

FLUOROSCOPY MODULE Jenniefer Kho, MD

I. Introduction to fundamentals of fluoroscopy

A. Background on fluoroscopy

The relationship between 2D imaging and 3D anatomy is a complex concept that is not formally taught in orthopaedic residency training programs. Novice surgeons learn on-the-go in the operating room on real patients, which pose concerns about patient safety and learning efficacy. Currently, fluoroscopy is the main imaging modality in orthopaedic surgery despite advancements in navigation surgery. There is more awareness about the risk of radiation exposure, which may be increased for junior residents with less surgical and C-arm experience. Therefore, it is important that we train residents on the fundamentals of fluoroscopy, and develop a standardized curriculum that can be taught in all orthopaedic programs. The goal of this program is to teach and assess junior residents about the fundamental principles of fluoroscopy.



B. Objectives

After completing this program, the learner should be able to:

- Understand general physics of fluoroscopy
- Describe the components of a fluoroscope
- Navigate a C-arm for optimal fluoroscopic images
- Practice radiation safety
- Understand general and specific fluoroscopic anatomy
- Understand basic and advanced principles of fluoroscopic assessment

II. Overview of Fluoroscopy

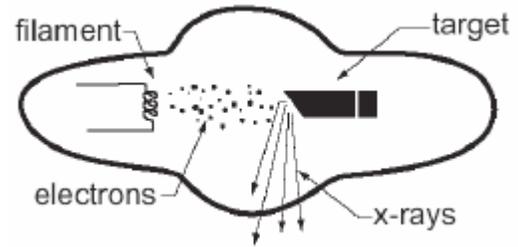
A. Physics behind fluoroscopy

1. Basic Physics

Radiation is the transfer of energy in the form of particles or waves. X-rays generated by fluoroscopy and radiography is a form of electromagnetic radiation; other examples of EM radiation include visible light and radio waves. However, unlike visible light and radio waves, x-rays generate enough energy to be ionizing, which allows for the removal of an electron from the outer shell of an atom. This can chemically alter important structures like DNA.

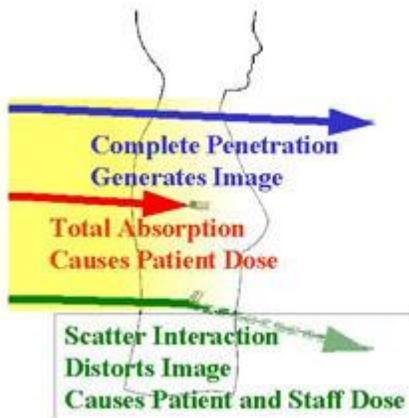
X-rays are produced when a heated filament (cathode) within an x-ray tube generates electrons that are accelerated to a tungsten target (anode) by application of high voltage (50-150 kVp) to the tube. The electron creates an electric field that interacts with the nucleus of the anode, thereby releasing energy in the form of x-rays.

The flow of electrons from the filament to the target is called the tube **current** and is described in units of **milliamperes (mA)**. Fluoroscopy is normally performed using 2-6 mA and an accelerating voltage of 75 to 125 kVp. The rate of x-ray production is directly proportional to the tube current, but is more sensitive to increasing kVp than mA. For example, increasing the kVp by 15% is equivalent to doubling the mA.



Fluoroscopy units are usually operated in an automatic brightness control (ABC) model, in which a sensory in the image intensifier monitors the image brightness. When there is inadequate brightness, the ABC increases the kVp first, which increases the x-ray penetration through the patient, and then adjusts the mA to increase the brightness. Thicker soft tissue or larger cross

sectional-area, such as the abdomen, will require greater exposure. For example, there is increased direct and scattered exposure for spine versus non-spine procedures by 10-12x.



When x-rays traverse tissue, they can result in **1) complete penetration, 2) total absorption, or 3) partial absorption with scatter**. Complete penetration means that the x-rays completely passed through the tissue, resulting in an image. Total absorption means that the x-ray energy was completely absorbed by the tissue, resulting in no image. Partial absorption with scatter involves partial transfer of energy to tissue, with the scattered x-ray possessing less energy and following a different trajectory. The scattered radiation is responsible for causing radiation exposure to the operator and staff.

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2. Units of Radiation Exposure and Dose

Radiation exposure is defined as the quantity of x-rays required to produce an amount of ionization in air at standard temperature and pressure. The x-ray machine output is described in terms of **Entrance Skin Exposure (ESE)** and is the amount of radiation delivered to the patient's skin at the point of entry of the X-ray beam into the patient. The traditional unit of exposure is the *Roentgen (R)* which is defined as $1R = 2.58 \times 10^{-4} \text{ C/kg air}$. The SI unit is Coulombs/kilogram (C/kg). The unit Roentgen is only defined for air and cannot be used to describe dose to tissue.

Radiation dose can be reported as **absorbed dose, dose equivalent** and **effective dose equivalent**.

- **Absorbed dose** is measured in *rad (Radiation Absorbed Dose)*. The SI unit is the Gray (Gy), $1\text{Gy} = 100 \text{ rad}$.
- **Dose equivalent** accounts for differences in biological effectiveness of different types of ionizing radiation. Dose equivalent is equal to **absorbed dose x radiation quality factor** specific to the type of radiation being used. The traditional unit is the *rem (Roentgen Equivalent in Man)*; the SI unit is the *Sievert (Sv)*, $1\text{Sv} = 100 \text{ rem}$. In diagnostic x-ray, the radiation quality factor is 1, so 1 rad is equivalent to 1 rem.
- The **effective dose equivalent (EDE)** takes into account that the potential health effect from single organ exposure is smaller than from whole body exposure. For example, a dose equivalent of 5 Sv to the arm would be smaller than 5 Sv to the lumbar spine or abdomen. The EDE is defined as the sum of the **absorbed dose to the tissue x weighting factor**, which thereby calculates risk of cancer from partial body irradiation versus whole body irradiation. Units are also rem or Sieverts. The table below compares the risk of cancer to different body parts.
 - $<20 \text{ mSv}$ is low or moderate
 - $20\text{-}50 \text{ mSv}$ high risk
 - $>50 \text{ mSv}$ very high
 - For example, pelvis AP has an effective dose of 0.6, with a risk ratio for fatal cancer of 1/33,300

Examination†	Adults		Children*	
	Avg. Effective Dose (mSv)	Risk Ratio‡	Avg. Effective Dose (mSv)	Risk Ratio§
Radiography				
Skull (AP and lateral)	0.1	1 in 200,000	0.016	1 in 690,000
Cervical spine	0.2	1 in 100,000		
Thoracic spine	1.0	1 in 20,000		
Lumbar spine (AP and lateral)	1.5	1 in 13,300	0.31	1 in 35,000
Chest (PA and lateral)	0.1	1 in 200,000		
Chest (PA)	0.02	1 in 1,000,000	0.016	1 in 690,000
Mammography	0.4	1 in 50,000		
Abdomen	0.7	1 in 28,600		
Pelvis (AP)	0.6	1 in 33,300	0.051	1 in 215,000
Hip	0.7	1 in 28,600		
Shoulder	0.01	1 in 2,000,000		
Knee	0.005	1 in 4,000,000		
Computed tomography				
Head	2.0	1 in 10,000	2.8	1 in 3900
Neck	3.0	1 in 6700		
Chest	7.0	1 in 2600		
Chest for pulmonary embolism	15	1 in 1300		
Abdomen	8.0	1 in 2300	3.7	1 in 3000
Pelvis	6.0	1 in 3300		
Three-phase liver study	15	1 in 1200		
Spine	6.0	1 in 3300		
Coronary angiography	16	1 in 1250		
Virtual colonoscopy	10	1 in 2000		

*Ten years old. †AP = anteroposterior, and PA = posteroanterior. ‡5.0% per sievert²⁴. §9.1% per sievert²⁶.

Giordano et al. *Radiation Exposure Issues in Orthopaedics*. JBJS 2011.

B. Components of Fluoroscope

Components of the fluoroscopic imaging chain are:

- x-ray generator
- x-ray tube
- collimator
- filters
- patient table
- grid
- image intensifier
- optical coupling
- television system
- image recording

The components pertinent to orthopaedic surgery are the x-ray generator, x-ray tube, collimator, patient table and pad, and image intensifier.

X-ray generator - Produces electrical energy and allows selection of kilovolt peak (kVp) and tube current (mA) that is delivered to x-ray tube.

X-ray tube - Converts electrical energy of x-ray generator to x-ray beam. Source of radiation; want to increase distance from x-ray tube (see below)

Collimator - contains multiple sets of shutter blades that define the shape of the x-ray beam. There is a rectangular and a round set of blades. By further collimating the beam, or "coning down" to the area of interest, the exposed volume of tissue is reduced, which results in less scatter production and better image contrast. It also reduces the overall patient and surgeon radiation dose by minimizing scatter and direct exposure.

Patient table and pad - Must balance adequate strength to support the patient's body weight while minimizing x-ray attenuation. This can be accomplished with carbon fiber composite materials. Thin foam pads are better than thick gel pads.

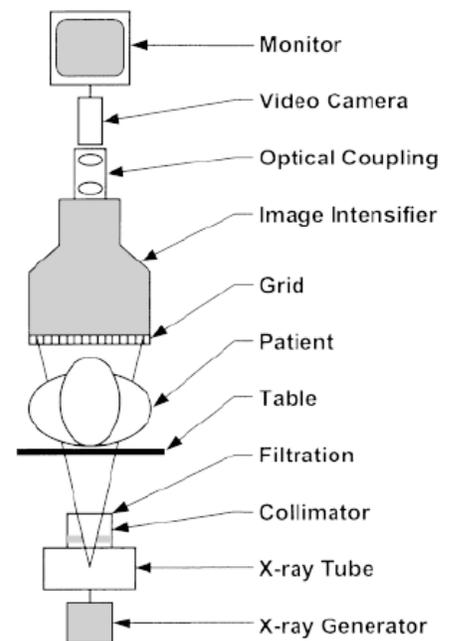


Image intensifier - Converts x-rays and amplifies image brightness. Major components include an input layer to convert x-rays to electrons, electron lenses to focus the electrons, an anode to accelerate them, and an output layer to convert them into a visible image. There are different diameters (mini versus standard C-arm) that can accommodate body parts of various sizes.



C. Optimizing C-arm position

Most often, there will be a radiology technician operating the C-arm. However, it is important to understand how the C-arm moves so that you can direct the technician.

The C-arm unit can be maneuvered in various ways, depending on whether one moves the entire unit or just the C-arm. The position of the image intensifier is also important.

- **Move the entire unit**
- **Move only the C-arm**
 - **Cant** - This enables one to angle the base cephalad or caudad.



- **"C" over** - This enables one to move the C-arm in the plane of the C-arm and is most commonly used for obtaining AP, lateral, and oblique views



- **Positioning the image intensifier (base)** - Structures closer to the image intensifier will appear smaller compared to those further away. To increase the field of view, bring the base as close as possible to the structure of interest; this is particularly important for assessing alignment and also results in the least amount of radiation exposure for the patient and physician.
 - In general, one should center the base of the C-arm over the area of interest.
- **Positioning the C-arm** - The final consideration is positioning the C-arm during pre-operative planning. It is difficult to work on the same side as the C-arm because of risk of contaminating the machine, in addition to the limited amount of space. It is easier to have the C-arm coming in from the opposite side of the area you will be operating on.
 - For example, when operating on a left ankle fracture, it is easier to position the C-arm on the right side of the room. However, when operating on the medial aspect of the left leg, it may be easier to position the C-arm on the left side so that there is more working area.



The C-arm is on the opposite side of where the surgeons are standing
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D. Radiation Safety

There has been increasing concern about radiation safety throughout all surgical disciplines. A recent article by Giordano, "[Radiation Issues in Orthopaedics](#)" highlights the relative ignorance regarding radiation among physicians. Here are some guidelines that are recommended for all personnel who operate diagnostic x-ray equipment.

- **Distance and positioning**
 - Positioning of the radiation source
 - Studies show decreased exposure dose when standing on the same side of the patient as the image intensifier. This is most useful when imaging a large body part that fills the entire radiation beam; a smaller body part will allow some beams to pass through.
 - It is also preferable to position the C-arm x-ray tube underneath the patient and the operating table, if possible.
 - Positioning of body part in relation to radiation source
 - Cadaveric study shows that positioning the image intensifier as close to the body part as possible (c) within the arc of the C-arm reduces patient exposure tenfold and surgeon exposure by half compared to positioning adjacent to the radiation source (a)
 - This is due to automatic increase in the mA to provide brightness, which increases the radiation dose.
 - Positioning the image intensifier closer to the body part also results in a sharper image.

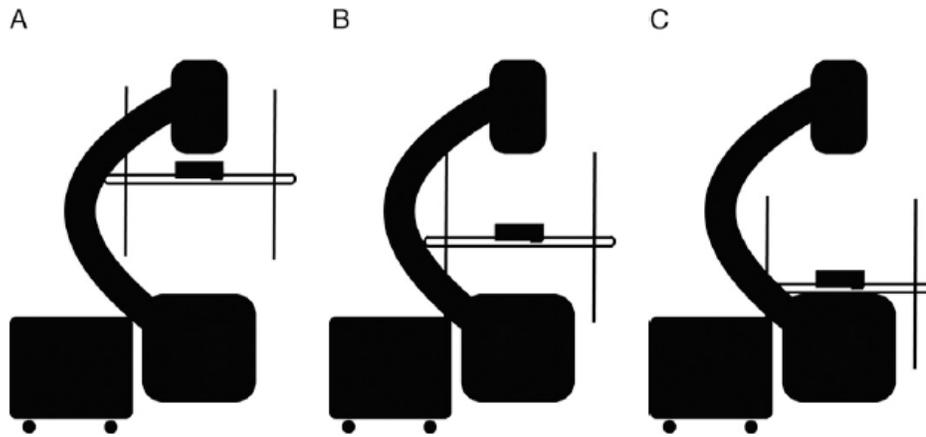
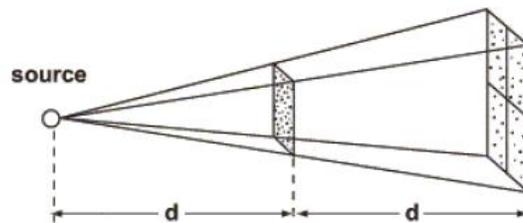


Fig. 1

The three positions tested with the standard c-arm fluoroscope included the worst-case scenario with the specimen placed 2 in (5 cm) from the radiation source (A), the midway position with the specimen placed 10 in (25.4 cm) from the image intensifier (B), and the best-case scenario with the specimen positioned at the intensifier (C). (Reprinted from: Giordano BD, Baumhauer JF, Morgan TL, Rehtine GR II. Patient and surgeon radiation exposure: comparison of standard and mini-c-arm fluoroscopy. *J Bone Joint Surg Am.* 2009;91:297-304.)

- Inverse square law
 - Radiation beams travel in both a parallel and divergent (scattered) manner when emanated from the source. Scattered radiation is the main source of radiation exposure to the staff. There is an inverse square relationship between the distance and divergence of the beams. So, if one doubles the distance there is $\frac{1}{4}$ the exposure.



- **Time of exposure**
 - Spot images are better than live or continuous fluoroscopy.
 - Be judicious and thoughtful about the number of shots taken.
 - Five minutes is the maximum time allowed on the fluoroscope, and the machine must be restarted if this time limit is exceeded
- **Use of Barriers**
 - Lead aprons - 1mm Pb thick lead gown can reduce >90% of scatter exposure, however it is not 100% protective
 - Any personnel within six feet of a fluoroscope must wear lead aprons, according to regulations
- **Other C-arm techniques**
 - Use the smallest field of view possible by collimating the image; this also improves image resolution. There is greater contrast between different tissue types for the smallest field of view.
 - Avoid magnification
 - Image only pertinent body parts

III. Basic Fluoroscopic Assessment

A. General Fluoroscopic Anatomy

When assessing a fluoroscopic image, there are a few basic concepts that will provide the foundation for being able to understand more complex fracture patterns.

Cortical versus cancellous bone

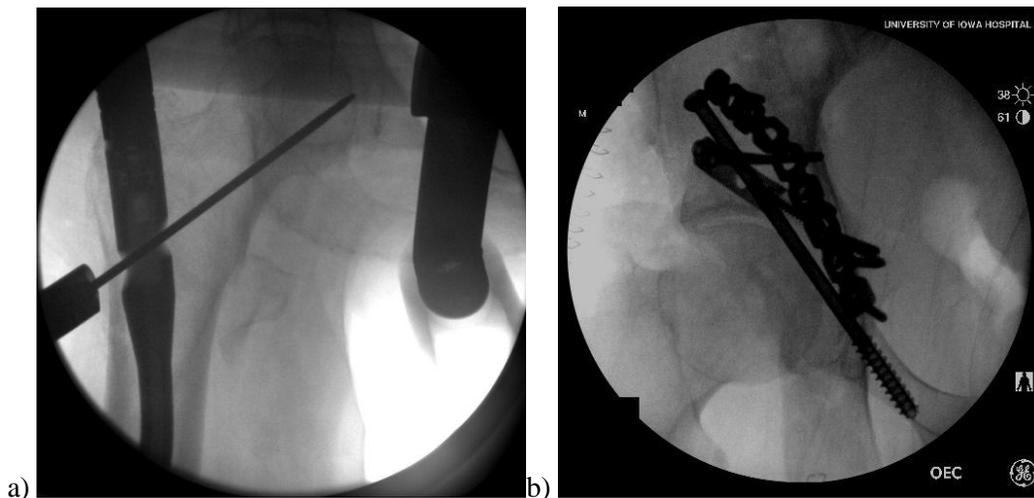
- Cortical bone will appear denser, or more opaque, than cancellous bone due to increased density of its microscopic composition.
- Osteopenic patients will have a thinner cortex and a wider medullary canal or isthmus.
- Cortical bone in diaphysis is thicker than that in metaphysis, which is well-demonstrated in the femur.

Articular surface

- Subchondral surface will also appear denser than the surrounding cancellous bone, similar to cortical bone.
- Identifying the articular surface is especially important in assessing reduction of articular fractures.

Concave versus convex surface

- Appreciating the overall geometry of the object of interest is important to take into consideration when assessing fluoroscopy, especially concavity versus convexity.
- For example, the femoral head is convex. Since the femoral head is spherical, if a wire or screw appears to be penetrating into the joint on any view, then it is definitely in the joint (a). If there is any question about joint penetration, one may take live fluoroscopic shots to make sure the wire or screw is out of the joint on all views.
- For convex surfaces such as the acetabulum, the opposite is true. As long as the instrument is visualized to be out of the joint on one view, one can be reasonably confident that the instrument has not penetrated, even though it appears to be in the joint on another view. (b)



B. Fluoroscopic Anatomy of Distal Tibia

Important landmarks

- Medial and lateral malleoli, tibial plafond, and talus
- Tibial plafond is rectangular in shape. Its surface is wider anteriorly versus posteriorly. It is centrally concave with posterior and anterior extensions. The posterior surface extends more distally.
- Fibula extends distal to tibia.



Radiographic and fluoroscopic measurements

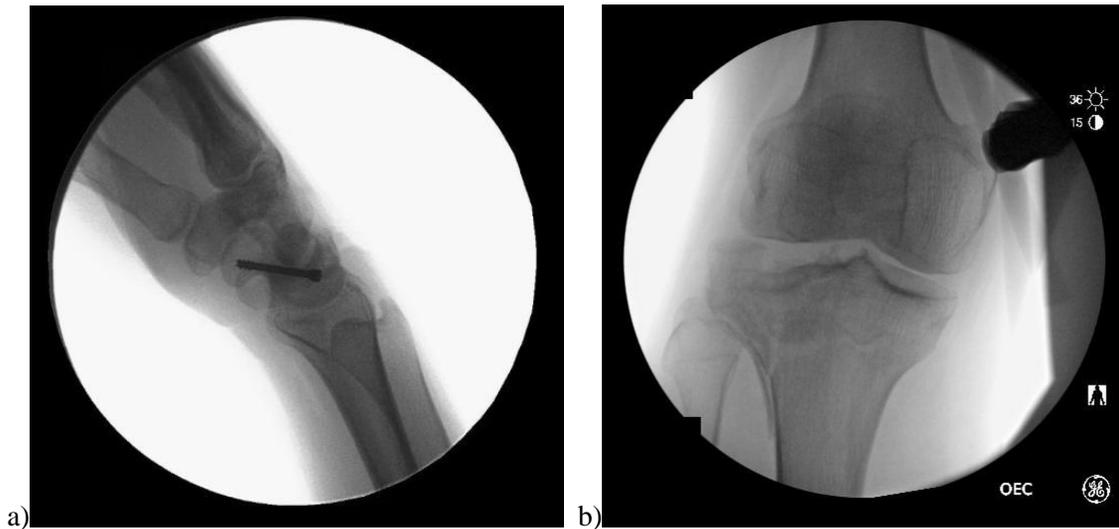
- Tibiofibular clear space, tibiofibular overlap, talar tilt, medial clear space
- An AP of the ankle or distal tibia should demonstrate intact mortise and normal tibio-fibular relationship
 - Anterior tubercle of tibia should overlap fibula by at least 10mm (tibiofibular overlap)
 - Tibiofibular clear space <5mm
 - Talar tilt 83 +/- 4 degrees
 - Medial clear space < 4mm
- Lateral view demonstrates relationship of talus to tibia and fibula position. The lateral malleolus overlaps the medial malleolus but projects slightly more distal and posterior. The lateral malleolus may not appear as long as expected if the image intensifier is closer to the fibula than the medial malleolus, in which case the fibula will appear somewhat smaller than the medial malleolus.
- Mortise view is a 15 degree internal rotation view.

C. Understanding Shadows and Densities

- One of the most difficult aspects about understanding fluoroscopy is interpreting overlapping shadows and densities. This comes from experience, although knowledge of the following concepts is helpful:
- **Normal radiographic densities** usually represent either cortex or articular surface. Disruption in the radiographic dense line is suggestive of fracture gapping, malreduction, or failure to restore normal anatomy.



- **Abnormal shadows** indicate overlapping of fracture fragments (b). It is important to be familiar with normal shadow patterns to avoid misinterpretation of what is pathologic versus anatomic; for example, in the hand, a lateral view will have many normal shadows due to overlapping of carpal bones (a). In this case, it will be difficult to interpret the shadows, and an oblique view may be more helpful.



D. Assessing Reduction on Fluoroscopy

- Assessing quality of reduction requires familiarity with normal radiographic anatomy and ability to interpret shadows. Many times, one will be unable to directly inspect the reduction and will have to rely exclusively on the fluoroscopic image to judge reduction.
- General principle is to restore the radiodense line of the cortex or articular surface, and eliminate any shadows representing displaced fracture fragments.



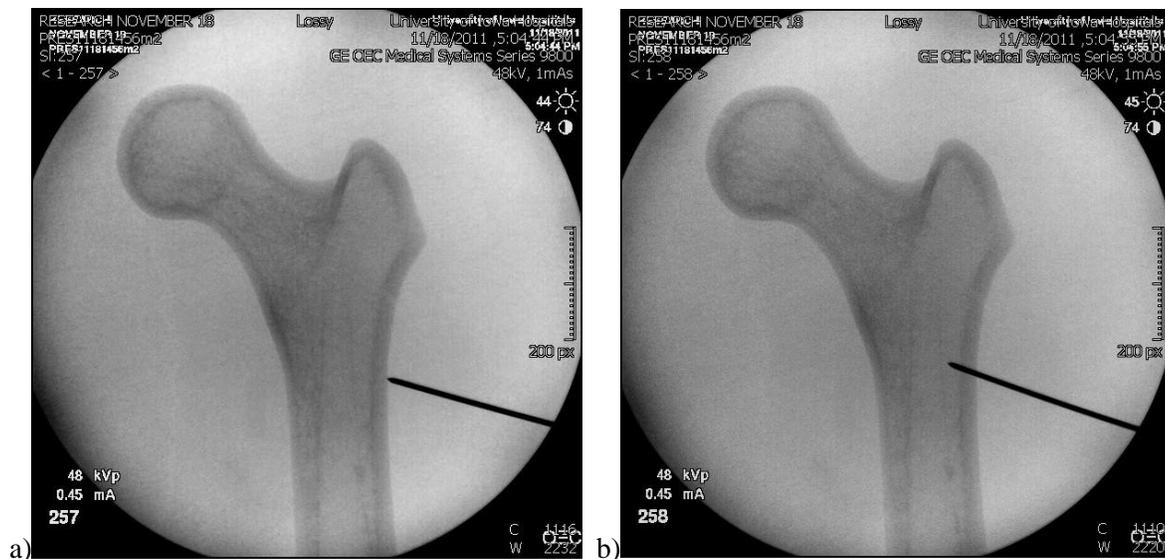
- Another basic concept is to always check 2 orthogonal views (e.g. AP and lateral), as the fracture may appear reduced on one view, but may be off in another plane.
- With articular fractures or bones of more complex anatomy such as the calcaneus or talus, multiple angles need to be checked to verify reduction. If the fracture is simple without much comminution, then reduction is judged based on the restoration of cortical and/or articular lines. Sometimes, there will be a large bony fragment that will

"key" in and guide the reduction. If the fracture is comminuted without any normal anatomic landmarks, then reduction must be assessed indirectly by assessing clinical rotation, length, and other variables.
Understanding Shadows and Densities

IV. Advanced Fluoroscopic Assessment

A. Fluoroscopic Assessment of Surgical Instruments

- Once one develops a basic cognitive understanding of fluoroscopy, it will be easier to understand the relationship of surgical instruments and bony anatomy. We will use the guide wire and the proximal femur as the main example.
- There are some basic facts about fluoroscopic assessment of instruments. When placing a wire on a flat surface, like the lateral femoral cortex, the wire tip must be directly contacting the outer cortex (a). If the wire feels like it is down on bone, but on fluoroscopy the tip is not seen directly on the cortex, then most likely the wire has slid off either anterior or posterior (b).



- The other possibility would be that the C-arm is not angled correctly and is giving one an oblique image. This rule also applies for more convex surfaces, such as the greater trochanter or humeral head, and a concave surface, like the trochanteric fossa. The key point to remember is the anatomy; for example, the trochanteric fossa is a depression behind the medial surface of the greater trochanter. Therefore, fluoroscopically, this region would be located inferior to the superior femoral neck.

Resources Cited:

[Giordano, Grauer, Miller, Morgan, Rehtine II; Radiation Exposure Issues in Orthopaedics. JBJS 2011 June;93\(12\)](#)

[Schueler B. General Overview of Fluoroscopic Imaging. RadioGraphics 2000.](#)

[Brown et al. Medical Fluoroscopy: A Guide for Safe Usage](#)