delayed attempts at air enema may be performed when initial attempts are unsuccessful, as long as the patient’s condition remains stable and initial attempts demonstrated improvement or partial reduction in the intussusception.

**Appendicitis**

Appendicitis is one of the most common causes of acute abdominal pain in children and represents up to 80% of pediatric surgical emergencies in the United States.31 The appendix is a blind-ending tube at the caput cecum. Acute appendicitis usually occurs as a result of appendiceal luminal obstruction, followed by fluid accumulation, luminal distention, inflammation,
and eventually perforation. Classic symptoms include periumbilical pain (initially), right lower quadrant pain localizing to McBurney’s point, and flank pain (in a retrocecal appendix). There may be associated fever, nausea, and vomiting; however, this progression is seen in only a minority of cases. Children often present with vague and non-specific signs and symptoms.

Abdominal radiographs are frequently normal in cases of appendicitis, apart from occasional findings such as a calcified appendicolith (<10% of cases), obliteration of the right psoas margin, splinting leading to lumbar dextroscaplosis, and right lower quadrant air-fluid levels that are nonspecific. Hence, initial imaging of appendicitis typically involves ultrasound or CT and occasionally MRI. There is significant debate regarding which imaging modality is preferred in the pediatric population. Advantages of ultrasound include lack of ionizing radiation, low cost, lack of intravenous contrast, and the ability to manually compress the appendix. Studies have shown that with carefully regimented techniques, ultrasound can achieve >98% specificity and sensitivity, as well as positive and negative predictive values in pediatric patients with appendicitis. Sonographic findings of appendicitis include a dilated appendix measuring at least 6 mm in the maximal outer diameter, a lack of compressibility, adjacent inflammatory changes (increased peri-appendiceal echogenicity of the mesenteric fat), and hyperemia on Doppler imaging (Figure 9). Additionally, a fluid-filled appendix may appear targetoid. Appendicoliths, peri-cecal or peri-appendiceal fluid, or enlarged mesenteric lymph nodes may also be present.

Advantages of CT over ultrasound include reduced operator dependence, enhanced visualization of tissues and surrounding phlegmon/abscess, and superior imaging of obese patients. CT scans are optimal when the study is performed with intravenous contrast. Findings of appendicitis on CT include a dilated fluid-filled appendix >6 mm, appendiceal wall thickening and enhancement, and peri-appendiceal inflammatory changes and/or fluid. Appendicoliths, phlegmon, abscess, and/or mesenteric adenopathy may also be seen. CT scans should be used judiciously in children with care taken to use the lowest possible dose appropriate for the patient’s size and to use only a single phase.

MRI of the appendix has recently become a topic of interest in the pediatric literature because of increased awareness of radiation exposure from CT. MRI for acute appendicitis has been shown to have a high sensitivity and specificity without negative effect on clinical outcomes. MR findings for acute appendicitis mimic those of CT, including a dilated tubular structure, peri-appendiceal fluid/infammation, wall thickening, and phlegmon or abscess formation (Figure 10).

When acute appendicitis is diagnosed, the patient should be admitted to the hospital for surgical consultation. Depending on whether the imaging findings suggest the presence of an uncomplicated appendicitis, without abscess, or complicated, with intra-abdominal or intra-pelvic abscess, patients should undergo either surgical intervention or, less often, treatment with minimally invasive techniques/antibiotic therapy.

**Mesenteric Adenitis**

Mesenteric adenitis typically presents in young adolescents with non-descript symptoms and signs, including right lower quadrant pain, nausea, vomiting, and fever. The pain may be periumbilical or localized to the right lower quadrant. The appendix is typically not visualized on imaging studies. The diagnosis is often made clinically and treated with a trial of antibiotics. However, surgical exploration may be necessary if there is persistent pain or signs of sepsis.
right lower abdominal pain, with or without fever, nausea, vomiting, and elevated white blood cell count. This condition is a common mimic of appendicitis clinically and can also mimic other conditions, such as colitis or pelvic inflammatory disease. Mesenteric adenitis is self-limiting, generally requiring only conservative management with resolution within approximately 2 weeks.

Mesenteric adenitis is characterized by a cluster of more than 3 lymph nodes in the right lower quadrant, often ≥ 5 to 8 mm in the short axis. Ultrasound and CT can both be used to diagnose this condition. Ultrasound with graded compression demonstrates enlarged lymph nodes in the right lower quadrant; the appendix is normal, and there is no bowel inflammation. Benefits of ultrasound include the lack of radiation and low cost; however, the examination is operator-dependent, and without definitive visualization of the appendix, the etiology for enlarged lymph nodes is unclear. CT remains the most sensitive modality to evaluate right lower quadrant pain, with its most significant limitation being radiation exposure.

**Meckel Diverticulum**

Meckel diverticulum is the most common congenital abnormality of the GI tract. This true diverticulum results from the incomplete obliteration of the omphalomesentric duct during embryologic development. Most cases of Meckel diverticulum are asymptomatic and found incidentally. In younger children who are symptomatic, the most common presentation is painless brick-red rectal bleeding, whereas older children tend to present with intestinal obstruction. Approximately 59% of Meckel diverticulum contain heterotopic tissue, most commonly gastric tissue, followed by pancreatic tissue. Meckel diverticulum can lead to intestinal obstruction, act as a lead point for intussusception, result in volvulus, or become incarcerated within an inguinal hernia (Littre hernia).

Meckel diverticulum can be identified on multiple imaging modalities; however, in a pediatric patient with rectal bleeding, technetium-99 (Tc-99) pertechnetate is the most sensitive modality available (sensitivity, 85%; specificity, 95%). The radiotracer accumulates in the parietal cells of the ectopic gastric mucosa within the right lower quadrant Meckel diverticulum (Figure 11A). False negatives may be seen in the setting of no or minimal ectopic gastric tissue or impaired blood supply to the bowel, whereas false positives may be seen in the setting of inflammatory bowel disease (IBD). Alternate imaging may be performed when the clinical picture is confusing. On ultrasound and CT, a blind-ending tubular structure may be identified near the cecum with adjacent inflammatory changes, similar in appearance to an inflamed appendix but in a more proximal location. Small bowel follow-through may show a blind-ending tubular structure originating from the distal ileum on the anti-mesenteric side (Figure 11B).

Surgical management of symptomatic Meckel diverticulum always results in excision. However, controversy exists regarding how to manage asymptomatic cases, with some authors suggesting removal regardless of symptomatology and others claiming that the complications of surgical excision outweigh the benefit of removal if asymptomatic.

**Inflammatory Bowel Disease**

Inflammatory bowel disease (IBD) is a complex chronic disease that is often difficult to diagnose in adolescents because of vague and intermittent symptoms, such as abdominal pain, diarrhea, and weight loss. IBD is thought to be caused by immune dysregulation leading to granulomatous bowel inflammation and ulceration. It is classified as either Crohn disease or ulcerative colitis (UC).

Imaging plays a key role not only in the diagnosis but also in the management and monitoring of patients with IBD.

Crohn disease typically involves the small bowel, most commonly the terminal ileum, although it can affect the entirety of the bowel. Frequent complications include the formation of fistulas and sinus tracts. Although the imaging findings of Crohn disease can be seen on a variety of modalities, fluoroscopy can only show the bowel complications, whereas cross-sectional imaging can demonstrate the extra-intestinal manifestations of disease. CT and MR enterography have a higher sensitivity for detecting these specific findings and can better assess bowel wall thickening, hyperemia, lymphadenopathy, perforation, and abscess. MRI is also useful in assessing...
perianal disease, including fistula formation, and in distinguishing between active bowel inflammation and bowel fibrosis. Active inflammation demonstrates mucosal enhancement on postcontrast T1 images, increased T2 signal on fat-saturated images, wall thickening > 3 mm, and restricted diffusion (Figure 12). In contrast, chronic changes such as bowel fibrosis are characterized by the lack of enhancement on postcontrast imaging and fibrofatty proliferation.

Ulcerative colitis primarily involves the colon and rectum and is associated with a nearly 30-fold increased risk of colorectal cancer. Fluoroscopic findings of ulcerative colitis include edematous, thickened haustra; symmetric colonic narrowing; punctate collections of contrast leading to mucus stipping; and postinflammatory polyps. As with Crohn disease, ulcerative colitis imaging findings are better delineated on CT and MR compared to fluoroscopy. A specific CT finding of UC includes the halo sign, which appears as a low attenuation ring around the bowel mucosa resulting from submucosal fat deposition. Additionally, the bowel contour appears smooth in ulcerative colitis, whereas the bowel in Crohn disease tends to be more irregular. Similar findings can be seen on MRI, additionally, MRI can be used to evaluate associated extra-intestinal findings such as sclerosing cholangitis, cirrhosis, and hepatitis.

Although CT and MRI are the preferred and most commonly used methods for evaluating the bowel, ultrasound also may be useful for screening given its low cost and lack of ionizing radiation. On color Doppler ultrasound, ulcerative colitis appears as thickened, inflamed bowel loops with hyperemia.

Summary

Pediatric GI complaints are among the most common and confusing clinical scenarios seen in the emergency department. Radiologists can help clarify the clinical picture in such cases by employing the most appropriate and useful imaging modalities and having a detailed understanding of the imaging appearances of various emergent GI pathologies. When choosing imaging modalities in children, radiologists must remain vigilant of the risks of radiation exposure in this patient population and be judicious in selecting the best modality to establish a diagnosis.

References

Pediatric PET/MRI: A Review

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Positron emission tomography (PET) is the imaging modality of choice for multiple pediatric neurologic and oncologic indications.1,2 In current practice, fludeoxyglucose F 18 (FDG) PET is performed in conjunction with computed tomography (CT); performed together, these techniques offer both attenuation correction and precise anatomic localization. MRI paired with PET offers several potential advantages over CT, including superior soft-tissue contrast, particularly when compared to low-dose, noncontrast “attenuation correction” CT scans. MRI also allows for a wide variety of complementary sequences, such as diffusion-weighted imaging (DWI) sequences.2 Perhaps the most important advantage of PET/MRI in the pediatric population is the potential radiation dose savings, which is particularly significant in a cumulative context.

In the past, postprocessing software allowed for fusion of the anatomic detail provided by MRI with the physiologic information provided by PET. Multiple technical challenges are inherent in the implementation of an integrated PET/MRI system.2 The PET detectors must be compatible with a strong magnetic field, and the MRI hardware must account for the PET detectors and perform more involved attenuation correction than is needed for PET/CT.2

In 2006, the first commercial PET/MRI insert was introduced (Siemens BrainPET, Erlangen, Germany). However, the insert design effectively reduced the gantry opening to 35 cm, limiting the use of this insert to neurological applications.3 Since 2010, three large imaging hardware vendors have introduced various PET/MRI implementations, including sequential and synchronous systems. Sequential systems include the Ingenuity TF (Philips, Cleveland, Ohio) and the initial trimo- dality PET/CT + MR Discovery system (GE, Chicago, Illinois). Synchronous PET/MRI systems include the Biograph mMR (Siemens, Erlangen, Germany) and the Signa PET/MR system (GE, Chicago, Illinois).

Sequential Vs. Synchronous PET/MRI Systems

In a sequential system, the PET examination is performed first, either in the same room as the MRI examination or in a different room. The patient is then introduced into the MRI gantry, and MRI scans are performed. The physical separation of the PET and MRI scanners offers advantages in terms of technical compatibility and cost. Disadvantages include the nonsynchronous nature of the imaging data and the potential for longer scan times.4

In a synchronous system, the PET and MRI data are obtained at the same time. A single gantry contains the PET detectors, which are located between the body and the gradient coils of the MRI system. This approach offers the advantages of truly synchronous data, a smaller scanner footprint, and the potential for shorter scan times.4 The primary disadvantage of this approach is the technical challenge of assuring mutual technical compatibility of the system’s components.

PET/MRI Technique

In both sequential and synchronous implementations, MRI is used to generate sequences to account for attenuation correction. In the Philips implementation, a 3-segment model
is used (air, lung, soft tissue). In the Siemens implementation, a 4-segment DIXON model is used (air, lung, fat, soft tissue). These sequences are then used to create an approximation of a mu map (Figure 1). For both commercial PET/MRI whole body scanners, standard uptake values (SUVs) of target lesions are generally similar between PET/CT and PET/MRI. However, neither technique accounts for the increased attenuation of bone, which may lead to significant underestimation of activity in or adjacent to bone (up to 11.2% ± 5.4%). Atlas-based attenuation correction has been proposed as a solution to retrospectively add bone attenuation information to PET/MRI. However, this approach is not effective when patient anatomy deviates from normal standards (e.g., because of large tumors, treatment effects, or anatomic variants).

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**Table 1. PET/MRI Epilepsy Protocol**

Axial T1 images substituted for fluid attenuated inversion recovery (FLAIR) images in patients < 2 years old.

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<tr>
<td>DIXON attenuation images</td>
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<td>Coronal T2 images</td>
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<td>Axial/coronal FLAIR images</td>
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<td>Sagittal/coronal T1 images</td>
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<td>Coronal MPRage images</td>
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<td>+/- axial/coronal postcontrast images</td>
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**Table 2. PET/MRI Body/Oncology Protocol**

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<td>DIXON attenuation images</td>
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<td>Axial/coronal T2 single shot (HASTE [half fourier single-shot turbo spin-echo]) images</td>
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After attenuation correction data are obtained, additional sequences can be obtained per the local protocol. Our examinations are performed by technologists dual-certified in MRI and nuclear medicine, and thus familiar with the technical considerations of both modalities. Example protocols from our institution are included for illustration. For seizures, we perform our routine epilepsy protocol of the head (Table 1). For oncologic indications, imaging of the neck and torso (“eyes to thighs”) or from head to toe (whole body) can be performed (Table 2). At our institution, we obtain fast T1- and T2-weighted images in the axial and coronal planes; additional images are obtained on a case-by-case basis at the discretion of the interpreting radiologist. Potential additional sequences include fat-saturated and DWI sequences.

Information obtained from postcontrast imaging using gadolinium-based compounds is thought to be largely concordant with physiological PET information. This was demonstrated in a recent pediatric review by Klenk et al that showed no significant difference in diagnostic accuracy for unenhanced and enhanced PET/MR images (with a possible exception for the evaluation of focal liver lesions). At our institution, we obtain postcontrast imaging on a
case-by-case basis at the discretion of the ordering physician in consultation with the interpreting radiologist. Additional full diagnostic imaging of a specified body part can also be performed. Although this adds to examination time, it can be useful in the locoregional staging of certain tumors.

Indications for PET/MRI

Given the recent introduction of PET/MRI, much of the data regarding effectiveness are extrapolated from the PET/CT or adult literature. The three broad categories of potential indications for pediatric PET/MRI are: neurologic, oncologic, and other/inflammatory processes.

Neurologic indications

The main neurologic indication for pediatric PET/MRI is seizure localization. As with PET/CT, PET/MRI is assumed to be obtained in an interictal state. This can be confirmed by performing intraprocedure electroencephalography (EEG), although this is not routinely performed at our institution. In the interictal state, the seizure focus should be hypometabolic relative to the normal brain parenchyma.

A variety of seizure foci can be detected by PET/MRI. Such foci can be the result of prior ischemic insult (Figures 2 and 3), cortical malformation/dysplasia (Figures 4 and 5), or mesial temporal sclerosis (Figure 6). Other incidental findings can also be more readily appreciated by the combined information provided by PET/MRI (Figures 7 and 8).

In a cohort study of 45 predominantly pediatric patients with cortical dysplasia (age range: 5 months to 55 years), PET/MRI software coregistration data were correlated with surgical

FIGURE 4. Extensive right occipital cortical malformation in a 13-year-old girl. Axial FLAIR image (A) shows asymmetric increased signal and decreased sulcation within the right occipital lobe. Increased FLAIR signal also extends to the margin of the occipital horn of the right lateral ventricle. Coronal MP-Rage (magnetization prepared rapid gradient-echo) image (B) shows the indistinct gray-white matter junction on the right compared to the normal contralateral left side. Fused PET/MRI image (C) shows markedly decreased metabolism associated with the right occipital malformation.

FIGURE 5. Right peri-insular malformation in a 16-year-old girl. Coronal T2 (A) and MPRage (B) images show malformation of the right posterior peri-insular region with associated nodular gray matter heterotopia along the margin of the right lateral ventricle (white arrow). Fused PET/MRI image (C) shows mildly decreased metabolism relative to normal gray matter at the medial aspect of the malformation and heterotopia (white arrow).
findings. The PET/MRI coregistration was found to add value to 33% of cases with nonconcordant EEG and neuroimaging findings. PET/MRI was particularly useful in cases of subtle Palmini type I lesions initially interpreted as normal on structural imaging scans. These patients required fewer invasive tests (such as use of intracranial electrodes) for identifying the seizure focus compared to an older cohort. An additional advantage was that the technique allowed for more precise surgical planning, as the borders of the cortical lesion could be more clearly identified, reducing the risk of an incomplete resection. It is assumed that these advantages can be extrapolated to PET/MRI scans performed either sequentially or simultaneously, although data for this extrapolation are lacking.

Oncologic indications

Oncologic applications for PET/MRI include lymphoma/leukemia and a variety of rarer indications; specific diagnoses for the 26 pediatric oncologic clinical cases seen at our institution over the last two years are shown in Figure 9. A recent literature review of more than 2300 published PET/MRI cases demonstrated that PET/MRI is clinically feasible and performs as well as PET/CT in most cancer types. However, PET/MRI was limited in cases of lung nodule assessment.

An early trial showed that fewer FDG-negative nodules were detected by PET/MRI than by low-dose PET/CT when only attenuation correction MRI sequences were used for anatomic localization. However, there was no significant difference between modalities on a patient-based evaluation. A subsequent study by Rauscher et al found that the detection of small (< 10 mm) FDG-negative lung nodules was limited with MRI despite the use of additional fast respiratory-gated, contrast-enhanced, T1-weighted sequences. Another study using respiratory-gated T1

FIGURE 6. Mesial temporal sclerosis in a 16-year-old girl. Coronal FLAIR image (A) demonstrates subtle increased signal and volume loss of the left hippocampal formation compared to the right. Fused PET/MRI image (B) shows corresponding asymmetrically decreased metabolism. Pathology was confirmed at resection.

FIGURE 7. An 8-year old boy with seizures. PET/MRI examination did not identify seizure focus. However, axial FLAIR (A) and coronal T2 (B) images show a cerebrospinal fluid (CSF) isointense cystic structure in the anterior middle cranial fossa, consistent with arachnoid cyst. Fused PET/MRI image (C) shows corresponding photopenic defect.
imaging showed that MRI had higher overall sensitivity for lung nodule detection than standalone PET (70.3% vs. 61.6%; P = .002) but significantly lower sensitivity than that of the reference standard (CT). However, improved MRI sensitivity was seen in nodules > 5 mm (88.6%) and FDG-avid nodules (95.6%). Most recently, Sawicki et al showed that the performance of PET/MRI in detecting lung lesions > 10 mm is comparable to that of PET/CT. However, the overall detection rate of PET/MRI was found to be inferior to that of PET/CT because of the limited detectability of < 10 mm on MRI. The clinical relevance of this decreased sensitivity is not well-known. A recent follow-up study showed that most lung nodules missed by MRI (78.6%) were benign; however, there were many undetected metastases, with one patient being upstaged from stage I to stage IV disease on the basis of a nodule not seen on MRI. Given the apparent decreased sensitivity of PET/MRI in this regard, we obtain an additional CT scan of the chest in malignancies that commonly metastasize to the lungs (eg, sarcomas).

Research in specific oncologic applications of PET/MRI is still scarce, and many of these early trials are limited by small numbers of participants, precluding generalization of results. Additionally, the better-studied malignancies were those of the head and neck and gastrointestinal and genitourinary systems, malignancies largely seen in older adult populations.

Studies of PET/MRI for pediatric oncologic indications are even scarcer. An early case series described 15 pediatric patients who underwent 21 clinical multisequence PET/MRI studies. Seven of the patients were evaluated for lymphoma; the remainder were evaluated for a variety of rarer malignancies, including neuroblastoma, primitive neuroectodermal tumor, Ewing sarcoma, soft-tissue sarcoma, acute myeloid leukemia with extramedullary manifestation, and metastatic germ cell tumor of the testis. Although this study did not compare the sensitivity or accuracy of PET/MRI and PET/CT for disease detection, the researchers demonstrated the technical feasibility of clinical PET/MRI in the pediatric setting. They also reported a potential radiation dose reduction of up to 80% with the use of PET-MRI.

Another pediatric-specific study included 18 patients undergoing 20 multisequence PET/MRI studies. Seven of the 20 studies were performed in patients with lymphoma; the remaining 13 were performed in patients with adrenocortical carcinoma, neuroblastoma, neurofibromatosis I, pancreatic carcinoma, hepatocellular carcinoma,
thyroid carcinoma, germ cell tumor of the testis, alveolar soft part sarcoma, osteosarcoma, and colon carcinoma. A total of 17 studies were performed for initial staging, and three were performed for follow-up. Similar SUVs were found for PET/MRI and PET/CT, with more significant deviation of SUV values in bone marrow. Correlation between the modalities in SUV values was also only moderate ($r = 0.32$) for lung parenchyma. On PET/CT, 62 areas of focal uptake were detected overall; 61 of these areas were also detected with PET/MRI. PET/MRI did not depict a single lung lesion with focal FDG uptake. In one patient, an artificial false-positive focus of pulmonary uptake was noted on PET/MRI. Relevant
additional findings were detected with PET/MRI in four patients; these findings included two cases of malignant bone marrow infiltration, one case of renal infiltration of non-Hodgkin lymphoma, and one case of a soft-tissue metastasis. Increased detection of infiltrative disease was thought to be due to conspicuous signal abnormality appreciated on MRI. On the other hand, multiple lung metastases detected by PET/CT in two patients with sarcoma were only partly seen on PET/MRI. However, no change in diagnosis resulted from this discrepancy on a per-patient basis. The authors concluded that dedicated CT of the chest may still be necessary. PET/MRI was associated with a radiation dose savings of up to 73%.

Only a few studies have assessed the use of PET/MRI in patients with lymphoma or leukemia. Figures 10-12 contain illustrative PET/MRI cases of lymphoma. In a small prospective study of 28 adult patients (mean age, 53.6 years; range, 30-85 years) with lymphoma, sequential PET/MRI was found to be equivalent to PET/CT. PET/MRI and PET/CT were equivalent in identifying all 51 FDG-avid nodal groups, whereas DWI alone identified only 32 nodal groups. PET/MRI and PET/CT were concordant in all but 1 patient (agreement of 96.4%); the disease in this patient was upstaged after PET/MRI because of bone marrow involvement not seen on CT.

In a more recent prospective trial of 25 pediatric patients with lymphoma...
who underwent 40 sequential PET/CT and PET/MRI examinations, the modalities demonstrated substantial agreement. Sensitivity for disease detection was almost identical (92% for PET/MRI vs. 95% for PET/CT), with a single low-avidity left hilar lymph node not well-appreciated on PET/MRI. SUV values were also strongly correlated between PET/CT and PET/MRI (ρ > 0.72), although PET/MRI showed systematically lower SUV measurements. The authors concluded that SUV values between the two modalities should not be directly compared to assess for disease response. In this study, PET/MRI offered an average 45% radiation dose reduction.

Even less literature is available for the use of PET/MRI in patients with nonlymphomatous indications. Figures 13-16 illustrate PET/MRI cases of rhabdomyosarcomas and neurofibromas. The few studies performed have assessed the use of PET/MRI in various rare pediatric malignancies. A significant disadvantage of PET/MRI in this setting is the relatively common occurrence of lung metastases. Given the previously described limitation of this modality regarding the detection of pulmonary nodules, continued dedicated evaluation of the lungs by CT is recommended. This is the practice at our institution, although it does partially negate the dose savings of PET/MRI in this setting.

Neurofibromatosis type I represents one such condition in which PET/MRI may prove useful (Figures 15, 16). Detecting the degeneration of a neurofibroma to a malignant peripheral nerve
sheath tumor is clinically challenging. Sudden growth is suspicious, but often the physical examination is unreliable in these patients. Additionally, the number of lesions makes clinical surveillance challenging. Investigators have described some MRI imaging characteristics associated with malignant degeneration, such as intralesional lobulation or intrinsic internal high T1 signal. FDG PET is often used in this patient population to better define suspicious lesions that warrant resection. Correlation with 11C-methionine, another marker of cell metabolism, may further increase specificity. One study used delayed imaging at 4 hours after FDG injection to define malignant lesions, with an SUV cutoff of 3.5; PET demonstrated a sensitivity of 97% and a specificity of 87%. Using the combined findings of PET and MRI could potentially further increase the specificity for this difficult clinical diagnosis.

Inflammatory indications

PET/MRI can also be used in patients with infectious or inflammatory conditions (Figure 17). PET/CT has a high sensitivity for diagnosing fever of unknown origin and inflammation of unknown origin. Therefore, PET/MRI could be considered as an alternative when standard diagnostic tests such as laboratory data, abdominal ultrasound,
**FIGURE 15.** A 17-year-old boy with neurofibromatosis on surveillance. Coronal (A) and axial (B) T2 fat-saturated images show extensive plexiform neurofibromas of the neck, abdomen, pelvis, and along the peripheral nerves. A dominant upper abdominal lesion encases the celiac/superior mesenteric axis and displaces the upper abdominal viscera. Fused coronal PET/HASTE (C) and axial T2 fat-saturated (D) images demonstrate no significant uptake that would raise concern about malignant degeneration.

**FIGURE 16.** An 18-year-old man with neurofibromatosis and smaller peripheral lesions. Fused coronal (A) and axial (B) PET/HASTE images demonstrate a dominant lesion lateral to the proximal fibula. It demonstrated increased uptake, with an SUV of 3.3. PET/MRI in this context may help clinicians select which lesions to biopsy/resect.
FIGURE 17. A 2-year-old girl with a history of acute lymphoid leukemia and subsequent infection. The patient developed a scalp lesion with a biopsy revealing leukemic recurrence. After excisional biopsy, the patient underwent PET/MRI (A), which demonstrated activity at the site of the resection but no distal malignant disease. While the patient was immunosuppressed from therapy, she developed a fever. CT through the chest (B) and abdomen (C) at this time demonstrated diffuse innumerable nodular pulmonary opacities, as well as punctate hypodensities throughout the liver and spleen, respectively; these lesions were suggestive of fungal infection, and blood cultures confirmed the presence of a Candida species. After antifungal treatment, follow-up PET/MRI was performed to evaluate for response before a bone marrow transplant. Fused coronal PET/HASTE images demonstrate foci of uptake in the thoracic spine and around the knees (D, E), consistent with persistent fungal disease. Fused axial PET/T2 FS images (F-H) demonstrate decreased but persistent lung and liver fungal disease. Bony uptake in the thoracic spine and around the knees (I) and ankles, also consistent with fungal disease, was better appreciated by PET/MRI than CT.
and chest radiography cannot provide a diagnosis.

Another possible application of PET/MRI is in patients with inflammatory bowel disease. In these patients, PET can highlight and quantify the inflammation, especially in parts of the bowel inaccessible to endoscopy.1

Conclusion

PET/MRI is a promising new modality with potential applications in multiple pediatric conditions. This modality combines the excellent soft-tissue contrast of MRI with the complementary physiologic information supplied by PET. Its most immediate application may be for seizure imaging; studies of software coregistration have proven its value in this setting. PET/MRI may also be useful for disease staging and assessing treatment response in a variety of pediatric malignancies. However, the low sensitivity of PET/MRI in the detection of small lung nodules has not yet been fully addressed. This limitation of PET/MRI necessitates the use of additional dedicated CT scans of the chest in patients with malignancies that have a propensity to metastasize to the lungs. Larger prospective systematic trials are needed to validate the performance of PET/MRI relative to the performance of PET/CT and also to evaluate the potential usefulness of this modality for various specific pediatric indications.

References

Cystic Pancreatic Mass in a Child

Matt Kiczek, D.O., Neil Vachhani, M.D.

Imaging Institute, Cleveland Clinic, Cleveland, OH

Case Presentation

A 16-year-old boy presented to the emergency department complaining of vague abdominal pain following a motor vehicle collision. Based on initial findings on contrast-enhanced computed tomography (CT, Figure 1A), additional workup included ultrasound (US, Figure 1B) and MRI (MRI, Figure 1C) through the abdomen.

FIGURE 1. Axial contrast-enhanced CT image (A) demonstrates a cystic mass with a few internal septations within the head of the pancreas. Transverse US image (B) shows the mass with heterogeneous internal echogenicity. Axial T1 fat-suppressed postcontrast MR image (C) reveals the cystic mass with enhancing solid components posteriorly (enhancing regions were hypointense on precontrast T1 sequences, not shown).
**Key Imaging Findings**

Cystic pancreatic mass in a child

**Differential Diagnosis**

- Solid pseudopapillary tumor (SPT)
- Pancreatic pseudocyst
- Pancreatoblastoma

**Discussion**

Given the history of trauma in the case presented, along with the imaging findings on CT, the initial differential diagnosis included a pancreatic pseudocyst vs. solid pseudopapillary tumor (SPT). Based on the patient’s age, pancreatoblastoma was considered unlikely. Follow-up imaging and cytological evaluation revealed the cystic mass to have intrinsic solid components with internal hemorrhage.

The overall occurrence of primary pancreatic neoplasms in the pediatric population is relatively rare, comprising only 0.1% of pancreatic tumors from all age groups. Various imaging modalities have proven useful in the evaluation of such lesions, with cytological evaluation providing definitive diagnosis.

**Solid pseudopapillary tumor**

Solid pseudopapillary tumor (SPT) is rare in the pediatric population, typically presenting as a heterogeneous and encapsulated mass with a combination of cystic, solid, and hemorrhagic components. These tumors can occur throughout the pancreas, with a predilection for the pancreatic head and tail. This tumor is seen predominantly in adolescent girls (91%), and overall is more common in African-Americans and Asians. Patients are often asymptomatic, with the tumor being discovered incidentally. A usual presenting symptom is vague abdominal pain, likely secondary to mass effect.

Imaging aids significantly in the diagnosis of SPT. This entity typically appears as a solid mass with internal heterogeneity and often an enhancing capsule on CT. Calcifications can be infrequently associated with these lesions. Ultrasound typically demonstrates solid and cystic components, with only some demonstrating internal vascularity upon sonographic interrogation. MRI provides more distinctive features, such as a fibrous hypointense rim and fluid-fluid levels. Internal hemorrhage can be identified on the T1-weighted images with enhancement of solid components and the fibrous capsule. The lesions are well-circumscribed and are usually large upon initial evaluation, ranging 8-10 cm.

Histological evaluation reveals polygonal cells in sheets and cords, with interspersed pseudopapillary structures and pseudorosettes. Although typically of low malignant potential, spread beyond the pancreas can occur in up to 15% of patients. Because of the risk of metastases, surgical excision, often with a Whipple procedure or distal pancreatectomy depending on tumor location, is recommended.

**Pancreatic pseudocyst**

Pancreatic pseudocyst is a common postinflammatory entity primarily comprised of amylase-rich fluid. These lesions are most often seen following a bout of pancreatitis or traumatic injury, usually appearing 4-6 weeks following the insult. Pseudocysts typically present as a unilocular peripancreatic lesion that is round or oval. Additional imaging clues include peripancreatic inflammatory changes, or findings of chronic pancreatic insult, such as atrophy or calcifications. On MR imaging, the lesions show bright fluid signal on T2-weighted sequences often with internal debris.

If pancreatic pseudocysts are < 6 cm and asymptomatic, the usual course of action is to perform follow-up imaging with conservative management. If there is concern or uncertainty of the etiology, cyst aspiration under ultrasound guidance can be done for cytological analysis. If symptomatic, treatment may involve image-guided, surgical, or endoscopic decompression for larger lesions.

**Pancreatoblastoma**

An unlikely diagnosis given the patient’s age, pancreatoblastoma is the most common pancreatic tumor of young children, although the incidence is rare, accounting for approximately 0.2% of all pancreatic tumors. It is primarily seen in children 1-8 years (mean: 5 years-old) with slight male predilection. They have been described as either arising from the ventral or dorsal anlage anatomically, with microscopic evaluation demonstrating resemblance to incompletely differentiated acini of the fetal pancreas. A congenital form of pancreatoblastoma has been associated with Beckwith-Wiedemann syndrome. Typical presentation is an asymptomatic, large and slow-growing mass with symptoms arising secondary to mass effect.

These lesions can appear on CT as a multiloculated mass with enhancing septae, which are usually located near the pancreatic head. Ultrasound demonstrates a heterogeneous mass with multiple cystic spaces. MR imaging will often demonstrate a lesion with intermediate T1 and increased T2 signal intensity. Definitive diagnosis is made with tissue sampling.

Surgical excision is the treatment of choice for pancreatoblastoma. In the rare instance of metastatic disease, chemotherapy and radiation are utilized. Tumors located in the body or tail carry a poorer prognosis.

**Diagnosis**

Solid pseudopapillary tumor (SPT) of the pancreas; the patient underwent surgical excision without complication.

**Summary**

Primary differential considerations for a cystic pancreatic lesion in a child in the setting of prior trauma or inflammation include pancreatic pseudocyst vs. neoplasm. Primary pancreatic neoplasms are rare in the pediatric population, with solid pseudopapillary tumors most commonly seen in adolescent girls. Imaging characteristics include a heterogeneous mass containing solid and cystic components with internal hemorrhage and a surrounding fibrous capsule. Lesions are often...
discovered incidentally or as a result of exploring vague abdominal pain. The tumor has low malignant potential; however, it is treated with surgical excision when possible due to the potential for metastases. Imaging and tissue sampling are imperative in differentiating this neoplasm from pancreatic masses with a similar appearance yet different prognosis and management.

References
Dural-based Mass in an Infant

Jennifer Joyce, D.O., Ihsan Mamoun, M.D.
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Case Presentation

A 6-month-old boy presented to the emergency department after falling from his bed onto a wood floor. The mother of the patient reported soft-tissue swelling over the posterior aspect of the head. Unenhanced computed tomography (CT) of the brain was performed, followed by contrast-enhanced MRI of the brain (Figure 1A-D).

**FIGURE 1.** Axial noncontrast CT image through the head (A) demonstrates a mixed attenuation mass with specks of calcification in the right peri-sylvian region. The peripheral component of the mass is hyperdense compared to brain parenchyma. There is mass effect on the underlying parenchyma with effacement of the right lateral ventricle and midline shift to the left. Coronal T2 MR image (B) better depicts central cystic appearing T2 hyperintense and peripheral solid T2 iso- to hyperintense components and confirms the extra-axial nature of the mass with displacement of underlying gray matter. Coronal (C) and axial (D) T1 postcontrast MR images reveal a broad dural base laterally (D) and avid enhancement of the peripheral solid components with extension into the right orbital apex and suprasellar region (D). There is scalloping of the right sphenoid wing (D), which was better demonstrated on initial CT imaging through the skull base (not shown).
Key Imaging Findings

Dural-based mass in an infant

Differential Diagnosis

Rhabdomyosarcoma
Metastatic Neuroblastoma
Leukemic masses
Meningioma

Discussion

Brain tumors represent the second most common malignancy in childhood after leukemia, comprising 20%-25% of all neoplasms in children under 15 years of age.1 Supratentorial neoplasms are more prevalent in children under 3 years of age, while infratentorial tumors are more prevalent in children over 3 years of age. The patient age and tumor location help guide an appropriate list of differential considerations. In the setting of a dural-based tumor in an infant, the primary considerations include rhabdomyosarcoma, metastatic neuroblastoma, leukemic mass, and rarely meningioma.

Rhabdomyosarcoma

Rhabdomyosarcoma represents the most common soft-tissue tumor subtype in pediatrics, with lesions commonly originating in the head and neck. Almost 65% of cases are diagnosed in children under 16 years of age. Rhabdomyosarcomas of the head and neck occur most often in the parameningeal areas (ie, middle ear, infratemporal region, paranasal sinuses, nasopharynx, etc.), orbit, scalp, parotid gland, and thyroid gland, among other areas.2 Clinical symptoms are site-dependent with chronic otitis from temporal bone/middle ear involvement, sinusitis from paranasal sinus involvement, cranial nerve palsies that may result from multiple sites of involvement, and proptosis from orbital involvement.3

CT demonstrates a soft-tissue mass that is often ill-defined with bony destruction. MR imaging is preferred due to its superior soft-tissue evaluation, demonstrating a heterogeneously enhancing soft-tissue mass in a location typical of rhabdomyosarcoma (usually the head and neck soft tissues with or without intracranial extension). Perineural and meningeal spread is characterized by abnormal contrast enhancement on MR. Fat-suppressed T1-weighted imaging can be employed to evaluate for spread into the skull base; however, CT is most useful for osseous involvement. Treatment options include chemotherapy, radiation therapy, and surgery. Parameningeal locations have the worse prognosis, with a 5-year disease-free survival of 57%.3

Metastatic neuroblastoma

Neuroblastoma is a malignant tumor that originates from primitive neural crest cells.4 Most commonly, neuroblastoma arises from the adrenal glands or retroperitoneum but can occur anywhere along the sympathetic chain; <5% of cases arise from the cervical sympathetic chain ganglia.5 The head and neck is the most common site of distant metastases, with metastases involving osseous, lymphatic, and dermal structures.6 The most common site of intracranial metastases is the dura; contiguous invasion into the brain parenchyma is rare since the dura acts as a barrier to spread.5 Symptoms of intracranial metastases are often attributable to lesion location with headache, nausea, and emesis being the most common symptoms.6

In the setting of osseous metastases, CT may demonstrate aggressive periosseous reaction (often termed “hair-on-end” appearance), lytic defects, and separation of sutures.5 Parenchymal metastases tend to be cystic with variable degrees of internal calcification and heterogeneous enhancement of solid components.5 It is theorized that the cystic components result from prior hemorrhage, as most lesions tend to have a variable degree of hemorrhage both on imaging and pathologic evaluation. MR imaging demonstrates dural-based masses with aggressive osseous destruction, often with internal calcification and hemorrhage.5 Increased T2 signal can be seen surrounding the mass from vasogenic edema.

Prognosis is variable, with some tumors regressing while others metastasize extensively despite aggressive therapy. The younger the patient is at the time of diagnosis, the more favorable the survival rate. High-risk patients have the worst prognosis despite multimodality therapy, with a 30%-40% long-term survival.5

Leukemic masses

Leukemic involvement of the head is variable but mainly involves the calvarium, orbital/periorbital region, and/or meninges.7 Brain parenchymal involvement is rare but is seen more often during relapse.8 Imaging findings of calvarial involvement consist of homogeneously enhancing mass(es) with expansion of the calvarium and adjacent meningeal enhancement. Orbital and periorbital involvement typically include enhancing soft-tissue masses mostly homogenous in appearance.

Meningioma

Meningeal tumors in children are rare, accounting for approximately 0.4-1% of intracranial tumors.9 There is a known predilection for meningioma formation, however, in patients with neurofibromatosis type 2 (NF-2), with a 19%-24% incidence.10 Meningiomas may also be seen with a higher frequency in children previously treated with whole-brain radiation for other central nervous system neoplasms. In contrast to adults, there is a male predominance with a male-to-female ratio of 2.4:1.11

Meningiomas in children tend to be more aggressive and behave differently than lesions seen in adulthood.9 Signs and symptoms at presentation vary according to location of tumor, with the most common symptom being headache. Infants may present with signs and symptoms of increased intracranial pressure, such as vomiting and/or increased head size; however, as brain tumors are relatively rare in infants, symptomatology can be frequently overlooked.

Pediatric meningiomas have a variety of tumor subtypes, as well as...
imaging characteristics. The various histologic subtypes of meningioma include meningothelial, fibroblastic, sclerosing, angioblastoid, sarcomatous, transitional, and malignant. The malignant variants include papillary, anaplastic, and rhabdoid subtypes, with the papillary subtype classified as a WHO grade III malignant tumor that accounts for 1.0%-2.5% of all meningiomas in children.

On CT, meningiomas often present as enhancing partially solid and cystic extra-axial masses with variable degrees of internal calcification and surrounding edema. Dural-based lesions are not as common as in adults. MR imaging demonstrates iso- to hypointense extra-axial masses on T1 and T2 sequences with heterogeneous contrast enhancement.

Prognosis of meningiomas in pediatric patients relates to degree of tumor resection, tumor location, and pathologic grade. If the diagnosis of meningioma is confirmed in a child without a prior history of radiation therapy, additional work-up for an underlying genetic disorder such as NF-2 is warranted. This patient had a positive work up for NF-2; a few small schwannomas were detected along the spinal nerve roots.

**Diagnosis**

Meningioma (papillary variant with rhabdoid features, WHO grade III)

**Summary**

The differential considerations for brain neoplasms in children depend on patient age and tumor location. When presented with an extra-axial dural-based mass in an infant, the primary considerations include rhabdomyosarcoma, metastatic neuroblastoma, leukemic infiltrates, and rarely meningioma. The imaging appearance of these entities have some overlap. However, in general, rhabdomyosarcomas originate from the head and neck soft tissues with or without intracranial extension; neuroblastomas have more osseous involvement and are likely to calcify; and leukemic infiltrates tend to be more homogeneous and less destructive in appearance. The diagnosis of meningioma in infants is rare in the absence of NF-2. When present, meningiomas in children are typically of higher grade with heterogeneous enhancement and cystic changes.

**References**

Uncommon Presentation of Burkitt Lymphoma

A 14-year-old boy with no prior medical problems presented to the emergency department with a two-week history of bloody diarrhea, decreased appetite, reflux, vomiting, abdominal fullness, and shoulder pain. Computed tomography (CT) revealed a large right abdominal mass with bulky nodular soft tissue anteriorly (A). He was admitted for workup of this presumed primary gastrointestinal malignancy.

PET/MRI (positron emission tomography/MRI) was performed and demonstrated substantial avid disease involving the chest, abdomen, and pelvis (B). Within the chest, pleural-based nodular and plaque-like masses with marked FDG (fludeoxyglucose F 18) uptake were seen bilaterally. Additionally, FDG avid nodular masses were in the bilateral parasternal and cardiophrenic regions (C). Large volume bilateral pleural effusions were presumed malignant. Within the abdomen and pelvis, a large bulky heterogeneously enhancing FDG avid mass in the right lower quadrant was identified. In addition to the dominant mass, there was bulky nodular thickening of the diaphragm, peritoneal surfaces, omentum, and mesentery with FDG avidity (B). Moderate volume abdominal ascites was presumed malignant.

Biopsy established a pathological diagnosis of Burkitt lymphoma. Carcinomatosis is typically associated with a primary gastrointestinal or ovarian malignancy. Other rarer differential considerations include gastrointestinal stromal tumor (GIST), granulomatous infections, and lymphoma as in our case.¹ The role of PET/MRI in the setting of pediatric lymphoma has been shown to be comparable to PET/CT in detection, classification, and staging of disease burden.² The potential for significant radiation dose savings makes this an interesting pediatric application of this emerging imaging modality.

REFERENCES

Neonatal Osteomyelitis

A 2-month-old boy presented with diminished shoulder movement. Radiographs revealed irregularity and sclerosis involving the proximal left humeral metaphysis (A). Differential considerations included healing proximal humerus fracture (including nonaccidental trauma [NAT]) and infection. An US image oriented in the sagittal plane showed the humeral head in appropriate position and a complex joint effusion (arrows, B). An axial MRI image showed a rim-enhancing joint effusion (arrow, C), abnormal signal within the humeral proximal metaphysis and epiphysis (oval, C), periosteal reaction, and soft-tissue edema (star, C). An enhancing lesion within the deltoid was concerning for abscess. Findings suggested multifocal osteomyelitis and septic arthritis.

Neonatal osteomyelitis is a problematic diagnosis. Since fever may be absent, radiographic findings are often misinterpreted as a healing fracture and dislocation or Salter Harris I injury. Multifocal bone abnormalities are often questioned as NAT.

Osteomyelitis is primarily a disease of infants and young children, with one-third of cases occurring before 2 years of age. The diagnosis is often delayed secondary to nonspecific symptoms. Neonates are at highest risk due to their immature immune system and transphyseal blood supply. In cases of delayed or missed diagnoses, 40% of infants have extremity deformity due to physeal injury. Adjacent septic arthritis is common in infants under 1 year of age.1

On radiographs, lucency and a permeative appearance can be seen at 7-10 days with bony destruction beginning at 7-10 days. Osteomyelitis commonly occurs in metaphyses, with long bones most frequently involved (70%). Sonography is useful for evaluating joint alignment and presence of a joint effusion, and demonstrating metaphyseal and epiphyseal destruction. Contrast-enhanced MRI is best for surgical planning. A bone survey and bone scintigraphy may evaluate multifocal disease.2

References