Imaging in Orthopaedic Trauma

Paulo R. Lourenço
Hospital Quinta D'or

Kenneth L. Koury, MD
Geisinger Wyoming Valley

Learning Objectives

- Understand imaging modalities available to the orthopaedic trauma surgeon
- Understand the benefits and limitations of each imaging modality
- Review radiation safety

Imaging in Orthopaedic Trauma

- Foundation of acute musculoskeletal trauma care
- Needed at all stages of care:
  - Initial diagnosis
  - Subsequent management
  - Prognosis
  - Follow up
  - Evaluation of complications

Imaging in Orthopaedic Trauma

- Common imaging modalities utilized in orthopaedic trauma:
  - X-ray
  - CT scan
  - MRI
  - Bone scan
  - Ultrasound
  - Fluoroscopy

Imaging in Orthopaedic Trauma

- Each modality presents unique benefits and limitations:
  - Cost
  - Availability
  - Image resolution
  - Patient risk
  - Provider risk

Imaging in Orthopaedic Trauma: X-ray

- Conventional Radiograph
  - High-energy electromagnetic radiation
  - X-ray beam produced by in a tube via electron emission
  - X-ray beam passes through patient onto a film cassette
  - Cassettes capture radiation and create the image

Imaging in Orthopaedic Trauma: X-ray

- Computed radiography (CR)
  - Introduced in the late 1970s
  - Screen/cassette is replaced by a cassette containing a photostimulatable phosphor
  - Phosphor interacts with x-rays, trapping electrons creating the latent image
  - Requires specialized CR cassette reader that produces an electrical signal, which is then digitized and stored

Imaging in Orthopaedic Trauma: X-ray

- Digital radiography (DR)
  - More recent advancement in flat panel detectors allowing for digital capture of X-ray images
  - Indirect and direct techniques
    - Indirect: detector elements are sensitive to light = convert x-rays into light and store as a net negative charge
    - Direct: the individual detector elements are coated with a photoconductive material that releases electrons when exposed to x-rays. Underlying detector elements capture electrons as a net negative
  - With both systems, the negative charges are electronically, digitized, and stored as images

Imaging in Orthopaedic Trauma: X-ray

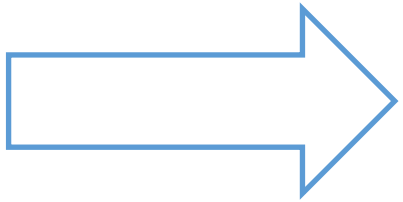
- Conventional vs. CR vs. DR
  - Conventional advantages:
    - better spatial resolution
    - CR and DR require additional equipment
  - CR and DR advantages:
    - can manipulate digital images and alter image contrast
    - decreased radiation dose to the patient and radiologic personnel
    - greater ease of storage and sharing of information
    - ultimately cost effective- storage space, less re-imaging, faster
  - DR more expensive than CR, but faster processing

Imaging in Orthopaedic Trauma: X-ray

- Benefits
  - Accessible in most health care situations
  - Potentially portable
  - Cost efficient relative to other imaging modalities
  - Provides a wealth of information quickly
    - Fractures
    - Dislocations

Imaging in Orthopaedic Trauma: X-ray

- <u>Benefits</u>
  - Accessible in most health care situations
  - Potentially portable
  - Cost efficient relative to other imaging modalities
  - Provides a wealth of information quickly
    - Fractures
    - Dislocations



Excellent screening tool

and

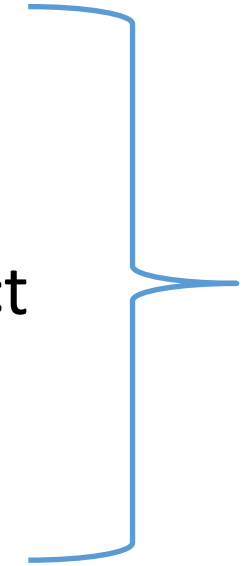
Efficient tool for follow-up

Imaging in Orthopaedic Trauma: X-ray

- <u>Limitations</u>
  - Requires radiation
  - Technique dependent
    - Equipment settings
    - Patient position
    - Increased patient BMI can affect
  - Knowledge dependent- specialized views

Imaging in Orthopaedic Trauma: X-ray

- <u>Limitations</u>
  - Requires radiation
  - Technique dependent
    - Equipment settings
    - Patient positioning
    - Increased patient BMI can affect
  - Knowledge dependent- specialized views



Can miss injuries if done poorly.

Can miss subtle injuries even when done appropriately.

Imaging in Orthopaedic Trauma: X-ray

- Overcoming limitations :
  - X-ray the joint above and below
  - Obtain Orthogonal views
  - Know “special” views for unique anatomy, e.g.:
    - Radiocapitellar view
    - Axillary view- various techniques
    - Judet views
    - Inlet/outlet views of pelvis
    - Tibial plateau view
    - Broden’s view of subtalar joint
    - Canale’s view of talar neck

Imaging in Orthopaedic Trauma: X-ray

- Importance of Orthogonal views
  - AP does not clearly show injury
  - Lateral demonstrates fibula fracture

Imaging in Orthopaedic Trauma: X-ray

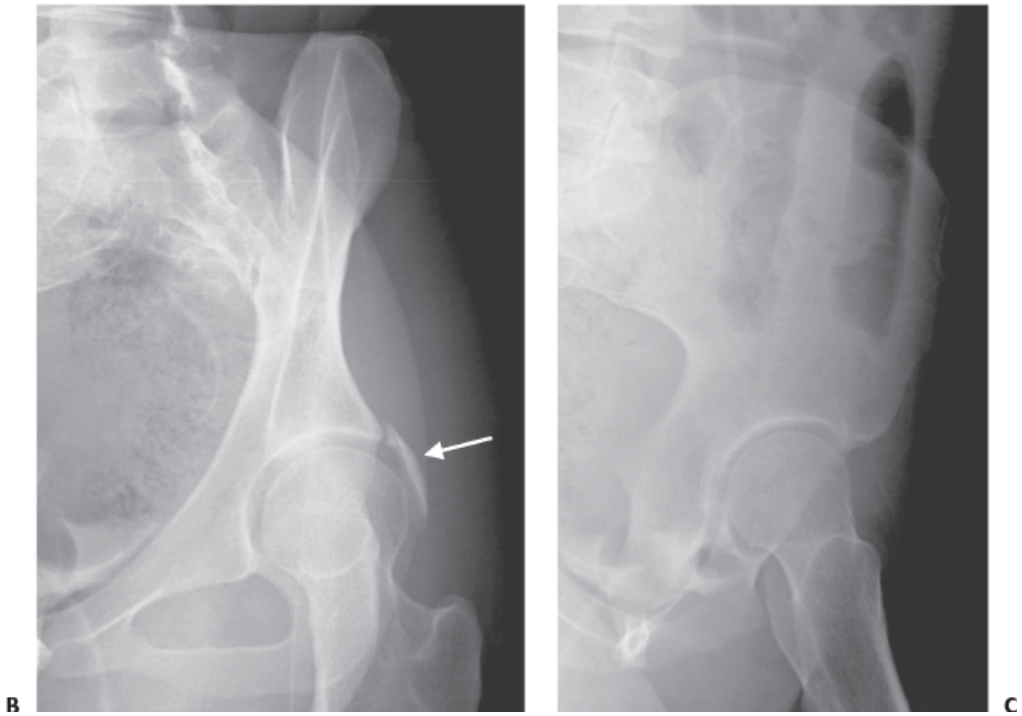
Radiocapitellar view- improves ability to assess radial head and capitellum

Rockwood and Green's Fractures in Adults 9th Edition Figure 40-1

Importance of an axillary view: Posterior dislocation better assessed with axillary image on the right compared to Grashey view on the left

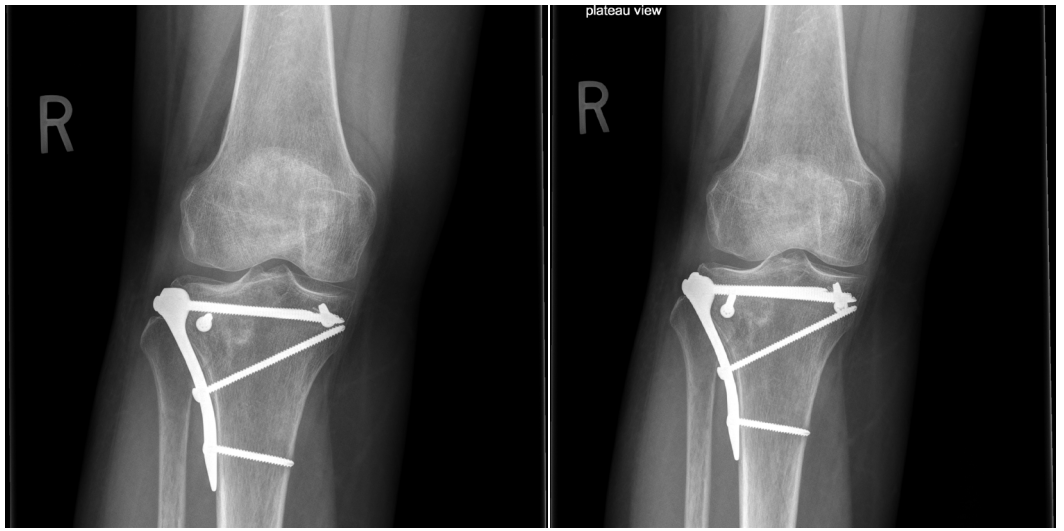
Rockwood and Green's Fractures in Adults 9th Edition Figure 34-4

Imaging in Orthopaedic Trauma: X-ray



Judet views of the acetabulum provided better visualization of the complex anatomy

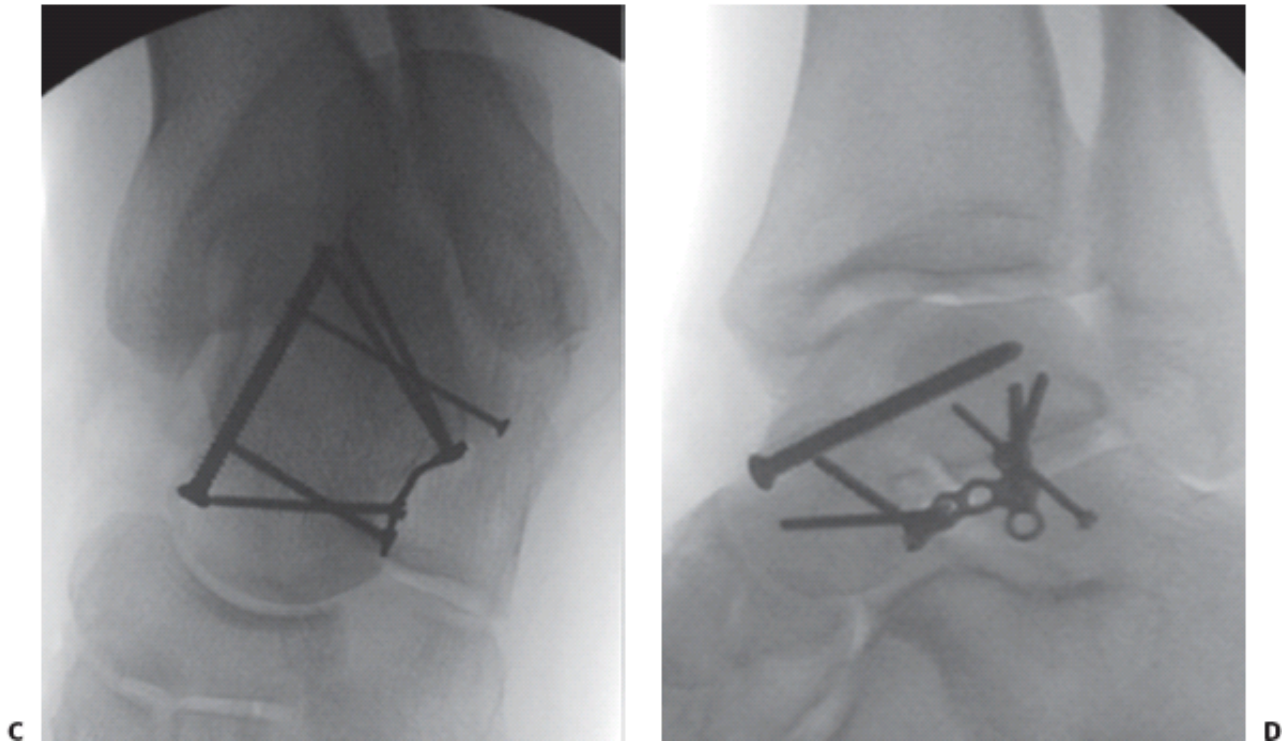
Rockwood and Green's Fractures in Adults 9th Edition Figure 50-16



AP view Vs. Plateau view of the knee- 10–15-degree caudal tilt provides better assessment of joint line in plateau view

Courtesy Kenneth L. Koury, MD

Imaging in Orthopaedic Trauma: X-ray



Canale (C) and Broden's (D) views provide better evaluation of the talar neck as well as the subtalar joint respectively.

Rockwood and Green's Fractures in Adults 9th Edition Figure 65-12

Imaging in Orthopaedic Trauma: X-ray

- Know “special” views for unique anatomy
  - These are only a handful of examples
  - Each anatomic location will have unique radiographic assessment
  - Knowledge of these views is essential for proper evaluation of injuries as well as for follow-up care

X-ray Summary:

- <u>Advantages:</u>
  - Relatively cheap
  - Available/Portable
  - Fast
  - **Screening tool**
  - **Primary tool used for follow up care**

- <u>Disadvantages:</u>
  - Radiation exposure
  - Technique dependent
  - May need “special” views

Imaging in Orthopaedic Trauma: CT Scan

- Computerized Tomography (CT) scan
  - Utilizes a series of radiographic images and computer processing
  - Provides axial view
  - Newer technology allows for multiplanar reconstructions as well as 3D modeling

Imaging in Orthopaedic Trauma: CT Scan

- <u>CT Scan benefits:</u>
  - Relatively fast (vs. MRI)
  - Quickly accessible in most hospitals
  - Excellent bone imaging
  - Provides critical information:
    - Axial view
    - Reconstruction views: coronal and sagittal
    - Ability to perform 3D reconstruction

Imaging in Orthopaedic Trauma: CT Scan

- <u>CT Scan benefits:</u>
  - Relatively fast (vs. MRI)
  - Accessible in most hospitals
  - Excellent bone imaging
  - Provides critical information:
    - Axial view
    - Reconstruction views: coronal and sagittal
    - Ability to perform 3D reconstruction

<u>Valuable tool for:</u>

- Identifying subtle fractures not seen on X-ray
- Evaluation of complex fractures for preoperative planning

Imaging in Orthopaedic Trauma: CT Scan

- <u>CT Scan limitations:</u>
  - More expensive than X-ray
  - Higher patient radiation doses
  - Metal artifact can obscure image
  - Inferior evaluation of soft tissue (vs. MRI)

Imaging in Orthopaedic Trauma: CT Scan

- <u>CT Scan limitations:</u>
  - More expensive than X-ray
  - Higher patient radiation doses
  - Metal artifact can obscure image
  - Inferior evaluation of soft tissue (vs. MRI)

Use selectively for complex bone injury

or

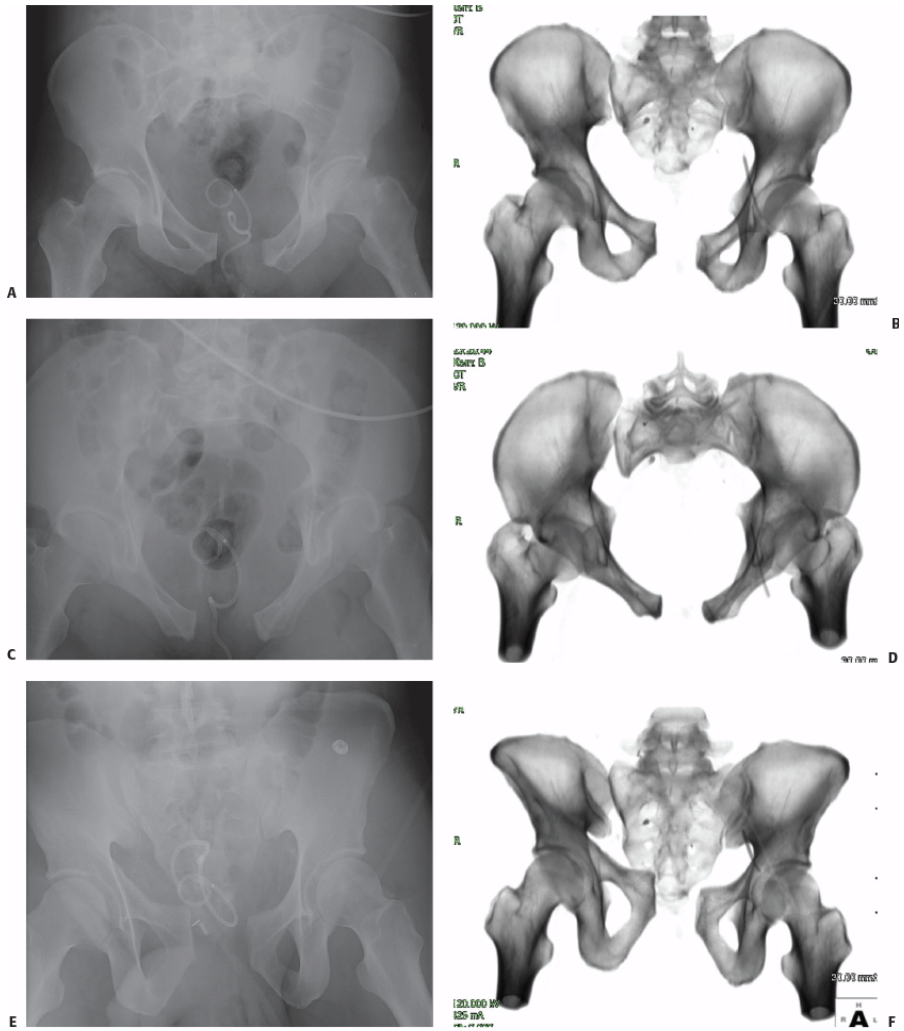
Suspected bone injury not seen on X-ray

Imaging in Orthopaedic Trauma: CT Scan

- <u>CT uses:</u>
  - Evaluation of injuries where axial views are critical, e.g. Spine and pelvis
  - Gathering further detail for preoperative planning, especially intra-articular injuries, e.g.:
    - Acetabulum
    - Plateau
    - Pilon
  - Post-operative evaluation of rotational alignment and non-union

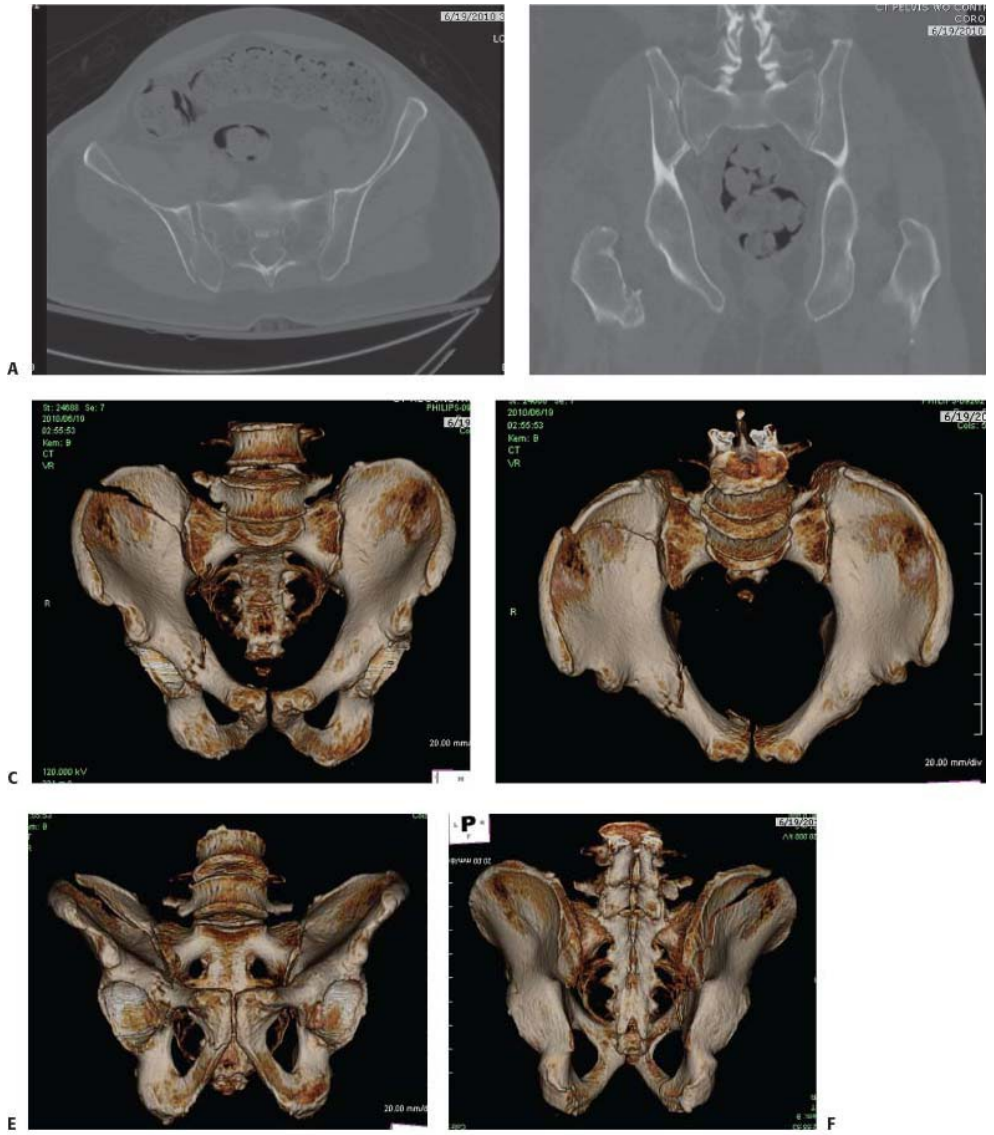
Imaging in Orthopaedic Trauma: CT Scan

- <u>CT uses:</u> Evaluation of injuries where axial views are critical, e.g. Spine and pelvis
  - While X-rays are helpful, the reconstruction images provided by CT can be invaluable for assessment and fixation planning
  - “Ghost images” based on CT processing seen here provide clearer detail of the injury



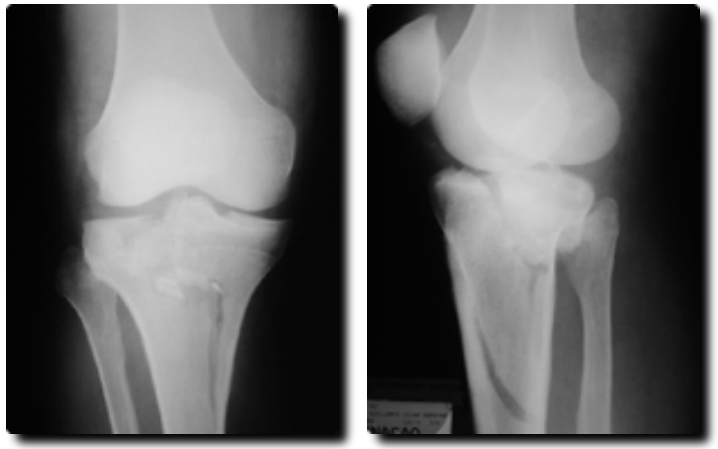
Imaging in Orthopaedic Trauma: CT Scan

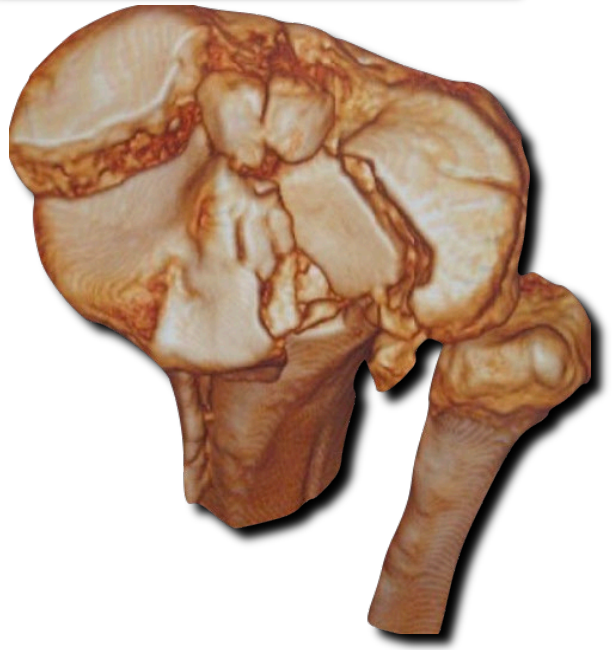
- <u>CT uses:</u> Evaluation of injuries where axial views are critical, e.g Spine and pelvis
  - 3D reconstructions are particularly helpful for these anatomic locations
  - CT images help create the 3D images used for pre-operative planning



Imaging in Orthopaedic Trauma: CT Scan

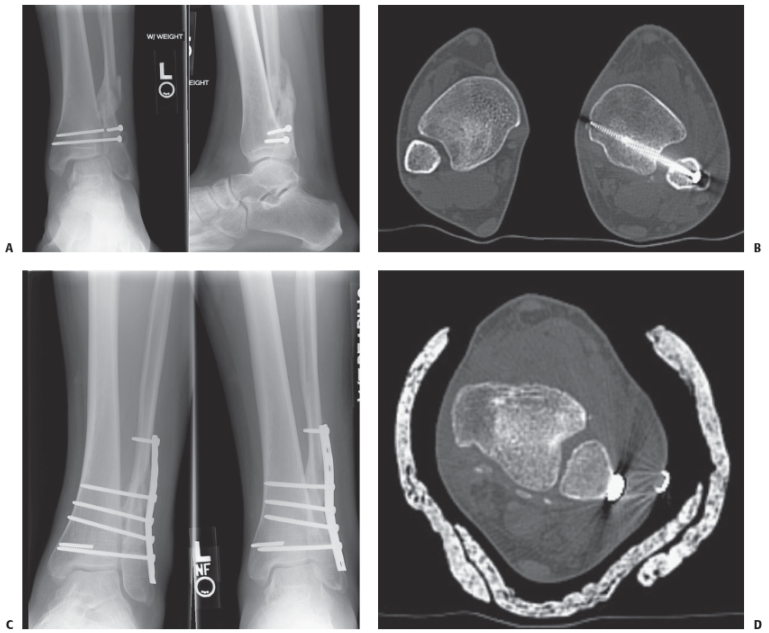
- <u>CT uses:</u> Gathering information for preoperative planning
  - CT provides finer detail of bone injury
  - Reconstruction views improve understanding of injury
  - 3D reconstruction offers even further information for fixation planning

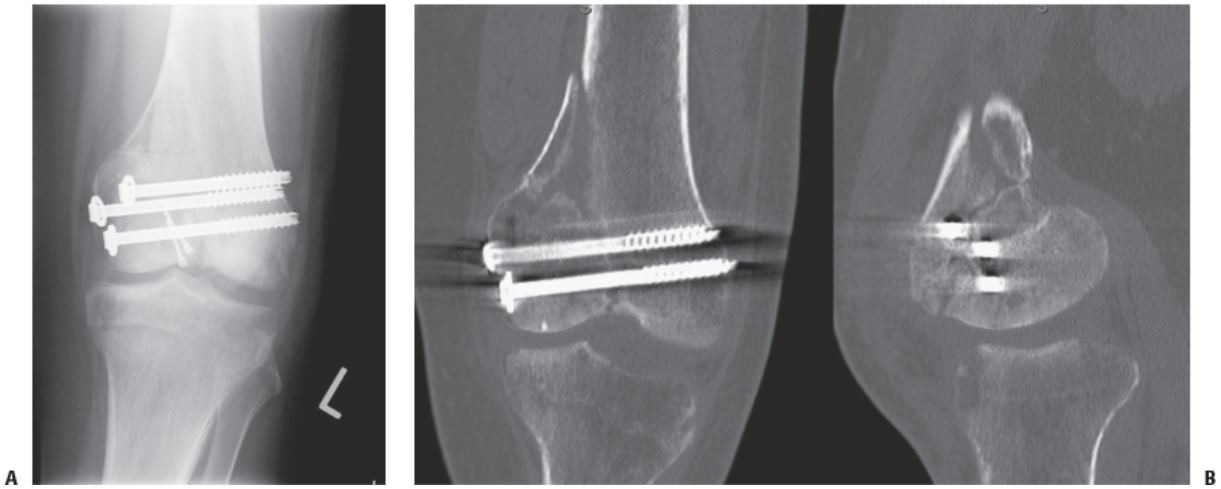




Imaging in Orthopaedic Trauma: CT Scan

- CT uses: Post-operative evaluation of rotational alignment and non-union
  - Axial views critical for assessment of rotation, e.g. syndesmotic reduction, as in images of the ankle to the right
  - Reconstruction views help assess callus formation or lack of union otherwise under appreciated on X-ray





CT Scan Summary:

- Advantages:
  - Fast
  - Accessible
  - **Axial view**
  - **Reconstruction views and 3D modeling**
  - **Fine bony detail**

- Disadvantages:
  - Radiation exposure to patient
  - Increased cost vs. X-ray
  - Metal artifact

Imaging in Orthopaedic Trauma: MRI

- Magnetic Resonance Imaging (MRI)
  - Radiofrequency (RF) waves and strong magnetic field
  - Interact with the patient's hydrogen atoms (protons) to create images
  - Different sequences yield different results:
    - T1-weighted (T1W)- better for assessment of anatomy
    - T2- weighted (T2W)- fluid-sensitive images, show pathology

Imaging in Orthopaedic Trauma: MRI

- <u>MRI benefits:</u>
  - Exceptional detail
  - Best modality for soft tissue, e.g. ligaments, meniscus, labrum, vascular injuries
  - Can evaluate bone edema:
    - Occult fracture
    - Osteomyelitis

Imaging in Orthopaedic Trauma: MRI

- <u>MRI benefits:</u>
  - No radiation
  - Exceptional detail, including axial view
  - Best modality for soft tissue i.e. ligaments, meniscus, vascular injuries
  - Can evaluate bone edema:
    - Occult fracture
    - Osteomyelitis

Helpful image modality for injuries requiring improved detail for diagnosis

Imaging in Orthopaedic Trauma: MRI

- <u>MRI limitations:</u>
  - Cost
  - Availability
  - Lengthy exam- some patients can not tolerate without sedation
  - Metal artifact

Imaging in Orthopaedic Trauma: MRI

- MRI limitations:
  - **Cost**
  - **Availability**
  - Lengthy exam- some patients can not tolerate without sedation
  - Metal artifact
  - Lacks reconstruction technology currently present with CT 3D processing

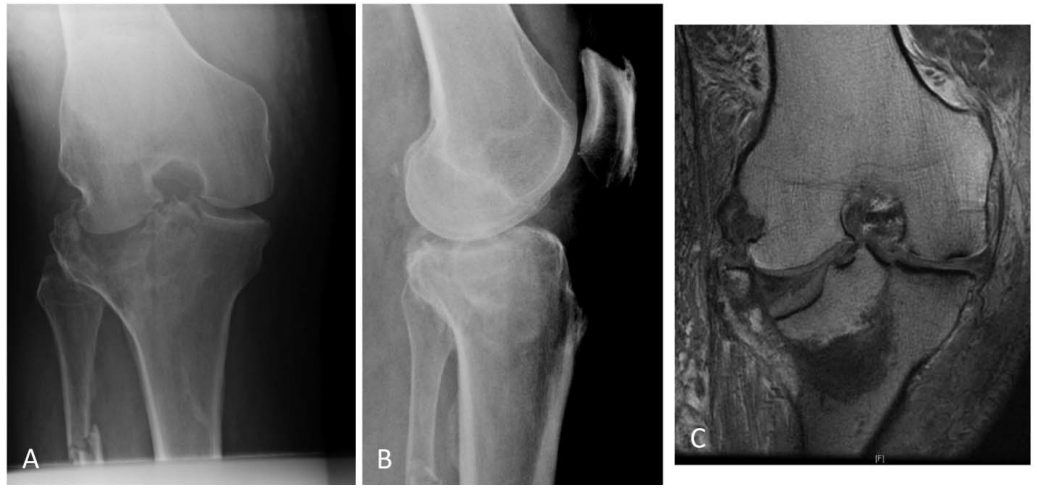
Use judiciously

Imaging in Orthopaedic Trauma: MRI

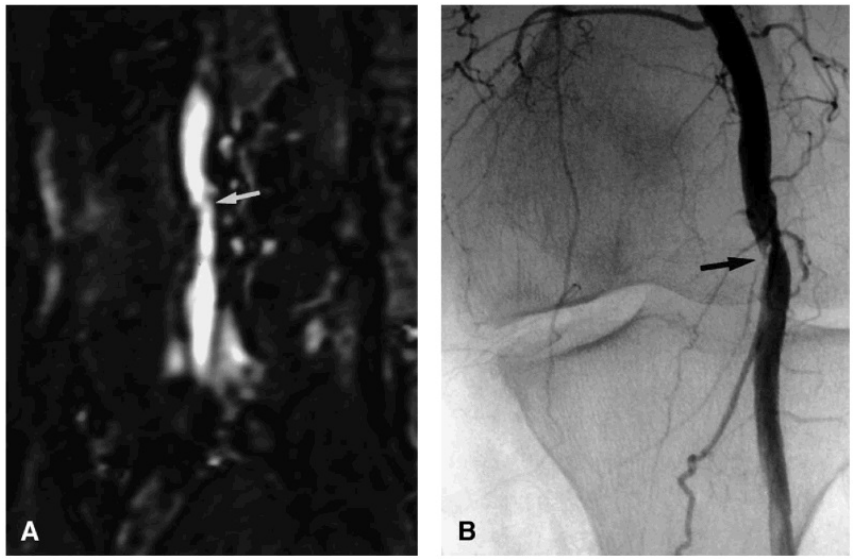
- <u>MRI uses:</u>
  - Soft tissue injuries, e.g. Shoulder, Spine and Knee
  - Evaluation of occult bone injuries, e.g. Occult femoral neck fractures, Scaphoid fractures
  - Evaluation of bone edema consistent with stress fractures and osteomyelitis

Imaging in Orthopaedic Trauma: MRI

- <u>MRI uses:</u> Soft tissue injuries i.e. Shoulder, Spine and Knee
  - Fracture/dislocations about the knee- MRI can evaluate meniscus, ligament, and vascular injuries



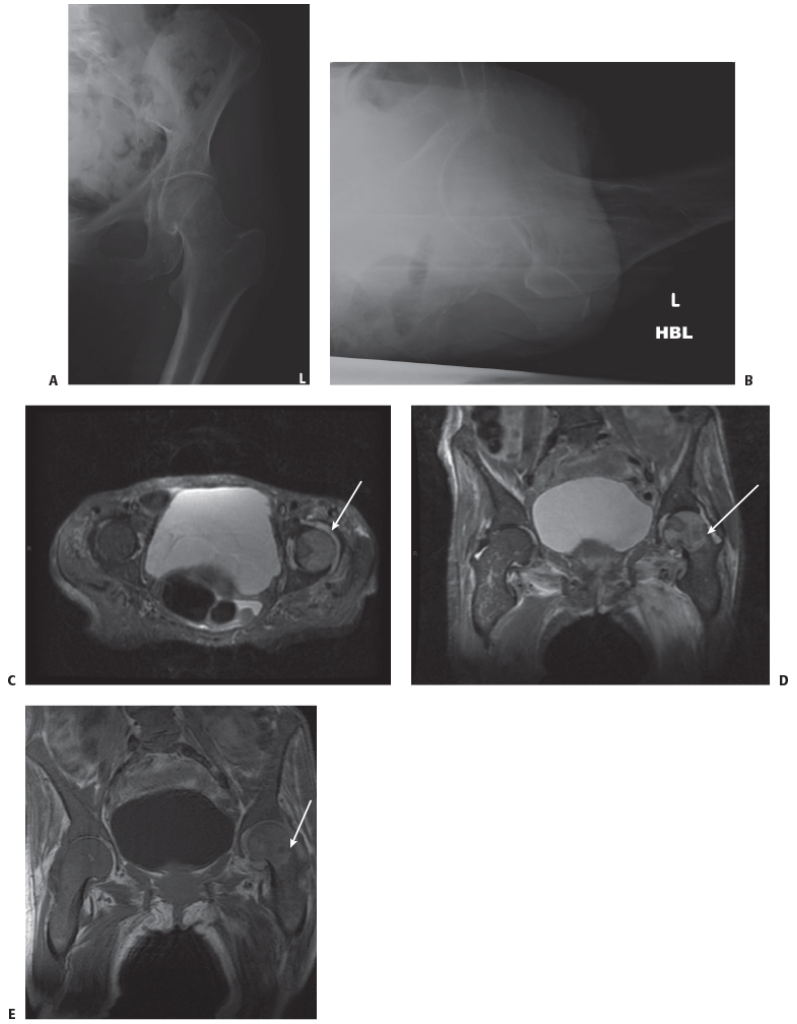
Journal of Orthopaedic Trauma 32 (3): 141-147, Mar 2018. Figure 2: Anteroposterior (A) and lateral (B) knee injury radiographs. Preoperative coronal proton density MRI demonstrating MCL and LCL ruptures and tears of the medial and lateral menisci



Journal of Orthopaedic Trauma 16(5):330-339, May 2002. Fig 8: An intimal flap (arrow) is seen in the popliteal artery above the knee joint. **B:** Conventional contrast arteriogram in the same patient confirms the presence of an intimal flap in the popliteal artery approximately 0.5 centimeter above the knee joint (arrow).

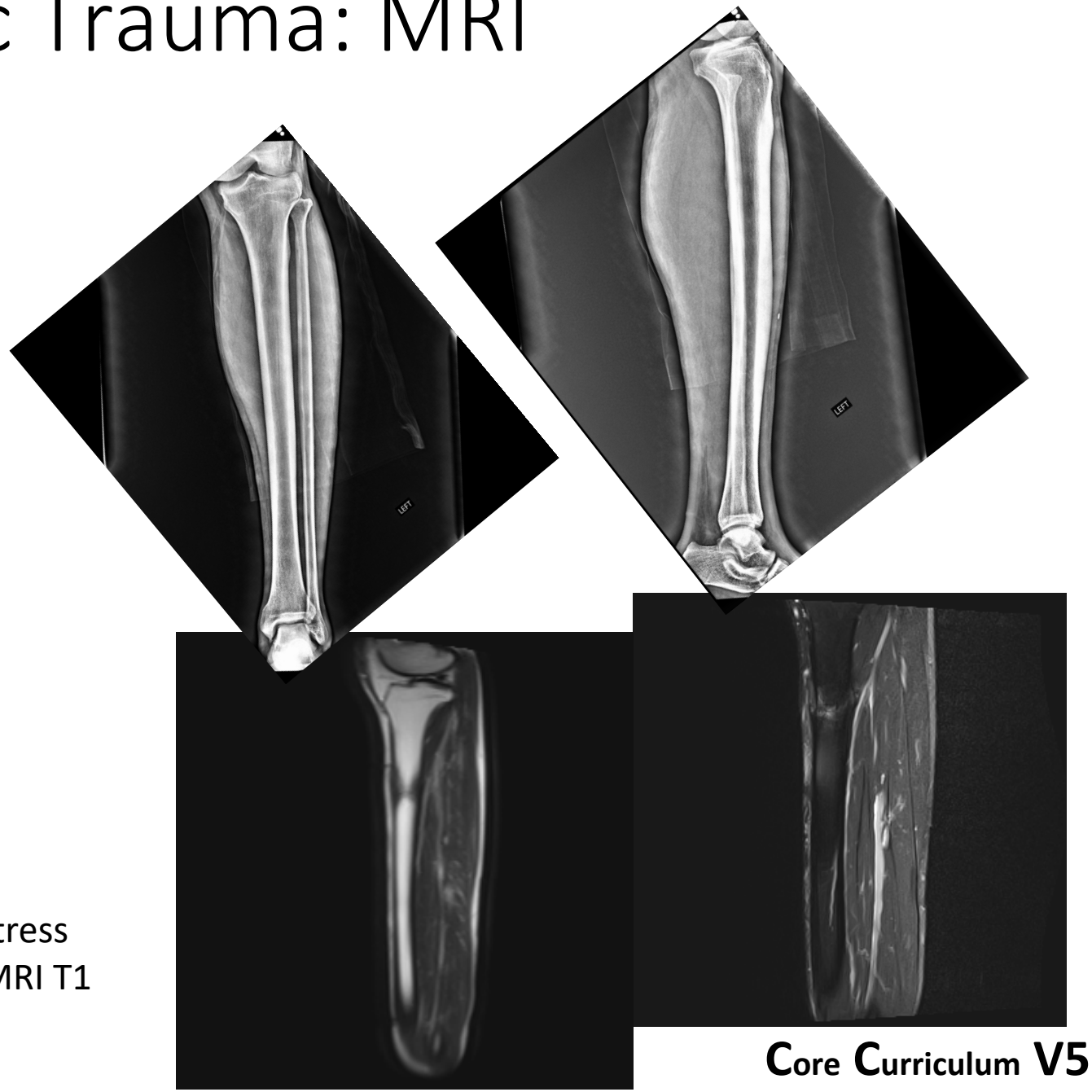
Imaging in Orthopaedic Trauma: MRI

- MRI uses: Evaluation of occult bone injuries, e.g Occult femoral neck fractures (to the right) and Scaphoid fractures (far right)



Imaging in Orthopaedic Trauma: MRI

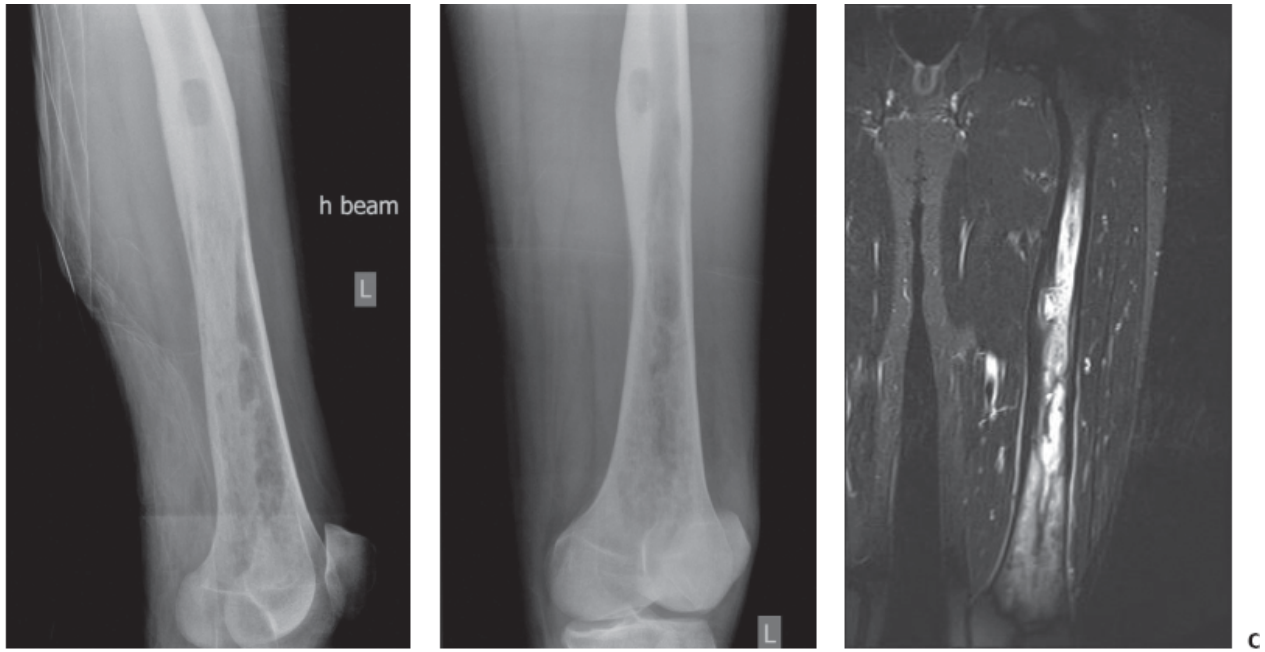
- <u>MRI uses:</u> Evaluation of bone edema consistent with Stress fractures



Courtesy of Kenneth L. Koury, MD. Tibial stress not seen on X-ray but evident on sagittal MRI T1 and T2.

Imaging in Orthopaedic Trauma: MRI

- MRI uses: Evaluation of bone edema consistent with osteomyelitis



MRI Summary:

- Advantages:
  - High resolution
  - No radiation
  - **Soft tissue injury diagnosis**
  - **Bone edema evaluation**:
    - Occult fracture
    - Stress fracture
    - Osteomyelitis

- Disadvantages:
  - Cost
  - Access can be a problem
  - Patient may not tolerate

Imaging in Orthopaedic Trauma: Bone Scan

- Nuclear medicine test using labeled pharmaceutical compound and a gamma scintillation camera

- 99mTc-labeled diphosphonate localizes to bone, especially areas with increases osteoblastic activity

- Three-phase bone scans
  - Phase 1: radionuclide angiogram, trace radiopharmaceutical through the arterial system
  - Phase 2: Immediate static images are then obtained for an additional 5 minutes “blood pool” or “tissue phase”
  - Phase 3: 2- to 4-hour delay, localizes the diphosphonate compound to bone

Imaging in Orthopaedic Trauma: Bone Scan

- <u>Bone Scan benefits:</u>
  - Minimal radiation exposure
  - Effective for occult fractures, osteomyelitis
  - Cheaper than MRI
  - Can scan entire body

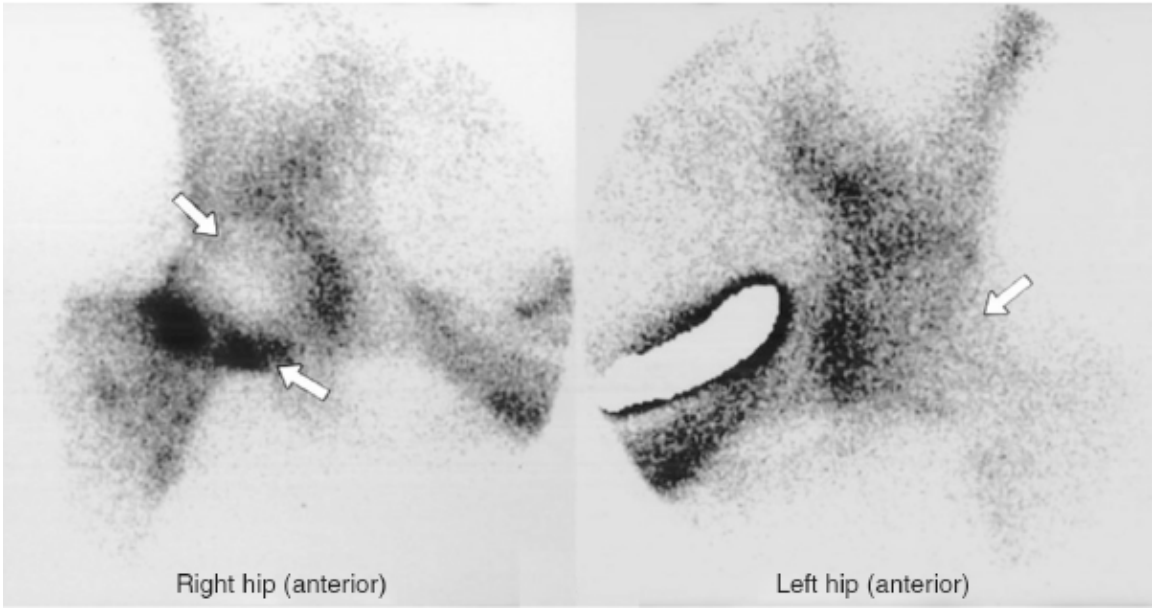


Figure 7-10. Pinhole bone scintigraphy (anteroposterior views) showing a photon-deficient area centrally in the right femoral head and increased uptake in the femoral neck and subcapital area compared with normal left hip findings.

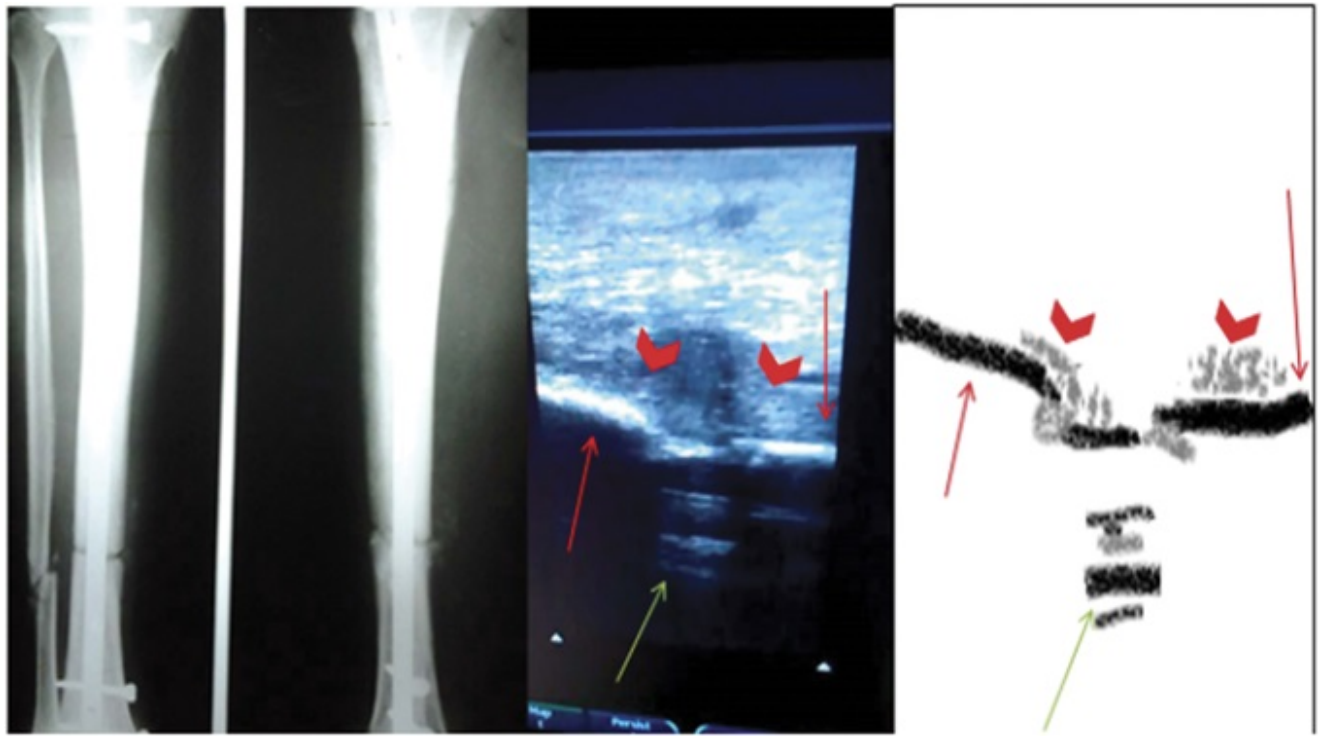
Imaging in Orthopaedic Trauma: Bone Scan

- <u>Bone Scan limitations:</u>
  - Access
  - Timing- need 72 hours for 95% sensitivity in detecting fractures
  - Not as precise as MRI

Imaging in Orthopaedic Trauma: Ultrasound

- Ultrasound (US)
  - Ultrasonic sound waves used to create a picture
  - Based on acoustic impedance of different tissues

Imaging in Orthopaedic Trauma: Ultrasound



Journal of Orthopaedic Trauma29(3):e133-e138, March 2015. Figure 2: A 32-year-old patient with delayed union radiograph at 20-weeks postoperatively showing delayed union of tibia fracture; ultrasonography (original and animation) at 16 weeks postoperatively showing bone cortex (red arrows), nail (green arrow), and periosteal soft callus (red arrow heads), predicting delayed union of fracture.

Imaging in Orthopaedic Trauma: US

- <u>US benefits:</u>
  - Fast
  - Inexpensive
  - No radiation
  - Can detect fractures, fracture healing, tendon injury, ligament injury

Imaging in Orthopaedic Trauma: US

- <u>US limitations:</u>
  - Operator dependent
  - Difficult to share/communicate findings
    - 2D image saved
    - Real time imaging during exam most useful

Imaging in Orthopaedic Trauma: Fluoroscopy

- Real time, low-dose x-rays to image patient anatomy

- Typical components of a fluoroscopy system include:
  - x-ray tube
  - collimator
  - image intensifier- converts x-ray beam into light image
  - video monitor- displays images

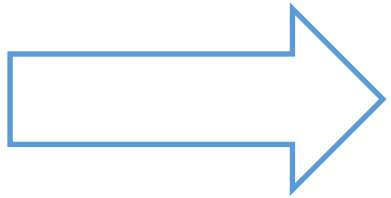
Imaging in Orthopaedic Trauma: Fluoro

Imaging in Orthopaedic Trauma: Fluoro

- <u>Fluoro benefits:</u>
  - Fast- real time imaging
  - Static and continuous imaging "live"
  - Lower dose radiation than traditional x-ray
  - Portable
  - 2D and 3D options available

Imaging in Orthopaedic Trauma: Fluoro

- <u>Fluoro benefits:</u>
  - Fast- real time imaging
  - Static and continuous imaging "live"
  - Lower dose radiation than traditional x-ray
  - Portable
  - 2D and 3D options available



Has become essential for the fixation of fractures in the modern OR

Imaging in Orthopaedic Trauma: Fluoro

- <u>Fluoro limitations:</u>
  - **Need for surgeon to understand radiation safety**
  - Less detail than X-ray
  - Technique dependent:
    - Patient position
    - Fluoro position
    - Patient BMI
    - Surgeon interpretation of image

Imaging in Orthopaedic Trauma: Fluoro

- <u>Fluoroscopy uses:</u> provides enough detail to reduce fractures and safely place implants in the OR

A

B

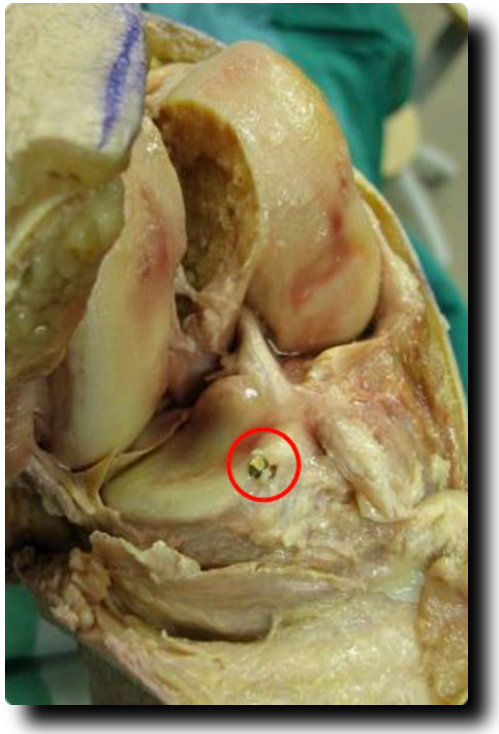
Imaging in Orthopaedic Trauma: Fluoro

- <u>Fluoroscopy uses:</u>
  - Provides enough detail to reduce fractures and safely place implants in the OR
  - Allows for real time images, providing ability to perform stress examinations:
    - Pelvis
    - Posterior wall
    - Knee
    - Ankle
  - Relatively quick and portable way to evaluate reductions in the ED

Imaging in Orthopaedic Trauma: Fluoro

- <u>Fluoroscopy limitations</u>: Technique

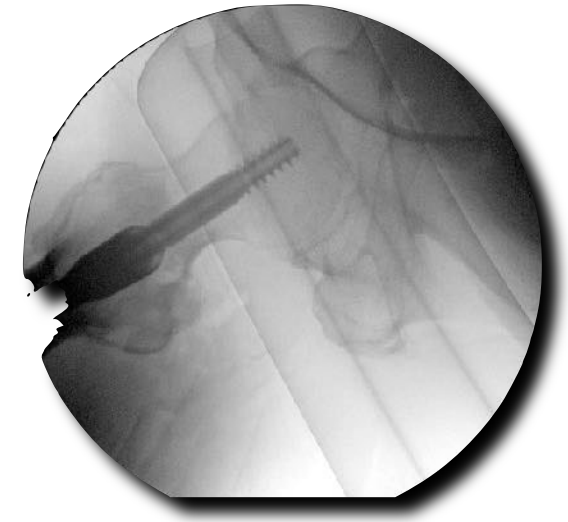
- Not as accurate or detailed as X-ray
- Therefore, need appropriate angle of beam to assess joint line
- Poor technique can mislead surgeon



Imaging in Orthopaedic Trauma: Fluoro

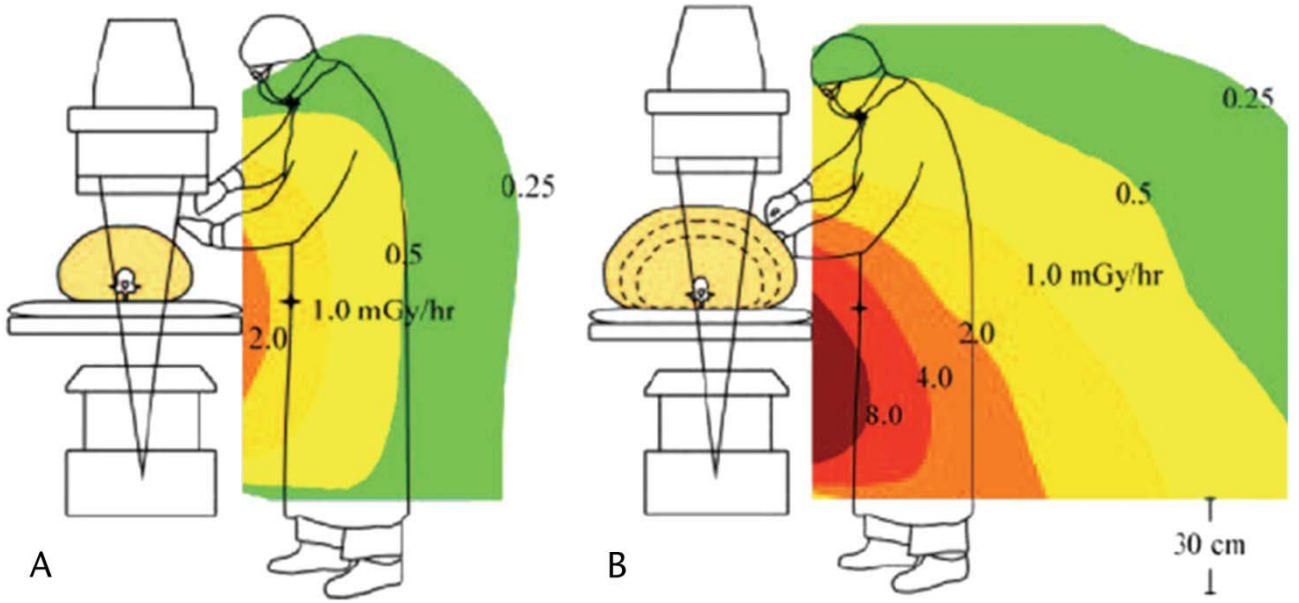
- <u>Fluoroscopy limitations</u>: Resolution

- Fluoro is adequate but X-ray provides greater detail



Imaging in Orthopaedic Trauma: Fluoro

- Fluoroscopy limitations: Radiation safety is critical
- Need Protective equipment
- Distance from beam decreases risk
- Obese patient increase scatter and exposure



J Orthop Trauma 2013 May;27:e97–e102: FIGURE 1. C-arm scatter radiation: surgeon radiation exposure during. C-arm fluoroscopy comes from 2 sources: primary (direct beam exposure) and scatter radiation. Surgeon exposure to scatter radiation increases as patients' BMI increases (compare A to B). This project used an obese cadaver (BMI 43.6) to increase the production of scatter radiation. Source: An Investigation of Operator Exposure in Interventional Radiology permission from RadioGraphics.14

Imaging in Orthopaedic Trauma: Fluoro

<u>Decrease radiation exposure:</u>

- Using personal protective equipment
- Using mini-C-arm when possible (vs. full size C-arm)
- Increase surgeon/staff distance from the x-ray tube
- Keep surgeon/staff body parts out of the direct x-ray beam
- Position image intensifier as close to the patient as possible/positioning x-ray beam as far from patient as possible
- Using collimator to decrease diameter of x-ray beam
- Communication with the radiology technician to decrease unnecessary imaging

<u>Increases radiation exposure:</u>

- Increased patient body mass
- Increased body part size, i.e. pelvis > hand
- Increased exposure time and/or going “live”

Imaging in Orthopaedic Trauma: Multi-Directional Intra-Operative Imaging

- Obtain multiple 2D fluoroscopic images
  - Imaging processing software = immediate 2D or 3D reconstruction of the target
  - Generates a reconstructed cross-sectional image similar to an axial CT image
  - Some programs allow for reconstruction views as well, e.g. Coronal, Sagittal
- Types
  - 3D Fluoro
  - O-arm

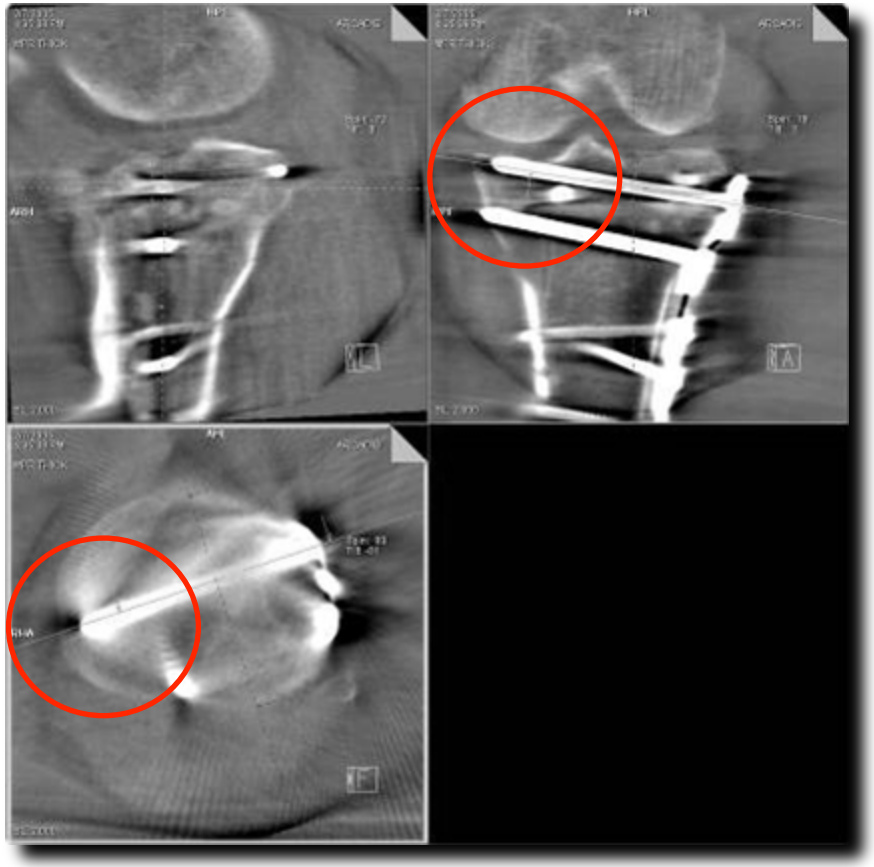
Imaging in Orthopaedic Trauma: Multi-Directional Intra-Operative Imaging 3D Vs. O-ARM

- 3D Fluoro
  - Similar to C-arm in appearance and maneuverability
  - Can obtain images in a 190 degree arc
  - Some models pair with surgical navigation systems
- O-arm
  - Larger machine, which requires additional staff and training to utilize
  - Allows for full rotation around patient
    - Collects more images than 3D C-arm
    - Better resolution than 3D C-arm
  - Pairs with surgical navigation systems

Imaging in Orthopaedic Trauma: Multi-Directional Intra-Operative Imaging 3D Fluoro and O-Arm

- Uses:
  - Implant placement in unique anatomy:
    - Spine, Pelvis
    - Can pair with navigation tools
  - Assessment of reduction:
    - Syndesmosis, Intra-articular fractures such as Calcaneus, Pilon, etc
    - Real-time Axial images for intra-operative evaluation

3-D Fluoroscopy: intraoperative assessment



Penetration of joint by screw not visible with conventional C-arm studies but easily seen in 3-D reconstruction

Imaging in Orthopaedic Trauma: Multi-Directional Intra-Operative and Navigation

- Uses:
  - Can pair with navigation tools
    - Spine
    - Pelvis- SI screw placement
      - Not statistically different Vs. C-arm
        - May be beneficial for more inexperience surgeons
        - May be helpful for more challenging patients, e.g. obese or dysmorphic sacral anatomy
      - Decreases radiation for surgeon- can use navigation without radiation exposure after obtaining images

Imaging in Orthopaedic Trauma: Multi-Directional Intra-Operative Imaging 3D Fluoro and O-Arm

- Potential concerns:
  - Increases OR time (conflicting data)
    - Set-up time
    - Time to process images
  - Cost
    - Machinery
    - Staff training
  - Radiation exposure to patient

Fluoro Summary:

- Advantages:
  - Fast
  - Real time
  - Portable
  - Less radiation than X-ray
  - 3D technology
    - provides axial imaging
    - possibility of pairing with navigation

- Disadvantages:
  - Technique dependent
  - Dependent on x-ray tech
  - **Radiation**

Summary

- X-rays provide an important screening tool for most orthopaedic trauma injuries
- CT scan provides improve bony detail, especially with reconstructions and 3D processing for preoperative planning
- MRI provides critical soft tissue information as well as evaluation of bone edema for certain pathology such as stress fractures, osteomyelitis and occult fracture
- US is useful for fracture and soft tissue screening, but difficult to communicate findings to other providers
- Fluoroscopy is the mainstay of intraoperative imaging but needs to be used with caution and with full understanding of radiation safety

References

- Tornetta, III, Paul; Ricci, William; Court-Brown, Charles M.; McQueen, Margaret M. **Rockwood and Green's Fractures in Adults 9th Edition.** Philadelphia, Wolters Kluwer Health, 2020.
- Warner SJ, Garner MR, Schottel PC, Fabricant PD, Thacher RR, Loftus ML, Helfet DL, Lorich DG. The Effect of Soft Tissue Injuries on Clinical Outcomes After Tibial Plateau Fracture Fixation. J Orthop Trauma. 2018 Mar;32(3):141-147.
- Potter HG, Weinstein M, Allen AA, Wickiewicz TL, Helfet DL. Magnetic resonance imaging of the multiple-ligament injured knee. J Orthop Trauma. 2002 May;16(5):330-9.
- Chachan, Sourabh MBBS, MS (Ortho); Tudu, Barsha MBBS, MS (Orth); Sahu, Biswajit MBBS, MS (Orth), MCh (Orth) Ultrasound Monitoring of Fracture Healing, Journal of Orthopaedic Trauma: March 2015 - Volume 29 - Issue 3 - p e133-e138
- Shuler FD, Daigre JL, Pham D, Kish VL. Laser targeting with C-arm fluoroscopy: effect on image acquisition and radiation exposure. J Orthop Trauma. 2013 May;27(5):e97-102.
- Bellapianta J, Gerdeman A, Sharan A, Lozman J. Use of the reamer irrigator aspirator for the treatment of a 20-year recurrent osteomyelitis of a healed femur fracture. J Orthop Trauma. 2007 May;21(5):343-6.Frane et al. JBJS REVIEWS 2020;8(1):e0060
- Kaplan DJ, Patel JN, Liporace FA, Yoon RS. Intraoperative radiation safety in orthopaedics: a review of the ALARA (As low as reasonably achievable) principle. Patient Saf Surg. 2016 Dec 12;10:27.
- Patra SK, Shetty AP, Jayaramaraju D, Rajasekaran S. Radiation Exposure to the Surgeon, Surgical Assistant, and Scrub Nurse During Closed Intramedullary Nailing of Long Bones-Does It Vary Depending on the Experience of the Surgeon? J Orthop Trauma. 2019 Feb;33(2):e52-e57.

References

- Araiza, Edgar T. MD; Medda, Suman MD; Plate, Johannes F. MD, PhD; Marquez-Lara, Alejandro MD; Trammell, Amy P. MD; Aran, Fernando S. MD; Lara, Daniel MD; Danelson, Kerry PhD; Halvorson, Jason J. MD; Carroll, Eben A. MD; Pilson, Holly T. MD Comparing the Efficiency, Radiation Exposure, and Accuracy Using C-Arm versus O-Arm With 3D Navigation in Placement of Transiliac–Transsacral and Iliosacral Screws: A Cadaveric Study Evaluating an Early Career Surgeon, Journal of Orthopaedic Trauma: June 2020 - Volume 34 - Issue 6 - p 302-306

- Richter PH, Gebhard F, Dehner C, et al. Accuracy of computer-assisted iliosacral screw placement using a hybrid operating room. Injury. 2016;47:402–407.
- Takao M, Nishii T, Sakai T, et al. Iliosacral screw insertion using CT-3D-fluoroscopy matching navigation. Injury. 2014;45:988–994.
- Takao M, Nishii T, Sakai T, et al. CT-3D-fluoroscopy matching navigation can reduce the malposition rate of iliosacral screw insertion for less-experienced surgeons. J Orthop trauma. 2013;27:716–721.
- Verma SK, Singh PK, Agrawal D, et al. O-arm with navigation versus C-arm: a review of screw placement over 3 years at a major trauma center. Br J Neurosurg. 2016;30:658–661.