MR Evaluation of Bone Marrow Disorders

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Introduction

- Nearly all imaging modalities evaluate the marrow, which is a site of significant pathology
  - Radiography
  - Nuclear Medicine
  - CT
  - MR

Topics of Discussion

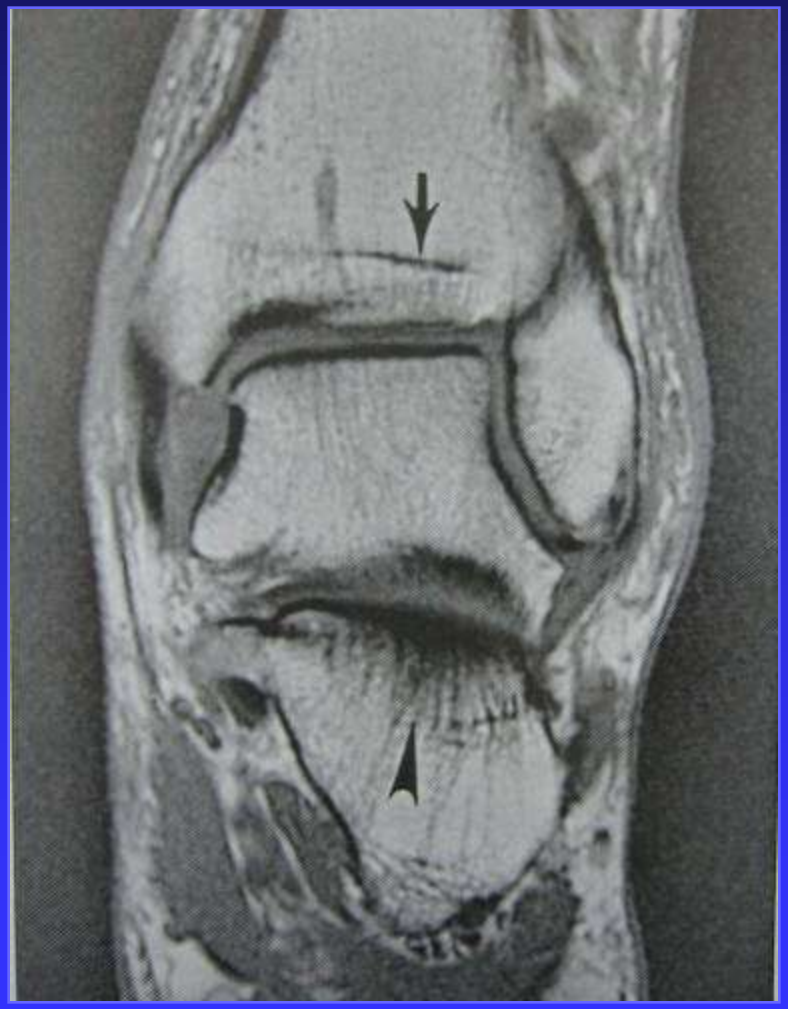
- Normal marrow anatomy and function
- MRI appearance of normal marrow
- Benign and malignant marrow pathology

Normal Marrow Anatomy and Function

- Three basic marrow components:
  - Trabeculae
  - Red marrow
  - Yellow marrow

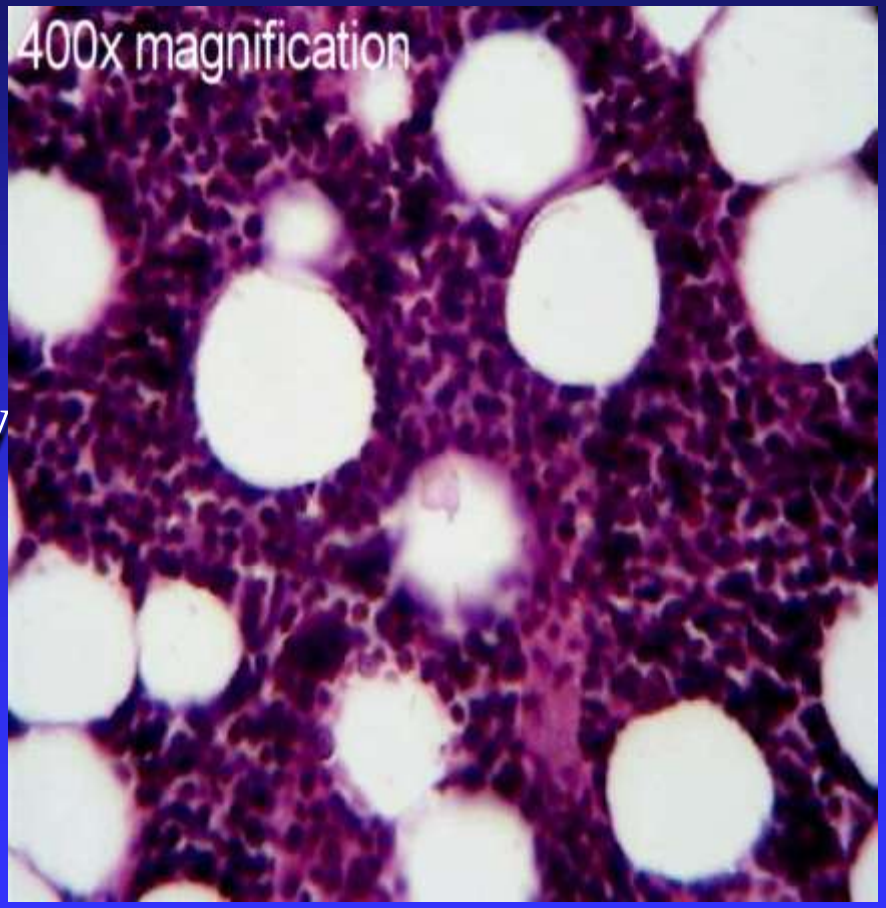
Trabeculae

- Serve as the architectural support for the marrow and as a mineral depot.
- Number of trabeculae decreases with age.



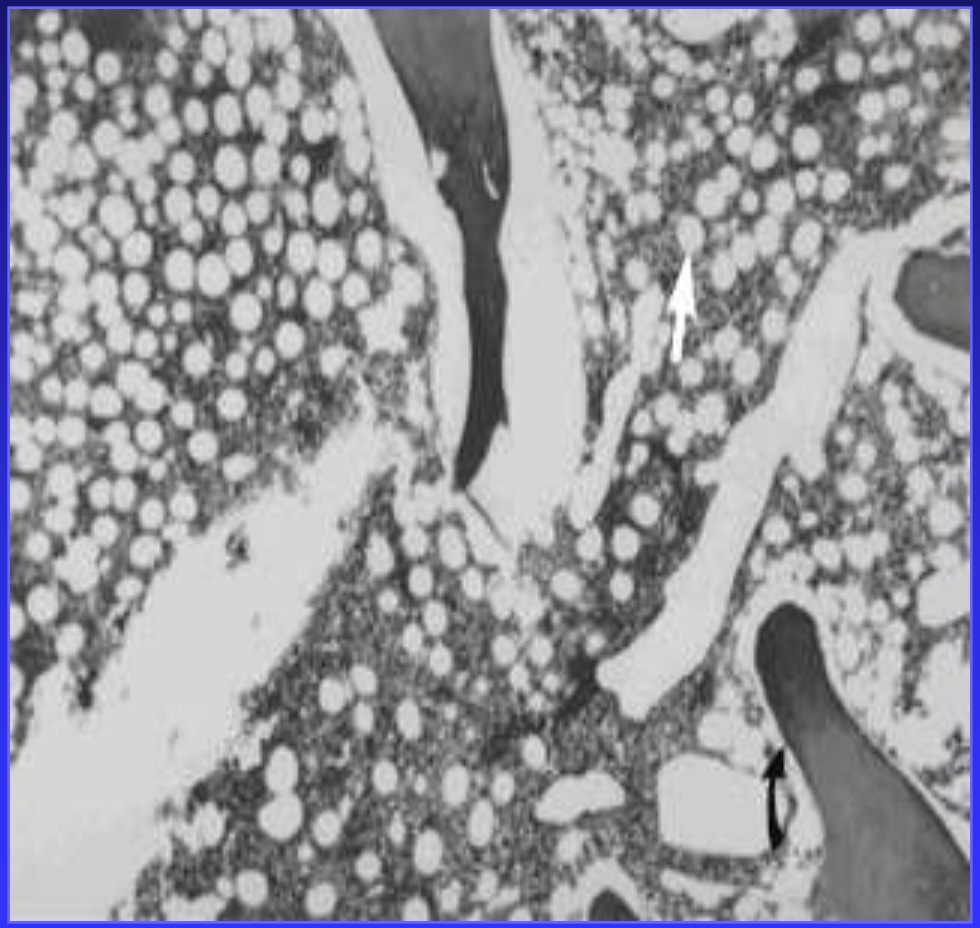
Red Marrow

- Composed of hematopoietic cellular elements (red and white cells and platelets), supporting stroma (reticulum), and rich sinusoidal vascular supply
- Smaller fraction of fat cells (40%)
- It increases if the demand for hematopoiesis increases



Yellow Marrow

- Smaller fraction of red marrow elements.
- Larger fraction of fat cells (>50%)
- Poor vascular supply
- Paucity of reticulum
- Increases with age

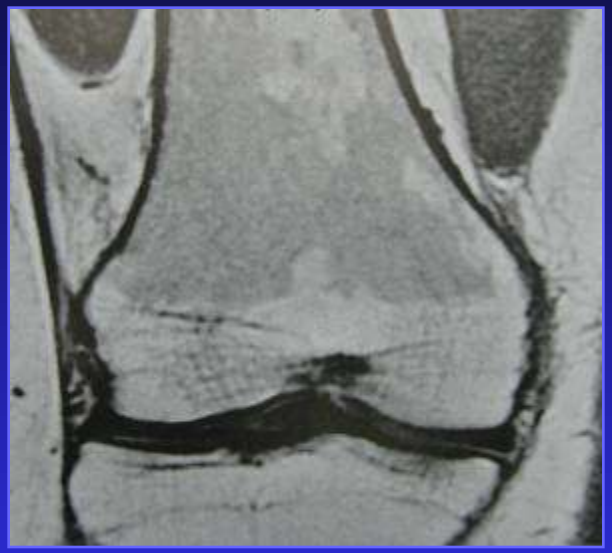


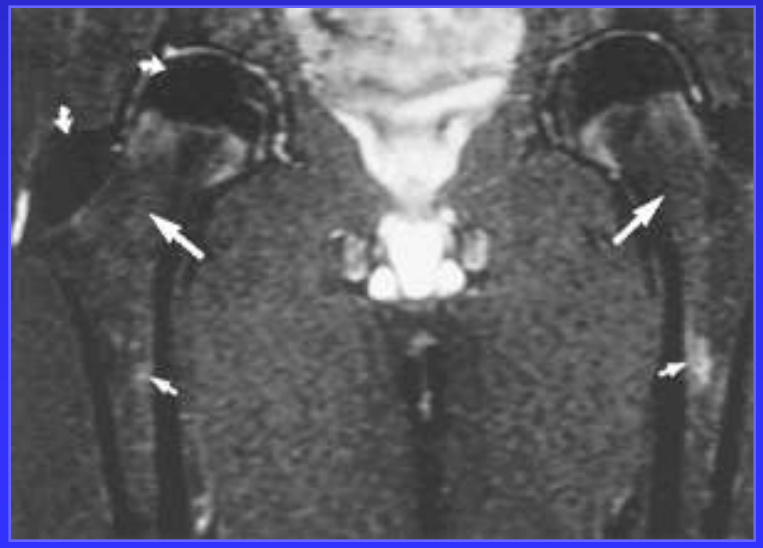
Topics of Discussion

- Normal marrow anatomy and function
- MRI appearance of normal marrow
- Benign and malignant marrow pathology

MRI Appearance of Normal Marrow

- T1W SE and STIR are most commonly used sequences to evaluate the marrow.
- In general, yellow marrow follows the signal intensity of subcutaneous fat, with relatively high signal on T1W images and low signal on STIR images.
- Red marrow follows the signal intensity of muscle and has an intermediate signal intensity on T1W images and STIR images.



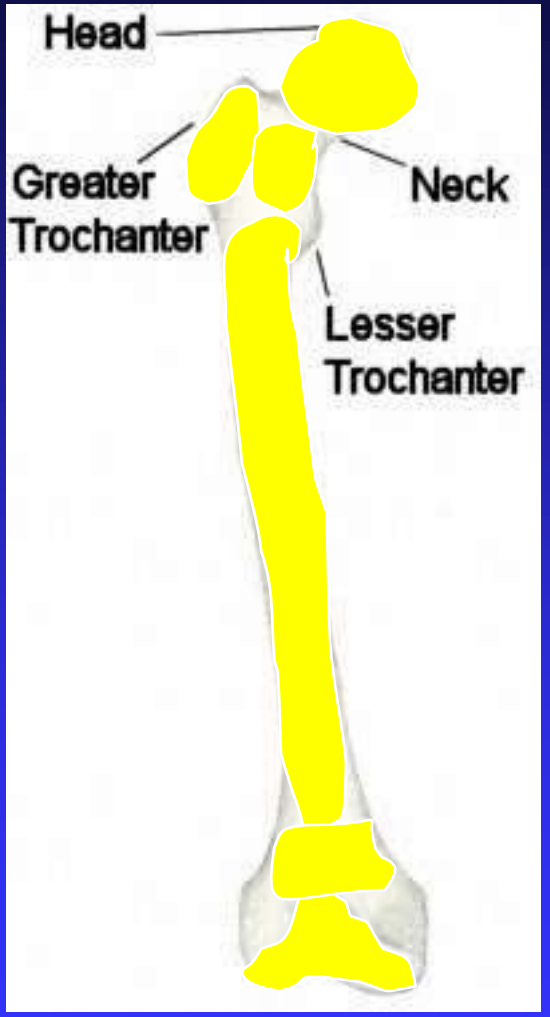


Marrow Conversion

- Amount and distribution of red and yellow marrow changes with time as well as in response to physiologic stresses
- Normal conversion of red to yellow marrow occurs in a predictable and progressive manner
- At birth, nearly the entire osseous skeleton is composed of red marrow.
- Conversion proceeds from the appendicular (distal to proximal extremities) and then to the axial skeleton in a bilateral symmetric fashion.

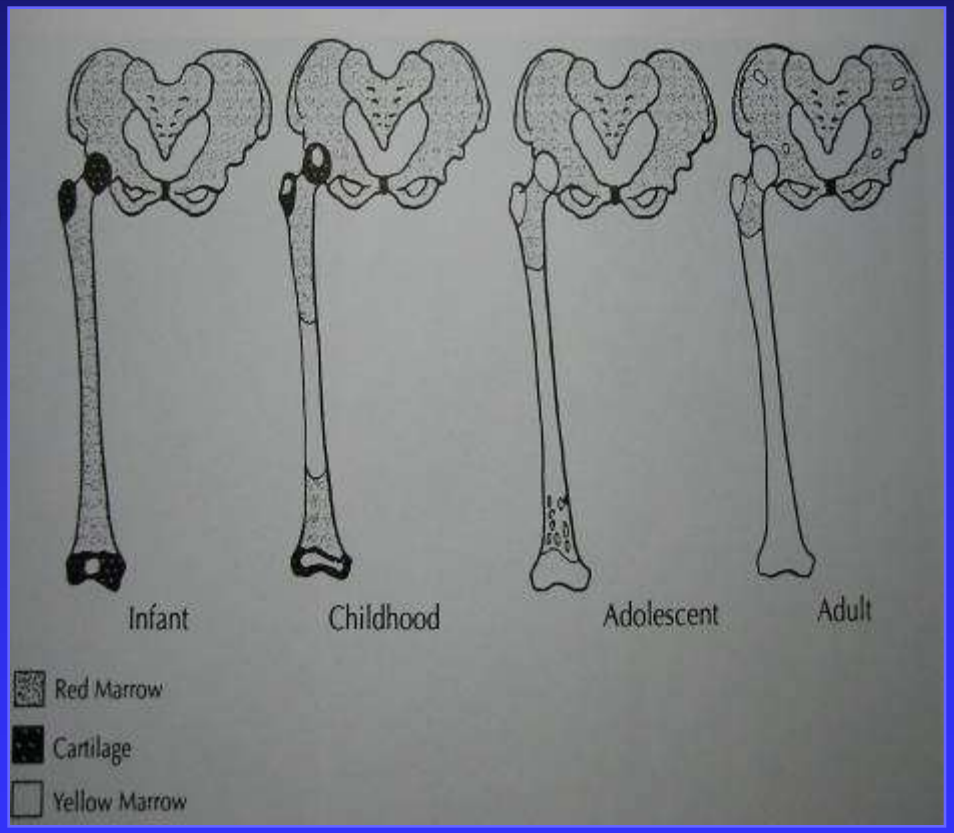
Within an individual long bone, conversion occurs in the following sequence:

Epiphysis and apophysis →
Diaphysis →
Distal metaphysis and proximal metaphysis



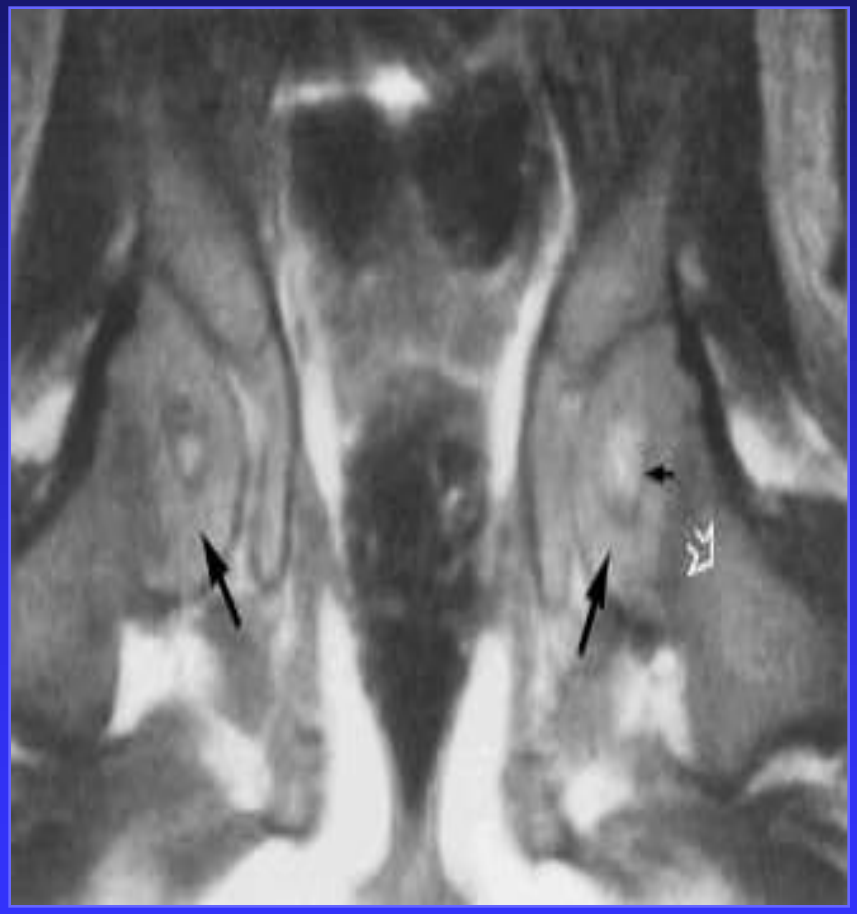
Marrow Conversion in Long Bones

- Infantile (0-1y)
- Childhood (1-10y)
- Adolescent (10-20y)
- Adult (25+)



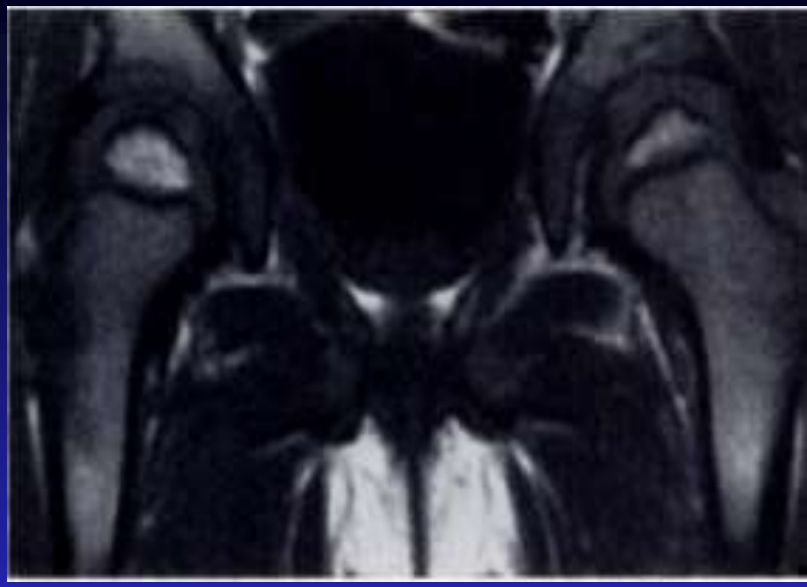
Infantile pattern

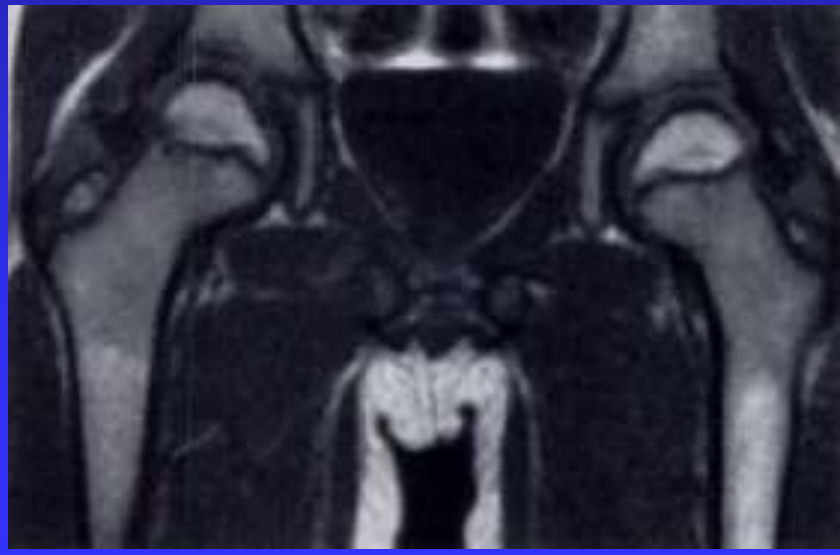
- 0-1 year
- Homogeneous low signal marrow in diaphyses and metaphyses



Childhood pattern

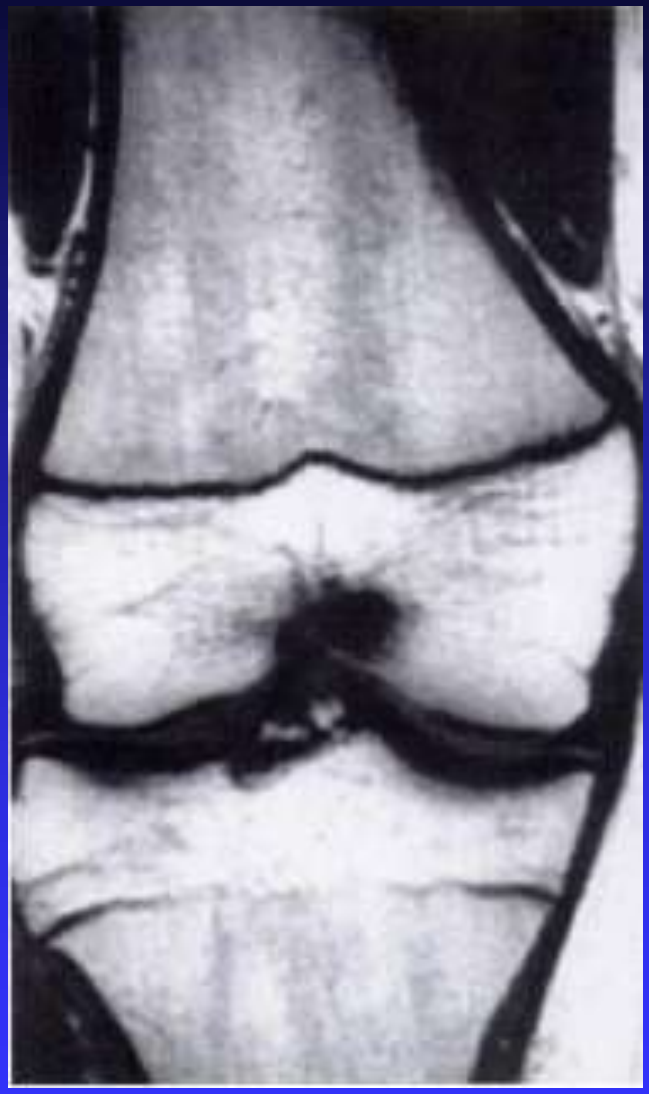
- 1-10 year
- Higher signal in diaphyses and metaphyses representing red→ yellow marrow conversion





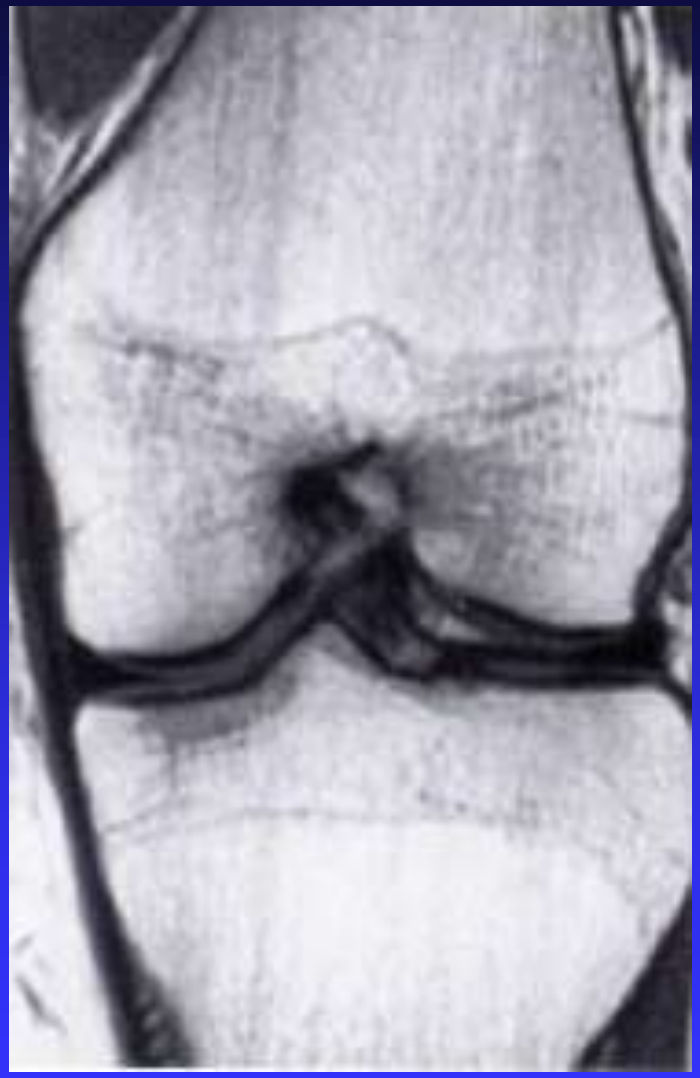
Adolescent pattern

- 11-20 year
- Distal metaphyseal marrow converts to yellow marrow
- Residual islands of red marrow leave a heterogeneous pattern to the metaphyseal marrow



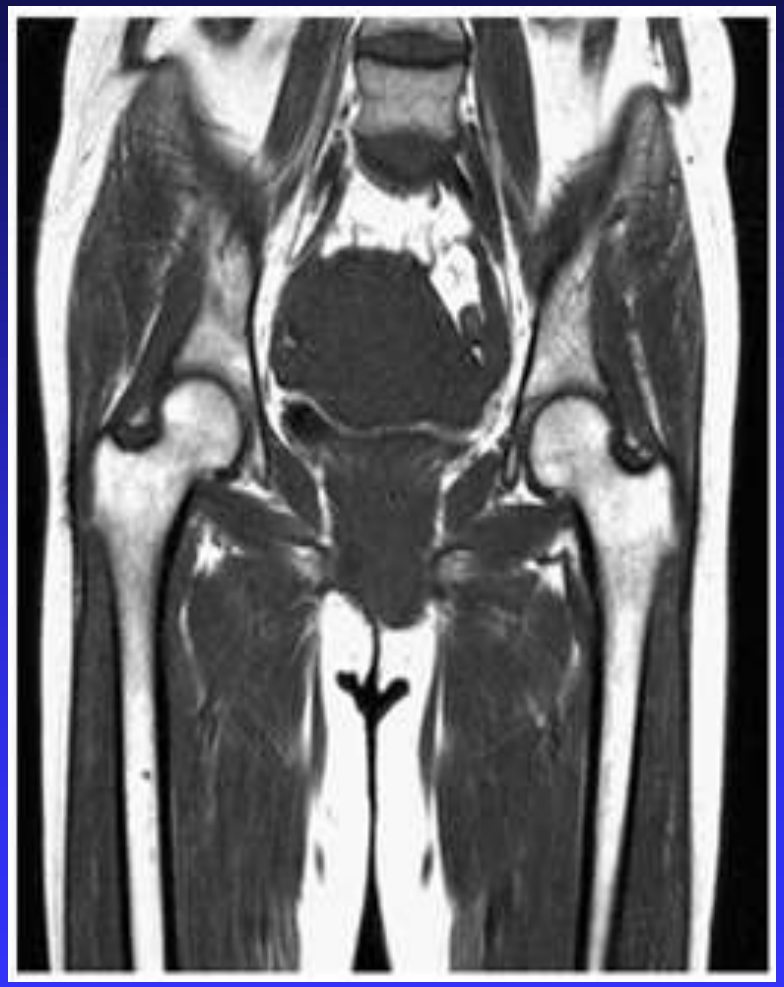
Adult pattern

- 25 years +
- Predominant homogeneous high signal diaphyseal and metaphyseal marrow
- Hematopoietic marrow concentrated in the axial skeleton (skull, ribs, vertebra, sternum, pelvis) and to a lesser degree in the proximal appendicular skeleton (proximal femora and humeri)



Adult pattern

- After adult pattern reached, there is continued and gradual further replacement of hematopoietic marrow with fatty marrow
- Spine and pelvis on T1 in elderly reflect this change



Topics of Discussion

- Normal marrow anatomy and function
- MRI appearance of normal marrow
- Benign and malignant marrow pathology

Bone Marrow Abnormalities

- Two USEFUL variables
  - Distribution of normal hematopoietic marrow
    - Has a characteristic distribution based on age and functional status
    - Thorough knowledge is important as any variation can represent disease
  - Signal intensity
    - Muscle or Disc serve as internal control
    - Normal marrow signal: isointense/hyperintense to muscle or disc on T1W
    - Diseased marrow: hypointense T1 signal compared to the muscle or disc

Marrow Pathology

- Disorders of marrow proliferation
- Disorders of marrow replacement
- Disorders of marrow depletion

- Vascular and Miscellaneous abnormalities

Marrow Proliferative Disorders

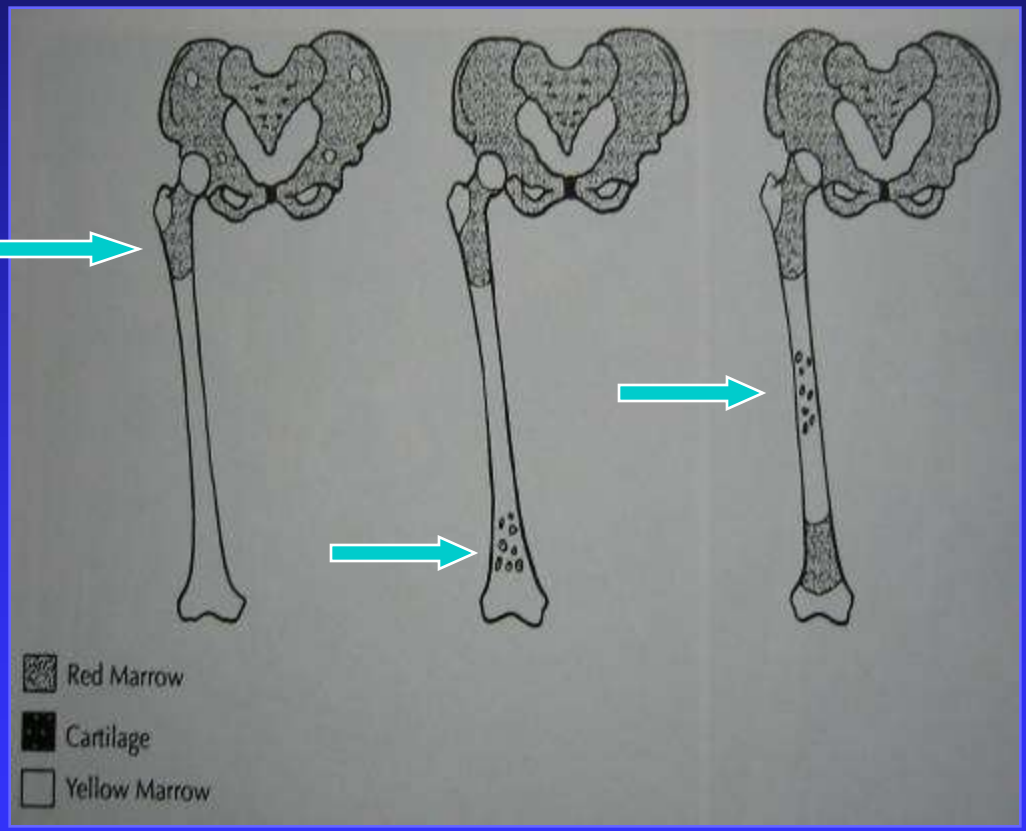
- Arise from the proliferation of cells that normally exist in the marrow
- Involve the marrow in a **diffuse** manner (except for focal multiple myeloma)

Marrow proliferative disorders

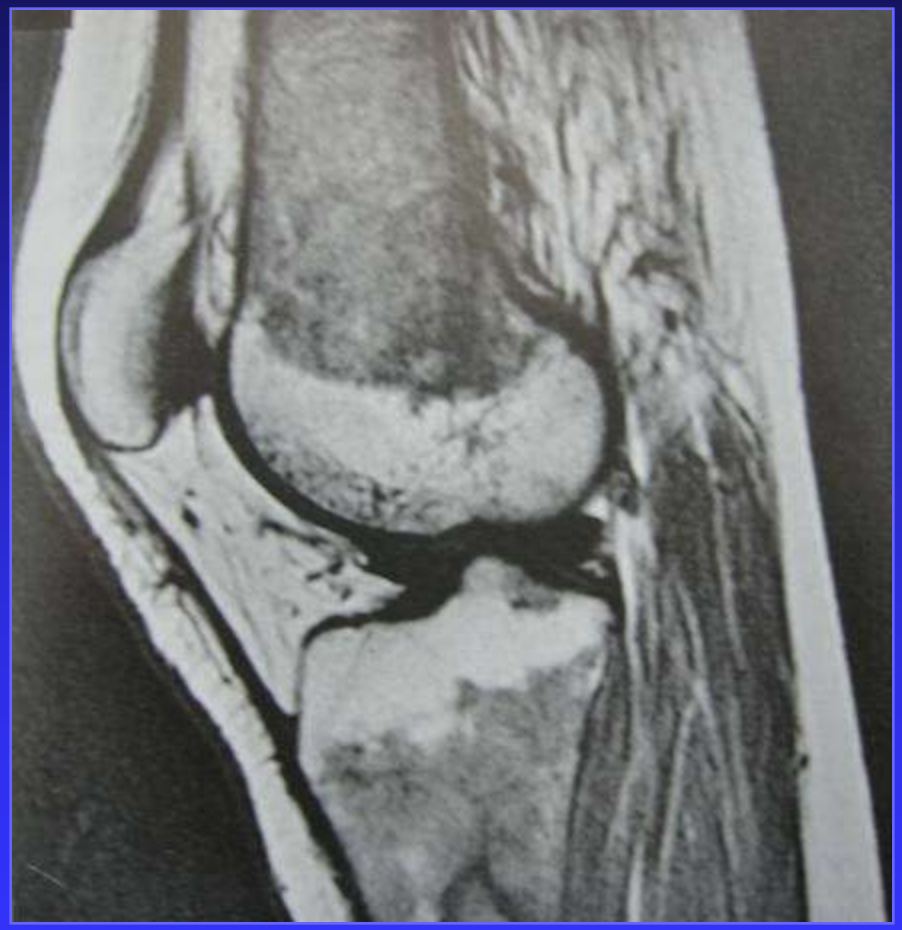
- **Benign**
  - Marrow reconversion
  - Mastocytosis
  - Amyloidosis
- **Malignant**
  - Polycythemia Vera
  - Myeloid Metaplasia with Myelofibrosis
  - Waldenstrom's macroglobulinemia
  - MM
  - Leukemia

Marrow Reconversion

- Reconversion is due to increased demand for hematopoiesis.
- Can be seen in hemolytic anemias, high level athletes, GCSF therapy, smokers, and destruction of red marrow.

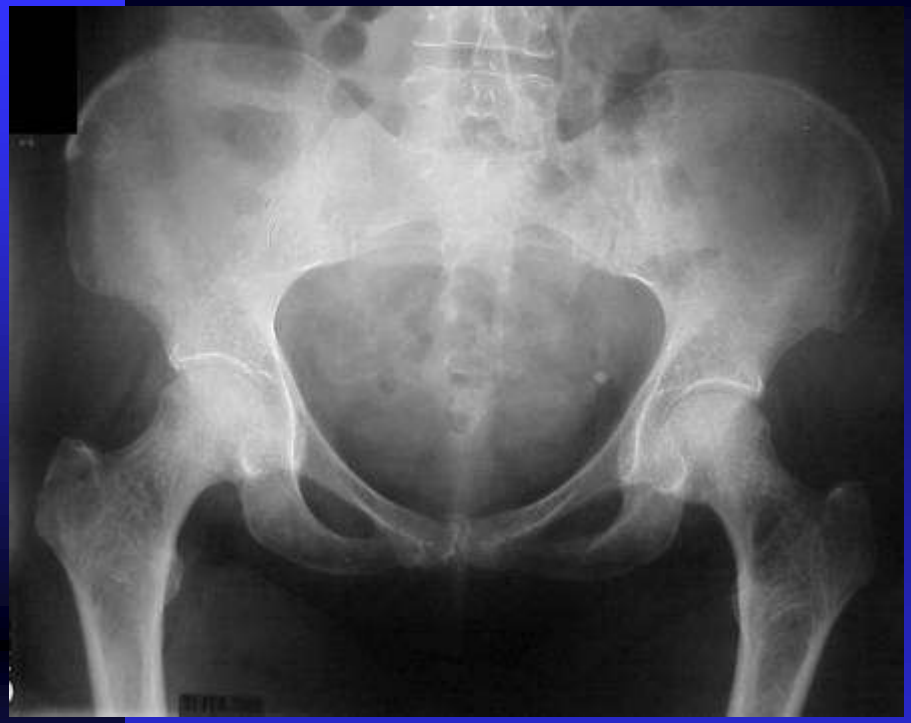


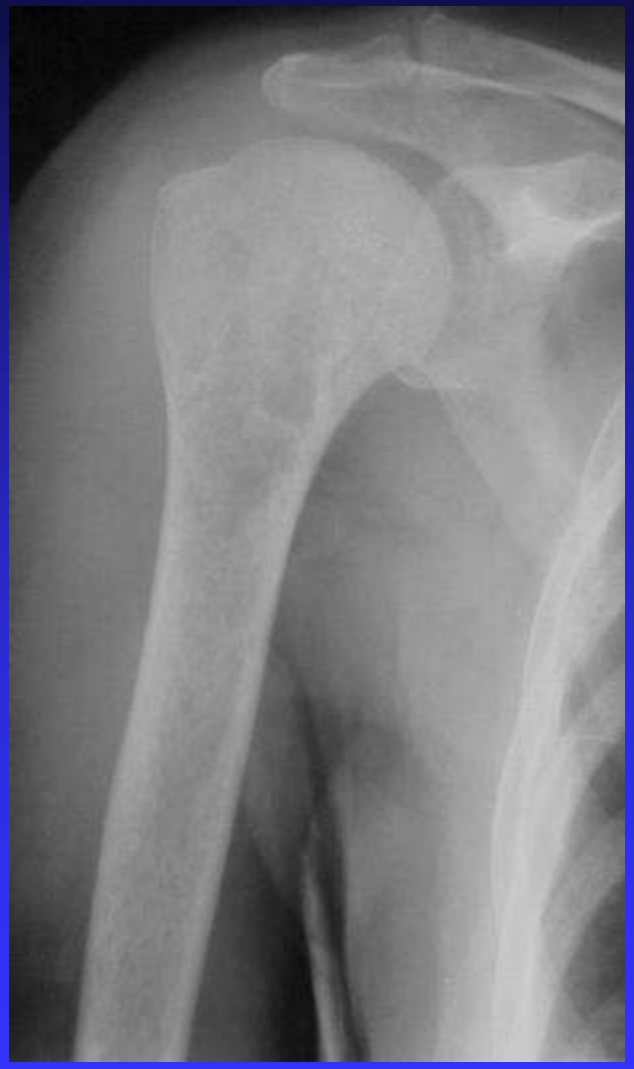
Marrow Reconversion



Mastocytosis

- Rare disorder characterized by mast cell proliferation
- Most commonly occurs as a skin manifestation (urticaria pigmentosa- generally a self-limited dermatologic disorder in children)
- Systemic form rarer and involves the bone marrow and internal organs
- Xrays
  - Lytic or sclerotic lesions in a focal or diffuse distribution
- MR
  - Nonspecific pattern ranging from normal, focally/diffusely heterogeneous
  - Typically involves axial skeleton





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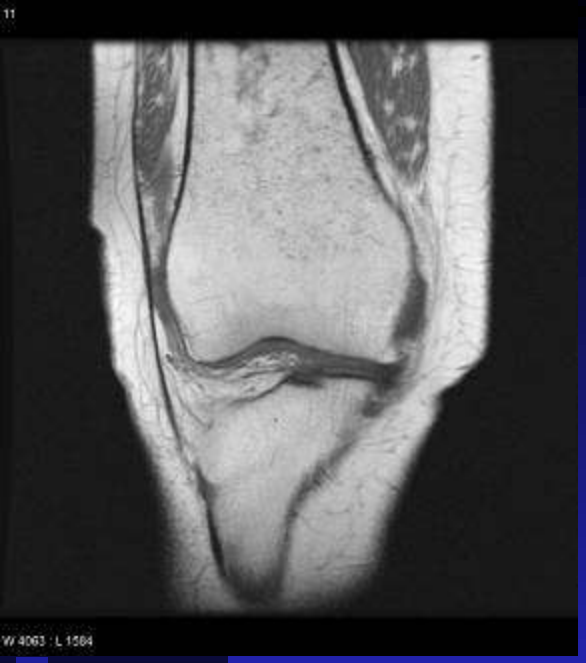

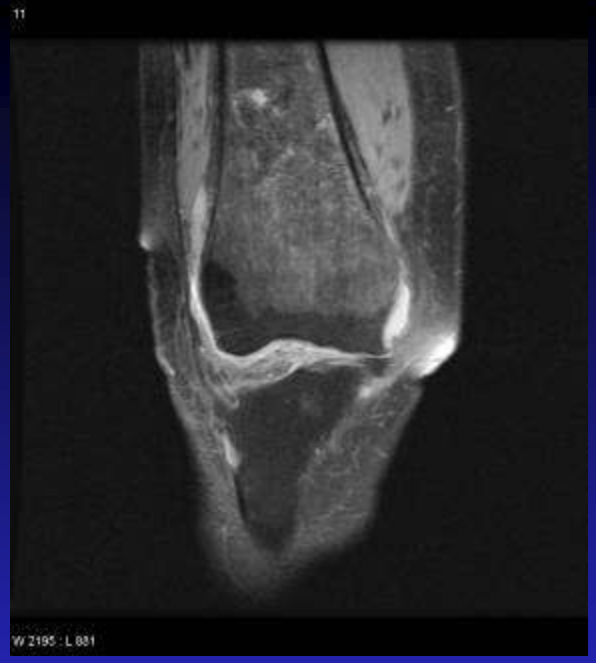

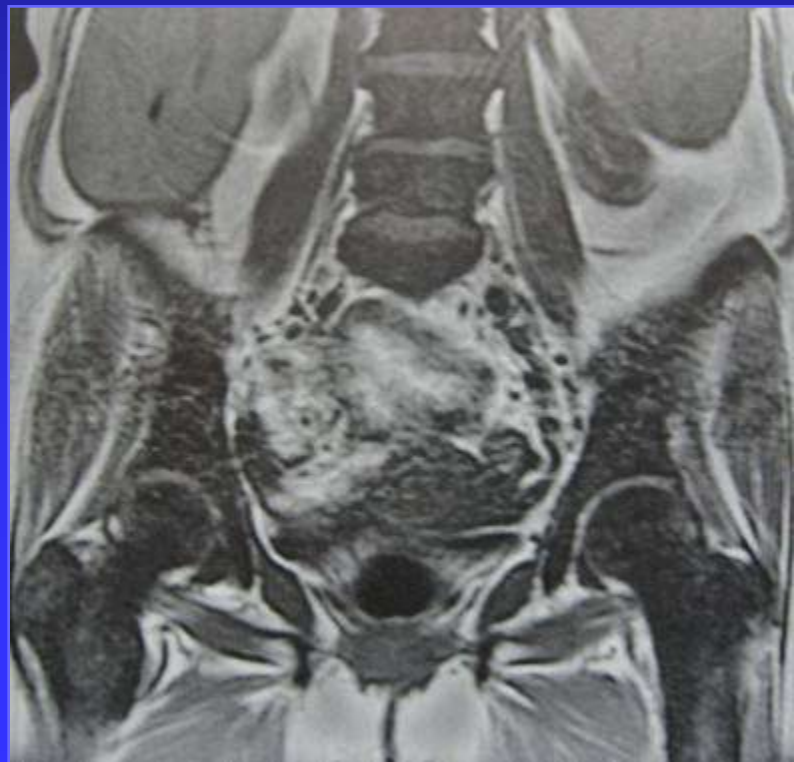

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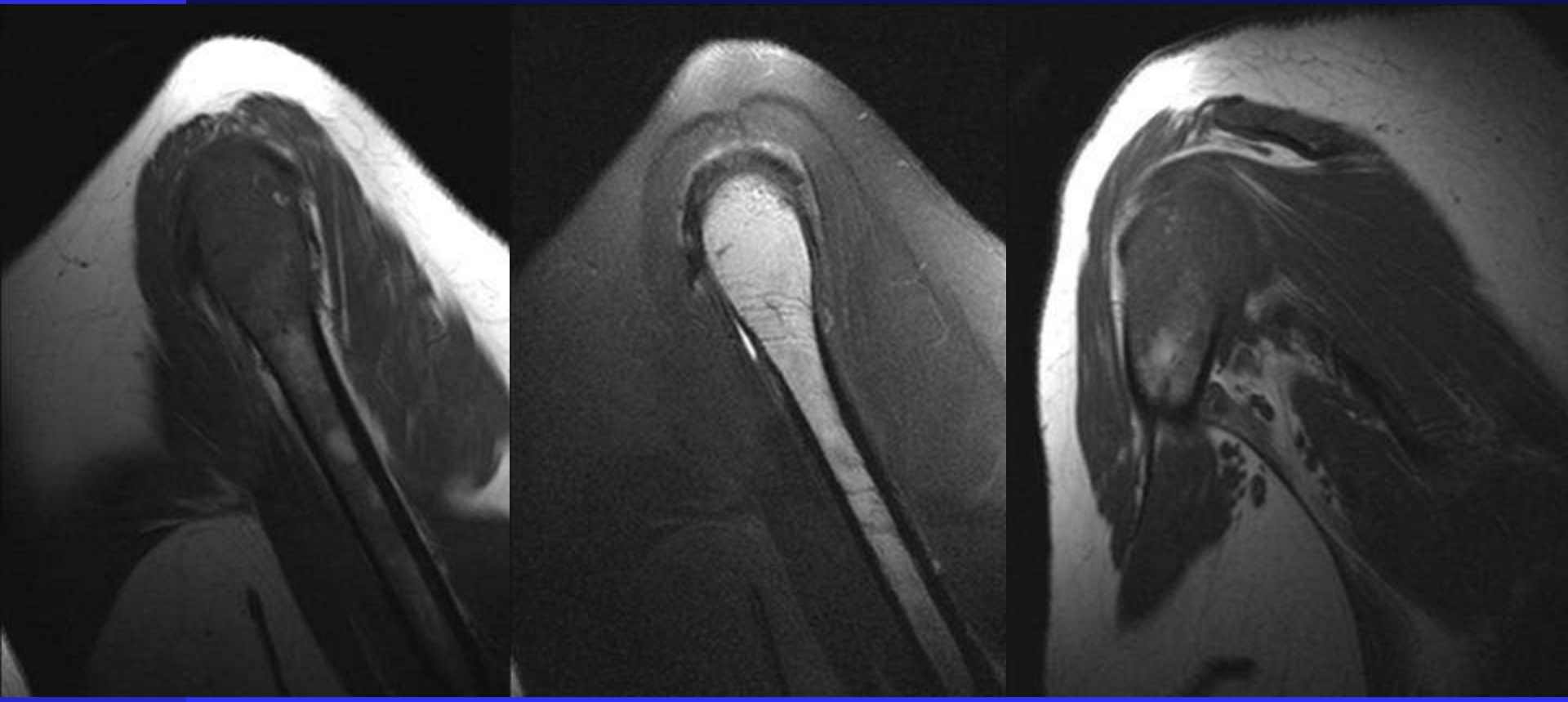
Myeloproliferative disorders

- Group of diseases
  - Polycythemia rubra vera
  - Agnogenic myeloid metaplasia (AMM) (Idiopathic myelofibrosis)
  - CML
  - Essential thrombocytopenia

- Older patients (6th-8th decade)
- Malignant transformation of pluripotent stem cells resulting in expansion of various BM elements
- PV and AMM have similar MR appearance
  - Diffuse intermediate T1 signal
- Myelofibrosis
  - Diffuse/Patchy sclerotic bone
  - Low T1 and T2 signal

Polycythemia Vera



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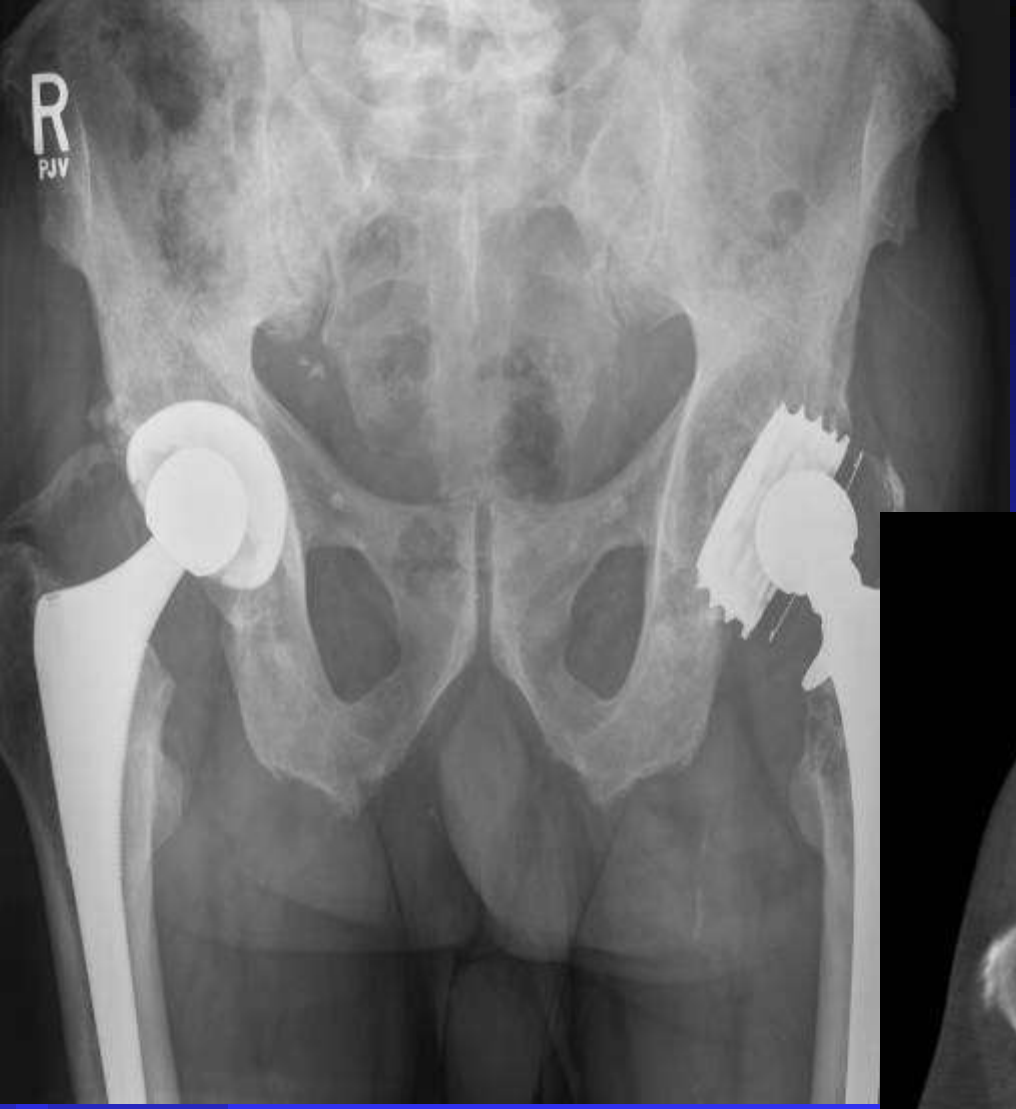
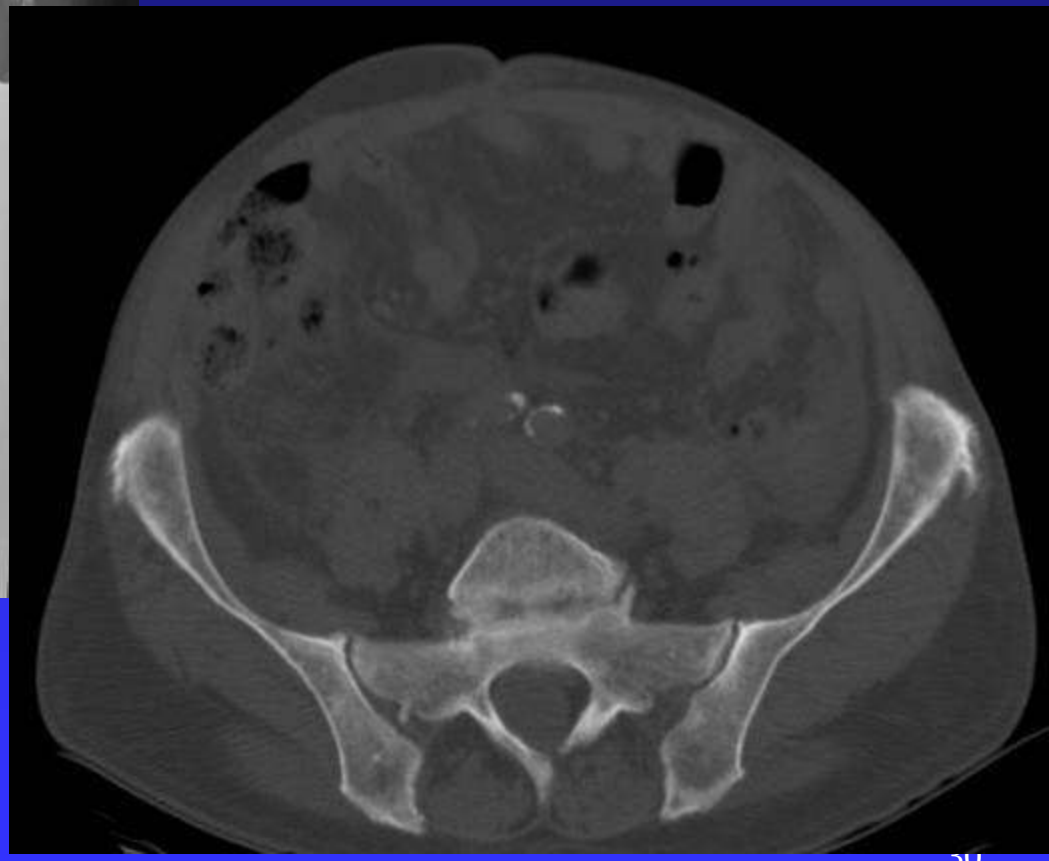
Myelofibrosis





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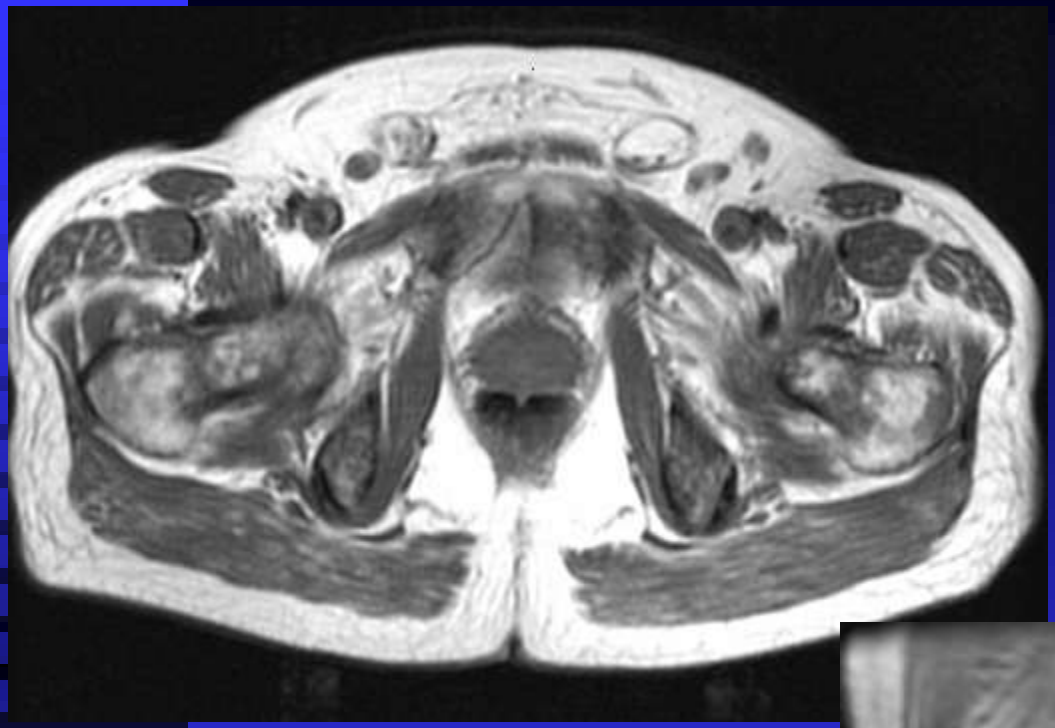
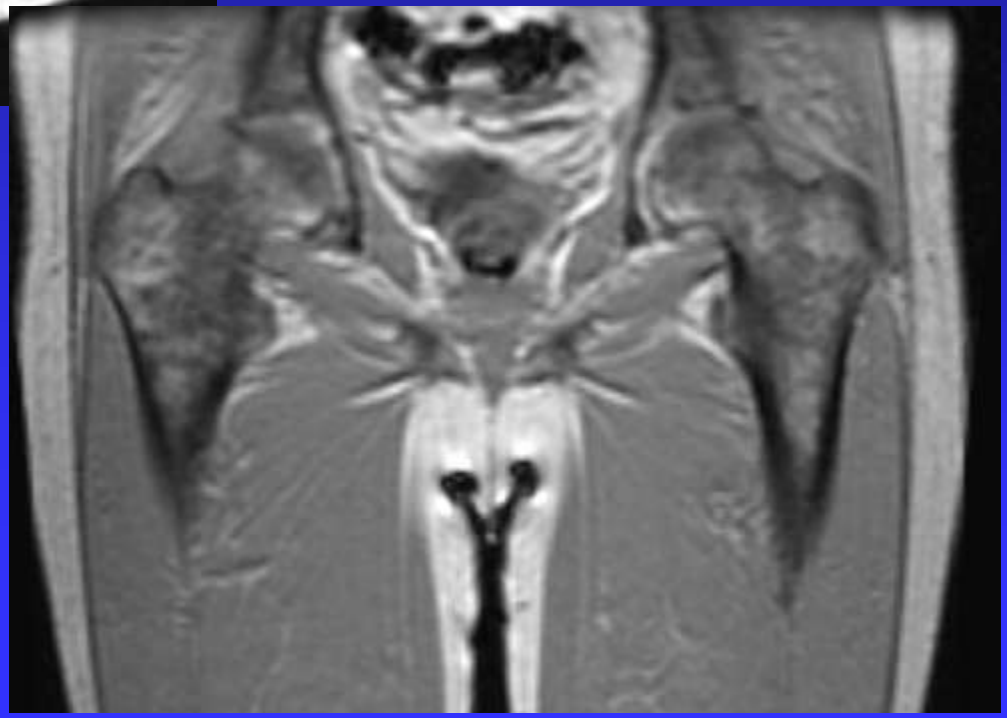
Myelofibrosis





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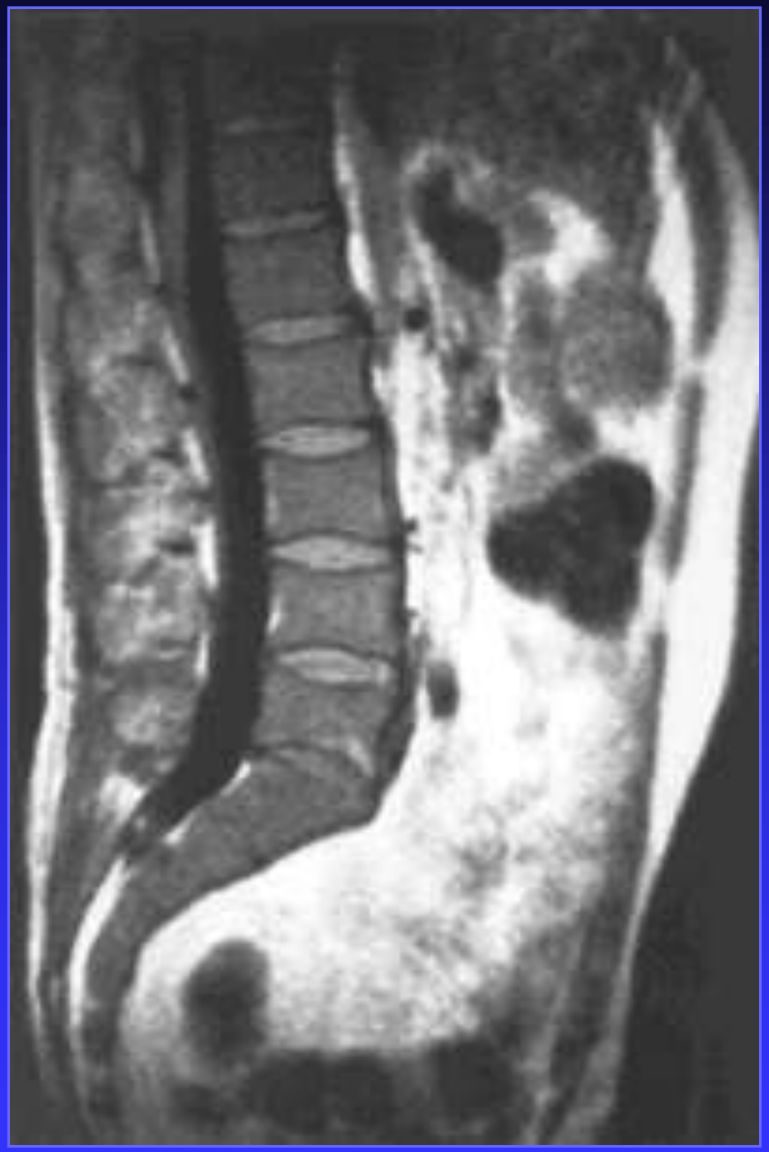
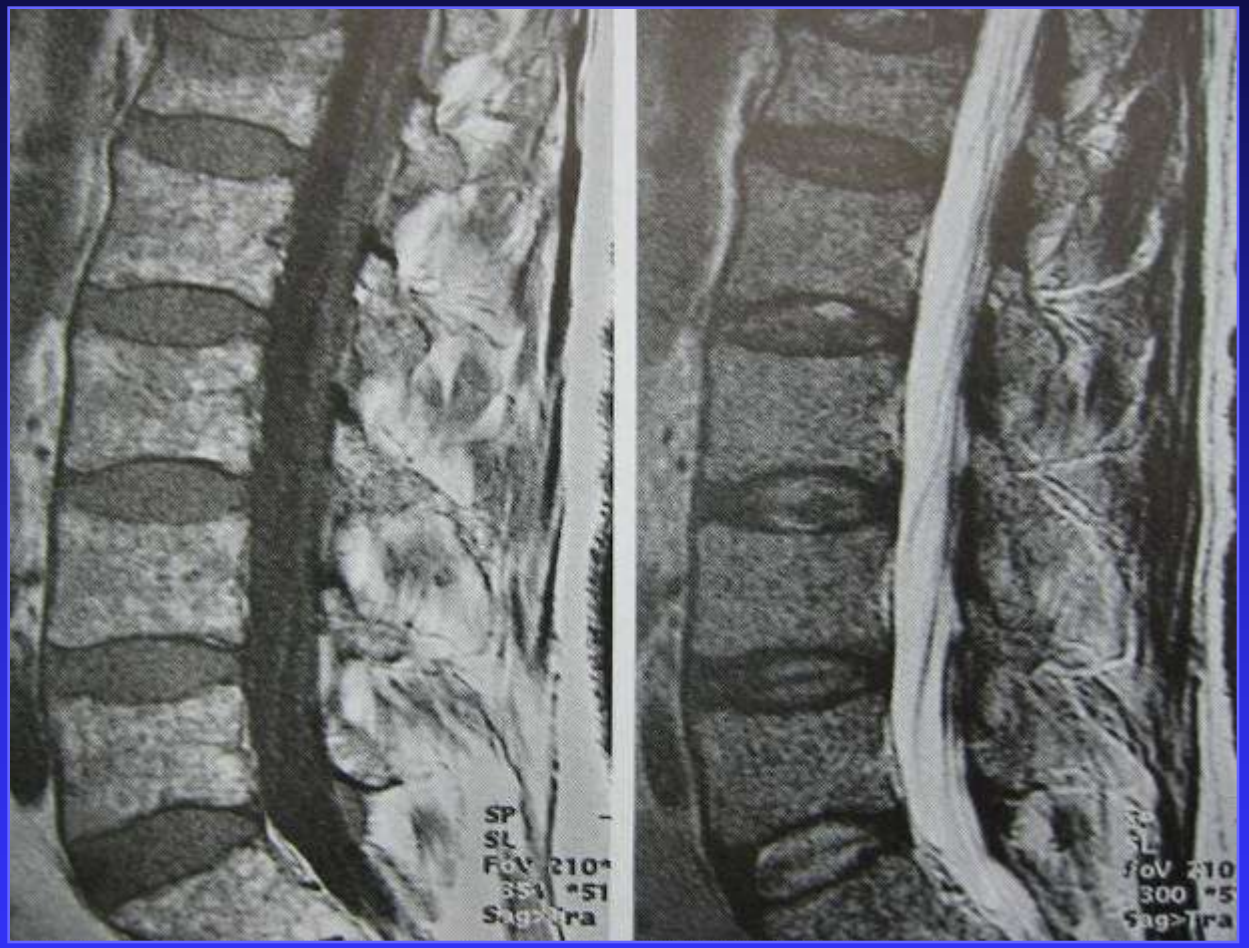
Leukemia

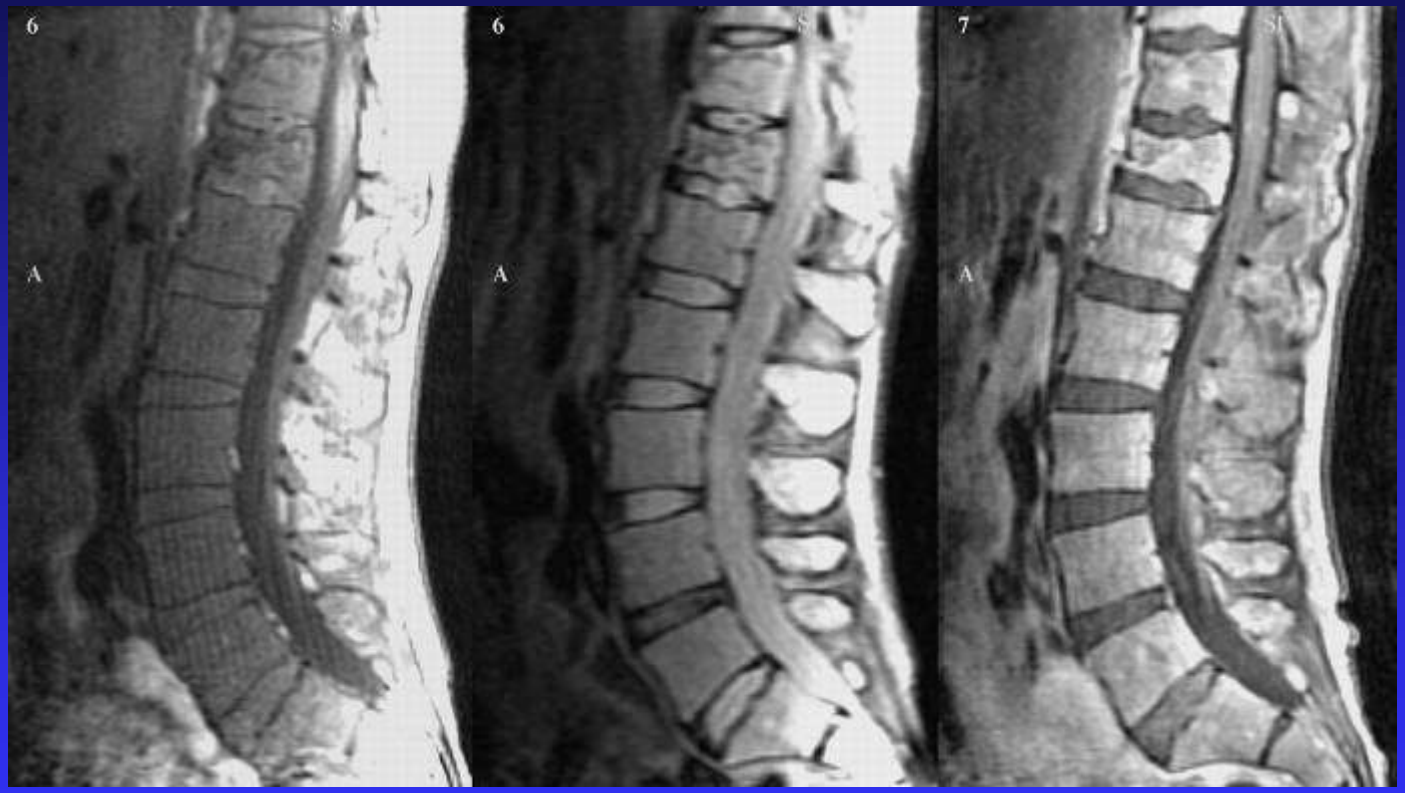
- Acute: diffuse skeletal involvement
- Chronic: (adults) involve areas of residual marrow in pelvis, spine, femurs
- Involvement of the epiphyses/apophyses at any age reflects higher tumor burden



Multiple Myeloma (MM)

- Most common primary bone tumor
- Solitary (plasmacytoma) form and more common multiple (myeloma) form
- Xrays
  - Solitary lytic lesion or numerous focal punched out lesions
  - Generalized osteopenia
- MRI patterns of MM in order of increasing frequency:
  - normal (low tumor burden)
  - focal lesion
  - heterogeneous (variegated)
  - homogenous (diffuse)





Angtuaco, E. J. C. et al. Radiology 2004;231:11-23

Marrow Pathology

- Disorders of marrow proliferation
- Disorders of marrow replacement
- Disorders of marrow depletion

- Vascular and Miscellaneous abnormalities

Marrow Replacement Disorders

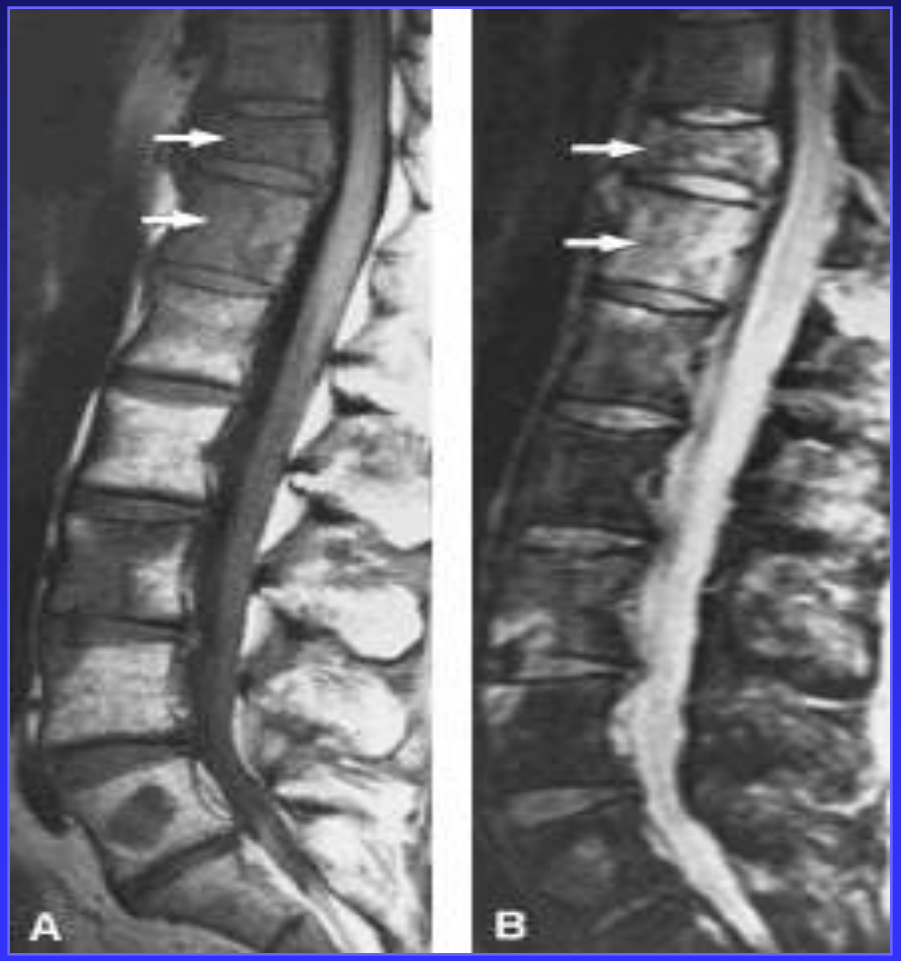
- Implantation of cells in the marrow that do not normally exist there
- Usually focal lesions
- MRI appearances include low T1 signal (equal or less than muscle or disc) and variable T2 signal (usually high, unless sclerotic).

Marrow Replacement Disorders

- **Benign**
  - Primary Bone tumors
  - Osteomyelitis
- **Malignant**
  - Metastasis
  - Lymphoma
  - Malignant Bone tumors

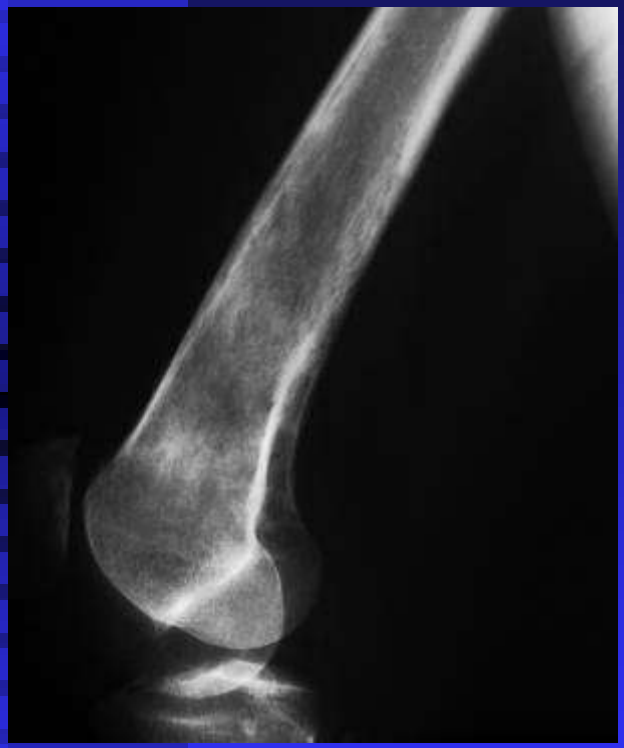
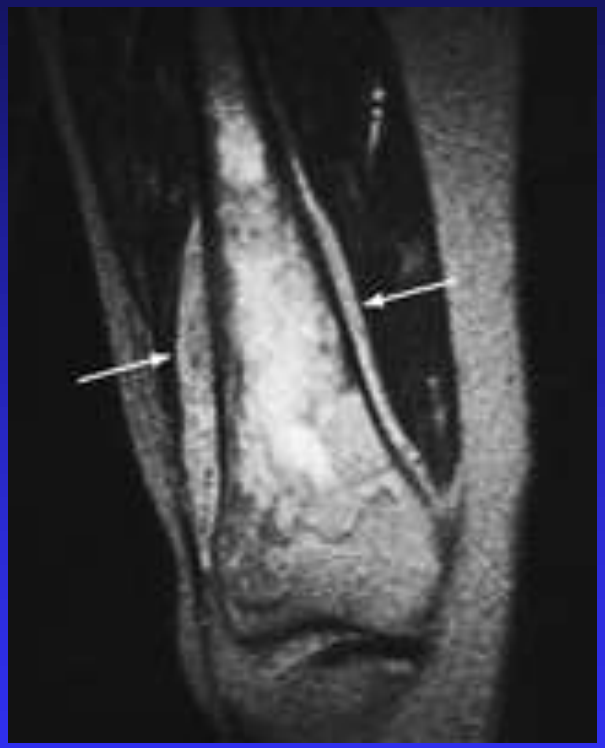
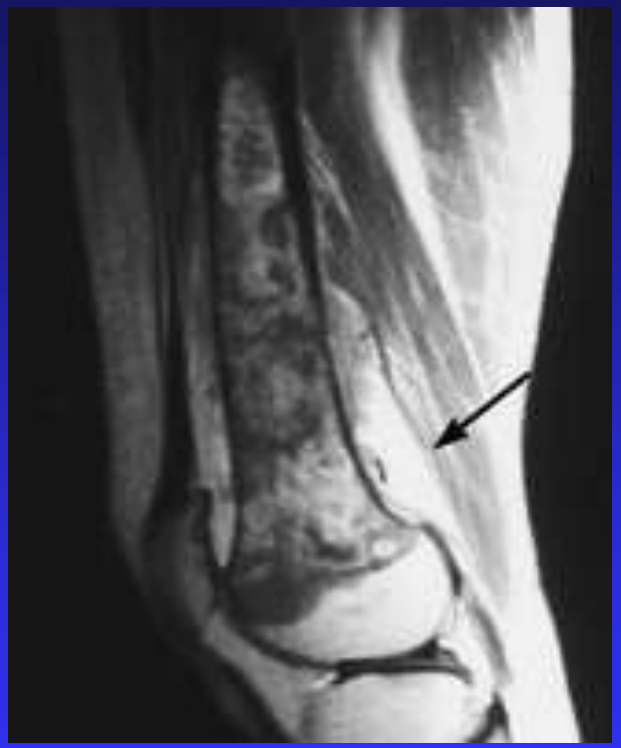
Metastasis

- Common primaries: breast, lung and prostate
- Involve red marrow in spine, pelvis, prox femurs and humeri
- Focal lesions with low T1 and high T2 and variable surr. edema

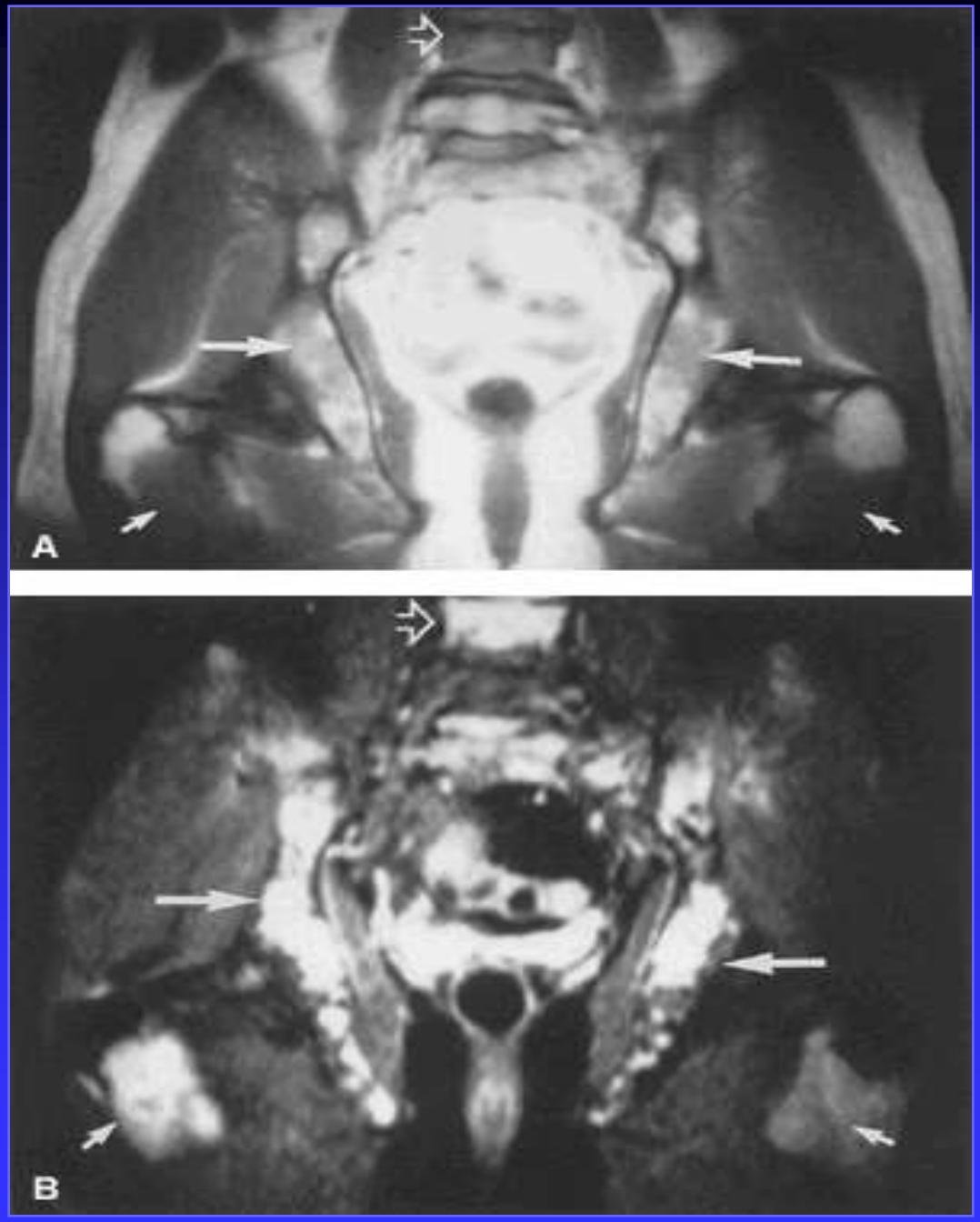


Lymphoma

- Primary lymphoma of bone rare
- NHL > HD
- Xray
  - Permeative and lytic
  - Appendicular skeleton in diaphyses of femur, tibia and humerus

Krishnan, A. et al. Radiographics 2003;23:1371-1383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Marrow Pathology

- Disorders of marrow proliferation
- Disorders of marrow replacement
- Disorders of marrow depletion

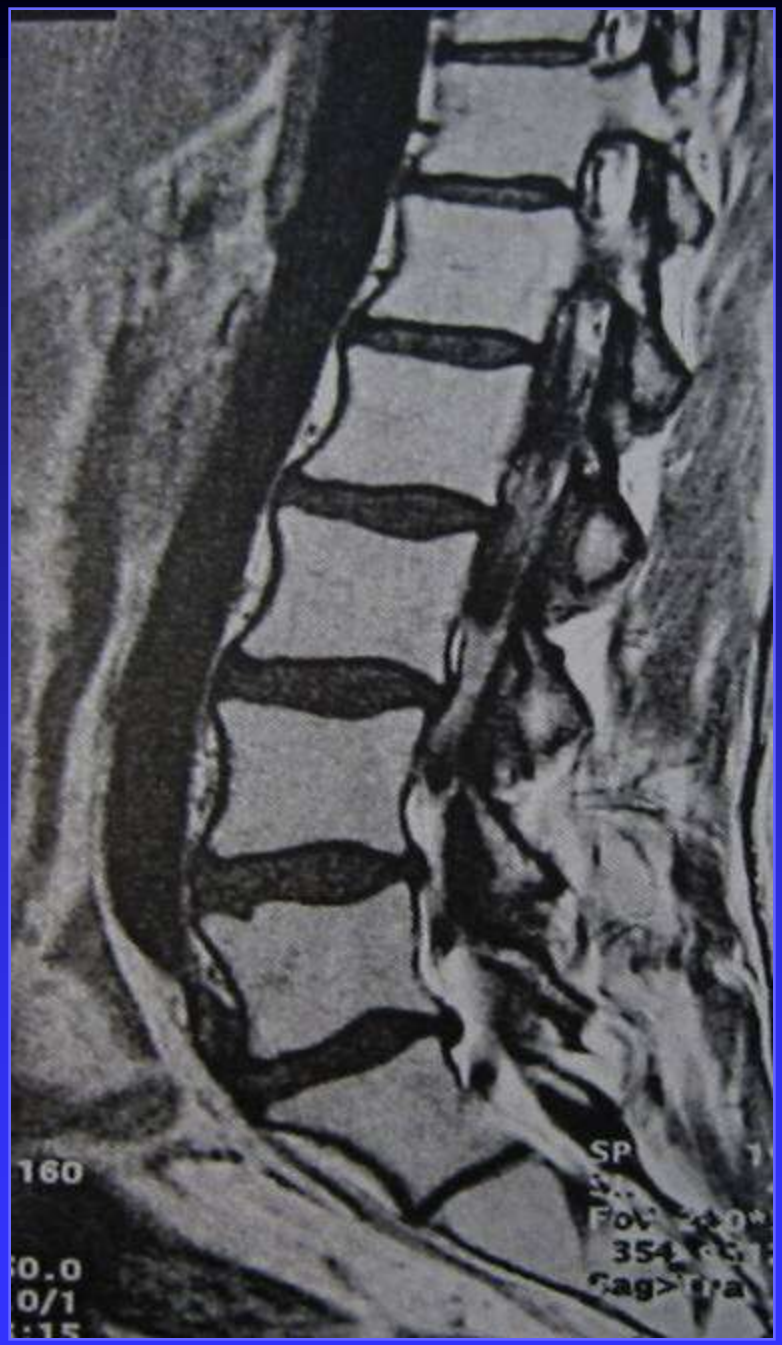
- Vascular and Miscellaneous abnormalities

Marrow Depletion Disorders

- Due to ablation of red marrow elements
- Involvement can be diffuse or regional in distribution
- 3 main causes include chemotherapy, radiation, and aplastic anemia
- MRI appearances follow the signal intensity of fat

Chemotherapy

- Systemically destroys normal hematopoietic marrow and tumor cells
- 1st week post chemo
  - Edematous and hypocellular marrow
- Post 1st week
  - Progressive fat replacement of marrow (similar to untreated aplastic anemia)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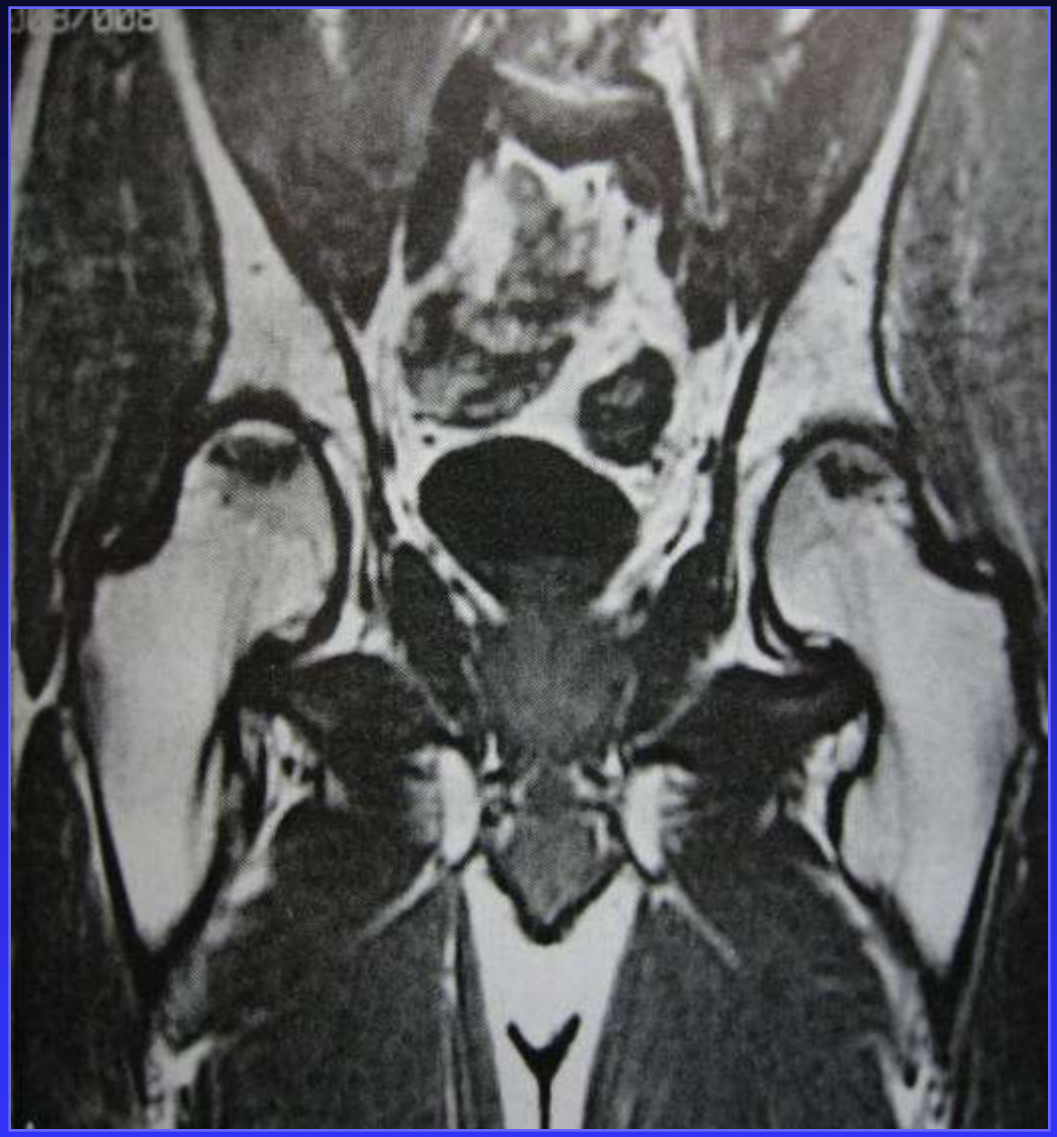
Aplastic Anemia

- Acquired (infections, drugs, toxins) or congenital causes (Fanconi, TAR Sx, etc)
- MR
  - Classic description
    - Diffuse fat replacement of marrow
  - Foci of low T1 signal may represent
    - Residual islands of red marrow
    - Post Rx regenerative marrow
    - Development of MDS/Leukemia



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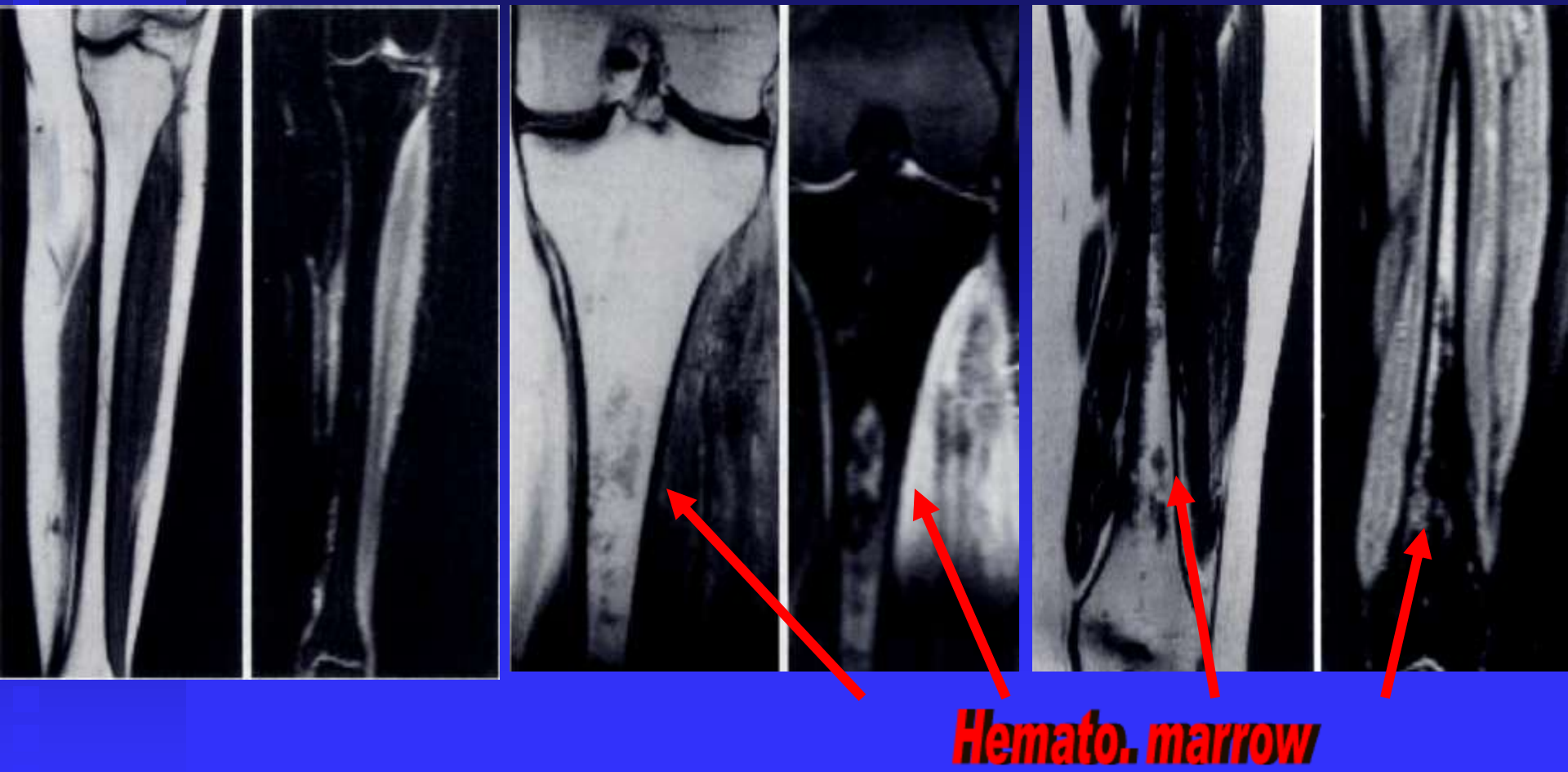
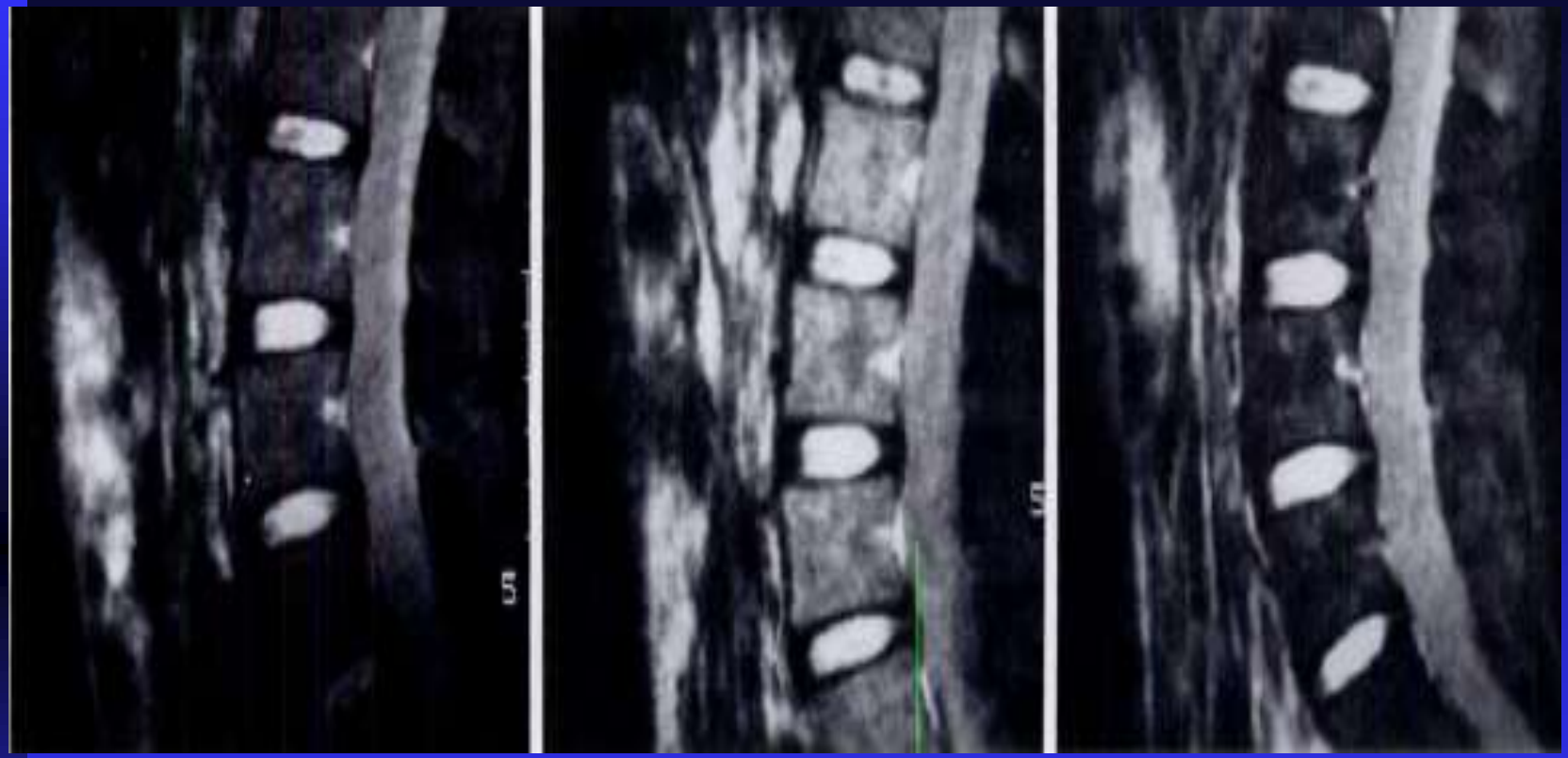


Pre Rx Course 1 Course 2

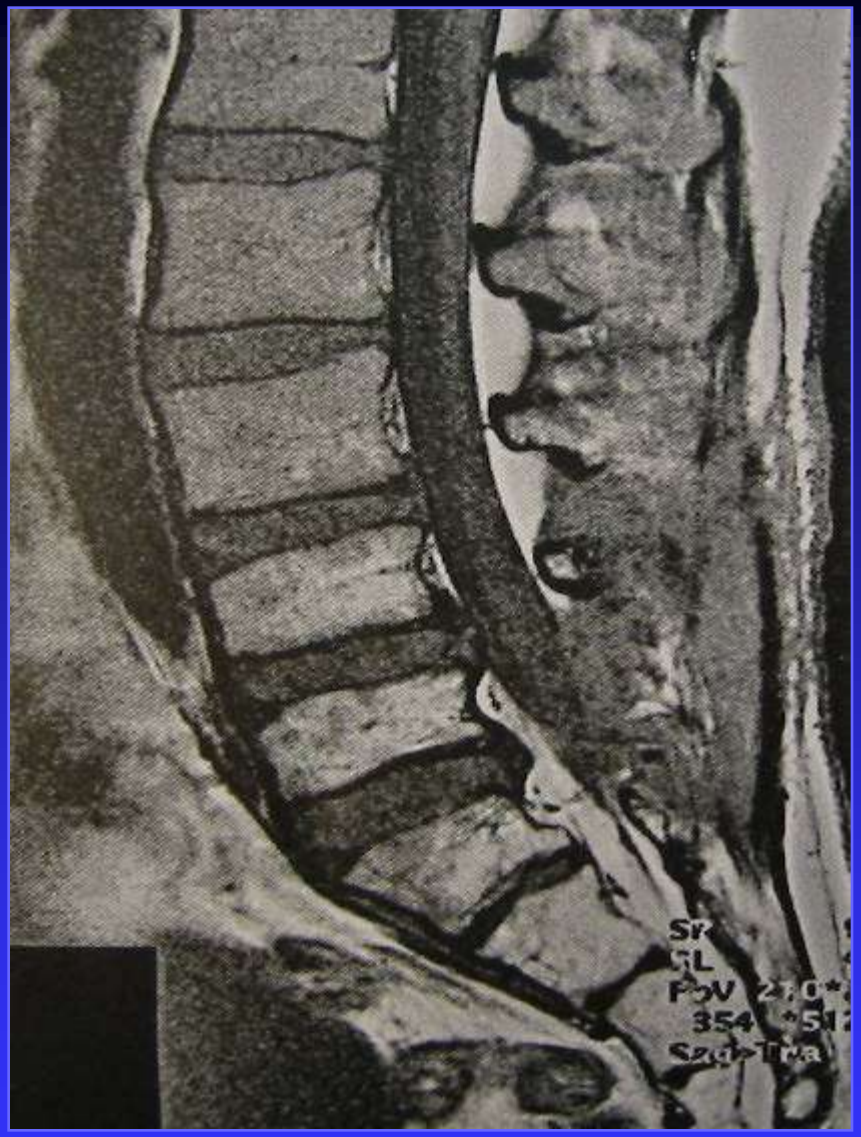
Radiation

- Acute and Chronic induced changes
- MR appearance of radiated marrow depends on phase in which it was imaged and dose
  - 1st 2 weeks: Increased STIR with slight increase in T1
  - 3rd-6th weeks: heterogeneous signal
  - >6th weeks: chronic changes of fat replacement

  - Dose < 30 Gy may have regeneration after 1 year
  - Dose >30-40 Gy irreversible changes



Stevens et al. AJR. 1990; 154: 745-750



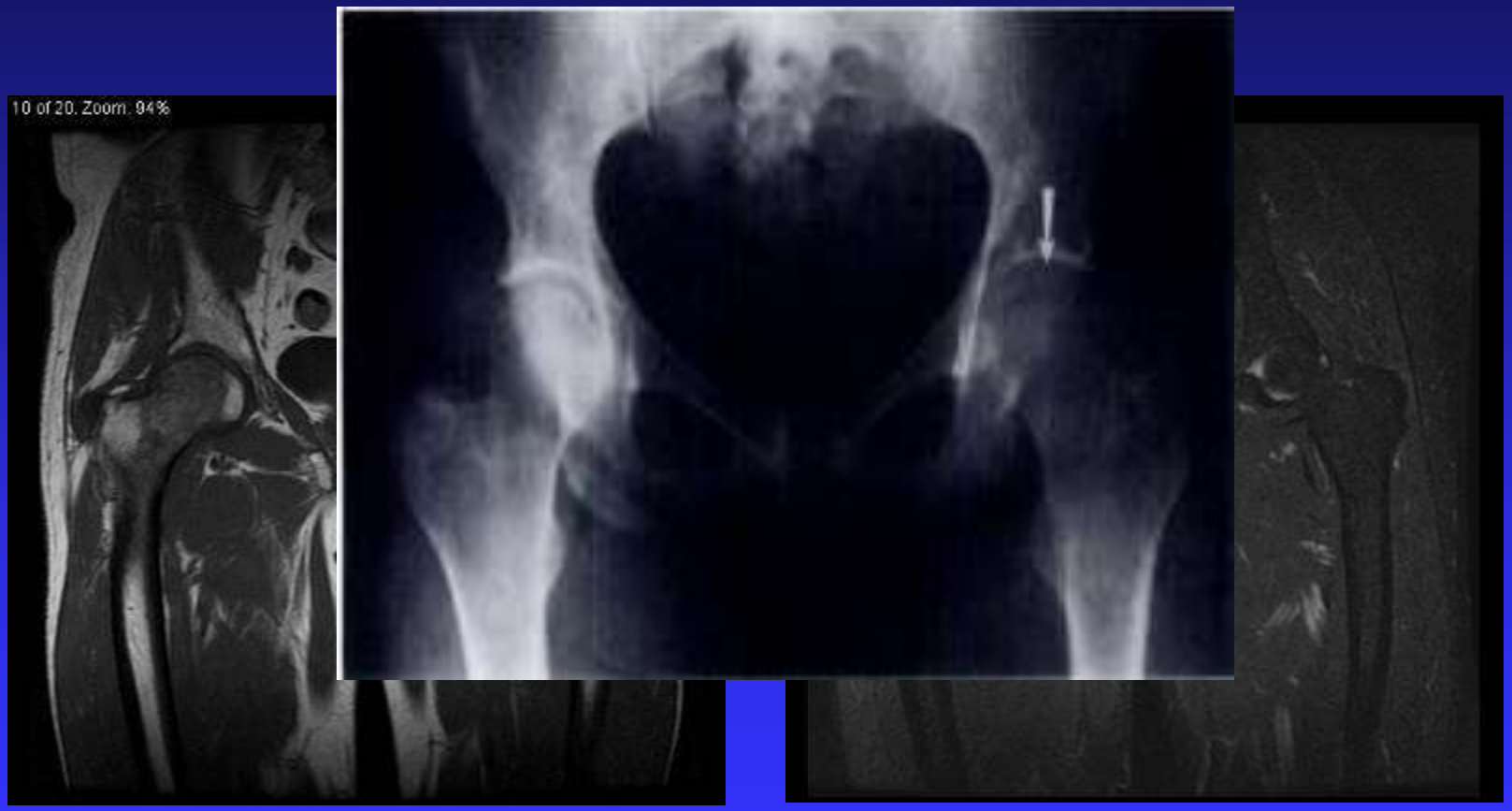
Marrow Vascular and Miscellaneous Abnormalities

- Vascular
  - Hyperemia and Ischemia
    - Transient and regional migratory osteoporosis
    - RSD
    - Osteonecrosis
    - Trauma
    - Infection
    - Tumors
    - Joint abnormalities (degenerative or neuropathic arthropathy)
- Other
  - Storage diseases: Glycogen (Gaucher's) or Iron
  - Paget's disease
  - Osteopetrosis

Transient Osteoporosis of the Hip

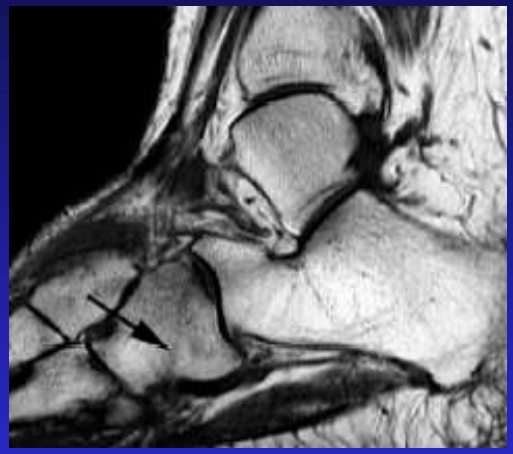
- Painful process that affects mainly young and middle age men in either hip or pregnant women more commonly in the left hip
- Osteoporosis can be severe enough to cause an insufficiency fracture
- MR
  - Homogeneous Focal/Diffuse well marginated edema
  - May spare medial and/or lateral margins of femoral head +/- greater trochanter
  - Occasional acetabular edema
  - Small-moderate joint effusion

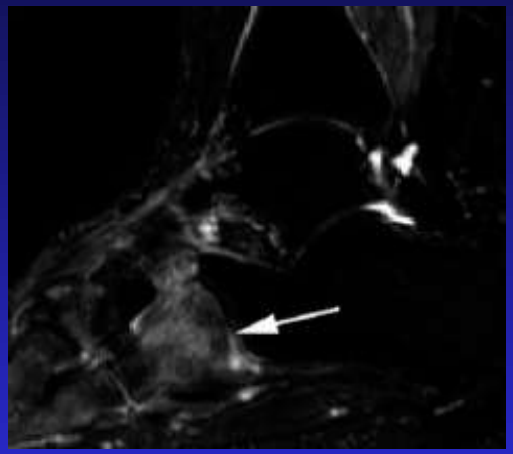
Transient Osteoporosis of the Hip

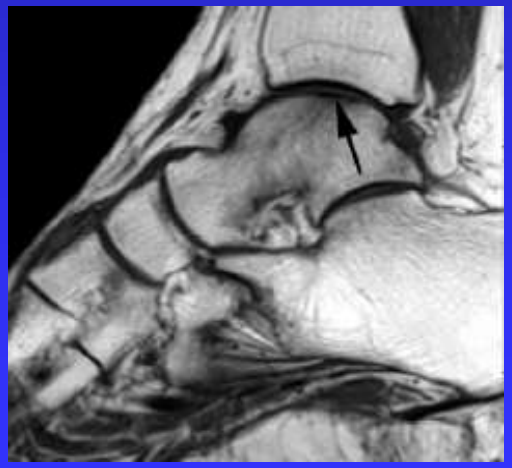


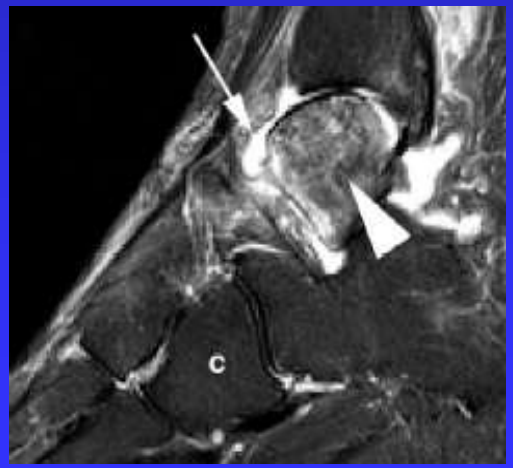
Regional Migratory Osteoporosis

- Similar MRI and clinical features as TOH
- Not confined to the hip and migratory in nature
- Subchondral regions of the knee, ankle, and hip each may be affected in turn



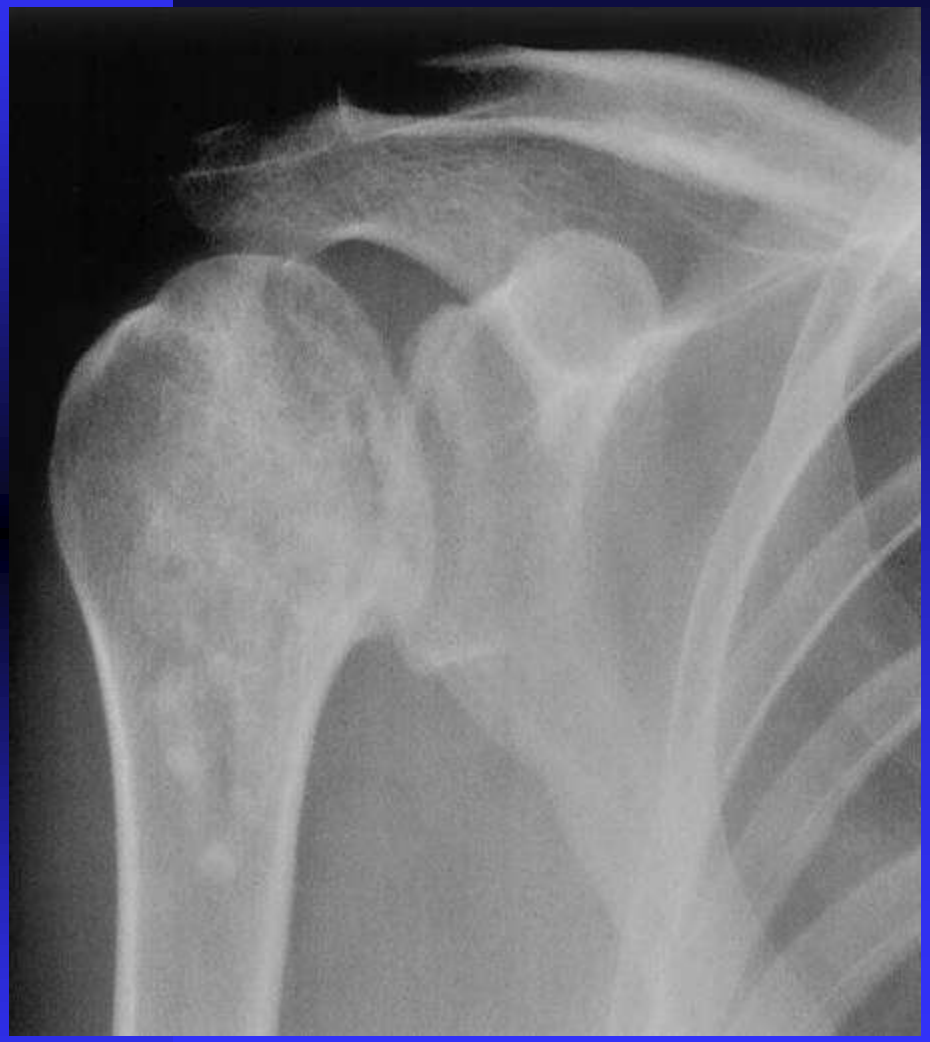


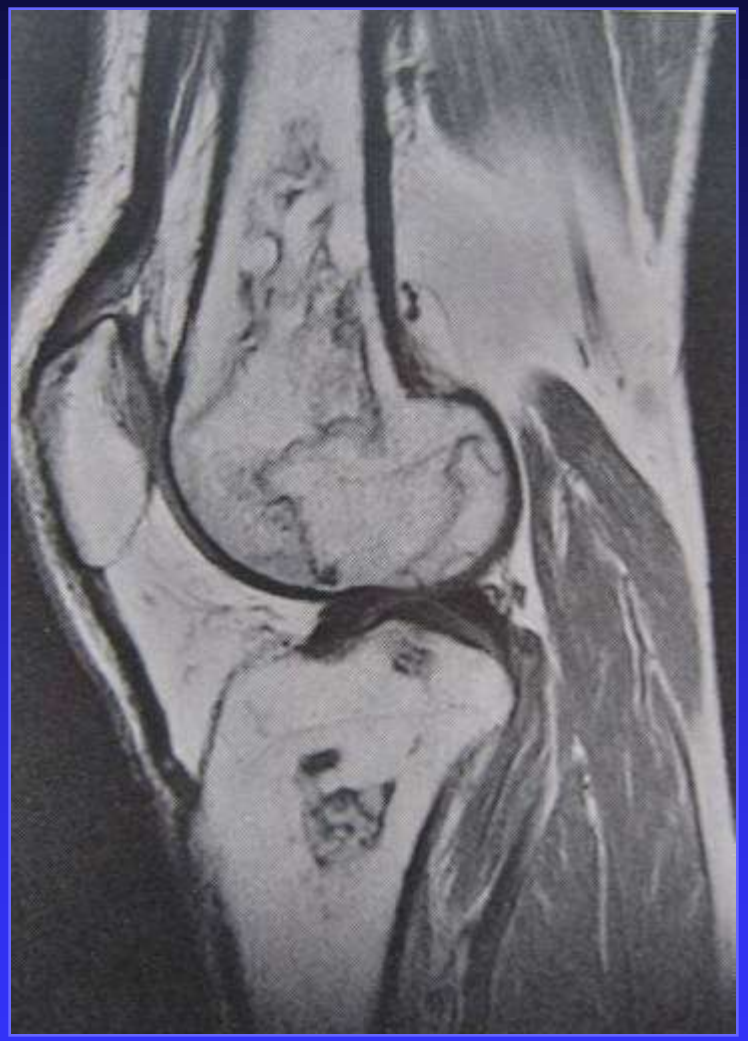



C

Marrow Ischemia (Osteonecrosis)

- Synonymous terms
  - AVN (Focal lesions in the epiphyses)
  - Bone infarct (Metaphysis or diaphysis)
- Causes
  - Trauma, steroids, HbS, SLE, Gaucher disease, ETOH, pancreatitis, and idiopathic





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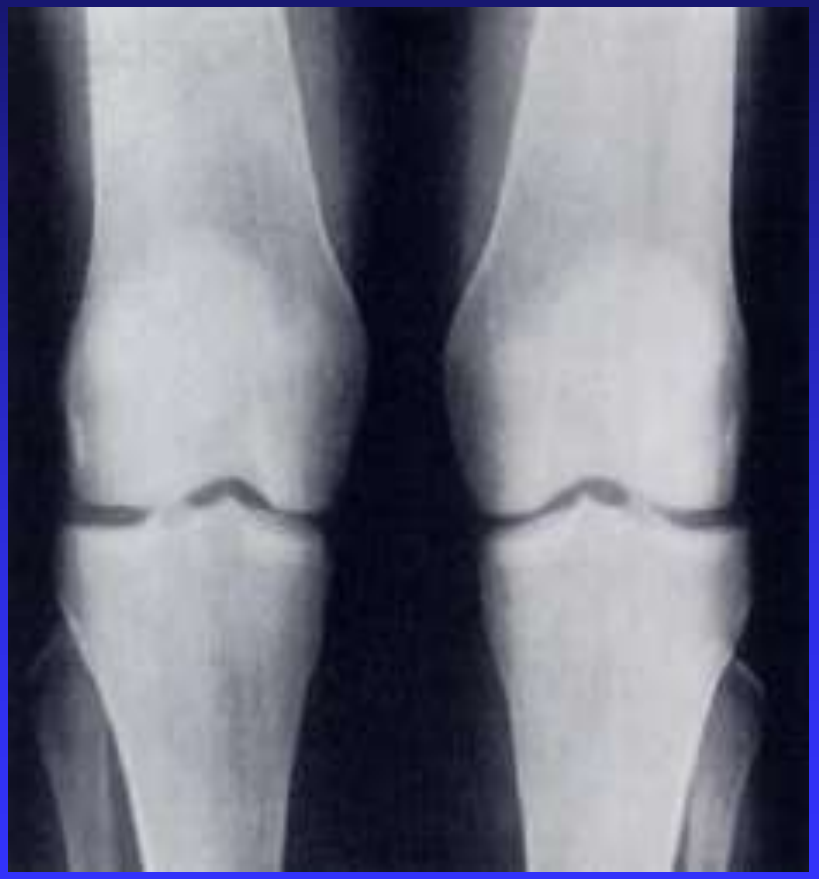
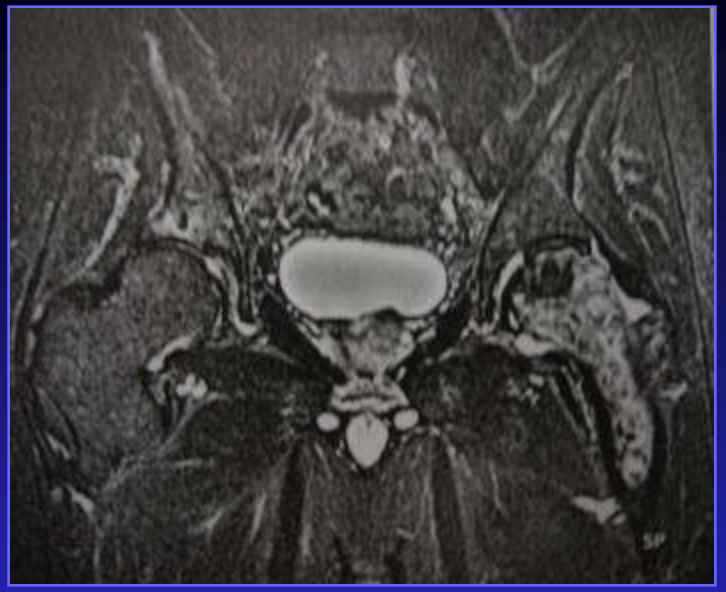
Gaucher Disease

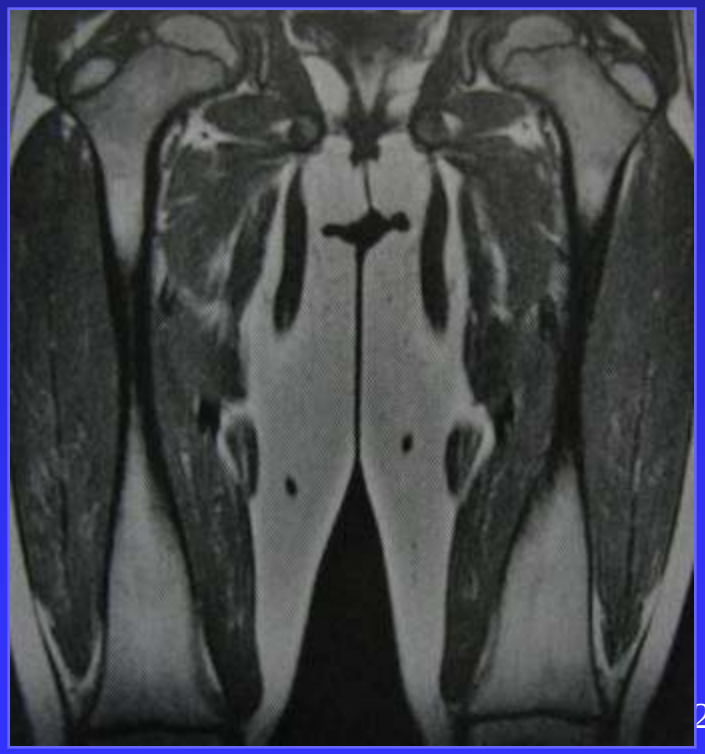
- Rare lysosomal storage disease leading to the accumulation of glucocerebroside within the RES
- MR
  - Focal/Diffuse hypointensity on T1 and T2
  - Active disease hyperintense on T2 FS and STIR
  - Lumbar spine involved first followed by appendicular skeleton



Gaucher Disease

- Treatment includes administration of the deficient enzyme
- MRI can be used to monitor treatment demonstrating decreased marrow infiltration on serial exams in those who are responding





Summary

- Bone marrow disorders have a nonspecific MR appearance but remembering the categories of diseases and correlating this with clinical history can be helpful
  - Marrow Proliferative
  - Marrow Replacement
  - Marrow Depletion
  - Vascular/Miscellaneous
- Two useful characteristics for evaluating marrow disorders
  - Distribution
    - Normal marrow conversion and reconversion patterns
  - Signal Intensity (muscle and disc serve as internal standard)
    - Normal marrow: same or higher signal
    - Abnormal marrow: lower signal

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