Spinal Bone Marrow Diseases

John R. Hesselink, M.D.
Bone Marrow

- **Mineralized osseous matrix.** Contributes little to marrow signal on MRI.

- **Hematopoietic (red) marrow.** Most abundant at birth.
  - Children 60%
  - Adults 30%

- **Fatty marrow**

MRI appearance of marrow is mostly dependant on the relative amount of red and fatty marrow

Evelyne Fliszar, UC San Diego
Bone Marrow Composition

- **Red marrow (Adult):**
  - Stem cells, red blood cells, white blood cells & platelets
  - 40% water
  - 20% protein
  - 40% Fat

- **Fatty marrow:**
  - Fat cells
  - 15% water
  - 5% protein
  - 80% Fat

The different proportions will influence the MR appearance of the marrow.

Cellularity of red marrow varies with age, is highest in infants, and decreases with conversion to fatty marrow.
Bone Marrow: Adult

- Conversion to fatty marrow begins at birth & proceeds from distal to axial skeleton
- Adult pattern by the end of third decade
- Hematopoietic marrow in axial skeleton and proximal metaphysis of humerus and femur
- Process is reversible, if increased demand caused by stress, anemia, or marrow replacement

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History: Newborn male with a mass on the lower back
23 month old Boy

T2 FSE

T1 FSE

T1-Gd-FS
6 y/o Girl

T2 FSE

T1 FSE
13 y/o Girl

T2 FSE  T1 FSE  STIR  GRE
Bone Marrow: MR Signal

**Fatty Marrow:**
- Bright on T1 & FSE T2
- Dark on T2-FS and STIR

**Hematopoietic:**
- Isointense or slightly brighter than muscle or disk on T1
- Isointense to muscle on T2 or STIR
Adult Bone Marrow Pattern

T2 FSE

T1 FSE

STIR
Adult Bone Marrow Pattern

T2 FSE

T1 FSE

STIR
Heterogeneous Bone Marrow
Normal Variation

T1 FSE
T2 FSE
STIR
Heterogeneous Bone Marrow
Normal Variation

T1 FSE
T2 FSE
STIR
Degenerative Disk Disease
Heterogeneous Marrow

T1 FSE

T2 FSE
MR Pulse Sequences

- **T₁ FSE**
  - Good contrast between fatty marrow and lesion

- **PD and T₂ Sequences**
  - Without FS, lack contrast & have low sensitivity

- **STIR**
  - Good fat suppression & high sensitivity

- **DWI**
  - Helpful to assess cellularity

- **T₁ -Gd-FS**
  - Helps characterize T₁ & STIR abnormalities
Bone Marrow Disorders

- Increased red marrow: failure of conversion / reconversion
- Decreased red marrow: marrow depletion
- Iron storage disorders
- Infiltration by abnormal cells, benign or malignant
- Marrow edema
- Bone infarcts
Reconversion from Yellow to Red Marrow

Red Marrow Hyperplasia

- Long standing chronic anemias
- Chronic hemorrhage – dysfunctional bleeding
- Congenital heart disease
- Drug therapies: hematopoietic growth factor during chemotherapy
- Endurance activities, high altitude
- Pregnancy, obesity, smoking

Reconversion will occur in the reverse order, from proximal to distal: axial skeleton before appendicular, proximal metaphysis before distal metaphysis.
Thalassemia

- Congenital disorder of defect in synthesis of one or more of the subunits of hemoglobin
- Gene expression can be homozygous, intermediate, or heterozygous, resulting in various degrees of anemia
- Erythropoiesis is ineffective, expansion of red marrow
- Massive splenomegaly causes splenic sequestration, increasing the anemia
- Iron overload deposited in bone marrow, liver & spleen
Thalassemia

- Red marrow hyperplasia
- Expansion of marrow cavities
- Marrow can have a lower signal on T1w and T2w if iron overload
- Extramedullary hematopoiesis
- Splenomegaly
Sickle Cell Disease

- 0.15% of African-American children in US are homozygous
- Abnormal hemoglobin causes the erythrocyte to become rigid, causing vascular occlusions and bone infarcts
- Abnormal shape causes hemolytic anemia
- Increased risk for osteomyelitis
- Imaging: Abnormal marrow, bone infarcts, H-shaped vertebrae
Sickle Cell Disease

- Combination of hematopoietic marrow and bone infarcts. Abnormal in distribution and signal
- Difficult to differentiate from acute osteomyelitis
History: 41 y/o HIV\(^+\) male with weakness, muscle pain & cramping
- DDx: Opportunistic infection, treatment-related reactive marrow change, lymphoma
History: 52 y/o HIV+ male with fevers for 6 months & back pain

- BM Bx 2 months earlier: hypocellular – no lymphoma
Red Marrow Re-conversion

66 y/o obese woman
Red Marrow Re-conversion

66 y/o obese man

T1 FSE  T2 FSE  STIR
Marrow Depleting Disorders

- Aplastic anemia (idiopathic, toxins, viral infection, drugs)
- Chemotherapy
  - 1st week edema, then increasing fat
  - Partly reversible
- Radiation therapy
  - 1st month edema
  - 2 – 12 months: fatty replacement
  - < 30 Gy – marrow regenerates after 1 year
  - > 30 Gy – irreversible
Spinal Metastases
Post Radiation Changes

- Sharp line of demarcation

- Acute phase: 1-4 weeks, edema

- Subacute phase: 2-12 months, fatty replacement

- Ability to regenerate depends on dose and age
Post Radiation Marrow Recovery

- Red marrow is more sensitive
- Marrow regeneration starts at the end plates of the vertebral body, producing a band-like pattern
Post Radiation complications

- Insufficiency fractures can occur within a few months
- Osteonecrosis, usually diagnosed years after RT
- Radiation-induced neoplasms: osteochondromas, osteosarcomas, malignant fibrous sarcomas, meningiomas
Insufficiency Fracture: 77 y.o. man

Evelyne Fliszar, UC San Diego
Infiltration by Abnormal Cells

- **Benign:**
  - Eosinophilic Granuloma (solitary or diffuse)
  - Gaucher (multifocal or diffuse)
  - Mucopolysaccharidoses
  - Mastocytosis
  - Sarcoidosis
Eosinophilic Granuloma
Langerhans Cell Histiocytosis
Gaucher’s Disease

- Metabolic storage disorder caused by a deficient enzyme
- Accumulation of glycolipids in the marrow
- Decreased T1 and T2w marrow signal
- Preferential involvement of the distal femurs causes *Erlenmeyer flask* deformity
- Marrow infarcts
- Splenomegaly
Sarcoidosis

- Cor T2FS
Marrow Proliferative Disorders

- Polycythemia vera
- Myeloid metaplasia with myelofibrosis
- Multiple myeloma
- Mastocytosis
- Leukemia
- Lymphoma

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Myelofibrosis

- Can be primary or secondary (toxins, irradiation, chemotherapy, leukemia)
- Bone marrow biopsy: increased megacaryocytes, fibrosis, and decreased fat
- Xrays: sclerotic bones
- MRI: Low T1 and T2 signal of the marrow
- Splenomegaly
Myelofibrosis

Sag T1

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Multiple Myeloma

- Malignant plasma cells derived from B-lymphocytes
- Rare before the age of 40
- Monoclonal gammopathies (benign to malignant)
- Plasmacytoma - solitary form
- May be diffuse, simulating leukemia
- Low T1w, variable T2w signal, variable enhancement
- 20% of MRIs can be normal despite diffuse marrow involvement
History: 49 y/o woman with pelvic pain

Dx: Plasmacytoma
History: 65 y/o woman with back pain & progressive leg weakness & gait problem for 2 months
Dx: Plasmacytoma – Multiple myeloma
Multiple Myeloma

Diffuse involvement is not as obvious as nodular involvement and can be easily overlooked.

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Multiple Myeloma – s/p Rx

3 months earlier

Sag T1WI

T1–Gd–FS
Diffuse Multiple Myeloma

Bhatia et al, Chapter 74, in Clinical MRI, 2006
History: 53 y/o woman with back pain & bilateral foot numbness
Dx: Plasmacytoma & Multiple myeloma
History: 32 y/o man with back pain

Dx: Epidural lymphoma
History: 35 y.o. male with back pain
Dx: Multiple myeloma
Multiple Myeloma

Tanenbaum LN, Diffusion imaging in the spine, Applied Radiology, April 2011
Leukemia / Lymphoma

- Lymphoma tends to cause focal marrow tumors, but may be diffuse.
- Leukemia is a diffuse process, but can be more focal and irregular in relapse.
- Diagnosis by MRI more difficult in children, who have predominantly red marrow.
- Chronic leukemia has a more indolent course, with prolonged survival.
Leukemia

Sag T1  Sag T2 FS  T1-FS post contrast

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History: 54 y/o woman with CLL & right foot numbess
Dx: Chronic lymphocytic leukemia
Lymphoma
History: 28 y/o female with back pain & urinary incontinence
Dx: Lymphoma
History: 80 y/o female with 10 weeks of progressive back pain
Dx: Lymphoplasmacytic Lymphoma (Waldenström's macroglobulinemia)
Diagnosed with Lymphoplasmacytic Lymphoma (Waldenström's macroglobulinemia) in 2011

- Low grade lymphoma
- mature plasmacytoid lymphocytes produce monoclonal IgM
- Abnormal lymphoplasmacytoid cells in bone marrow or lymph nodes
- Can be clinically indolent
  - Or fatigue, hyperviscosity syndrome, hepatosplenomegaly
Metastatic Disease

- Low T1w signal
- T2w signal variable depending on cell density.
- Lytic metastases are bright on T2w.
- Sclerotic metastases may be dark, intermediate or bright on T2w.
- “Halo” sign: rim of high T2w signal or rim enhancement on T1w images is very specific.

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Metastatic Squamous Cell CA
History: 72 y/o man with esophageal CA

Sag T1  Sag T2  T1-Gd-FS
History: 70 y/o woman with back pain
Dx: Renal cell CA
History: 64 y/o woman with back pain

Dx: Diffuse Breast metastases
Dx: Diffuse Prostate metastases

History: 62 y/o man with back pain
Iron Storage Disorders

- **Hemochromatosis**
  - A genetic disorder
  - Increased intestinal absorption of iron despite normal dietary intake
  - Increased iron stores in hepatocytes of liver only

- **Hemosiderosis**
  - Hemolytic anemia
  - Multiple blood transfusions
  - Increased iron stores in RE systems of marrow, liver & spleen
  - Can mask signal from other marrow components

- Decreased signal on all MR sequences
History: 54 y/o woman with chronic lymphocytic leukemia, anemia, & s/p bone marrow transplant

Dx: Anemia of chronic disease
Bone Marrow Edema

- Degenerative disk disease (Modic Type I)
- Fracture
- Infection / inflammation
- Tumor
- Reflex sympathetic dystrophy
Degenerative Disk Disease
Bone Marrow Edema

T1 FSE
T2 FSE
STIR
Benign Vertebral Collapse

Osteoporosis

T1 FSE

T2 FSE

STIR
Acute Vertebral Fracture

T2 FSE

T1 FSE

STIR
History: 30 y/o man with neck pain
Dx: IVDA - Staph osteomyelitis
Bone Marrow Transplantation

- For leukemia, lymphoma, metabolic & immune disorders, other malignancies
- High dose chemo & whole body radiation
- Infusion of stem cells to re-populate marrow
- T₁WIs: central fat sandwiched between bands of hypointensity
  - Re-populating hematopoietic cells
  - Progresses to more homogeneous marrow
  - Can simulate recurrent disease
History: 50 y/o man with weakness & numbness of extremities
Dx: Marrow infarct post BMT
In Conclusion...

- Be aware of normal variations of marrow patterns
- T1w and STIR sequences are most useful
- Diffuse marrow processes can be more difficult to detect
- Benign and malignant processes can look very similar