MRI of Bone Marrow
Radiologic-Pathologic Correlation

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Conflict of Interests

• None
Lecture Objectives

• Discuss MRI marrow techniques
• Review normal bone marrow anatomy
• Describe MR features of normal marrow
• Recognize MR findings of pathologic marrow
Part I: Techniques

- 2 techniques, vary with clinical indications
- Dedicated MRI of limited body part for evaluation of localized pain or to follow focal lesion
- Whole body MRI is used for staging, restaging and surveillance
Basic Pulse Sequences

• Dedicated MRI:
  – T1-Wt, FS T2-Wt, Gd
  – images through area of interest
  – multiple planes

• Whole body MRI
  – STIR only
  – Vertex to toes, coronal plane
Part II: Normal Bone Marrow Histology

- **Red Marrow**
  - cellular, active or myeloid marrow
  - red & white blood cells & platelets
    » (& minimal yellow marrow)

- **Yellow Marrow**
  - inactive or fatty marrow
  - fat cells
    » (& minimal red marrow)
Red and Yellow Marrow: Different Chemical Composition

<table>
<thead>
<tr>
<th></th>
<th>RED</th>
<th>YELLOW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>40%</td>
<td>15%</td>
</tr>
<tr>
<td>Fat</td>
<td>40%</td>
<td>80%</td>
</tr>
<tr>
<td>Protein</td>
<td>20%</td>
<td>5%</td>
</tr>
</tbody>
</table>

MRI appearance of marrow reflects the relative fractions of red & yellow marrow.
PART III: MRI: Normal Marrow

- **Red Marrow**
  - T1: *intermediate* (> muscle < fat)
  - STIR/FS: *intermediate* (> muscle > fat)

- **Yellow Marrow**
  - T1: bright (= fat)
  - STIR/FS: black (< muscle)

- T1: “Fat finder” sequence
- FST2: “Pathology finder” sequence
Normal Marrow

T1

FST2
MR Normal Marrow: Variations in Distribution

- Conversion of red to yellow marrow occurs during growth and development and has a predictable and orderly pattern
- You need to know this to avoid mistakes in diagnosis
Patterns of Marrow Distribution

- Neonate: virtually all red marrow
- Shortly after birth red-to-yellow marrow conversion begins
  - Overall: extremities to axial
  - In a given bone: epiphysis/apophysis → diaphysis → metaphysis
Marrow Conversion
Appendicular to Axial Conversion

Graph showing the percentage of red marrow by age for various bones, including vertebra, rib, sternum, tibia (diaphysis), and femur (diaphysis). The graph illustrates the conversion of appendicular to axial bone marrow as age increases.
Marrow Distribution

- Adult distribution by age 25 years
- From nearly 100% red marrow at birth to 40% red marrow in adulthood

Variations in Marrow Distribution

• Red marrow persists in the proximal humeral and femoral metaphyses

• Red marrow can persist in the proximal humeral epiphyses
  – subchondral, curvilinear focus
  – other patterns are abnormal
Bone Marrow Variations: Vertebral Marrow Distribution

- Yellow marrow around basivertebral vein common in children
- Other patterns common in adults
- Islands of fat can mimic metastases

Summary Key Points: Criteria for Normal Marrow

- Shows expected signal intensities on all image sequences
- Shows expected distribution in the skeleton for patient age
- Is symmetric
- % of fatty marrow increases with age
PART IV: Marrow Pathology

- Reconversion
- Replacement (tumor)
- Depletion (post tx)
- Fibrosis (post tx)
Marrow Reconversion

• Opposite of conversion
• Generally symmetric
• Causes:
  – Chronic anemia
  – Increased $O_2$ needs
    » altitude, athletes, smokers
  – Granulocyte colony stimulating factor
  – Cyanotic heart disease
Reconversion

Axial skeleton responds first, followed by extremities
Reconversion: Sickle Cell Anemia

- Increased red cells
- No fat cells to generate signal
- $T1:=/>\text{muscle}<\text{fat}$
- STIR/Fat sat $T2: \implies \text{muscle} > \text{fat}$

**INTERMEDIATE**
Marrow Replacement

• Implantation of cells in marrow that do not normally exist there

• Follows red marrow distribution
  – Vertebrae > pelvis > femur > skull

• Causes
  – Hematologic tumors-lymphoma, leukemia
  – Metastases
Marrow Replacement: Imaging

- T1 WT: intermediate SI
  - > muscle < fat
- STIR/Fat Sat: very bright
- Can be diffuse or focal
- Predominates in red marrow (axial skeleton)
Review: Hyperplasia or Tumor?

• Distinguishing criteria:
  – Red marrow: orderly distribution
    » Tumor: random distribution
  – Red marrow: usually symmetric bilaterally
    » Tumor: usually asymmetric
  – Red marrow: minimally bright on STIR/FS
    » Tumor: extremely bright
Hyperplasia or Tumor? STIR (or Fat Sat) Images

Red marrow
SI: = or slightly > muscle

Tumor infiltration
SI: >>>>>> muscle
Metastases: Diagnostic Pitfalls

- Osteomyelitis
- Compression fractures
- Trauma
- Marrow infarction
- Reconversion
- Normal variants
Osteomyelitis

- Infection increases marrow cellularity and water content (edema)
- $T_1$: muscle $<$ fat
  - intermediate
- $FS$: $>$ fat (bright)
- Soft tissue edema
Malignant Compression Fracture

- Abnormal signal intensity
- May involve pedicle, posterior element or entire vertebral body
- Convex posterior cortex
- Epidural mass
- Paraspinal soft tissue mass
- Marrow enhancement post gadolinium
Osteoporotic Fracture

- Partial body involvement
  - Usually involves end plate
- Signal of spared marrow is normal
- Thoracolumbar junction
- Clustering of abnormalities
- Thin paraspinal soft tissue mass
- Improves in 6 to 8 weeks
Pathologic and Osteoporotic Fractures

T1-GD MRI
Abn SI
Mass

T1-WT MRI
Nl SI
No mass
Vascular Mediated Disorders: Edema

- Results in increased extracellular water
- Signal changes are those of water
- T1: > muscle < fat
- STIR/FS: bright signal (> fat/ > muscle)
- Regionally limited
- Causes: trauma, inflammation
- Mimics tumor, infection**
Acute Marrow Infarction

• Sequela of
  – marrow packing by tumor
  – treatment (steroids)
• Acute infarction
  – T1: low SI (= or > muscle)
  – FS: high SI (>muscle > fat)
Treatment-related Changes

- Effects of chemo- & radiation therapy
  - Myeloid depletion
  - Myelofibrosis
Fatty Replacement
Marrow Depletion

- Absence of red marrow
- Marrow signal = fat
- T: high signal (bright)
- FS: low signal (dark)
Myelofibrosis

- Marrow replacement by fibrosis
- Low signal all sequences
  - \( \Rightarrow \) muscle < fat
Other Diseases: Low Signal Intensity

- Gaucher disease
  - Marrow replacement by glucocerebrosidase-laden cells
- Hemosiderin deposition
  - Marrow replacement by iron
  - Usually from transfusion therapy
- Paget disease
To Sum It Up........

- Fat is usually bad, but OK in the marrow
- T1: Normal fat is bright
  - Darker is bad
- STIR/FS: Normal fat is black
  - Brighter is bad