

Imaging of the Musculoskeletal System

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Overview

Imaging is an essential tool for the modern physician. It allows us to analyze anatomy, detect pathologies and monitor disease healing or progression. In the musculoskeletal system, imaging is invaluable to detect injuries and other pathologies.

Objectives

Upon completion of this module, the learner will be able to:

1. Describe the imaging modalities and techniques commonly used in the evaluation of the musculoskeletal system,
2. Describe common indications for the use of each modality,
3. Quantify in broad terms the relative radiation exposure associated with each imaging modality,
4. Demonstrate an organized approach to the analysis of plain radiographs of the musculoskeletal system.

Reference

Read [Rheumatology 3: Getting the most out of radiology](#) by Graham Reid and John M. Esdaile in CMAJ • May 2, 2000; 162 (9)

Fundamentals of Imaging

Introduction

All imaging modalities have the same principle components:

1. An object to analyze (i.e. the patient)
2. An energy source (i.e. light or sound waves)
3. A detector (i.e. x-ray film, MRI detector)

Each modality has advantages and disadvantages and therefore is best suited to the investigation of particular clinical scenarios. Clinical examples will be used to illustrate the indications for each type of imaging described in this module.

Fundamentals of Imaging – continued...

Types of imaging

The most common types of imaging used in the investigation of the musculoskeletal system will be discussed. These are:

1. [Plain radiographs](#) (x-rays)
2. [Computed Tomography](#) (CT)
3. [Magnetic Resonance Imaging](#) (MRI)
4. [Ultrasound](#) (USS)
5. [Bone Scan](#)

Fundamentals of Imaging – continued...

Many imaging tests are costly. It is important to have an understanding of relative costs of the different modalities available.

Technique	Site	Relative cost
Plain radiography	Hand (3 views)	1
	Knee (3 views)	1
	Lumbar spine (3 views)	2
Ultrasonography	Knee	2
Arthrography	Knee	4
Radionuclide scintigraphy	All joints	7
Computed tomography	Lumbar spine	8
Magnetic resonance imaging	Knee	18
	Lumbar spine	20

*Costs vary with jurisdiction; these numbers are intended only as a rough guide. For example, the cost of ultrasound examination of a knee is roughly double and that of an MRI is about 18 times the cost of plain radiography.

From "Rheumatology: 3. Getting the most out of radiology" - Reprinted from Reid, G. et al. CMAJ 2000;162:1318-1325 by permission of the publisher ©2000 Canadian Medical Association

Plain radiographs

Introduction

Plain radiographs (or x-rays) are the first line in imaging technology. X-rays are inexpensive, quick, specific, and highly available.

How they work

X-rays contain high-energy photons which are transmitted through a patient at a specific angle (the [view](#)), toward a cassette containing photographic film. The x-rays cause the film to darken. The relative density of the structures that are imaged modulates the number of photons that reach the film; dark areas on the completed radiograph indicate areas of low density (i.e. air) and light areas indicate a high density structure (i.e. bone).

X-ray is not very good at visualizing soft tissue because these appear as [shades of grey](#) that are difficult to interpret. Substances which absorb x-rays (such as barium or iodine), can be injected or inserted in the body to improve the delineation of non-bony structures. The lower intestine can be visualized using a barium enema; joints are seen with the help of [arthrography](#).

Plain radiographs - continued...

Advantages

X-rays are inexpensive, widely, and they provide an excellent initial evaluation of bone detail and anatomic relationships. They are the **most specific** imaging modality.



This child has a fracture of the ulna and associated dislocation of the radial head at the elbow. Two orthogonal x-rays are sufficient for diagnosis. Note that the radial head should point to the capitellum in all x-ray views.

Plain radiographs - continued...

Disadvantages

X-rays are **not very sensitive**: they are less sensitive to bone marrow pathology than bone scan or MRI, and less sensitive to cortical bone pathology than CT scans. They are not optimal for evaluating soft tissue. Some x-ray views (e.g. pelvis; lumbar spine) result in relatively large radiation exposure to the patient. The associated use of contrast agents adds additional risks including allergic reaction.



Plain radiographs - continued...

Radiation Risk

The radiation dose of x-rays varies based on the body part imaged, the technique used and the views required. The “effective dose” of radiation, used for quantification and comparisons of risk, is the dose averaged over the entire body. This can range from a chest x-ray (0.1 mSv – which corresponds to 10 days ‘natural’ background radiation) to a barium enema (4 mSv or the equivalent of 16 months of environmental radiation exposure).

In the vast majority of cases, the benefits of conventional xray imaging outweigh the radiation risk, however the risk to benefit ratio should always be considered. Physicians should be able to justify each x-ray request in terms of how the anticipated result might alter clinical outcome or treatment.



Adolescent females with scoliosis often require frequent x-rays over a period of several years which expose their breast and reproductive tissues to repeated doses of radiation.

Plain radiographs - continued...

When x-rays are not required

Unnecessary x-rays should be avoided. This table summarizes rheumatologic conditions for which radiography is not required.

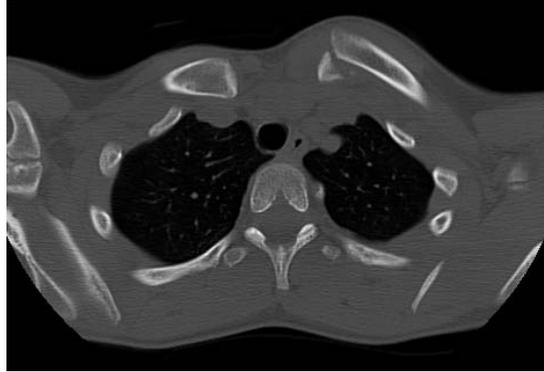
Condition	Explanation
Osteoarthritis	Management is usually determined by amount of pain and disability, not by documenting progression on radiographs.
Gout	Radiologic findings are nonspecific early in the course of the disease. Examination of synovial fluid for crystals is diagnostic.
Early septic arthritis	Early on, soft-tissue swelling is nonspecific. Synovial fluid analysis and culture are essential.
Rotator cuff syndromes	Acute tendinitis or bursitis on clinical examination does not usually require radiography; it will not alter management.
Patellofemoral knee pain	Radiographs are usually normal in young patients. Clinical diagnosis is more important than documenting radiographic abnormalities.
Bunions	Radiographs are needed only if surgery is contemplated.
Chronic back and neck pain	Once documented, radiography does not need to be repeated unless the symptom complex changes; it should not be repeated simply because the severity of pain has increased.

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CT

Introduction

CT (Computed Tomography), provides a more detailed radiographic picture of the anatomical area that is imaged. It is often used as a follow-up to an abnormal radiograph or is requested when radiographs fail to completely answer the clinical question. CT scan provides very good bone detail and improved soft tissue resolution.



Fracture of the medial aspect of the left clavicle with anterior displacement of the distal fragment. The medial clavicle and sternoclavicular joint are often difficult to visualize on plain radiographs due to overlapping structures.

CT - continued...

How it works

CT uses a rotating X-ray beam to pass through "slices" of the body. These are detected by a computer and recreated into axial images. These images can be reconstructed in any plane or three-dimensionally to demonstrate the anatomy and pathology.

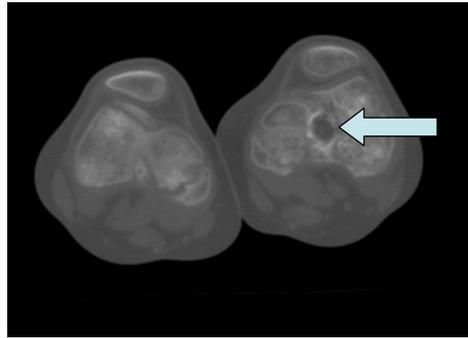


Three dimensional reconstruction CT of an adolescent's hips demonstrating bilateral overgrowth of the greater trochanters.

CT - continued...

Radiation Risk

CT scans deliver the highest radiation exposure used in current medical imaging practice. This occurs because multiple x-ray scans are used to construct the images. A CT scan generates approximately 10 mSv, or the equivalent of 3 years 'background' radiation. CT scans require a more careful risk vs benefit evaluation than conventional radiographs.

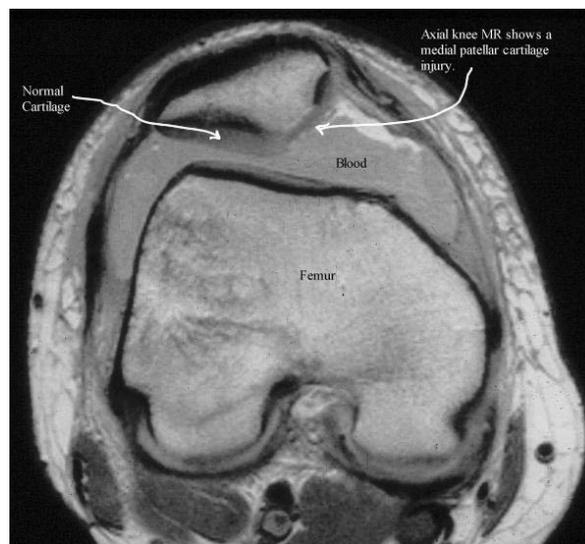


CT through both distal femora in a child demonstrates central arrest of growth plate (left leg) following fracture.

MRI

Introduction

MRI stands for Magnetic Resonance Imaging. It is the "gold standard" of soft tissue imaging, and has the added advantage of requiring no ionizing radiation.

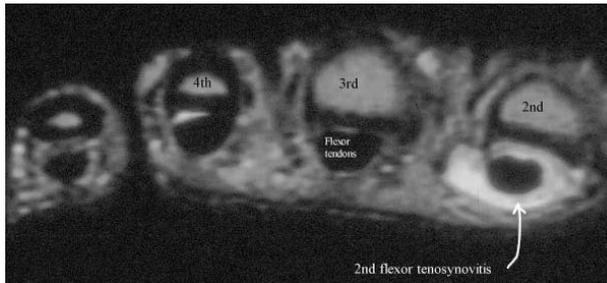


MRI - continued...

How it works

The MRI machine creates a large external magnetic field, which causes the protons (H+) in the body to polarize and align with the magnet. A special radio-frequency pulse is applied and causes the protons to 'tip' out of alignment into a higher energy state (excitation phase). The pulse is relaxed, the protons remove to the lower energy state, during which they emit energy. Each tissue has slightly different characteristics due to the proton environment (relaxation phase). This differential is used to generate the MRI image.

Each tissue-type has a unique appearances on MRI which helps the radiologist to identify anatomy and pathology such as trauma, infection, inflammation or tumour.



Cross-sectional MRI view of the hand demonstrating septic tenosynovitis of the 2nd flexor tendon

MRI - continued...

Image contrasts



Torn posterior horn of medial meniscus seen on sagittal plane T2 weighted MRI scan

Depending upon when the emitted signal is detected coming from the patient, different tissues will have different imaging properties. If the signal is detected very shortly after the beginning of the procedure, the image that results is called "T1 weighting". In a "T1 weighted" image, fat is bright, fluid and other soft tissue is intermediate grey and bone/fibrous tissue is dark.

If the signal is detected later, the image that results is called "T2 weighted". In a "T2 weighted" image, fat is dark, and fluid is bright. Pathologic conditions often contain more "free" fluid and will also be bright.

MRI - continued...

Advantages

- Excellent soft tissue contrast
- Multi-planar
- No radiation

Disadvantages

- Expensive
- Poorly available as MRI scanners are not available in all hospital imaging departments
- Poor bone detail
- Uncomfortable procedure (long, noisy, claustrophobic) for some patients
- Children may require general anesthetics because of the need to lie still for extended periods of time
- Cannot use if patient has certain metal or electronic implants such as pacemakers, heart valves, aneurysm clips. Check with the MR technologist if uncertain.
- Safety in pregnancy has not been established



MRI of hip in child with Legg-Calve-Perthes disease demonstrating collapse of the epiphysis as well as hypertrophy and deformity of the articular cartilage.

MRI - continued...

Radiation Risk

MRI scans do not use ionizing radiation therefore there is no radiation risk.

Ultrasound

Introduction

Ultrasound uses sound waves to provide real-time imaging of anatomic structures. It is most commonly used to evaluate soft tissues and in obstetrics. Ultrasound is useful for identifying joint effusions and has limited use in the evaluation of other skeletal structures. It is commonly available, low cost, and offers the advantages of real-time imaging without any radiation risk.

How it works

Sound waves are transmitted from a probe placed in contact with the skin. These waves are reflected back to a receiver. The characteristics of the returning sound waves are used to generate a picture, as different tissues cause the sound waves to be reflected differently. Ultrasound produces a tomographic (cross-sectional) image.

Ultrasound - continued...

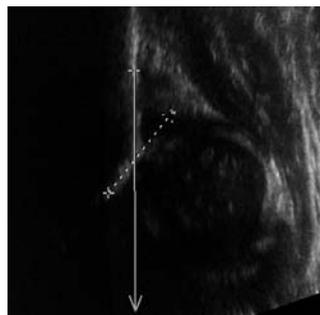
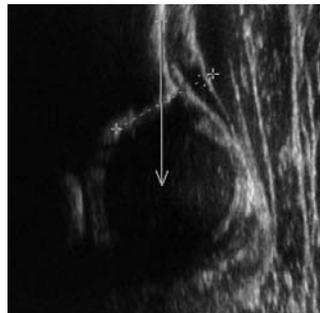
Advantages

- Highly available
- Real-time
- No ionizing radiation
- Good soft tissue contrast

Disadvantages

- Results vary with expertise of technologist and radiologist.
- Ultrasound waves cannot penetrate bone or air.

Ultrasound is the preferred imaging technique to visualize infant hips (up to 8 months of age). Normal (top) and dislocated (bottom) hips in three week old infant.



Ultrasound - continued...

Radiation Risk

Ultrasound scans do not use ionizing radiation therefore there is no radiation risk.

Bone Scan

Introduction

Bone scan is used to detect metabolically active bone. This is useful to detect occult fractures, infections, and bony metastases which may be difficult to detect with other imaging modalities.



Bone scan demonstrating increased radioactive tracer uptake at site of proximal humeral primary bone tumour.

Bone Scan - continued...

How it works

A radioactive tracer (Technetium 99 is commonly used) is injected intravenously. This accumulates in areas of bone undergoing rapid metabolic activity. Over a period of several hours, the tracer passes from the vascular system to bone. A gamma-detector is used to produce an image. "Hot spots" occur where the radionuclide has accumulated, demonstrating areas of high metabolic activity.



Bone Scan - continued...

Advantages

- Early detection of metastases and infection
- Detection of occult fractures not visible on plain radiographs
- High sensitivity

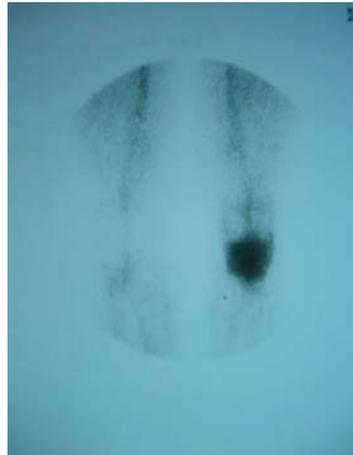
Disadvantages

- Moderate radiation risk (more than plain films but less than CT)
- May be difficult to interpret in children due to the presence of metabolically active growth plates
- Not available in all imaging departments; may not be available off-hours
- Poor specificity

Bone Scan - continued...

Radiation Risk

The radiation risk varies with the radioactive tracer used. A routine bone scan has a radiation dose of approximately 3 mSv, but some tumour imaging procedures with thallium can reach up to 37 mSv.

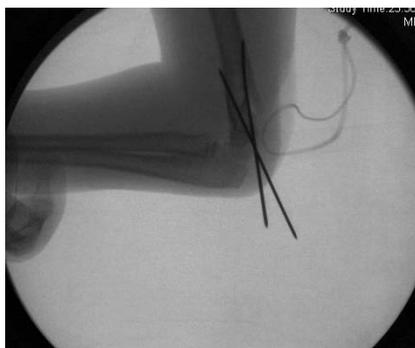


Bone scan demonstrating increased uptake at upper tibial site of Ewing's sarcoma.

Other modalities

Other imaging modalities include:

- Fluoroscopy
 - Often used for real-time imaging during fracture reduction or other surgical procedures.
 - The radiation dose is time dependent and can be large.
- Tomography
 - This technique is now rarely used as it has been supplanted by computed tomography. The multiple x-ray images required to image a structure in thin slices had the disadvantage of a large radiation dose to the patient.

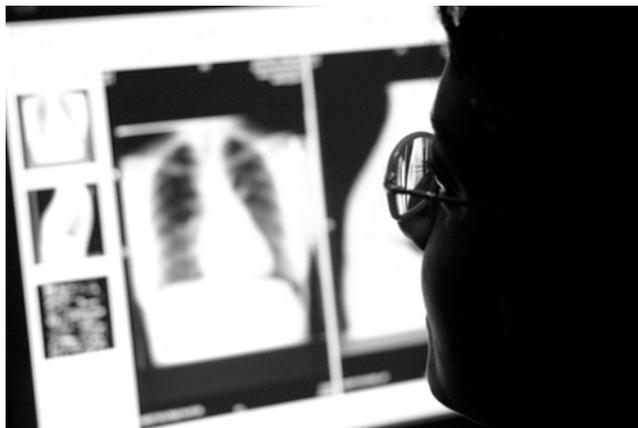


Fluoroscopic image taken during operative treatment of a supracondylar humeral fracture. Note the surgeon's finger in the image. Radiation exposure to the operator and surgical team is a concern with the use of fluoroscopy.

Articulate Quizmaker Quiz Placeholder - Imaging01

Uses of imaging

Radiographic imaging is used in many disciplines and in many situations. The next section of the module outlines common clinical indications for imaging, along with a synopsis of the general principles and modality choices for each category of disorder.



A final year Queen's medical student reviews a chest x-ray

Trauma

Plain radiographs are indicated when fracture or dislocation is suspected. The patient must be examined in advance of imaging to ensure hemodynamic stability and to guide the choice of views requested. Pain, tenderness, deformity and loss of function are used to guide the choice of images. A minimum of two perpendicular views of the suspected areas of injury are required. Oblique or special views may be necessary in certain circumstances. The x-ray should be centered on the area to be examined. In trauma, it is often prudent to x-ray the whole bone ("joint above and joint below") to avoid missing adjacent injuries.



AP and lateral views of the elbow demonstrate a displaced olecranon fracture

Trauma Continued...

Modality choice

Plain films should precede other types of imaging. CT provides additional detail of the severity and extent of a trauma fracture, and is very useful for interpreting complex fractures intra-articular fractures. MRI is often indicated with spinal injury to determine the status of the cord and ligaments.



CT with coronal plane reconstruction demonstrating comminuted, intra-articular tibial fracture. This is helpful in planning a surgical reconstruction of the fracture.

Infection

Bone infection

The early stages of bone infection (osteomyelitis) are not apparent on plain radiographs. Soft tissue swelling may be noted, but is a non-specific finding. Bone destruction and periosteal elevation become apparent after approximately 10 days of infection. Chronic osteomyelitis is signaled by areas of bony lucency and sclerosis. The latter may indicate the presence of a sequestrum (retained piece of infected, avascular bone). In the early stages of infection, bone scans and MRI scans are both highly sensitive but poorly specific. MRI has the added advantage of demonstrating the extent of associated soft tissue changes.

Lateral x-ray of the lumbar spine demonstrating evidence of disk destruction and vertebral collapse caused by infection.



Infection continued

Joint infection

Joint infection (septic arthritis) does not initially involve bone. Joint distension may be suggested by soft tissue shadows on x-ray and is more reliably diagnosed by ultrasound. The latter can be used to guide diagnostic joint aspiration. If untreated, septic arthritis may progress to involve subchondral bone surfaces on either side of the joints. Untreated septic arthritis may lead to joint dislocation and destruction, both of which are visible with plain radiographs.

Infection

Soft tissue infection

Soft tissue infection is usually imaged via MRI or CT. This is particularly useful for deep collections of pus in the epidural or retroperitoneal space. Plain film are not usually helpful in diagnosis of soft tissue infections, however they can be useful to quickly detect the presence of gas, such as in a clostridial gas gangrene.

Arthritis

Characteristic radiologic findings

This table provides a summary of radiologic findings in various rheumatologic disorders.

Diagnosis	Radiologic features	Commonly involved joints
Osteoarthritis	Osteophytes, joint-space narrowing, bony cysts and bony sclerosis	1st CMC, DIP, PIP, knee, hip, MTP, apophyseal (facet) joints of the cervical and lumbar spine
Rheumatoid arthritis	Soft-tissue swelling, para-articular osteoporosis, joint-space narrowing, marginal erosions	All of the small and large peripheral joints can be affected with the exception of the 1st CMC and DIP joints. C1-C2 subluxation of the neck can occur.
Psoriatic arthritis	Fusiform (sausage) swelling, periosteal reaction, bone resorption of joints	Similar to rheumatoid arthritis, except the DIP joints are frequently involved and para-articular osteoporosis is less common.
Pseudogout	Chondrocalcinosis	Wrist, knee
Gout	Late erosion with overhanging edge, so-called 'rat bite'	MTP, ankle including midtarsal, knee
Spondylitis*	Sacroiliitis, syndesmophytes	Sacroiliac, lumbar spine
Spondylosis	Osteophytes, disc-space narrowing	C5-C6-C7, L4-L5-S1
DISH	Flowing calcification in the anterior longitudinal ligament of the spine, ossification of entheses	Thoracic spine

Note: CMC = carpometacarpal, DIP = distal interphalangeal, PIP = proximal interphalangeal, MTP = metatarsophalangeal, C = cervical, L = lumbar, S = sacral, DISH = diffuse idiopathic skeletal hyperostosis

*Spinal changes may also be seen in Reiter's disease, psoriatic arthritis and arthritis with inflammatory bowel disease.

[Click on image to enlarge](#)

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Arthritis

Osteoarthritis

OA is usually diagnosed via plain films by the identification of some or all of the following features:

- Asymmetrical joint space narrowing
- Osteophytes (bony spurs)
- Degenerative cysts
- Subchondral bone sclerosis



The carpometacarpal joint is a common site of osteoarthritis in middle-aged women.

Arthritis

Rheumatoid arthritis

RA is normally diagnosed clinically through by history and physical features. X-rays are often normal in the first few years of disease. Characteristic radiological findings include:

- Osteopenia (early – periarticular portion of bone, late – generalized)
- Uniform joint space narrowing
- Marginal erosions
- Subluxation and deformity of hands/wrists/feet

Rheumatoid involvement of the cervical spine may result in cord compression or bony instability. Flexion/extension views and MRI are used to identify these problems.



Tumours

Bone tumours

There are many types of benign and malignant bone tumours. These may be primary (originate from bone/cartilage cells) or secondary (originate elsewhere in the body and metastasize to bone). Some tumours (e.g. renal) present as osteolytic lesions or "holes in bone" while others are osteoblastic (e.g. prostate) with characteristic areas of increased density. Most bone lesions found in adults are metastatic deposits.

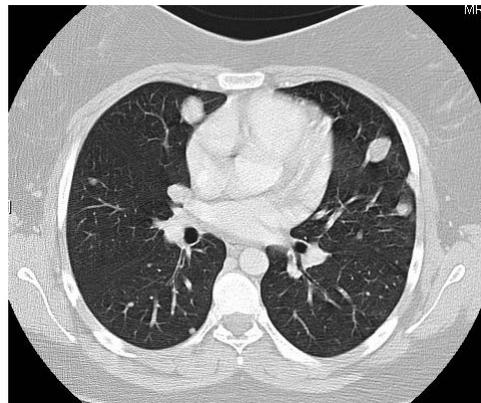
Plain films are the most specific of all modalities to help narrow the differential diagnosis of a bone tumour. These allow the assessment of tumour characteristics, biological activity, cortical destruction and periosteal reaction.



Tumours continued

Bone tumours

CT can be used to better visualize areas of bony destruction and to assess for pulmonary metastases. MRI is often used to evaluate the extent of a lesion and soft tissue invasion, and for following the response to treatment. Bone scans are very useful for identifying metastatic foci or multifocal tumours.



Metastatic tumour in lungs of patient with known primary Ewing's sarcoma of bone.

Tumours continued

Soft tissue tumours

Soft tissue tumours are usually best imaged with MRI. Cysts and tumours with vascular components may also benefit from ultrasound imaging.



Interpretation of plain radiographs of the musculoskeletal system

General approach

When reviewing plain radiographs of the musculoskeletal system, it is important to follow an organized, systematic approach. Start with **evaluation of the soft tissues** and then move on to the skeleton. Correlate your knowledge of normal anatomy with a minimum of two orthogonal images. Evaluate **alignment**, **bone** quality and density as well as **cortical** continuity and **cartilage** (as the latter is not visible on plain radiographs, evaluation is often indirect by evaluating joint space on weight bearing films).

X-ray – soft tissues

General swelling →



X-ray – soft tissues

Fat (low density) →

Deviation of elbow fat pads is often a clue to underlying bony injury



X-ray – radiographic densities



Large lipoma in medial thigh.

Air - black

Fat - dark grey

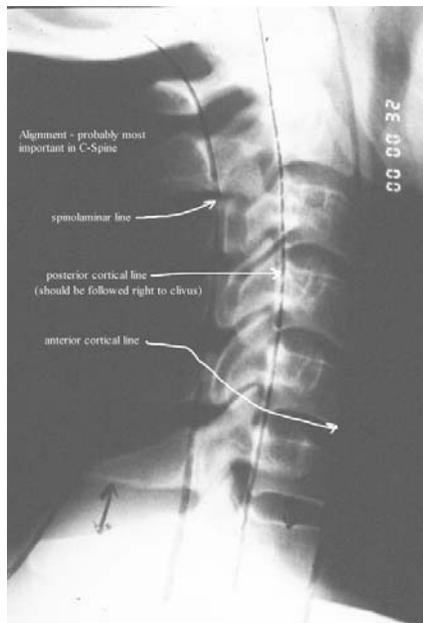
Muscle/Water - light grey

Bone/Calcium - white

X-ray – skeleton

Systematically evaluate the
“A,B,C” s of the skeleton:

- A - anatomy, alignment
- B - bone
- C - Cortex, Cartilage



X-ray – skeleton

When evaluating the spine, follow the alignment of the vertebral bodies (anteriorly and posteriorly) as well as the spinous processes. Malalignment is sometimes not apparent until motion or stress views are performed.



X-ray views

X-rays are two-dimensional representations of three-dimensional structures (i.e. the body) and thus a number of 'views' may be required to detect abnormalities. The traditional views are AP (or PA) and lateral. AP stands for antero-posterior, where the x-ray travels from front to back. PA is the reverse. Lateral is for x-rays that travel from one side of the patient to the other. A minimum of two orthogonal views are required to assess a body part. Specific joints and parts of the body might have "special" views designed to more clearly view pathologies.



AP ankle



Lateral ankle

X-ray views

This table summarizes the radiographic views commonly ordered when common rheumatologic diagnoses are being investigated or followed.

Joint	Common diagnostic possibilities	Radiographic views to order
Hand and wrist	Osteoarthritis, pseudogout, inflammatory arthritis*	Single PA view
Elbow	Post-traumatic osteoarthritis, inflammatory arthritis	Standard 3 views†
Shoulder	Rotator cuff syndrome, inflammatory arthritis	Standard 3 views
Neck	Spondylosis, rheumatoid arthritis, physical trauma	AP, lateral and oblique views (flexion-extension views if C1-C2 subluxation considered)
Hip	Osteoarthritis, osteonecrosis, inflammatory arthritis	AP pelvis and frog-leg lateral
Knee	Osteoarthritis, inflammatory arthritis, ligament or meniscal injury, pseudogout	Standing AP and lateral
Ankle	Secondary osteoarthritis, inflammatory arthritis, "sprain"	Standing PA and lateral
Foot	Osteoarthritis, inflammatory arthritis	Standing PA and lateral
Sacroiliac	Spondyloarthritis,‡ osteoarthritis	15° cranial-angled view of the pelvis
Spine	Spondylosis, compression fracture, spondyloarthritis, diffuse idiopathic skeletal hyperostosis	AP and lateral

Note: AP = anteroposterior, PA = posteroanterior.

*Inflammatory arthritis includes conditions such as rheumatoid arthritis, psoriatic arthritis and Reiter's disease; Reiter's disease is more likely to affect the joints of the lower extremities.

†The standard 3 views are AP, lateral and oblique.

‡Includes ankylosing spondylitis, Reiter's disease, psoriatic arthritis and arthritis with inflammatory bowel disease.

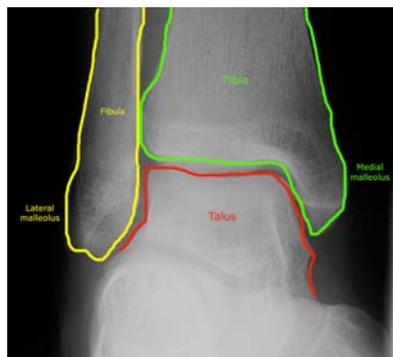
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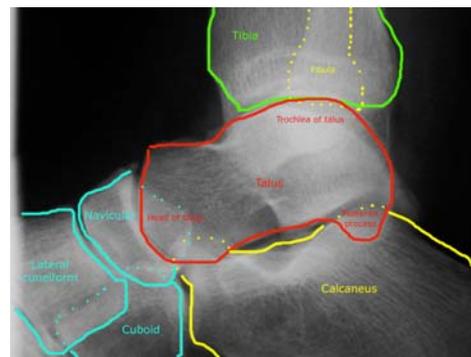
X-ray - ankle

Correlation with normal anatomy

It is important to be able to correlate the structures seen on plain x-rays with a knowledge of normal anatomy. The bones of the ankle and hindfoot have been outlined on the x-rays below to illustrate normal relationships. Click on the links provided so see similar images of the [shoulder](#), [elbow](#), [hand](#), [hip](#) and [knee](#).



AP ankle

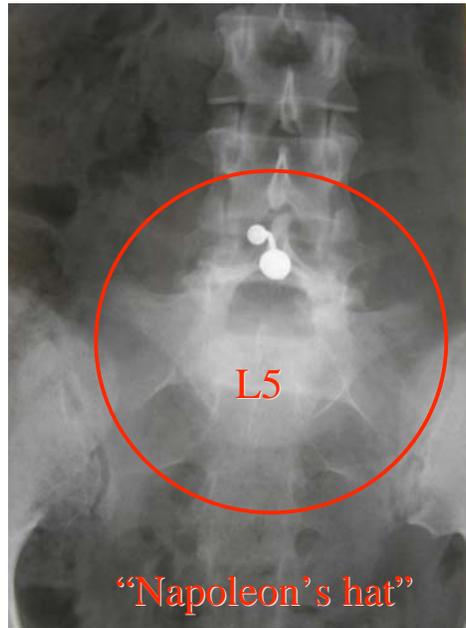


Lateral ankle

Articulate Quizmaker Quiz Placeholder - Imaging02



The AP view of the lumbar spine further demonstrates the severe malalignment of L5 which effectively lies perpendicular to the x-ray beam. This has been likened to the shape of Napoleon Bonaparte's hat.



Summary

Final thoughts

Now that you have worked through the entire module, you should be familiar with the most common imaging modalities and their potential application to the investigation of musculoskeletal conditions. In particular, make sure that you are comfortable with an organized approach to the analysis of standard views of the major anatomic regions in the body. While you may not have the expertise of a trained radiologist, a systematic approach, combined with a good understanding of normal anatomy is an important first step in becoming comfortable with the interpretation of imaging studies. Practice this at every opportunity as you enter the clinical portion of your training.

Congratulations!

You have now completed the Imaging module.

Credits

This web-based module was developed by [Dr. Lindsay Davidson](#) using Articulate Presenter based on content developed by [Dr. Paul Fenton](#) and Craig Goldie with support from [MEdTech](#) for the School of Medicine at Queen's University

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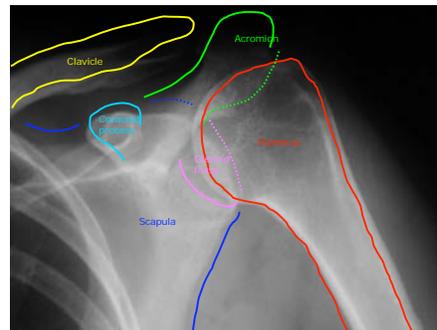
X-ray - shoulder

Correlation with normal anatomy

- [Ankle](#)
- [Elbow](#)
- [Hand](#)
- [Hip](#)
- [Knee](#)



AP shoulder



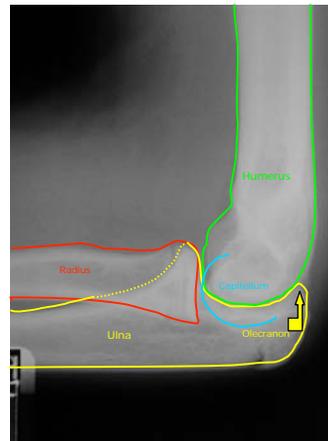
Annotated AP shoulder

X-ray - elbow

Correlation with normal anatomy



Lateral elbow



Annotated lateral elbow

- [Shoulder](#)
- [Ankle](#)
- [Hand](#)
- [Hip](#)
- [Knee](#)

X-ray – hand and wrist

Correlation with normal anatomy



AP hand and wrist



Annotated AP hand and wrist

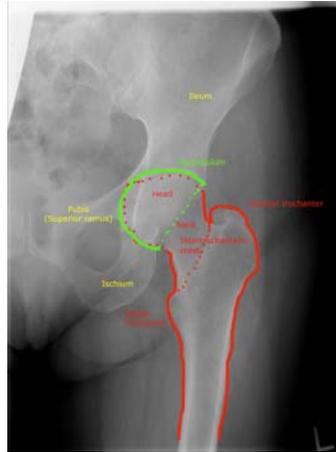
- [Shoulder](#)
- [Elbow](#)
- [Ankle](#)
- [Hip](#)
- [Knee](#)

X-ray – hip

Correlation with normal anatomy



AP hip



Annotated AP hip

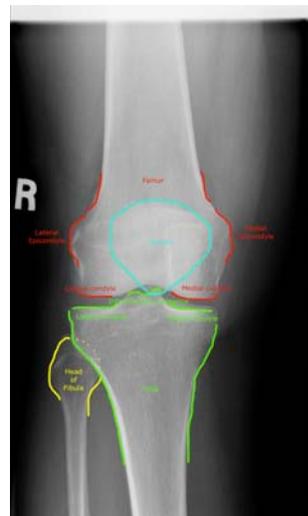
- [Shoulder](#)
- [Elbow](#)
- [Hand](#)
- [Ankle](#)
- [Knee](#)

X-ray – knee

Correlation with normal anatomy



AP knee



Annotated AP knee

- [Shoulder](#)
- [Elbow](#)
- [Hand](#)
- [Hip](#)
- [Ankle](#)