MRI of Bone Marrow

R. Paul Guillerman, MD
Professor of Radiology
Disclosure of Commercial Interest

- Neither I or a member of my immediate family have a financial relationship with a commercial organization that may have an interest in the content of this educational activity.
Topics

- Normal Marrow Composition, Conversion and Variants
- Marrow Hyperplasia
- Marrow Infiltration
- Marrow Depletion
Composition of Bone Marrow

- Cancellous trabeculae
- Stromal tissue
- Hematopoietic cells
- Fat

Hwang et al. Skeletal Radiol. 2007;36:913-920
Marrow Signal Intensity on MRI

- Varies with age
  - Largely depends on the proportion of fat
- Best assessed on T1-W images
  - Yellow marrow similar to subcutaneous fat
  - Red marrow equal to or slightly greater than skeletal muscle and intervertebral discs after infancy
Age-Related Red to Yellow Marrow Conversion

3-month-old  10-month-old
Age-Related Red to Yellow Marrow Conversion

6-year-old

16-year-old
Age-Related Red to Yellow Marrow Conversion

- Appendicular to axial
- Distal to proximal
- Diaphyseal to metaphyseal

Chan et al Radiographics 2016;36:1911-1930
Adult Distribution of Red Marrow

- Primarily in the axial skeleton
Physiologic Residual Appendicular Red Marrow

- Spotty or flame-shaped, juxtaphyseal
Slightly higher signal intensity than skeletal muscle on T1-W or PD
Tarsal “Edema-Like” Marrow

- Present in 60% of asymptomatic children and adolescents
- Also common in carpal bones
Tarsal “Edema-Like” Marrow

- Fibrovascular tissue related to microtrauma repair
12-year-old girl with sickle cell disease
Red Marrow Hyperplasia

T1-W

STIR
Red Marrow Hyperplasia

- Conditions with increased hematopoiesis
  - Chronic hemolytic anemia (sickle cell disease, thalassemia)
  - Menorrhagia
  - Obesity
  - Increased oxygen demands or impaired oxygen delivery
    - Smoking
    - High altitude residence
    - Endurance athletics
    - Cyanotic congenital heart disease
17-year-old with right femoral Ewing sarcoma on chemotherapy and GM-CSF
Red Marrow Hyperplasia

- Conditions with increased hematopoiesis
  - Treatment with hematopoietic growth factors
    - G-CSF
    - GM-CSF
    - Erythropoietin
Acute Leukemia

- Diffuse abnormal marrow signal intensity
  - Low on T1-W, high on T2-W FS and STIR
Bilateral symmetry may be misinterpreted as normal.
6-year-old with fever, knee pain and normal CBC

T1-W

STIR
“Aleukemic” or “Subleukemic” Leukemia

- MRI abnormal before leukocytosis or blasts appear in the peripheral blood
“Aleukemic” or “Subleukemic” Leukemia

- Clinical mimic of orthopedic or rheumatologic disorder
8-year-old with history of treated ALL
Relapsed Leukemia

- Well-defined marrow lesions
3-year-old with constipation
Metastatic Neuroblastoma
Solid Tumor Metastases to the Marrow

- Usually multifocal
- Can be diffuse
  - Neuroblastoma
  - Rhabdomyosarcoma
  - Ewing sarcoma
1-month-old with foot right sarcoma, ? metastases
Solid Tumor Metastases to the Marrow

- Easier to detect in yellow than in red marrow
- Lack of signal drop-out in red marrow on out-of-phase T1-W suggests tumor
9-year-old with ALL in remission and knee pain
Osteonecrosis (Avascular Necrosis, Bone Infarction)

- Geographic lesions
- Outer rim of sclerosis, inner rim of granulation tissue or chondroid metaplasia
3-year-old girl with bone pain and fever
ALL with Bone Marrow Necrosis

- Geographic lesions with central hypo-enhancement
- Necrosis of myeloid cells, fat and stroma
Bone Marrow Necrosis

- Distinct from osteonecrosis
  - Preserved bony trabeculae
  - More axial
  - More extensive

- Due to microvascular occlusion
  - Associated with malignancy (especially ALL), sickle cell disease, infection
19-year-old sickle cell disease, acute leg pain, fever

- Infarction detectable by MRI in 1/3 of acute pain crises
19-year-old sickle cell disease, acute leg pain, fever

- Sickle cell disease predisposes to Staphylococcus and Salmonella infection
Sickle Cell Acute Bone Marrow Infarction vs. Infection

- Each can present with pain, swelling, fever, and leukocytosis
- Marrow edema and extra-osseous fluid collections common in both
Acute Bone Marrow Infarction

- High signal intensity lesion on T1-W FS (packed rbc’s increase T1 relaxivity)
Acute Bone Marrow Infarction

- Infarction 50X more common than infection
Malnourished 21-year-old with cellulitis, ? osteomyelitis
“Flip-flop” of the normal pattern of marrow and subcutaneous fat signal
Gelatinous Transformation (Serous Atrophy) of Marrow

- Hematopoietic cell loss, fat cell atrophy, deposition of gelatinous mucopolysaccharides
Gelatinous Transformation (Serous Atrophy) of Marrow

- “Starvation marrow”
- Cachexia (anorexia nervosa, cancer, AIDS), radiation therapy, scurvy
8-year-old autistic boy refusing to walk
Scurvy

- Distinctive gelatinous transformation of the metaphyseal marrow
Summary

- Must be aware of deviations from the normal age-related pattern of red and yellow marrow
- Symmetry and homogeneity are not always friendly
A 3-year-old with refusal to walk and normal peripheral white blood cell count undergoes and MRI of the lower extremities (see images). What is the most likely diagnosis?

A) Leukemia
B) Osteomyelitis
C) Osteonecrosis
D) Metastatic neuroblastoma
SAM Question #1
Correct Answer is A

Explanation:

An MRI pattern of low signal intensity of the marrow on T1-weighted images and high signal intensity of the marrow on STIR images diffusely involving the epiphyses, metaphyses, and diaphyses is most characteristic of leukemia. This pattern may be observed on MRI before the development of peripheral blood abnormalities.

Osteomyelitis and osteonecrosis are focal or multifocal rather than diffuse. Diffuse marrow infiltration by neuroblastoma metastases is less common than leukemia and is typically accompanied by an extraosseous primary tumor.
SAM Question #1

References:


A 9-year-old autistic boy with anemia and refusal to walk undergoes MRI of the lower extremities (see images). What is the most likely diagnosis?

A) Osteomyelitis
B) Leukemia
C) Red marrow hyperplasia
D) Scurvy
SAM Question #2

T1-W

STIR
Correct Answer is D

Explanation:

The MRI findings of bilaterally symmetric bands of edema-like signal intensity of the marrow of the long bone metaphyses with juxta-osseous edema is most characteristic of scurvy. This pattern is due to gelatinous transformation of the marrow from malnutrition, and is reversible with nutritional supplementation.

Osteomyelitis typically involves the metaphyses, but is usually less sharply defined and rarely bilaterally symmetric. Leukemia typically demonstrates a more diffuse pattern of marrow infiltration that involves the epiphyses and diaphyses in addition to the metaphyses. Red marrow hyperplasia associated with hemolytic anemia may involve the metaphyses symmetrically, but should not be associated with juxta-osseous edema or refusal to walk.
References:


Brennan CM, Atkins KA, Druzgal CH, Gaskin CM. Magnetic resonance imaging appearance of scurvy with gelatinous bone marrow transformation. Skeletal Radiol 2012;41:357–360