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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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# Pediatric Imaging

**Editor:** William E. Shiels II, D.O., M.S., FAOCR

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In this Issue

William E. Shiels II, DO, MS, FAOCR

Department of Radiology, Nationwide Children’s Hospital, Columbus, Ohio

It is my pleasure to serve as the Guest Editor of the first Pediatric Radiology issue of the Journal of the American Osteopathic College of Radiology. My hope is that the readers find this issue informative, interesting, and most importantly supportive in our radiologists’ efforts to maintain state-of-the-art expertise in life-long pediatric radiology learning and care. The review articles cover a broad range of topics, including diagnostic and therapeutic care issues in pediatric radiology. As a specialty college, the AOCR members largely practice in community hospital settings and are often responsible for the radiological care of children. To this end, the primary goal of this issue of the JAOCR is to provide current information that allows the AOCR members to properly care for children in their hospitals and outpatient centers, to the degree possible, and know the scope of tertiary and quaternary level care that is now available, when needed.

In this issue, the authors and I have selected topics with practical importance for the care of children, teenagers, and young adults with inflammatory bowel disease. MR enterography, when performed properly, provides elegant anatomic depiction of the disease processes and structures involved, clearly guiding medical and surgical care. Drs. Wildman and Henwood-Finley provide the readers with a well written, state-of-the-art reference for the use of DXA imaging in pediatric patients. Bone health in children continues to grow as a key area of concern for surveillance, prevention, early detection and early intervention of metabolic bone disturbance. My article on lymphatic malformation provides the readers with a pathologic basis for understanding the classification and diagnostic imaging findings of lymphatic malformations, as well as options and rationale for successful percutaneous therapy. Our individual case discussions should maintain the readers’ interest with diagnoses and therapies that are both intriguing and of practical value.

In summary, the authors and I hope that this first Pediatric Radiology issue of the JAOCR meets focused needs as you continue on your path of life-long learning in the care of your pediatric patients and their families.
Lymphatic Malformation: Radiologic-Pathologic-Therapeutic Correlation and Management Implications

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Pathology and clinical presentation

Lymphatic malformation (LM, previously known as lymphangioma) is a common vascular malformation and represents a disturbance in the development of the lymphatic ductal system. The pathology of LM is central to understanding the science and design of effective therapeutic interventional procedures. Pathologically, LM is a complex of multiple cysts lined with lymphatic vascular endothelium (Fig. 1). The supporting matrix of the LM is a combination of fibrous tissue and smooth muscle with small feeding vessels and aggregates of lymphocytes in the interweaving septations. The cystic spaces may or may not communicate and contain serous or hemorrhagic fluid. Lesions can be classified as macrocystic (>1 cm), microcystic (< 1cm), or mixed (combined microcystic and macrocystic).

Microcystic LM may infiltrate multiple soft tissue planes, including skin. Pathologically, the solid matrix elements of LM may be a minor component (predominantly cystic as defined with diagnostic imaging studies) or large volume percentage of an LM (few cysts defined with imaging studies). When macrocystic disease predominates, pathologists refer to these as cavernous lesions or the typical “Cystic Hygroma”. Histologically, solid elements of LM not only contain fibrous tissue and smooth muscle, but also contain microscopic cystic spaces that are not resolved with current diagnostic imaging studies (US, CT, MR). This understanding of the histologic composition of solid LM tissue is critical to therapeutic planning and outcomes expectations, and thus, important in patient care plans and communication. As a result, the author includes “solid LM” as a fourth classification category, as this is readily understood by patients undergoing treatment that may target ablation of cystic spaces and leave residual solid LM tissue, as well as referring physicians (particularly surgeons), for future treatment decisions that include surgical resection or non-surgical ablation techniques (e.g. radiofrequency ablation).

Lymphatic malformations represent approximately 5% of all benign masses and may present at any age. More than half are recognized at birth and 90 percent before 2 years of age. Occasionally, LM may first manifest with a visible mass in early or late adulthood. A LM that is diagnosed at birth usually presents as a soft, spongy, non-tender mass. In older children and adults, a LM may present with rapid development of a firm painful mass, occurring as a result of hemorrhage into previously undiagnosed LM locules. LM is most frequently diagnosed in the head and neck, but can present in numerous locations throughout the body.
locations, to include the orbit, mediastinum, retroperitoneum, chest, abdomen, extremities, scrotum and penis. LM in the orbit may lead to severe disability, acute bradycardia, visual loss, or complete blindness. Microcystic LM that infiltrates skin may manifest as cutaneous vesicles (cutaneous LM or “lymphangioma circumscripta”) with chronic drainage of serous fluid.

Diagnostic Imaging Evaluation
Diagnostic imaging is best performed with a combination of MRI and sonography. MR is the imaging modality of choice for global assessment of the extent of a LM. MR demonstrates LM extension in areas invisible to sonography, such as LM behind airway and boney structures. MRI and sonography demonstrate LM to be a multiloculated cystic mass with variable appearance of the cyst fluid depending on the presence or absence of intracystic hemorrhage. Sonography may be the sole diagnostic imaging modality if the lesion is well localized in a superficial location, also providing definition of microcystic and solid elements, distinct from macrocystic elements. The definition of LM with MRI and sonography demonstrates cystic spaces without fast (high) flowing fluid (arterial blood flow), thus LM is characterized as a “low flow” vascular malformation.

Treatment of Lymphatic Malformation
Surgical resection has been considered standard treatment for these lesions, despite recurrences in 15 to 53 percent of reported clinical series. Significant complications in up to one-third of cases, including nerve paralysis, have been reported following operative resection. Surgical literature studies recognize the benefit of an interdisciplinary approach to treatment, often including percutaneous treatment as the first line therapy prior to surgical debulking and/or resection.

Radiological therapy is focused on selective ablation of vascular endothelium that lines LM cysts. Interventional radiological therapy has been attempted around the world over the past two decades using intralesional sclerotherapy with single agents including bleomycin, doxycycline, ethanol, Ethibloc<sup>TM</sup>, OK-432, and sodium tetradeccyl sulfate, with excellent response in only 20 to 67 percent of patients. A recent literature analysis of various sclerosant agents reported LM treatment requiring one to 23 treatment sessions with complete ablation of LM in 20 percent and good response in 51 percent of patients. Previously, complications from sclerotherapy have been observed in 22 to 46 percent of patients, including nerve damage, persistent pain, skin ulceration, fever, airway obstruction, and myoglobinuria. New dual-drug treatment regimens (detergent followed by ethanol, short dwell time) with improved outcomes and fewer complications have been reported. The scientific rationale for dual-drug therapy is based on the cellular level of action of detergent as an agent of “poration” that removes lipoproteins and opens cell membrane pores, enhancing ethanol permeability for intracellular destructive action.

Percutaneous treatment is divided into two therapeutic regimens, one for macrocystic disease and one for microcystic disease. Percutaneous LM therapy reports vary, with the majority grading response either on gross cosmetic patient appearance or degree of shrinkage of LM cysts. Alternative outcomes measure reporting uses simple presence or absence of cysts (successful complete ablation as the treatment goal) for LM in a broad spectrum of locations including the head, neck, trunk, extremities, and orbit.

Macrocystic LM Treatment
Macrocyst (>1cm) access is most frequently performed with ultrasound guidance and placement of either a 5-8F pigtail catheter in each cyst or needle/angiocatheter cyst puncture for individual cyst treatment. Macrocyst treatment with simple needle puncture, aspiration, and injection (sclerosant not aspirated following injection) has been most frequently reported with OK-432, bleomycin, and doxycycline (10 mg/ml). Results with both “injection only” techniques are similar for doxycycline, OK-432, and bleomycin,
with good-to-excellent results reported in 80-90% of patients.6,9,16,18-19

Two series reports of catheter-based doxycycline therapy studies report similar 3-day treatment techniques, injecting doxycycline (10 mg/ml) into individual cysts and maintaining the doxycycline 4-6 hours, then aspirating, and repeating these treatments, as inpatients, daily for 3 days (each day with sedation or general anesthesia). In these series, treatment outcome of good-to-excellent was reported in 65 and 90%, respectively, with average number of treatment sessions of 3.6 and 2.9 (range 1-10 treatment sessions).16,17 Minor complications in these two series were reported as 10 and 14%, respectively, and included hemolytic anemia, hypoglycemia, metabolic acidosis, transient hypotension, skin blistering, and hair loss.16,17 In the same series, major complications were reported with a frequency of 2 and 14%, including Horner’s syndrome, facial nerve palsy, and phrenic nerve palsy.16,17 Complications with bleomycin therapy include skin blisters, pulmonary fibrosis (acute and chronic), and flagellate hyperpigmentation.18-22

Macrocystic LM treatment using a short dwell time, catheter based, dual-drug technique resulted in 100% ablation of macrocysts has been reported in the head and neck, as well as trunk and extremities.3-4 In these two reports, 100% of macrocysts were ablated with mean number of treatment sessions of 1.1 and 1.3, respectively.3-4 Infection was the only complication (6 and 13%, prior to routine use of peri-procedural antibiotic administration) with the short dwell time, catheter based, dual-drug technique.3-4 In both series, no major complications occurred (no nerve injury, including treatments involving the brachial plexus, face, orbit, and neck). The dual-drug catheter based technique includes 5-8F pigtail catheters placed in cysts larger than 10 mm (Fig. 2-5). Following complete drainage of the macrocysts and contrast cystogram definition, macrocysts are treated with a dual-drug system, each drug with short dwell time treatment. Cyst lining cells are first washed with detergent (sodium tetradecyl sulfate, 3%) maintained in the cyst for 2 minutes prior to aspiration. The detergent removes cell membrane lipoproteins, thus increasing membrane permeability for intracellular delivery of ethanol for protein denaturation and cell death. Following detergent aspiration, 98% ethanol (50% cyst volume) is injected and maintained for 15 minutes. Following aspiration of the ethanol, macrocysts are placed to suction drainage for 3 days prior to catheter removal. The dual-drug catheter based treatment is routinely performed as an outpatient.3-4 Patients with 5F pigtail catheters (including orbit, head, and neck) reported no pain from the indwelling catheter (Fig. 2 and 3).3-4 Furthermore, the dual-drug macrocystic therapy can be performed without sedation using intracystic local anesthetic in older children and adults (Fig. 5).3-4

**Figure 2.** Macrocystic lymphatic malformation of the orbit in a 13-year old boy with proptosis, pain, and bradycardia. Axial T2 image (A) demonstrates a retrobulbar lymphatic malformation of the left orbit (arrows). Note the stretched optic nerve (arrowhead) encased by the LM. A pontine cavernous malformation is noted. B shows a 5F drainage catheter (arrow) in position for drainage and ablation. A contrast cystogram (C) defines the cystic mass (arrowhead) prior to ablation. Axial T2 image (D) 2 years following treatment demonstrates normal globe, optic nerve, and orbital contents. The patient has normal vision following sclerotherapy. Images reprinted with permissions Pediatric Directions 2011; Vol. 38, NCH
Figure 3. Macrocystic and microcystic lymphatic malformation of the orbit in 6-year-old girl. Clinical photo of a 6-year-old girl (A) demonstrates severe proptosis and ecchymosis due to a massive intraorbital LM. Coronal T2 image (B) reveals a left orbital mixed macro-and microcystic LM (arrow) encasing the optic nerve (arrowhead). Coronal T2 image (C) defines microcystic elements of the LM (arrow). Contrast cystogram image (D) shows a 5F drainage catheter with contrast for drainage and ablation of the macrocystic element (arrowhead). Image during US guided microcyst treatment (E) with 25G needle (arrowhead) in the leftmost of 2 microcysts, containing echogenic doxycycline foam (curved arrow). Straight arrow indicates the adjacent microcyst that will be treated next with echogenic doxycycline foam. Clinical photograph 10 months following treatment (F) demonstrates resolution of proptosis and visual acuity improvement to 20/100. Images reprinted with permissions Pediatric Directions 2011; Vol. 38, NCH

Figure 4. Mixed (macrocystic and microcystic) lymphatic malformation of the neck, retropharynx, and mediastinum. Clinical photograph of 13-month-old girl (A) with a massive LM of the left neck. Coronal T2 image (B) demonstrates the LM (arrows) extending from the neck into the superior mediastinum. Axial T2 image (C) shows the LM (arrows) encasing the carotid sheath and extending into the retropharynx. Contrast cystogram (D) during macrocystic LM (arrow) ablation treatment. Axial T2 image 4 years following treatment (E) demonstrates no macrocysts or microcysts, and small amount of fibrofatty tissue (arrows) remaining after cyst ablation. Photograph at age 5 (F) shows no visible mass effect or scar in the left neck. The scar (arrow) on front of the neck is from the plastic tracheostomy frame skin abrasions. Images reprinted with permissions Pediatric Directions 2011; Vol. 38, NCH
A new protein foam formulation of doxycycline (5 mg/ml) has been developed for treatment of microcystic LM (Fig. 3). Treatment of microcystic LM involves aspiration of each individual microcyst and injection of doxycycline foam, the foam changing the color of the microcyst on ultrasound from black to white, defining treated from untreated microcysts. This study reports safe and successful treatment of over 1200 LM microcysts as small as 1 mm in the eye, head, neck, trunk, and extremities, with successful microcyst LM ablation in 93% of patients following 3 treatment sessions (including sessions with simultaneous macrocystic treatment). The use of stable protein microfoam for bleomycin injection has also been reported for safe and accurate treatment of microcystic LM.

Figure 5. Macrocystic LM in the neck of a 47-year-old woman treated with a single session of outpatient percutaneous sclerotherapy performed under local anesthesia. US image (A) demonstrates the large macrocystic LM (arrows) of the left neck prior to treatment. Contrast cystogram (B) defines the left neck macrocystic LM (arrow) during dual-drug treatment. US image 6 months following treatment (C) demonstrates normal neck soft tissues (arrow on normal carotid artery) and no evidence of cysts or scar from treatment. Images reprinted with permissions Pediatric Directions 2011; Vol. 38, NCH

Microcystic LM Treatment

Percutaneous treatment of microcystic LM (includes those with purely microcystic or mixed LM) using liquid doxycycline, OK-432, and bleomycin yields good-to-excellent results in 60-63% of patients in recent reports. A new protein foam formulation of doxycycline (5 mg/ml) has been developed for treatment of microcystic LM (Fig. 3). Treatment of microcystic LM involves aspiration of each individual microcyst and injection of doxycycline foam, the foam changing the color of the microcyst on ultrasound from black to white, defining treated from untreated microcysts. This study reports safe and successful treatment of over 1200 LM microcysts as small as 1 mm in the eye, head, neck, trunk, and extremities, with successful microcyst LM ablation in 93% of patients following 3 treatment sessions (including sessions with simultaneous macrocystic treatment). The use of stable protein microfoam for bleomycin injection has also been reported for safe and accurate treatment of microcystic LM.

Figure 6. Six-year-old girl with right forearm microcystic LM. US image (A) demonstrates a mixed solid and microcystic LM with arrows on the small microcysts treated with doxycycline foam. US image of the LM (B) (margins outlined with curved arrows) with arrow on a moderate-sized microcyst treated with doxycycline foam. US images of the LM (C) following doxycycline microcystic sclerotherapy. Curved arrows outline the residual solid LM tissue with lack of discernible microcysts. Surgical resection of residual solid LM mass was performed following sclerotherapy of definable microcysts. Histology (D) demonstrates microscopic cysts (arrows) that remain following sclerotherapy, adjacent to fibrous (arrowheads) and adipose (curved arrows) LM matrix. Fluoroscopic image during lymphocele therapy (E) with arrow indicating a large lymphocele that was successfully treated over a 3 week period (dual drug sclerotherapy every 3 days).
Limitations and surgical planning

New techniques and drug combinations discussed above offer patients and physicians options for LM cyst ablation with success rates approaching 100%. Following sclerotherapy, small amounts of residual solid LM fibrofatty tissue may not result in cosmetic deformity and may not require surgical resection (Fig. 4). Annual surveillance of patients with residual LM solid tissue may reveal new microcysts that mature into definable cysts (with diagnostic imaging studies) and may be treated with intermittent sessions of microcystic therapy. In the setting of significant solid LM tissue, there is potential for both residual cosmetic mass effect and development of new cysts from the solid tissue that contains microscopic LM cysts (not large enough to be defined with diagnostic imaging modalities) following percutaneous sclerotherapy (Fig. 6). Multidisciplinary planning should include discussion of need and choice of timing for debulking surgery, either before or following sclerotherapy.

Two primary issues are important for both surgeons and radiologists on the Vascular Anomalies team to consider in these planning discussions. When doxycycline sclerotherapy is performed prior to debulking surgery, surgeons must be prepared to encounter significant scar tissue encasing nerves, blood vessels, and other vital structures. This potential for encasing scar tissue may drive a decision for debulking surgery prior to sclerotherapy (to treat residual or recurrent cysts). The second issue for planning is the post-operative tissue bed and the potential for lymphoceles development (and need for subsequent percutaneous treatment). If an LM lies superficially, surgical resection may result in tenuous blood supply to the overlying skin that may be compromised or lost with lymphocele sclerotherapy. Furthermore, patients with post-operative lymphoceles should be prepared for the significant time commitment required for multi-session sclerotherapy of the lymphocele over a 2-week period. These issues are best discussed with the patient/family, the surgeon, and interventional radiologist prior to initiation of treatment.

Solid LM with microscopic cysts, especially LMs infiltrating skin and oral mucosa, present a unique challenge for surgeons and radiologists. Since sclerotherapy is best directed at cysts defined with high-resolution ultrasound, solid LM tissue is not well treated with current sclerotherapy techniques. Radiofrequency ablation (RFA) offers an alternative treatment for solid LM with recurrent mucosal and lingual vesicles, as well as lingual microcystic LM that results in an enlarged tongue. The author has utilized RFA successfully for reduction of mass effect and treatment of cutaneous vesicles. Patient care plans with RFA must include clear expectations and a treatment plan for the RFA burn site.

Summary

Treatment of LM involves a multidisciplinary vascular anomalies team approach, with an expanding clinical armamentarium that offers patients excellent treatment options and hope for superb clinical results. In this multidisciplinary team, the interventional radiologist plays a critical role in the provision of innovative and excellent patient care.

References

MR Enterography of Pediatric Inflammatory Bowel Disease: Review of Imaging Techniques and Findings

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Introduction
Inflammatory bowel disease (IBD) consists of ulcerative colitis (UC), Crohn disease (CD), and indeterminate colitis. While sharing many clinical features, ulcerative colitis and Crohn disease are considered separate entities with unique characteristics. Due to the chronic nature of these diseases, frequent and repeated imaging is often necessary for diagnosis and therapeutic planning. Magnetic resonance enterography (MRE) has emerged as a robust imaging modality for the evaluation of IBD, offering many advantages over conventional imaging techniques while sparing the patient exposure to ionizing radiation. This review will briefly discuss the pathology and epidemiology of IBD, provide a practical guide to the performance of MRE, and highlight various classic imaging findings frequently encountered in these patients.

Background
Inflammatory bowel disease is, by nature, a chronic relapsing inflammatory condition. Crohn disease is a granulomatous process which leads to transmural inflammation with lymphoid aggregates extending to the serosal surface. In distinction, ulcerative colitis is nongranulomatous with inflammatory change typically limited to the mucosa. UC involves the colon in a contiguous fashion extending from the anorectum proximal to a variable extent. In cases of pancolonic ulcerative colitis, a mild inflammatory process may also involve the terminal ileum, the so-called “backwash ileitis”. Crohn disease may involve any portion of the intestinal tract from the mouth to the anus in a decidedly non-contiguous pattern. While terminal ileal involvement is frequently seen and favors the diagnosis of CD, it is not requisite. The histologic hallmark of CD is a nonnecrotizing sarcoid-like granuloma found within the deep submucosa or lymph nodes. The aphtous ulceration which leads to fissures and forms the cobblestone mucosal appearance visualized endoscopically may also extend through the bowel wall and lead to sinus tracts or fistula formation. This transmural process may incite a regional inflammatory response and lead to fibrofatty proliferation and hyperemia in addition to abscess formation.

The etiology of IBD appears to be complex with both genetic and environmental components. Multiple genes have been implicated in the pathogenesis of both UC and CD. The genetic subtleties involved in IBD are beyond the scope of this review, however in addition to defects in innate immunity, genetic abnormalities have been implicated which lead to alterations in cytokine-mediated immune response. Patients harboring specific gene mutations are likely predisposed to developing IBD in response to a multitude of environmental triggers.

While more frequently encountered in the adult population, approximately 25% of IBD cases are diagnosed in pediatric patients. The incidence of ulcerative colitis in patients less than age 20 is estimated at 28:100,000 and Crohn disease at 43:100,000. Recent studies have shown that the incidences of both CD and UC are rising. The chronic and debilitating nature of these diseases is substantial and lead to frequent and prolonged hospital stays. The estimated annual inpatient cost to care for pediatric patients with IBD is $152.4 million and requires nearly 65,000 hospital days, stunning figures for diseases with relatively low incidences.

There has been a significant increase in awareness both within the medical community and the public at large regarding the potential increase in cancer risk associated with diagnostic medical radiation. A majority of the collective dose from radiologic exams results from high-dose procedures
such as CT and fluoroscopic studies. The ensuing organ doses are sufficiently large as to result in small, but statistically significant, increase in cancer risk. Such as CT and fluoroscopic studies. The ensuing organ doses are sufficiently large as to result in small, but statistically significant, increase in cancer risk.9 Children with IBD have traditionally been evaluated with CT or fluoroscopy for both initial diagnosis and for the evaluation of disease recurrences and complications such as fistula or abscess formation. While all children with IBD are typically exposed to a higher level of radiation than their unaffected peers, a smaller subset of IBD patients are exposed to particularly high levels of medical radiation. This group includes patients with Crohn disease, those requiring IBD-related surgery, those with an increased number of hospital admissions, and those with elevated platelet counts at the time of diagnosis.10,11 Diagnostic modalities which do not involve ionizing radiation should be favored in children with IBD, particularly in light of their unique pre-existing elevated lifetime cancer risk and the increased sensitivity to radiation noted in pediatric population, in general. MR enterography has been shown to be an excellent substitute for CT in the evaluation of IBD.12,13 In fact, the information gained with MRE regarding activity of disease and the extent of extraluminal processes such as fistula and sinus tracts is unmatched by other conventional modalities.

Technique

Patient preparation, coil selection, and sequences utilized at our institution will be reviewed. While many variations on MRE technique have been described, we have found the following protocol produces consistent results for patients with UC, CD, or indeterminate colitis.

Patients are instructed to arrive two hours prior to their examination time to begin their oral contrast preparation. Oral contrast consists of 1 teaspoon of Metamucil (Proctor & Gamble, Cincinnati, Ohio) dissolved in 8 ounces of water. The patient drinks one dose of oral contrast every 30 minutes for a total of four glasses (32 ounces of contrast) prior to scanning. Diluted barium products such as those used for CT enterography may also be used. We have found that Metamucil is well tolerated by patients and produces reliable small bowel distention. This product is also cost effective and is conveniently stored and administered by technologists (Metamucil is available prepackaged in 1 tsp doses).

High quality MRE studies can be easily obtained using conventional 1.5 Tesla magnets. With minor modifications, our protocol can also be translated to 3.0 Tesla systems. The majority of MRE exams at our institution are performed on a 1.5T Siemens Avanto (Siemens Medical, Erlangen, Germany) with a standard 8 channel body coil. Patients are scanned in the supine position without sedation.

The following sequences are specific to Siemens magnets; however, equivalent GE sequences have been provided (Table 1). After the initial 3-plane localizer sequences, axial T2 images with fat suppression (T2 HASTE) are performed with patient breath holding extending from above the diaphragms through the perineum. In larger patients, this sequence may be divided into two acquisitions to avoid impractically long breath holds. This heavily T2-weighted sequence is exceptionally fluid sensitive and allows for detection of bowel wall thickening (Fig. 1).

### Table 1. MRE Sequences.

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<th>Sequence</th>
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<th>GE</th>
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<td>T2 HASTE (Half Fourier Acquisition Single shot Turbo spine Echo)</td>
<td>SSFSE (Single Shot Fast Spin Echo)</td>
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<tr>
<td>T2 TrueFISP (True Fast Imaging with Steady state free Precession)</td>
<td>FIESTA (Fast Imaging Employing Steady state Acquisition)</td>
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<tr>
<td>DWI Diffusion weighted images</td>
<td>Diffusion weighted images</td>
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<tr>
<td>T2 (3D) SPACE (Sampling Perfection with Application oriented Contrasts using)</td>
<td>FSE-Cube</td>
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<td>T1 Post VIBE (Volume Interpolated B reathhold)</td>
<td>FAME (Fast Acquisition with Examination)</td>
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<tr>
<td>T1 Post FLASH (Fast Low Angle SHot)</td>
<td>MPGR (MultiPlanar Gradient R recalled acquisition in the steady state)</td>
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![Figure 1. Axial T2 HASTE image showing bowel wall thickening (arrows).](image-url)
Coronal steady state free precession images (TrueFISP) are then performed to cover the entire abdomen and pelvis. This sequence gives valuable information regarding bowel distention, bowel wall thickening, and extent of disease (Fig. 2). Image contrast is largely determined by the TR in this T2*-weighted sequence. The speed of TrueFISP imaging produces clear images despite bowel peristalsis, helping to obviate the need for glucagon administration. The coronal TrueFISP is then repeated as a non-gated, non-breath hold cine sequence similar to a cardiac bright blood sequence. The cine TrueFISP runs for 7-8 seconds per coronal slab and results in approximately 40 images per slice position. This sequence allows for evaluation of normal peristalsis and highlights aperistaltic loops as seen in Crohn disease.

If the study is performed on a 3T system, the static and cine SSFP sequences will suffer from dielectric effect and should be replaced with corresponding gradient echo sequences. While dielectric artifact is not fully resolved in this situation, artifact is generally confined to the periphery of the image and does not hinder the diagnostic quality of the exam (Fig. 3).

After cine imaging, axial diffusion-weighted images (DWI) are performed with the same coverage as the axial fat-suppressed T2 images. DWI is obtained with β values of 0, 500, and 1000 (Fig. 4). Unlike neuroimaging where the β 1000 value is relied upon, the β 500 images are often the most revealing in body imaging.

The final precontrast sequence is a 3 dimensional isotropic T2-weighted sequence with fat suppression (T2 SPACE) obtained in a sagittal plane through the midline pelvis (Fig. 5). This sequence is obtained with 0.9 mm contiguous slices which allows for reformatting in the curved plane coronal and oblique axial planes (Fig. 6).
sagittal orientation allows for the most efficient coverage of the anorectum and distal sigmoid colon. A 3D fat suppressed T2-weighted sequence is vital for the evaluation of rectal fistulas encountered in Crohn disease.

After the administration of a standard dose of gadolinium, post contrast axial and coronal T1-weighted images are obtained. For coronal imaging, we perform a contiguous thin section fat suppressed T1-weighted sequence (VIBE) with the same coverage as the precontrast coronal SSFP sequences (Fig. 7). Axial T1-weighted images with fat suppression (FLASH) are then performed with breath holding. Typically, two to three axial acquisitions are required to cover the abdomen and pelvis with tolerable breath hold durations.

The entirety of the MRE protocol can be performed in under an hour, including time for patient positioning, starting an IV for contrast, and contrast injection. Imaging parameters for the above sequences have been provided (Table 2).

Figure 6. Orientation of oblique axial T2 SPACE reformats (A). Oblique axial T2 SPACE reformat (B). Orientation of T2 SPACE curved plane coronal reformat (C). Curved plane T2 SPACE reformat (D).

Figure 7. Coronal T1 VIBE post contrast showing hyperenhancement of bowel wall (arrows).

Table 2. MRE imaging parameters.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Plane</th>
<th>TR (ms)</th>
<th>TE (ms)</th>
<th>Slice Thickness (mm)</th>
<th>Gap (mm)</th>
<th>Fat Sat</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLASH</td>
<td>Axial</td>
<td>3.72</td>
<td>3.35</td>
<td>1.6</td>
<td>0.52</td>
<td>Strong SPAIR</td>
<td></td>
</tr>
<tr>
<td>TrueFISP (Fast)</td>
<td>Coronal</td>
<td>3.57</td>
<td>1.55</td>
<td>4</td>
<td>0</td>
<td>None</td>
<td></td>
</tr>
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<td>TrueFISP (Cine)</td>
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<td>1.56</td>
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<td></td>
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<tr>
<td>MANSI</td>
<td>Axial</td>
<td>1500</td>
<td>119</td>
<td>0.9</td>
<td>0</td>
<td>Strong SPAIR</td>
<td></td>
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<tr>
<td>DWI</td>
<td>Axial</td>
<td>3900</td>
<td>75</td>
<td>1.25</td>
<td>0</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

Imaging findings

Many of the imaging findings of IBD depicted with MRE will be familiar to those already versed in the CT evaluation of UC and CD. The colonic wall thickening noted in ulcerative colitis is well depicted with MRE. Contiguous involvement of the colon beginning at the anorectum and extending a variable distance proximal is the sine qua non of UC. Wall thickening is concentric and even, typically measuring less than 10 mm in width (Fig. 8). Loss of haustral markings may also be observed resulting in the so called “lead-pipe” colon (Fig. 9). Another frequently visualized feature of ulcerative colitis is the “target sign”. Hyperemia of the mucosa and serosa with interposed mural edema results in a target appearance of concentric hyper- and hypoenhancement on postcontrast T1-weighted images (Fig. 10).
Figure 8. Axial T1 FLASH postcontrast (A) showing concentric wall thickening (arrow) in a patient with ulcerative colitis. Axial T1 FLASH superior to first image (B) showing contiguous involvement of the sigmoid (arrow).

Figure 9. Coronal TrueFISP in a patient with UC demonstrating a “lead-pipe” colon (arrows).

Figure 10: Axial T1 FLASH postcontrast in a patient with UC showing enhancement of the mucosa and serosa of the descending colon with intervening mural edema resulting in a “target sign” (arrow).

Patients with UC are often treated with complete colectomy with a small bowel pull-through. The resulting neorectal pouch may become inflamed, a condition termed pouchitis. The isotropic fat suppressed T2-weighted sequence which depicts anorectal fistula in patients with Crohn disease excels equally for the evaluation of pouchitis (Fig. 11).

Figure 11. Axial T1 FLASH (A) in a patient with UC and pouchitis. Pouch (*) is surrounded by inflammatory change with breakdown and abscess formation (arrow). Coronal T2 SPACE (B) in the same patient shows the abscess (arrow) through the left side of the pouch (*).

The MRE evaluation of Crohn disease surpasses CT, fluoroscopy, and endoscopy in its scope and effectiveness. Unlike the concentric wall thickening seen in UC, Crohn disease typically manifests as eccentric wall thickening often measuring greater than 10 mm in width (Fig. 12). Bowel which is actively inflamed will demonstrate restricted diffusion, a feature which is vital for the discrimination of disease from unaffected collapsed loops of bowel or chronic quiescent strictures (Fig. 13). It is our institutional experience that the presence of diffusion abnormalities is more reliable than wall thickening or enhancement as a sign of active disease, particularly when dealing with the proximal small bowel (Fig. 14).

Figure 12: Axial T2 HASTE in a patient with CD shows multiple loops of bowel with eccentric wall thickening (*).

Alternating regions of affected bowel and normal bowel are also seen, unlike the proximally contiguous disease pattern of UC (Fig. 15). Affected loops of bowel often demonstrate decreased motion due to inflammation or chronic scarring and stricture formation. Dysmotility is well visualized on the coronal cine SSFP sequence.
Transmural pathology is the hallmark of Crohn disease and may result in sinus tract or fistula formation. Fat suppressed T2-weighted and postcontrast T1-weighted images are excellent for the depiction of transmural disease (Fig. 16). Transmural disease may also result in abscess formation. A fluid collection noted on T2-weighted imaging which demonstrates an enhancing rim and restricted diffusion is indicative of abscess formation (Fig. 17).

Figure 13. Axial DWI (A) in patient with CD shows restricted diffusion (arrow) in the bowel wall indicating acute disease. Corresponding ADC map (B) confirms diffusion abnormality.

Figure 14: Axial T2 HASTE (A) in a patient with CD reveals apparent diffuse bowel wall thickening throughout the jejunum. DWI in the same patient (B) shows active disease within a short segment of the jejunum (arrow).

Figure 15. Coronal TrueFISP in a patient with CD showing an dilated “skip lesion” (*) with wall thickening proximal (black arrow) and distal (white arrow) to the segment.

Figure 16. Axial T1 FLASH postcontrast (A) reveals sinus tract (arrow) extending through the abdominal wall musculature in a patient with CD. Coronal T1 VIBE in the same patient (B) reveals sinus tract connection to the bowel (arrow).

Figure 17. Axial T2 HASTE (A) in a patient with CD with fever and abdominal pain. Axial DWI (B) in the same patient shows focal fluid collection with restricted diffusion (arrow). Corresponding ADC map (C) confirms diffusion abnormality. Abscess was found at surgery.

Classic extraluminal imaging findings such as fibrofatty proliferation and prominence of the vasa
recta ("comb sign") are as well illustrated with MRE as with traditional imaging modalities such as CT (Fig. 18). Patients suffering from Crohn disease often are affected by perianal fistula. Acquisition of a three dimensional isotropic fat suppressed T2-weighted sequence centered in the midline pelvis allows for exquisite evaluation of fistula. Fistula should be described as intersphincteric or transphincteric depending on their course (Fig. 19). Location of a fistula is best described with reference to a clock face as the patient lies in a dorsal lithotomy position (i.e. 12 o’clock is the anterior aspect of the anorectum and 3 o’clock is the patient’s left side).

Figure 18. Axial T1 VIBE (A) showing fibrofatty proliferation (arrow) in the ileocecal region in a patient with CD. Axial T1 VIBE (B) in a different patient showing prominence of the vasa recta (arrow).

Figure 19. Curved plane coronal reformat of T2 SPACE (A) in a patient with CD reveals a left intersphincteric fistula (arrow). Coronal T2 SPACE (B) in a different patient shows a right-sided transphincteric fistula (arrow).

Summary

MR enterography is an elegant and efficient means to image inflammatory bowel disease. The inherent tissue contrast of MRI makes MR enterography the modality of choice for the depiction of extraluminal processes such as fistula or abscess formation. The lack of ionizing radiation and superior image quality more than offset the increased time and cost associated with MRE compared to CT or fluoroscopic studies. The ability to evaluate the entirety of the small and large bowel in addition to the noninvasive nature of the exam makes MRE a desirable alternative to endoscopy. MR enterography can be performed with conventional scanners and will be quickly adopted by radiologists familiar with conventional imaging techniques for IBD. In pediatric patients with suspected or known inflammatory bowel disease, MRE should be considered the imaging modality of choice.

References

10. Fuchs Y, Markowitz J, Weinstein T, Kohn N, Choi-Rosen J, Levine J. Pediatric inflammatory bowel disease and imaging-related radiation: are we increasing the likelihood of

Accurate assessment of bone density in the pediatric patient differs significantly from bone density assessment in adults and is essential for preventing misdiagnosis and unnecessary treatment. This article reviews current indications, technique, and accurate interpretation of pediatric dual energy x-ray absorptiometry (DXA). Specifically, current methodology for acquisition of pediatric DXA, guidelines for precise and meaningful interpretation of results, and the most comprehensive pediatric normative database compiled to date, as well as its implications for DXA interpretation, will be discussed. Case reports will be provided for further study.

Introduction
The medical approach to assessing and managing low bone mineral density in pediatric patients is consistent with the osteopathic philosophy of treating the whole patient. Knowledge of the individual’s overall health, particularly with respect to chronic illnesses and/or risk factors that may predispose to impaired bone health and specific history of fractures, is essential for diagnosing and treating low bone density. Physicians, including radiologists who interpret pediatric DXA, must apply two major concepts: (1) identify current DXA indicators of pediatric bone health; and (2) accurately interpret these indicators for correct description of pediatric bone health. The radiologist’s knowledge of pediatric bone health indicators and accurate and informed interpretation of pediatric DXA results can contribute significantly to the bone health of young individuals over their lifespan.

DXA has traditionally been used to measure pediatric bone mineral density (BMD) and bone mineral content (BMC) and is still considered the gold standard for assessing and monitoring of pediatric bone health. The measurement of BMD and BMC in growing subjects, however, presents a unique set of challenges, both technical and theoretical. Technical challenges relate to the patient’s positioning, the performance of the bone scan, and the analysis of data. Theoretical challenges are related to the identification of a suitable control population for the growing skeleton and to the interpretation of results to determine whether the patient’s bone status can be considered “normal.” The interpreting clinician must be aware that reportable measures and description of pediatric bone density differ significantly from adult DXA measures and reporting, as will be discussed in more detail, and that the diagnosis of osteoporosis in children and adolescents cannot be made based on densitometric data alone. This article reviews pediatric DXA and its measures as summarized at the 2007 Pediatric Position Development Conference (PDC), held in Montreal, Quebec, Canada, by the International Society for Clinical Densitometry (ISCD).

Indications
According to the ISCD, DXA is an appropriate tool for the monitoring of bone health in apparently healthy children with “clinically significant” fractures and as a part of the comprehensive skeletal health assessment in children and adolescents with disease states associated with an increased risk of fracture (Table). The definition of a “clinically significant fracture” is as follows: long bone fracture of the lower extremities, vertebral compression fracture, or two or more long bone fractures of the upper extremities.

Epidemiologic studies indicate that the incidence of fractures, particularly forearm fractures, has shown an upward trend in children with 27-40% of girls and 42-51% of boys sustaining...
at least one fracture during growth.\textsuperscript{1} Of these individuals, up to one-third will sustain more than one fracture.\textsuperscript{6-9} Pediatric fractures occur most commonly in the peripheral skeleton, with some reports that forearm and wrist fractures are associated with low bone density in children.\textsuperscript{8-14} Still, these epidemiologic studies and other similar reports are insufficient for reliable or conclusive stratification of how BMD relates to fracture risk in growing children based on DXA bone density measurement alone.\textsuperscript{1} Though evidence does support the relationship between lower bone mass and increased fracture risk in apparently healthy children, there is less direct correlation between DXA results and fracture risk in pediatric patients than in adults. Consequently, the ISCD has concluded that in children and adolescents neither a diagnosis of osteoporosis nor associated fracture risk can be made on the basis of densitometric data alone, in contrast to how DXA data is utilized in the adult population.\textsuperscript{1}

<table>
<thead>
<tr>
<th>Disease States Associated with Increased Risk of Low BMD and/or Fracture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary Bone Disease</strong></td>
</tr>
<tr>
<td>Osteogenesis Imperfecta (OI)</td>
</tr>
<tr>
<td>Idiopathic Juvenile Osteoporosis</td>
</tr>
</tbody>
</table>

| **Secondary Bone Disease**                       |
| Chronic Illness / Inflammatory Diseases         |
| Cystic Fibrosis                                 |
| Gastrointestinal disease (IBD, celiac disease)  |
| Juvenile idiopathic arthritis                   |
| Endocrine disorders (e.g., diabetes mellitus)   |

| **Medical Therapies**                            |
| Glucocorticoids                                 |
| Anti-epileptic drugs                            |
| Chemotherapeutic agents                         |

| **Immobilization States**                        |
| Cerebral palsy                                  |
| Muscular dystrophy                              |
| Other neuromuscular disorders                   |

| **Inadequate Nutrition**                         |
| Anorexia Nervosa                                 |

Table. Disease States Associated with Increased Risk of Low BMD and/or Fracture.

### Technical Aspects

**Principles of operation.** DXA technique relies on the differential absorption of x-rays of two different energy levels to distinguish tissues of different radiographic density. At low energy (30-50keV), bone attenuation is greater than soft tissue attenuation, whereas at high-energy (greater than 70keV), bone attenuation is similar to soft tissue attenuation. Utilizing this data and a mathematical algorithm, bone mass, soft tissue mass, and bone mineral content can be quantified. DXA quantifies (in grams) the BMD and BMC at various body sites. Unlike other density measurements, however, the DXA-derived BMD is not a true volumetric measure, as it is based on the two-dimensional x-ray projected area of a three-dimensional structure (i.e., areal BMD). The third dimension, depth, is not directly measured because it is in the same direction of the x-ray. This fact contributes to inherent error in the DXA process (Fig. 1).\textsuperscript{15} In addition, growth of individual bones over time is not uniform in 3 dimensions. Consequently, inherent error caused by serial measurements of aBMD in the growing pediatric skeleton makes comparison of follow-up with baseline DXA studies more challenging to interpret in pediatric patients.\textsuperscript{15-17}

**Figure 1.** Impact of bone size on DXA scan results. Smaller bones (e.g. cube A) will have lower areal BMD (aBMD) despite being equal in volume to larger bones (e.g. cube B). BMC, bone marrow content; BA, bone area; vBMD, volumetric bone mineral density.
DXA performance. Positioning the patient and selecting regions of interest (ROI) require precision by the technologist performing the scan and careful evaluation by the radiologist interpreting DXA results.\textsuperscript{15,18} The ISCD Official Position for DXA performed on children and adolescents (males and females 5-19 years) indicates that when technically feasible, the lumbar spine (LS) and whole body (WB) aBMD and BMC should be performed, as these measures are the most accurate and reproducible skeletal sites for performing aBMD and BMC.\textsuperscript{1} The lumbar spine should be straight and centered in the image, with the last rib pair and the upper sacrum visualized (Fig. 2). The ROIs are generated automatically using edge-detection software and are selected for the L1 to L4 vertebral segments. Artifact, including enteric tubes, orthopedic hardware, and jewelry should be excluded from the image if possible, as artifact contributes to false elevation especially of aBMD numeric results and Z-score for any ROI that includes such objects.

In contrast, the BMC value is not felt to be as affected by the presence of artifacts. If the artifact cannot be removed and obscures the spine, one vertebral body can be excluded and aBMD of the lumbar spine still considered a reliable measure. If evaluation of the spine is not feasible because of extensive orthopedic hardware or patient positioning issues, DXA of the forearm or distal femur may be performed and serve as a surrogate measure of aBMD.\textsuperscript{1,15} In growing children, the hip is not a reliable site for measurement of aBMD given the significant variability in skeletal development and lack of reproducible ROIs.\textsuperscript{1}

Pediatric DXA Interpretation. Z-score vs T-score: As with other laboratory tests, the numeric aBMD and BMC values generated are meaningless without comparison to the appropriate normal controls.\textsuperscript{15} Once a comparison is made to the normative database, as performed by software analysis, the reported pediatric DXA value is given as a percentile or a standard deviation score, the Z-score (Fig. 2). A Z-score of zero is equivalent to the mean, whereas Z-scores of -1 and +1 are equivalent to one standard deviation below and one standard deviation above the mean, respectively. It is important to understand, however, that the normative databases utilized for generation of Z-score vary according to DXA manufacturer. The largest database is that of Hologic systems, in which the most current software includes the normative database for children ages 5 through 23 years, as obtained during the Bone Mineral Density in Childhood Study (BMDCS).\textsuperscript{19}

The T-score that is used in adult interpretation of DXA should not be included in the pediatric DXA report. Because T-score reflects comparison to peak aBMD and BMC in adults, as based on the NHANES III study that incorporates normal values for adults within the age range of 20-85, and provides an indication of bone density loss since early adulthood, its use in children who have not yet reached peak aBMD is meaningless and may result in an inaccurate diagnosis of low BMD and/or unnecessary medical intervention.

Definition of Osteoporosis. As mentioned previously, the diagnosis of osteoporosis in childhood cannot be made, and associated fracture risk cannot be extrapolated, from the pediatric aBMD, BMC or their associated Z-scores as measured by DXA. The 2007 ISCD Official Position Statement dictates that the diagnosis of osteoporosis in children and adolescents cannot be made on the basis of densitometric criteria alone, unlike DXA interpretation in the adult.\textsuperscript{1} Because the World Health Organization’s DXA-based definitions of osteopenia and osteoporosis in adults are based on T-scores, T< -1.0 and T< -2.5, respectively, a different terminology is required for children. The preferred descriptive terminology is as follows. When aBMD or BMC Z-scores are between -1.0 and -1.9, “at risk for low bone mineral density or bone mineral content for chronologic age” is suggested. When aBMD or BMC Z-scores are less than or equal to -2.0, “low bone mineral density or bone mineral content for chronologic age” is suggested.\textsuperscript{1} The term “osteopenia” should never appear in pediatric DXA reports, and the term “osteoporosis” should not appear in pediatric DXA reports without knowledge of clinically significant fracture history. In the
pediatric population, osteoporosis is a clinical diagnosis and is reserved for those patients with a aBMD Z-score less than or equal to -2.0 in combination with a clinically significant fracture.\(^1\)

**Limitations.** In addition to the fact that DXA does not yield a true volumetric measure of bone density, limitations of DXA include (1) different normative reference databases for each manufacturer, which restricts cross comparison between systems and facilities in the case of patient care transfer; (2) the relative contribution of the head and skull to whole body bone density; and (3) limitations of the existing manufacturer normative reference curves that may not account for patient population homogeneity. The different DXA manufacturers (Hologic, Norland, and GE) utilize different pediatric normative database for generation of Z-scores.\(^20\) Software upgrades within one system may incorporate newer and more up-to-date normative reference data, so it is prudent for the interpreting radiologist and clinician to know which DXA system and software are installed within the facility and which normative reference database is current for the software type. Since normative reference databases vary according to DXA manufacturer and software, data from two different systems cannot be simply interchanged in the case of patient care transfer to or from another facility (i.e., site specific aBMD and its interpretation as measured by Hologic may vary compared to aBMD as measured by Norland). There are, however, software programs with calculators available for purchase that can convert site specific aBMD from one DXA scanner to the next.

Though LS and WB aBMD and BMC are considered the gold standard measures for initial assessment and follow-up of bone density, the current ISCD Position prefers total body less head (TBLH) aBMD or BMC. Using this technique, the calvarium is excluded from whole body measures due to (1) the high contribution of the relatively static head to WB aBMD and BMC during growth of the remainder of the axial and appendicular skeleton and (2) the importance of the postcranial skeleton in fracture risk assessment. Current reference data curves utilized by Hologic, however, are from the BMDCS, a large national cohort of children for whom standardized DXA measurements were obtained and from which standardized normative reference curves for aBMD and BMC of the total body to include head, lumbar spine, forearm, and proximal femur for children aged 7-17 years were generated. Therefore, although TBLH aBMD and BMC are suggested as the gold standard whole body measures, most software versions currently in use reflect inclusion of the head in total body aBMD and BMC Z-scores.

Another limitation of current DXA relates to the homogeneity of current normative reference curves, from which the Z-score is extrapolated from age matched controls based only on age and sex. There is, however, ongoing effort to further stratify normal reference curves based on height and ethnicity. For example, as greater aBMD and BMC levels in black versus non-black adults and children have been reported in prior studies using DXA, Zemel et al most recently generated extended black versus non-black normative reference curves for aBMD and BMC of the total body to include TBLH, LS, hip, and forearm following a multicenter longitudinal study.\(^19\) These new reference curves provide the most robust normative databases to date, provide some adjustment factors for height status, and are sure to be incorporated into next generation DXA software upgrades. Current studies are underway and future work remains to be done with reference to ethnicity and disease specific reference curves in order to facilitate improved characterization of pediatric bone health in specific populations.

**Future Directions for DXA/Comparison to Other Modalities**

The future of DXA includes expansion of reference curves not only for ethnicity and height but also to include larger normative databases for site specific measurement and for specific disease states. Currently, normative reference curves are available for the distal 1/3 radius and at the distal lateral femur for bone assessment in non-weightbearing patients such as those with cerebral palsy, muscular dystrophy, severe scoliosis in whom LS aBMD cannot be reliably measured, and spinal or body orthopedic hardware that falsely
Pediatric DXA, Wil

d elevates WB aBMD and limits accuracy of the data.\textsuperscript{15,21,22} When distal 1/3 radius or the distal lateral femur is measured in these patient populations, a Z-score is generated that can be used to infer risk for low aBMD and BMC at these locations.

Once primarily an investigational tool, peripheral quantitative computed tomography (pQCT) is a low dose CT measure of bone density being used increasingly in clinical practice for more accurate assessment of BMD and BMC. Benefits of pQCT include its ability to provide a true volumetric measurement since it is a three dimensional technique and its ability to distinguish cortical from trabecular bone, the latter of which is eight times more metabolically active.\textsuperscript{23} Disadvantages include the relative paucity of normative reference data for pQCT, as compared to the more comprehensive DXA reference databases, and the higher radiologic dose administered. pQCT also requires specific software algorithms for incorporation into standing CT systems that are not yet widely available. Though normative reference data are available for pQCT measurements of the appendicular skeleton in children, reference data for the axial skeleton are lacking. Radiologic dose of pQCT, though decreased by use of low dose CT, should still be expected to be higher than that delivered by standard DXA. The general estimated effective dose delivered to L1-L3 by pQCT is 1.0-1.5mSv\textsuperscript{21} versus an estimated total effective dose of 1 to 10 uSv for an entire DXA exam including lumbar spine and whole body scanning. In comparison, natural background radiation delivers approximately 5-8 uSv per day,\textsuperscript{15} a PA and lateral chest X-ray approximately 50-150uSv, and a diagnostic CT of the neck, chest, abdomen and pelvis in oncologic follow-up approximately 12-14mSv.

Peripheral quantitative ultrasound (pQUS) is less expensive, portable, and relatively easy to use. Although initially promising because it lacks radiation exposure, it is rarely used as a single modality for assessing skeletal health. Normative pediatric databases are even more limited than those for pQCT, and precision and reproducibility of pQUS may never reach that of DXA or pQCT due to much greater operator variability.

Clinical Case Studies

The following case studies are brief examples of common DXA examinations performed at Nationwide Children’s Hospital and illustrate the principles used in DXA interpretation:

Patient 1 is a 14 year old male with myelomeningocele, scoliosis, and a history of femur fracture. His WB aBMD was measured as 1.156 g/cm\(^2\) with a corresponding Z-score of 1.5. According to the manufacturer’s database, which accounts for age and sex, the patient’s WB Z-score indicates normal bone mineral density for chronologic age (Fig. 3a). Given extensive spinal hardware, however, which contributes to false elevation of aBMD and its corresponding Z-score, a distal forearm (FA) study was performed (Fig. 3b). The distal FA aBMD value of 0.408g/cm\(^2\) can be followed longitudinally to evaluate for interval change. Its corresponding Z-score of -1.7 more accurately reveals increased risk for low bone mineral density for chronologic age for this patient.

Patient 2 is a 3 year old non-weight bearing male with a diagnosis of mitochondrial disorder and fracture. Technician notes identify the patient’s G-tube which overlies the left lateral margin of the L4 vertebral segment (Fig. 4a). As the child is just 3 years of age, only a lumbar spine (LS) image was obtained. Because the patient’s G-tube partially obscures the L4 segment, the technician redrew ROIs to exclude this segment (Fig. 4b). Although the patient’s LS Z-score is markedly low both with and without inclusion of L4, note that exclusion of G-tube artifact does alter the Z-score value. Recall that it is acceptable practice to exclude one vertebral body segment in the case of confounding artifact in order to increase accuracy of data.

Example scanning technique

**Nationwide Children’s Hospital DXA Examination.**

The typical scan includes the lumbar spine, total left hip, and total body for all patients. For children younger than 12 years, the hip is not scanned because of lack of well-controlled norms; in these patients, only scans of the whole body and lumbar spine are performed. In patients less than 4 years
Figure 2. DXA Performance. Frontal view of the lumbar spine demonstrates appropriate regions of interest (ROIs) along the margins of the L1 through L4 vertebral bodies. The lumbar spine is straight and centered within the image. The lowest rib pairs and upper aspect of the sacrum are within the field of view.
Figure 3. 14-year-old boy with myelomeningocele. Initial DXA image (A) demonstrates pronounced bony deformities as well as significant hardware throughout the thoracolumbar spine, which falsely elevates the aBMD and corresponding Z-score. Therefore, a distal forearm study (B) was performed, which shows increased risk for low BMD for chronological age.
Figure 4. 3-year-old non-weight-bearing boy with G-tube. Initial DXA (A) reveals a G-tube projecting over the left lateral margin of the L-4 vertebral body. Repeat analysis with exclusion of the affecting segment (B) results in a more accurate measure of BMD with a markedly decreased Z-score for age.
of age, only the lumbar spine is scanned. The manufacturer’s database (Hologic version 12.7.3) includes normative data that extends down to 3 years of age. In patients younger than 3 years of age and in patient populations for whom there is no reference database for generation of a Z-score, the aBMD and BMC of the lumbar spine are reported as absolute values for clinicians to use as baseline measurements and to follow longitudinally over time. For patients with an increased risk of vertebral compression fracture, including those with osteogenesis imperfecta, and patients with known low bone mineral density and known vertebral body fractures, a vertebral morphologic assessment is performed with a lateral scanogram. The distal 1/3 forearm scan is performed in patients with spinal hardware, as well as in non-weight bearing and sarcopenic patients who may have movement disorders such as cerebral palsy complicated by contractures, Duchenne Muscular Dystrophy, and Rett syndrome. The distal lateral femur scan is currently being integrated into our practice for the same patient populations, with current consideration given to the future incorporation of pQCT and pQUS.

Sample DXA Report
Note: the following can be used as a template for voice dictation.

TECHNIQUE
Utilizing [Hologic Delphi] technique and pediatric software analysis, regions of interest were drawn about L1 - L4, the total left hip, and the total body. [He or she] is [x] years of age. Additional technician notes include [e.g., presence of G-tube, VP shunt tubing, spinal or orthopedic hardware].

FINDINGS:
The bone mineral density of the lumbar spine is [x] g/cm2. The corresponding Z-score for this value is given as [z]. (Report T-score if given for patients >20 years of age)

The bone mineral density of the total left hip is [x] g/cm2. The corresponding Z-score for this value is given as [z]. (Report T-score if given for patients >20 years of age)

The total body bone mineral density is [x] g/cm2. The corresponding Z-score for this value is given as [z]. (Report T-score if given for patients >20 years of age)

The total body bone mineral content is [x] grams.

(IF distal 1/3 radius or distal lateral femur values are given, report in same fashion).

(Report lateral scanogram findings, if performed)

The patient has [x]% body fat.

IMPRESSION:
1. Compared to the manufacturer’s database which accounts for age and sex, the patient’s bone mineral density is ...[at risk for low bone mineral density for chronologic age (if Z-score is between -1.0 and -1.9)] or [low for chronologic age (if Z-score is < or = -2.0)]
2. When compared to the prior study, absolute values for bone mineral density as measured at [x] site have [increased/decreased].
3. When compared to the prior study, absolute value for the patient’s whole body bone mineral content have [increased/decreased].

Final Recommendations
Radiologists are assuming a more prominent role in pediatric DXA performance, interpretation and research, necessitating expertise with DXA as a radiologic procedure, a numeric result, and a clinical diagnostic examination. The radiologist who interprets pediatric DXA can be an advocate for children’s bone health and, by ensuring the appropriate clinical use of DXA, can contribute significantly to the bone health of young individuals over their lifetime.

References
Ultrasound Guided Removal of an Intratendinous Foreign Body in an Adolescent

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Department of Radiology, Nationwide Children’s Hospital, Columbus, OH

Case Presentation:
Our patient was a 13-year-old boy who presented to the emergency department with a 15 mm laceration to his left forearm that he sustained earlier in the day while “chopping wood and metal” with his father. A radiograph of the forearm was obtained which demonstrated a 1.3 x 0.7 x 0.5 cm metallic foreign body (FB) within the soft tissues of the distal forearm (Fig. 1). The patient was then referred to the interventional radiology department for percutaneous removal of the foreign body. Ultrasound (US) of the area was performed in the interventional suite which showed the FB to be located within the flexor digitorum tendon sheath (Fig. 2). Under realtime US guidance, 10 ml of lidocaine HCl 1% local anesthestic was injected in the operative field to the level of the flexor digitorum tendon. Under realtime US guidance, an incision was made in the flexor digitorum tendon sheath with an 11 blade scalpel and a small forceps was introduced into the tendon sheath. With realtime US guidance, the metallic fragment was grasped and removed intact, without fragmentation or injury to the tendon. The skin wound was closed steri-strips. The patient was discharged with oral cephalexin.

Figure 1. AP and lateral views of the wrist demonstrate a metallic foreign body in the volar soft tissues of the distal forearm (arrow).

Figure 2. Sonographic image show the echogenic foreign body (long arrow) within a hematoma-filled tendon sheath (arrowheads). The foreign body is embedded deep to the flexor digitorum tendon (short arrow).
Key Clinical Findings
Laceration with soft tissue metallic FB

Key Imaging Findings
Intratendinous metallic FB with hematoma

Differential Therapeutic Considerations
Observation
Open surgical tenotomy with FB removal
Ultrasound guided wire localization followed by surgical removal
Percutaneous US guided FB removal

Discussion
Soft tissue FBs are relatively common in children.\textsuperscript{1,2} Attempts at blind removal of nonpalpable FBs can be very difficult and are often unsuccessful. Surgical removal often necessitates general anesthesia as well as significant time and exploration to encounter and remove the FB. These factors contribute to unnecessary cost and potential morbidity associated with FB removal. With the development of high resolution sonographic techniques, advantages of US localization of nonradiopaque FBs such as wood and plastic have been clearly documented.\textsuperscript{1-4} Ultrasound also offers precise and real time multiplanar guidance of instruments used for blunt tract dissection and fragment removal, preventing unnecessary injury to normal tissue.

In the author’s experience, the majority of FBs are located within the superficial soft tissues and are embedded due to low velocity injuries. Occasionally, high velocity injuries are encountered which can result in FBs within deeper soft tissues including muscles, tendon sheaths, joint spaces, cartilage, bone, and the orbit. Using sonographic techniques, FBs in all of these locations have been successfully and safely removed by our institution by pediatric interventional radiologists. In certain deep tissue situations (in deep muscle compartments, within joints, or a mobile FB within an abscess cavity) US guidance is used for precise administration of local anesthesia and initial access, followed by fluoroscopic forceps guidance for FB removal. Therapeutic options for our patient are discussed below.

\textbf{Observation:} Observation would be an unacceptable option in this patient. FBs, particularly within a tendon sheath can result in pain, tendon injury, and functional impairment. Early and late complications also include infectious and inflammatory reactions such as abscess, tenosynovitis, and chronic granuloma formation.\textsuperscript{2}

\textbf{Surgical Removal:} Surgical removal would require general anesthesia, as well as an open tenotomy and procedure. Open surgical removal of FBs can be challenging, unnecessarily costly, and carries a greater risk of complications.\textsuperscript{2} Surgeons, emergency physicians, and infectious disease specialists at our institution prefer interventional radiological percutaneous image-guided removal of FBs with greater than 98% success rate (and no complications) whenever possible. Open surgical FB removal is reserved for cases in which the interventional radiologist evaluates the FB and determines the FB to be in a location that requires open surgical removal (FB behind an artery, nerve or vein, inaccessible for percutaneous FB removal).

\textbf{Ultrasound guided wire localization followed by surgical removal:} Image-guided preoperative localization can benefit the surgeon, particularly in cases of FBs which can fragment during percutaneous removal. This technique can also be advantageous when the radiologist is uncomfortable with percutaneous removal or access is limited due to FB location (i.e. adjacent to neurovascular bundle). Preoperative localization techniques include providing the surgeon with anatomic coordinates or marking the skin overlying the foreign body site.\textsuperscript{1} Precise localization of the foreign body under ultrasound guidance with a hooked-type localization wire provides excellent surgical support.\textsuperscript{1} In this situation, two wires are recommended, one placed immediately deep to each end of the FB.

This technique was not chosen in this case as the patient would require two procedures, one for wire localization and a second (with general anesthesia) for open surgical FB removal.

\textbf{Percutaneous image guided removal:} Given excellent visualization of the FB with ultrasound,
safe access, and availability of pediatric interventional radiologists competent in US guided FB removal, this approach was selected. The minimally-invasive procedure was performed in an outpatient setting without sedation. The FB was removed intact without tendon injury or other complication.

**Summary**

This unique case highlights the potential for successful percutaneous removal of an intratendinous FB in a child. Although most FBs are located within the superficial soft tissues, US guidance is an excellent modality for safe and successful FB removal in deeper soft tissues. Percutaneous FB removal by radiologists is a minimally invasive and valuable service which can obviate the need for unnecessary open surgical procedures.

**References**

Draining Skin Lesion Following Insect Bite

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Case Presentation

The patient is a 19-year-old male who presented to his pediatrician for evaluation of an insect bite received during a Costa Rican cruise approximately 3 weeks prior. He denied any trauma during the trip, but did notice a small reddened area in his left mid calf several hours following a zip-line tour while on shore. On physical examination, there was a small area of erythema with a small open area centrally which was spontaneously draining serous fluid. A wound culture was performed at his initial office visit, and the patient was placed on a 10-day course of cefdinir. Repeat examination after the full course of antibiotics demonstrated no change to the appearance of the lesion. A repeat culture was performed, and the patient was referred to the Infectious Disease Department at our hospital. Three days following his second visit and before his appointment with the Infectious Disease specialist, the patient experienced severe pain at the site, prompting a visit to a local Emergency Department. A third wound culture was performed, and the patient was again placed on cefdinir. Two days later, the patient presented to a different Emergency Department again with the complaint of severe pain, where plain radiographs demonstrated a small, linear foreign body per the patient’s mother. The patient was placed on a third course of antibiotics, this time DS TMP/SMX, with no change in his symptoms.

The Infectious Disease specialist referred the patient for an ultrasound (Fig.) to evaluate for abscess or retained soft tissue foreign body. Of note, the patient had no other symptoms other than pain at the site.

Figure. Longitudinal US images (A and B) demonstrate a highly echogenic lesion (A) which causes dense posterior shadowing. There is a characteristic contour with a hypoechoic tract leading towards the skin surface (B). Transverse image (C) again shows the contour and echogenicity of the lesion and posterior shadowing. Doppler image (D) shows intense flow centrally.
Key Clinical Finding(s)
Draining skin lesion after insect bite

Key Imaging Finding(s)
Superficial lesion with a dermal tract

Differential Diagnoses
Abscess
Foreign body reaction
Lymphadenopathy
Furunculosis
Furuncular myiasis
Ruptured epidermoid cyst

Diagnosis
Furuncular myiasis

Discussion
The most common cause of a superficial inflammatory lesion with drainage to the skin is an infection, described as abscess, boil, furuncle or carbuncle depending on the location and origin of the lesion. However, other causes should be considered in the differential diagnosis of a superficial lesion with a dermal tract, which include foreign body with surrounding inflammatory changes, ruptured epidermoid cyst and parasitic infestation.

Abscess. An abscess is a localized tissue infection comprised of a collection of pus surrounded by inflamed tissue. Skin abscesses are often polymicrobial from normal regional skin flora as well as organisms from adjacent mucous membranes. S. aureus is present in superficial cutaneous abscesses as the only organism in approximately 25% of cases. On ultrasound, abscesses appear as hypoechoic fluid collections with internal debris. There is often a relatively thick capsule with hyperemia. Adjacent inflammatory changes are seen within the surrounding soft tissues.

Foreign body reaction. The most common soft tissue foreign bodies are wood, glass, metal and plastic. On ultrasound, foreign bodies are typically echogenic. Smooth foreign bodies will cause dirty shadowing or reverberation artifact, while those foreign bodies with more irregular surfaces will produce clean posterior shadowing. Some foreign bodies will produce both clean and dirty shadowing. When a foreign body is present for greater than 24 hours, an inflammatory reaction can develop, manifested as a hypoechoic rim on ultrasound.

Lymphadenopathy. Normal and reactive lymph nodes typically have an oval shape and are hypoechoic to adjacent muscles on sonography. They have an echogenic central fatty hilum. With superimposed infection, the normal nodal architecture becomes distorted and phlegmonomatous changes and frank abscess formation can be seen.

Furunculosis. A furuncle, also known as a boil, is an infection involving the hair follicle. These infections are most often caused by S. aureus. They can occur anywhere on hair-covered skin. The infection extends into the subcutaneous tissues through the dermis. The lesion is an inflammatory nodule that forms a pustule through which the hair emerges. When more than one follicle is involved, the infection coalesces, and the lesion is then termed a carbuncle.

Furuncular myiasis. Cutaneous infestation by dipterous (2-winged) larvae is known as myiasis. Furunculoid myiasis is caused by the human botfly Dermatobia hominis. Despite the name, this entity does not represent a true furuncle. The human botfly is endemic in tropical regions of Central and South America and Mexico. Other insects which can cause a similar type of lesion as the botfly include the African tumbu fly and the horse botfly.

The gravid botfly female captures a hemotophageous insect, usually a mosquito or fly, and deposits her eggs onto this insect. This vector insect then transfers the eggs of the botfly onto the host as it takes its blood meal. The increased temperature of the host stimulates the eggs to hatch, and the newly hatched, 1mm (stage 1) botfly larvae then will penetrate the human host’s skin either through the bite site or through a hair follicle within minutes. The botfly larvae will molt...
twice over the subsequent 4-18 weeks. The infestation site will begin to enlarge and will appear as a small boil or abscess, with a small central opening which allows the maggot access to air. As the larva matures into its second and third stages, the human host will often complain of pain and itching, and may be able to feel the larvae as it moves, usually at night.4

The cephalic end of the larva has two hooks, which are able to extend and retract, enabling the insect to feed as it tears the surrounding tissue. The larva attaches itself to the host’s tissues through the concentric, parallel hooks which are found throughout its body. The anterior end of the insect is thicker than the posterior end, and the posterior end also has two additional hooks which keep the skin open to allow the insect to breathe.5 Because the deeper (anterior) portion of the larva is thicker than the smaller more superficial (posterior) end, extraction without treatment is difficult.6

Treatment options include occluding the larval air hole, which can be accomplished by applying adhesive tape, occlusive membranes, petroleum jelly, and even bacon. Once the larva begins to emerge, it can be extracted. The larva can also be surgically excised, or can be allowed to complete its growth cycle and naturally exit the host’s skin when mature (less well accepted by the patient than the previously described treatments).4

Ruptured epidermoid cyst. An epidermal inclusion cyst is a slow growing subcutaneous or intradermal lesion. They are most often found in the hair-bearing portions of the body which include the scalp, face, neck, trunk and back. Less than 10% of these lesions occur in the extremities. These cysts are filled with keratin debris, and are frequently asymptomatic. They can become symptomatic when infected or rupture into the surrounding soft tissues.7 On ultrasound, unruptured epidermoid cysts tend to be circumscribed and hypoechoic with small hyperechoic foci centrally. When ruptured, the margins may be lobulated with adjacent vascularity.

Summary

A superficial subcutaneous abscess is the most common cause of an inflammatory lesion with a drainage tract to the skin’s surface. However, other entities can appear clinically very similar to an abscess and should be included in the differential diagnosis, especially in those lesions that do not demonstrate the expected response to therapy.

Furunculoid myiasis is an unusual infestation in the U.S., but should be considered in the differential diagnosis of any non-healing lesion/insect bite in any patient with history of travel to endemic regions. The ultrasound findings of a very echogenic soft tissue foreign body with marked internal signal on color Doppler is highly suggestive of this diagnosis.

References

**Lingual Thyroid:**
Can you guess why this patient was imaged after routine examination by a pediatrician? The sagittal T1 image demonstrates an isointense to slightly hyperintense round mass at the base of the tongue, which was visualized on physical exam. The appearance and location is consistent with ectopic lingual thyroid tissue. The findings can also be easily made on CT and nuclear medicine I-123 scans. The thyroid gland originates embryologically at the base of the tongue and descends to its normal cervical position during the first 8 weeks of gestation. The foramen cecum is the remaining anatomic landmark that corresponds to the embryologic origin of the thyroid gland. Arrest of normal migration results in deposition of thyroid tissue anywhere along its path of descent. Most cases result in complete arrest with no cervical thyroid tissue identified. The presence or absence of cervical thyroid tissue on imaging studies is pertinent, as it helps determine if and how much thyroid replacement therapy may be required if symptoms require surgical resection.
Choroid plexus papilloma:

This two-year-old boy presented with vomiting and lethargy. Axial pre (A) and post-contrast (B) TI MR images demonstrate a large mass within the temporal horn of the right lateral ventricle with lobulated margins and characteristic frond-like surface projections. There is homogeneous, intense enhancement after contrast administration (B). Associated marked hydrocephalus is noted. Axial unenhanced CT image (C) shows subtle calcifications within the lesion.

Choroid plexus papillomas (CPPs) are WHO grade I tumors which most commonly present in children under 5 years of age. Typical locations mirror the most prevalent locations of choroid plexus, to include the lateral and 4th ventricles. The atria of the lateral ventricle is the most common site in children, while the 4th ventricle is the most common site in adults. These lesions cause hydrocephalus primarily by overproduction of CSF; there is also likely some degree of impaired CSF resorption. CPPs are typically isointense on T1, iso- to hyperintense on T2, and enhance avidly. They are highly vascular with a vascular pedicle and flow voids often visible on T2 sequences. Calcification is seen in ~25% of cases.

Complete surgical resection is curative and recurrences are uncommon. Choroid plexus carcinomas (CPCs) are WHO grade III lesions and are differential considerations for an avidly enhancing intraventricular mass in regions of choroid plexus. CPCs typically demonstrate aggressive characteristics, such as heterogeneous enhancement and parenchymal invasion; however, oftentimes, they may be indistinguishable from CPPs on imaging. Choroid plexus tumors are prone to CSF seeding; therefore, the entire neuroaxis should be imaged prior to surgical intervention.

The views expressed in this material are those of the authors, and do not reflect the official policy or position of the U.S. Government, the Department of Defense, or the Department of the Air Force.
Gorlin Syndrome:
Panoramic dental radiograph (A) in a young girl shows an expansile lucent lesion oriented along the long axis of the mandible with smooth, corticated margins. Several supernumerary, unerupted, and displaced teeth are identified. Non-contrast CT of the head (B) shows calcification of the falx cerebri; additional findings (not shown) included colpocephaly, agenesis of the corpus callosum and bridging of the sella turcica. A coned-down radiograph of the left lower chest (C) demonstrates bifid morphology of left anterior ribs.

Gorlin syndrome, also known as Gorlin-Goltz or Basal Cell Nevus syndrome, is a phakomatosis with an autosomal dominant inheritance pattern. Patients present with multiple basal cell carcinomas, various craniofacial and musculoskeletal anomalies, and an increased incidence of additional neoplasms. Typical craniofacial anomalies include odontogenic keratocysts (A), cleft lip, macrocephaly, bilamellar calcification of the falx cerebri (B), and uncommonly, agenesis of the corpus callosum. Musculoskeletal anomalies include bifid ribs (C), additional rib anomalies (fusion, agenesis), and shortened 4th metacarpals. Lastly, neoplasms which have an increased incidence in patients with Gorlin syndrome include medulloblastomas, ovarian fibromas, and cardiac fibromas. Treatment depends on associated anomalies, and is typically supportive. The severity of the basal cell carcinoma(s) tends to determine the patient’s overall prognosis.

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