Chapter 5

Imaging

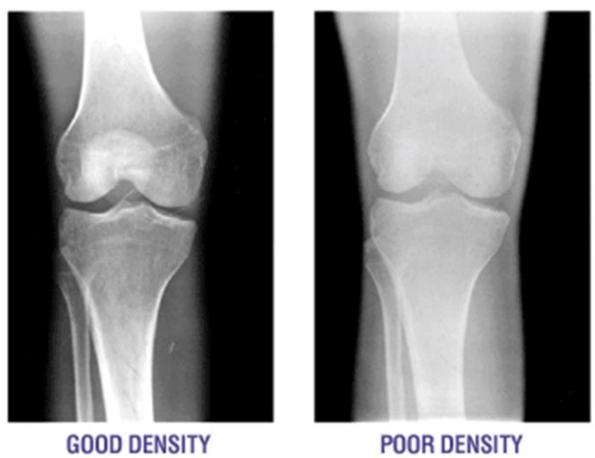
Photographic Properties

Contrast and Density

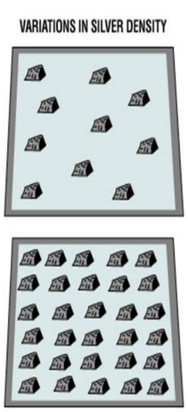
In radiography, exposure involves the proper combination of the **prime factors** of exposure; kVp, mA, the exposure time and distance (SID), as well as many other factors that affect the image. The two most important **photographic properties** are density and contrast.

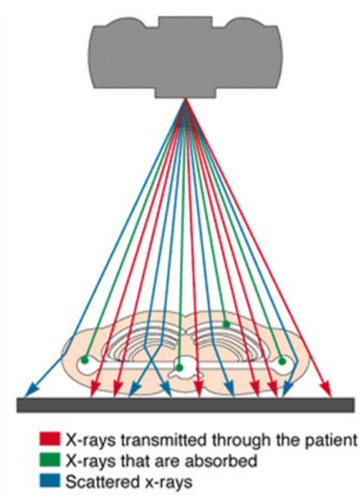
Density

Density-The overall blackening on a radiograph

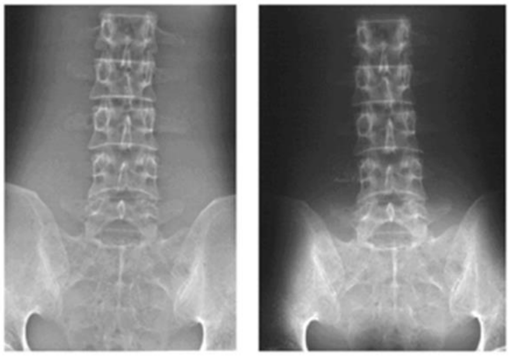


When x-rays pass through a patient's body, three things can happen: (1) the x-ray photon is transmitted, passing through the body, interacting with the film, and producing a dark area on the film; (2) the x-ray photon is absorbed in an area of greater tissue density, producing lighter areas on the film; and (3) the x-ray photon is scattered and reaches the film causing an overall gray fog.





What the radiographer sees on the finished radiograph are variations in the amount of black metallic silver (from silver halide crystals in the emulsion) that stays on the film after film processing. The exposed crystals are converted into black metallic



TOO LIGHT TOO DARK

silver as the film is developed. The blackness of an area of a radiograph depends on the amount of exposure that reaches the film emulsion.

Densities on the film may range from total black to nearly clear. If the density of the image is too light or too dark, the image does not show as much detail. A radiograph that is too dark has been overexposed (too much radiation reached the image receptor). A radiograph that hasn't been exposed to enough radiation is underexposed and will be too light. Both may be difficult to interpret. If a poor exposure results in an image that is too light or too dark, it may be necessary to repeat the examination, resulting in more exposure to the patient. Sometimes a film that is slightly overexposed can still be used. A film that has absorbed too many photons has recorded more information than necessary, but a computerized optical scanner or a bright light may be used to salvage the film.

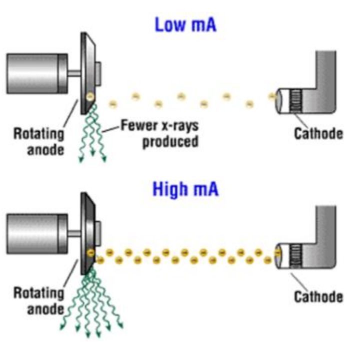
Milliamperage (mA) is a key factor affecting density. When you multiply mA by the exposure time in seconds (s) you have mAs. Milliampere seconds is abbreviated mAs and indicated the total quantity of x-rays in the exposure. X-ray currents are measured in milliamperes, or thousandths of an ampere. Normal household current is a few amperes.

FACTORS AFFECTING DENSITY

Primary control factors
- mA
- Exposure time

Influencing factors
- kVp
- Distance from source (SID)
- Object to image receptor distance (OID)
- Intensifying screens
- Anode-heel effect
- Grids
- Beam restriction
- Filtration
- Body structures
- Processing

The exposure rate, C/kg per second, is directly proportional to the mA. If the mA is too low, x-rays may penetrate the part of the body being studied but the density may be too low to allow good visualization. When you double the mA, the x-ray exposure rate doubles, when you triple the mA, the rate triples, and so on: this increases the density. But the energy of the x-ray photons themselves isn't affected.

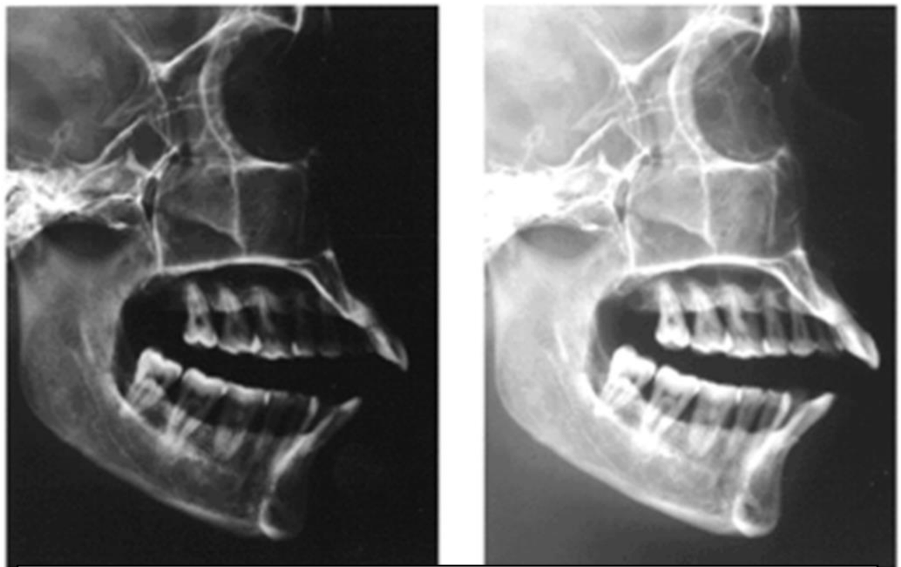


A film that's too light because it hasn't absorbed enough photons, however, cannot be used because it hasn't recorded enough information in the first place.

A radiograph has light and dark areas or variations in density. The range of that variation between light and dark is called radiographic contrast. Another definition of **contrast** is the difference in density of adjacent areas on a radiograph. Density represents the amount of silver deposited in an area during film processing. Contrast, on the other hand, represents how that silver is distributed in various areas. Contrast is what enables us to see anatomic detail. Radiographic contrast results from factors involving the subject, called subject contrast, and factors involved in the film, called film contrast.

The 15% Rule

While mAs controls density kVp influences density. An increase of 15% in kVp about doubles the exposure. This principle is referred to as the 15% rule. For example, changing the kVp selection from 70 to 80 (a 15% increase) will double the exposure. In other words, while density increases as kVp does, it isn't a proportional relationship.

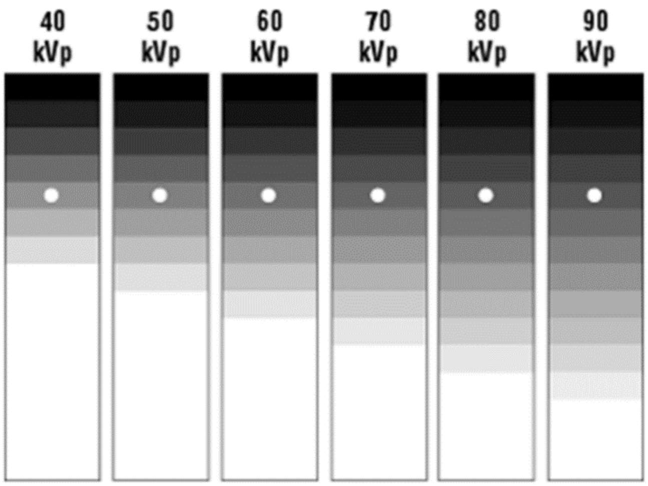


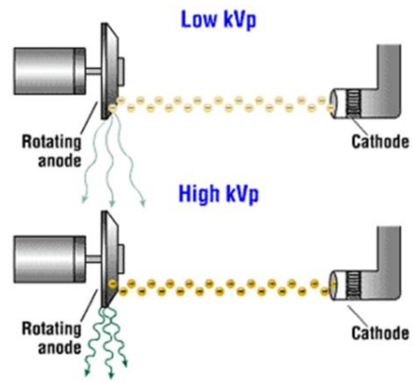
A few shades of gray — Lots of shades of gray

Scatter radiation is something to avoid because it reduces the contrast and the visibility of recorded detail in the image on a radiograph. X-rays are scattered when the direction they're traveling in changes and they lose energy. That causes unnecessary darkening (density) on the film, also called fog.

Although it's true that increasing kVp will show a corresponding increase in density, altering kVp can have complex effects. Changing the setting affects a lot of other properties, such as penetration, patient dose, scatter, and contrast. As you gain more experience in radiography, you'll come to know whether a radiographic image can best be improved by a change in density or contrast. This illustration of contrast variations shows how higher kVp typically increases the contrast range.

These calculations may seem complicated now, but as you learn more about these controls you'll soon be more comfortable choosing the best settings for a given examination. As you'll learn, predetermined guidelines and settings will govern most exams.





As a general rule: if a radiograph needs to be repeated because of improper density, you need to either double the original mAs if it was too light or cut the mAs in half if it was too dark.

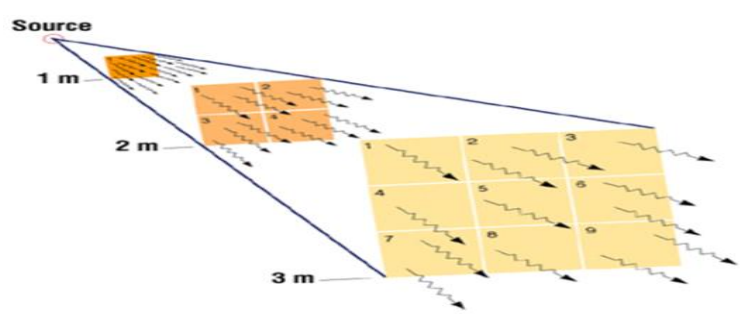
Your goal is to produce images with proper density. The mA setting is usually made by following the technique chart for that particular equipment.

Exposure time for any particular examination may be selected by the technologist based on body part and thickness, using a control panel, or it may be controlled by an automatic exposure control system that shuts the exposure off when a proper density has been achieved

The Inverse Square Law

Another factor affecting density is referred to as source-to-image receptor distance (SID). This term refers to the distance between the source of x-rays and the image receptor.

A good way to understand the effect of distance on x-rays is to think about how light from a single source diminishes as you get further from it, like shining a flashlight on a more distant object. The light is much brighter on nearby things than on distant things, because light rays spread out as they move farther from the source. You should remember from your study of radiologic physics that this is called the inverse-square law.



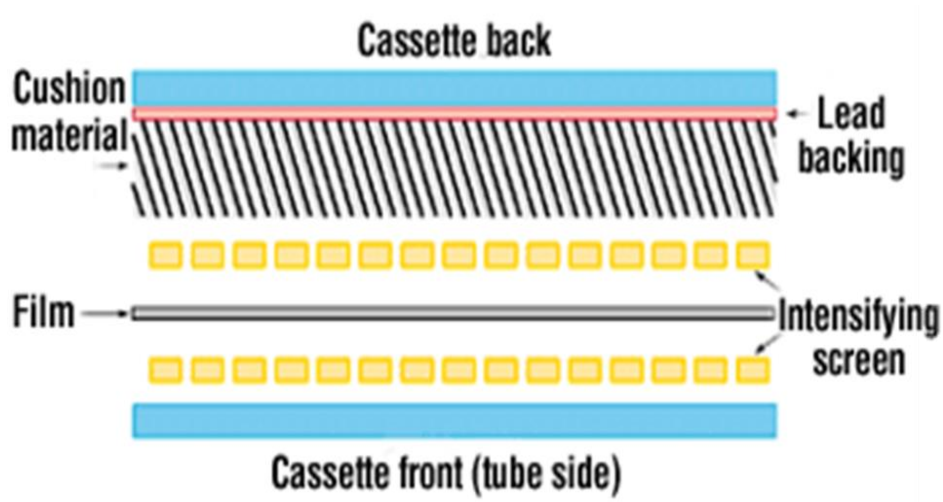
The x-ray beam spreads from a focal spot in the x-ray tube in a cone like shape. The beam becomes wider as the distance from the target increases, so usually a beam-limiting device called a collimator is used to restrict it. A collimator has dials or levers you can adjust to change the radiation field size. It's mounted permanently on the tube housing.

In other words, the same amount of radiation spreads out over a larger area the farther that area is from the tube. That means the density at a farther distance is less for a given exposure because the area receives less radiation than an area closer to the x-ray tube. You can compensate for this by increasing the mAs.

Even slight variations in SID make a significant difference in density because of the inverse-square law, which says that the intensity of x-rays (and the film density) is inversely proportional to the square of the distance between the point at which the radiation is received and its source. For example, if you reduce the SID to half of the original distance, intensity and density will increase by a factor of 4.

Screens

Only about one third of the x-rays that strike a screen interact with it. But each one emits many visible light photons. A screen, therefore, amplifies the x-ray beam, meaning that fewer x-ray photons need to pass through the body to produce an image. That allows a lower dose of radiation to the patient. Most radiographic exams use intensifying screens, even though they tend to cause a slight degree of image unsharpness.



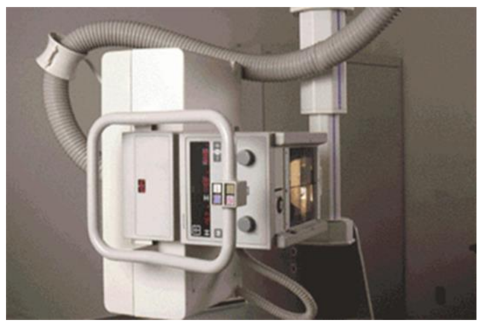
Grids

A grid is made of thin lead strips separated by a radiolucent material. The primary radiation passes in a straight line through the material, and the lead strips absorb scatter radiation emitted in other directions. Scatter radiation produces a generalized unwanted exposure on the image referred to as **fog**. Grids have a profound impact on contrast and will be discussed in more detail in the second lesson on contrast.

Collimator

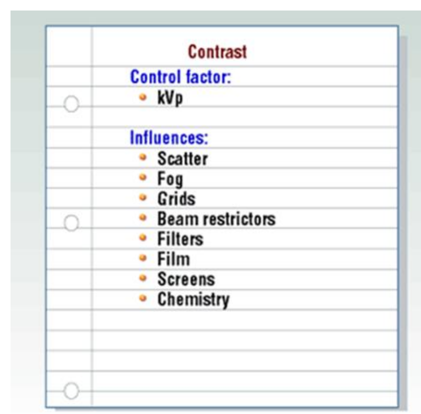
A collimator, the most common beam restrictor, reduces the amount of scatter radiation produced in the patient but doesn't eliminate it. You control collimation by adjusting a double set of lead shutters located directly under the x-ray tube port, using two controls such as those on the collimator shown here.

It takes a change of at least 30% in mAs to create a change in density on the radiograph that is visible to the naked eye.



Contrast

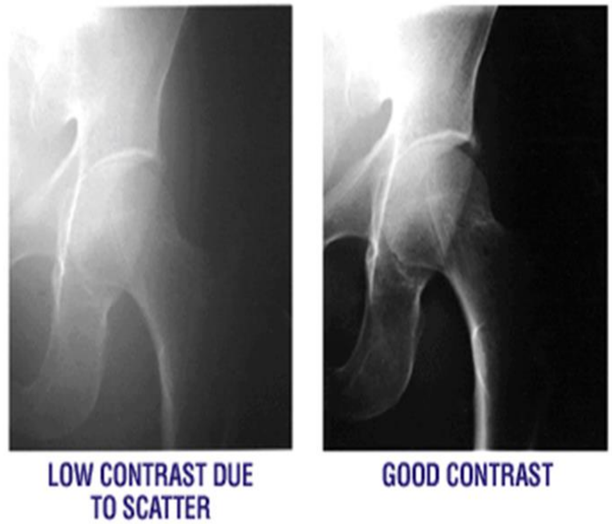
Contrast is defined as the density differences on adjacent areas of the radiograph. Contrast consists of the blacks, whites, and shades of gray on the image. Proper contrast allows us to see detail of body structures. For example, bone usually appears white in an image and soft tissue dark.



Radiographic contrast is a result of two factors: subject contrast and film contrast. Scatter radiation also directly affects the contrast in an image.

Look at the chest radiograph, for example. The ribs and mediastinal area appear white, the heart as a shadow, pulmonary markings as a shade of gray, and the air-filled lungs as darker areas. These differences occur because the different tissues absorb various amounts of radiation. Scatter radiation negatively affects contrast. Unless it's controlled by some of the techniques we've discussed, scatter fogs the film (making it gray) and reduces the contrast. The more scatter there is, the lower the contrast. You can reduce the amount of scatter radiation by selecting the best kVp and using beam-restricting devices. Even so, more than half the x-rays that leave the film side of the patient will scatter in all directions.

High-contrast radiographs are called short scale because they have a fairly narrow range of densities. High contrast occurs more often with a low kVp because with a lower energy beam, the patient absorbs more x-ray photons. Those that are not absorbed in more dense tissues get through to expose the film. The result is a radiograph with very black and very white places and few shades of gray.



Automatic exposure control (AEC)

Automatic Exposure Control (AEC) is an X-ray exposure termination device. A medical radiography x-ray exposure is always initiated by a human operator. X-ray termination is done by the same human operator or an exposure control device such as an electronic timer or an AEC device. The intention of the AEC termination device is to provide consistent x-ray film appearance.

An AEC system uses a physically thin radiation ionization detector "AEC detector" which is positioned between the patient being x-rayed and the x-ray film cassette. X-rays passing through the patient also pass through this "AEC detector" before they strike the x-ray film.

A weak ionization signal from the AEC detector is integrated as a ramp shaped voltage waveform. This ramp signal rises until it matches a pre-set threshold. At this point the x-ray exposure is terminated. AEC devices are calibrated to ensure that similar exams have linearity in exam densities. This is due to the fact that a milliamperage station is no longer selected and instead relies upon the ionization within the selected chambers.

Because patients vary in size and shape, an AEC device is very useful in achieving good consistent x-ray film densities compared to non AEC x-ray exposures.

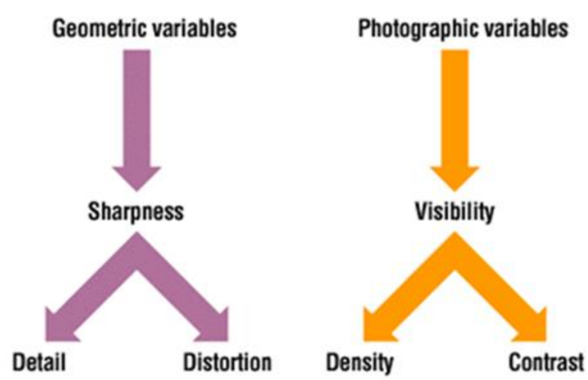
AEC devices are susceptible to operator error (usually due to incorrectly positioned anatomy or having the incorrect AEC chamber selected). Prosthetic devices such as total hip hardware can also cause the selected ionization chamber to overexpose the image receptor. This is due to the absorption of the x-ray beam into the metal of the hardware as opposed to exposing the ionization chamber.

Anatomically Programed Radiography (APR)

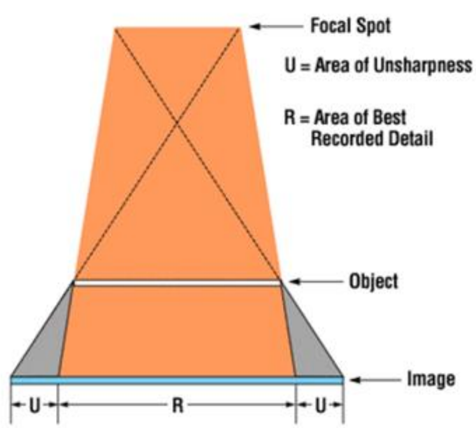
Also known as anatomical programing, APR is an electronic technique chart built in to the x-ray control panel. You select the body part and the projection through a system of menus on the control. Next, you enter the part measurement in centimeters.

The concern is that the techniques must be programed by the vendor and it is possible for the techniques to be less than accurate.

Geometric Properties



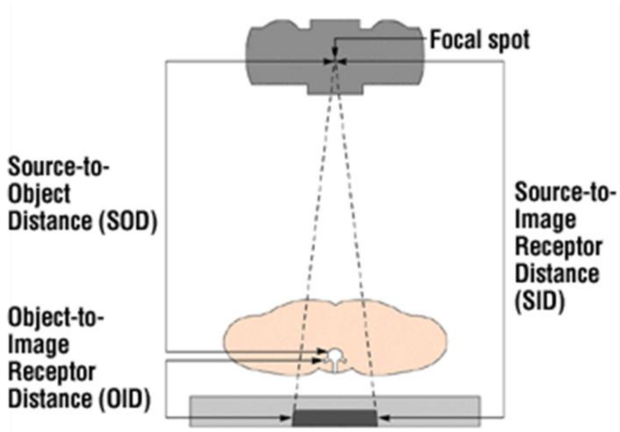
High-quality images help a physician diagnose disease and prescribe treatment. Poor-quality images don't provide much diagnostic help and can even lead physicians to make incorrect treatment decisions. Another problem with poor-quality images is that if they can't be read accurately, they may need to be retaken, and that exposes the patient to unnecessary additional radiation. In general, the quality of a radiograph results from two different sets of factors: sharpness and visibility.



Distortion is the misrepresentation of the size or shape of the structure on a radiograph.

Image sharpness, or recorded detail, depends on several geometric factors. Image visibility depends on the photographic properties of the image: contrast and density. More specifically, geometric sharpness is affected by the size of the focal spot, the distance between the x-ray source and the image receptor (SID), and the distance between the part of the body to be examined and the image receptor (OID).

Just as there is always some degree of unsharpness, it's also true that all images recorded on a radiograph are larger than the actual object they represent. This phenomenon is called magnification. Like a magnifying glass, the radiographic process makes things just a little bigger. **Penumbra** is an unwanted fuzzy appearance around the structures of an image. Penumbra can be reduced by switching from a large to small focal spot.

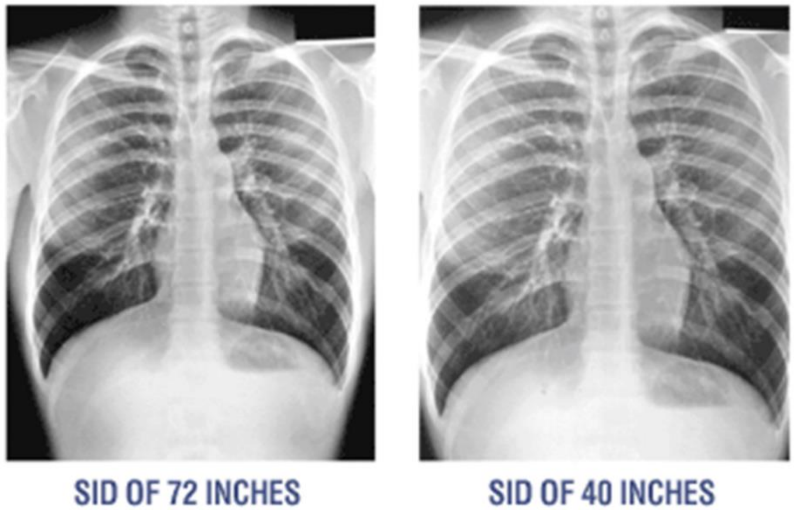


When the x-ray beam exits from the tube's focal spot, it naturally fans out. Imagine shining a flashlight beam toward a wall with something between the flashlight and the wall casting a shadow. As that object moves closer to the flashlight and farther from the wall, the shadow grows larger. With a single light source, the shadow on the wall will always be somewhat larger than the object itself.

Magnification is a type of size distortion. Most of the time you want as little magnification as possible. Sometimes, however, you might want objects to be even larger than they appear with natural magnification, and you can plan for this. This kind of exam is called magnification radiography. In the radiographs shown here, the ankle on the right was farther from the film, producing more magnification.

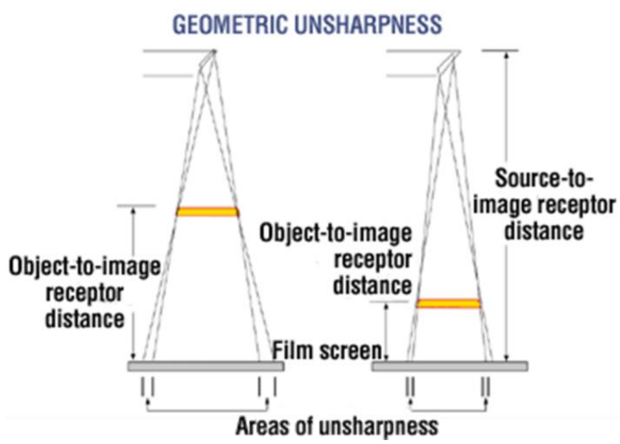
A 40-inch SID is standard for most routine radiographic procedures. At this distance, it's possible to get good detail and a magnification level that is acceptable for diagnosis. As previously illustrated, a longer SID results in less magnification and less unsharpness and therefore results in better detail.

Some routine exams, such as a chest radiograph, use an SID of 72 inches. That provides, for example, excellent recorded detail of the structures of the chest and decreases the magnification of the heart. Once again, this results in less unsharpness around the image, and therefore a sharper image. This excellent recorded detail and minimum magnification is a result of a large SID and small OID. You can see in these images how the 40-inch SID causes more magnification.



Magnification can also be decreased by decreasing the OID while keeping the SID and the focal spot size constant. Unsharpness is decreased when the object to be examined is positioned close to the film, which improves the recorded detail, as you can see when you compare these two diagrams.

That is why it is important to always position the patient as close to the film or other image receptor as possible. However, because you'll never be able to put the body part directly on the film inside the cassette, there will always be some unsharpness.



Let's sum up these three influencing geometric factors. You get better recorded detail with: (1) a long source-to-image receptor distance, (2) a short object-to-image receptor distance, and (3) a small focal spot size.

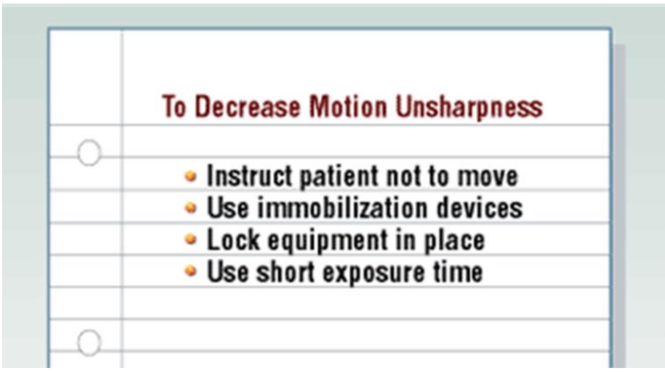
Don't worry if you feel a little confused by all the acronyms like SID and OID, because as you study more and get used to using radiographic equipment, they'll become easy to remember.

Patient Motion

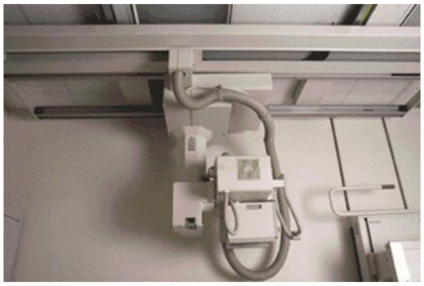
Patient motion is either voluntary or involuntary. When patients move their bodies, arms, or legs, or breathe during the exam, that's considered voluntary movement.

Voluntary movement is the easiest for you to control. A few well-placed words to the patient, like the familiar "Take a big breath, hold it, and stay still," can do the job. But patients are usually anxious during an exam and may move even though they don't mean to. You can decrease the possibility of motion by using restraining devices such as sandbags, angle sponges, compression bands, and foam pads. Most radiography departments have special restraints to use with children. If we are producing a radiographic image with blur or motion one option might be to decrease the exposure time.

When you're radiographing some parts of the body, such as the head, use some kind of restraint to minimize the possibility of having to repeat the exposure. For example, some radiographers put a strip of tape across the patient's forehead to prevent movement.



Patient motion is usually, but not always, the cause of blur. The equipment can sometimes be the problem. The x-ray tube can vibrate and cause blur. If a Bucky lock assembly is damaged, it may allow motion in the Bucky tray and cassette.



Rotating anodes with damaged bearing assemblies can vibrate. An unbalanced tube suspension system can drift. Check your equipment before you perform an exam to make sure it is in good working order. The suspension system, such as the overhead system shown here, should allow for easy tube positioning but should also ensure the tube is immobile during the exposure.

Technical Factors

Technical Factors The technical factors that are under our control are;

1. **mA and time (s)= mAs- Milliamperage seconds**
2. **kVp- killovoltage peak**
3. **S.I.D- Source to Image Receptor Distance**

This chapter is a discussion of how we select the correct technical factors to create diagnostic quality radiographs. For the most part this chapter will cover analog radiography. The next chapter on Digital Imaging Systems will go over the changes that will need to be made if you are operating in a digital environment.

mAs

The first technical factor we will discuss is **mAs**. Milliamperage is the measurement of the x-ray tube current- it controls the number of electrons passing from the cathode to the anode per second. Milliamperage is abbreviated **mA**, mA determines the **quantity** of x-ray photons in the x-ray beam. Time is represented in seconds and is abbreviated **s**. This determines the amount of time that the exposure lasts. Combined they become milliamperage seconds. We multiply the mA times the seconds. **mA x s= mA**

The **mAs** is responsible for the amount of exposure to the patient. The higher the mAs the greater the exposure. As we have already learned mAs is the factor that controls density, or how dark a radiograph is.

Fixed kVp Technique for AP Abdominal Exam

Chart A

Patient thickness (cm)	kVp	mAs
16	80	12
18	"	15
20	"	22
22	"	30
24	"	45
26	"	60
28	"	90
30	"	120

The only way to determine what mAs to use for a particular exam on a particular patient is by using a technique chart. We will discuss technique charts in more detail later in this chapter. Basically we would measure the thickness of the body part that we are examining from where the central ray enters to where it exits the patient. Then we will look up the body part that we are examining on the technique chart, and find the appropriate mAs. Chart A is a technique chart for an AP abdominal exam. If we were to measure our patient and she measured 18 cm in thickness then we would set the mAs on our x-ray control panel at 15. If the control panel that you are using has separate settings for mA and time then your technique chart will look like Chart B. We would set the mA at 200 and the time at .o75 seconds. Notice that if you multiply 200 by .075 the product is 15, we are still using the same mAs. **(200mA x .075s= 15mAs)**

Chart B

Part Thickness	kVp	mA	s
16	80	200	0.06
18	80	200	0.075
20	80	200	0.11
22	80	300	0.1
14	80	300	0.15
26	80	300	0.2
28	80	300	0.3
30	80	300	0.4

kVp

The **kVp** controls the voltage of the current that flows across the x-ray tube. kVp stands for killovoltage peak. Killo means one thousand, so 70 kVp would be equal to 70,000 volts peak. The higher the **kVp** the more energy the photons in the x-ray beam have, kVp is said to be responsible for the **quality** of the x-ray beam.

The best way to determine what kVp to use for a particular exam is simply to look on the technique chart near the x-ray control panel. In the absence of an accurate technique chart "optimal kVp" factors have been developed and are able to be used in most circumstances. Even if you are uncertain of other factors these kVp settings will likely work for you.

Contrast, or the number of shades of gray on a radiograph is controlled by the kVp. The higher the kVp the more shades of gray that will be in the radiograph. This is why a hand has a low kVp and a chest has such a high kVp. There are more tissue densities in a chest than a hand: therefore, we need more shades of gray in order to be able to visualize them.

Optimal kVp

Body Part	kVp
Hand	54
Wrist	57
Forearm	60
Elbow	60
Humerus	70
Shoulder	75
Foot	60
Ankle	60
Tib/Fib	63
Knee	65
Femur	70
Hip	65
Pelvis	70
C-Spine	75
T-Spine	80
L-Spine	85-95
Chest	110-130
Abdomen	75
Ribs	60
Skull/ Sinuses	80

kVp should be consistent for each body part. In most cases for the kVp for a knee for example should always be the same, no matter what the measurement of the part thickness might be.

S.I.D.

The **S.I.D** is the distance from the source of radiation (the x-ray tube) to the image receptor. It is important to remember that the intensity of the x-ray beam gets much more intense as the distance becomes shorter.

This is the result of a law of physics called the **Inverse Square Law**. The inverse square law states that the intensity of the beam is inversely proportional to the square of the distance from the source. In English that means that as the distance is doubled the intensity is cut to one fourth of the original value. If we were to accidently leave the S.I.D. at 72" when it should be 40" there would not be enough intensity and our image would be under exposed by almost a factor of four. On the other hand if we accidently left the tube at 40" instead of 72" then the image would be over exposed by a factor of four.

All of the projections that we do are at 40" except the chest and the lateral c-spine, they are at 72".

Notes:

Chapters 5 Quiz
Imaging

1. Which of the following are the prime factors of exposure in radiography?
A. Density, contrast, recorded detail, and distortion
B. Density, contrast, distortion, and kilovoltage
C. mAs, kilovoltage, density, and distance (SID)
D. Milliamperage, exposure time, kilovoltage, and distance (SID)

2. The unit used to indicate the total quantity of x-rays in an exposure is:
A .mAs.
B. SID.
C. kVp.
D. volts.

3. If an image were made using 500 mA, 0.1 seconds, and 75 kVp, what would the mAs be for this exposure?
A. 5 mAs
B. 50 mAs
C. 25 mAs
D. 500 mAs

4. Two exposures are made using the following technical factors:
Image A: 500 mA, 0.05 seconds, 72 kVp
Image B: 200 mA, 0.125 seconds, 72 kVp
Which image would have the greater density?
A. Image A would exhibit greater density.
B. Image B would exhibit greater density.
C. Image A and B would exhibit equal density.
D. Density cannot be determined from the provided factors

5. Which of the following will result in increased radiographic density?
1. Increased mA
2. Increased exposure time
3. Increased kVp

A. 1 and 2 only
B. 1 and 3 only
C. 2 and 3 only
D. 1, 2, and 3

6. If the radiographic image is overexposed, which of the following changes in exposure factors should be used to correct the problem?
A. Decrease kVp
B. Increase kVp
C. Increase mAs
D. Decrease mAs

7. The distance between the tube and the IR is termed:
A. source-image distance (SID).
B. target-image distance (TID).
C. total image distance (TID).
D. tube-target distance (TTD).

8. The relationship between SID and beam intensity is expressed in the:
A. proportional square law.
B. inverse square law.
C. reciprocity law.
D. target-distance law.

9. The inverse square law states that the intensity of the x-ray beam is ______ to the square of the distance.
A. directly proportional
B. inversely proportional
C. not related

10. The overall darkness, or blackness, within a radiographic image is referred to as:
A. density.
B. contrast.
C. recorded detail.
D. mAs.

11. Density is primarily controlled by varying the:
A. mAs.
B. kVp.
C. SID.
D. OID.

12. The difference in density between adjacent portions of the image is called:
A. tissue density.
B. sharpness of detail.
C. radiographic recorded detail.
D. radiographic contrast.

13. Contrast is primarily controlled by altering the:
A. milliamperage.
B. exposure time.
C. kVp (kilovoltage)
D. mAs.

14. When an image demonstrates only a few densities the image is described as having:
A. short-scale contrast.
B. long-scale contrast.
C. low contrast.
D. increased recorded detail

15. A low kVp setting produces an image with:
A. a long scale of contrast.
B. a short scale of contrast.
C. high recorded detail.
D. a low level of contrast.

16. Generalized unwanted exposure on the image is called:
A. overexposure.
B. overpenetration.
C. fog.
D. penumbra.

17. A variation in the size or shape of the image as compared with the subject it represents is called:
A. recorded detail.
B. distortion.
C. unsharpness.
D. fog.

18. The unsharp, "fuzzy" appearance of margins of structures within the radiographic image is called:
A. fog.
B. distortion.
C. penumbra.
D. umbra.

19. A change from the small focal spot to the large focal spot results in:
A. decreased image sharpness.
B. magnification.
C. hyperintensity
D. increased contrast.

20. An increase in OID will result in:
A. increased magnification.
B. increased image sharpness.
C. loss of contrast.
D. increased radiographic density

21. If a radiographic image appears blurred, which exposure factor should be used to correct this problem?
A. Decrease in SID
B. Decrease in exposure time (seconds)
C. Increase in exposure time (seconds)
D. Increase in OID