## Chapter 7

# Principles of Exposure and Image Quality

### Learning Objectives

At the conclusion of this chapter, you will be able to:

- List the four prime factors of exposure
- State the formula for determining milliampere-seconds (mAs) and explain how this unit is useful to the radiographer
- Explain the radiographic effect caused by changes in each of the four prime factors of exposure
- Recognize changes in radiographic density and state the exposure factors used to control radiographic density
- Identify high, low, and optimum contrast on a radiograph and state the exposure factor that primarily controls radiographic contrast
- Define radiographic distortion and explain the difference between magnification and shape distortion
- Define spatial resolution and list factors that influence it
- List and explain the geometric factors that affect spatial resolution and explain why magnification affects resolution
- List and discuss methods for minimizing motion blur on radiographs

### Key Terms

brightness
collimation
contrast
density
distortion
elongation
fog
foreshortening
high-contrast
inverse square law
involuntary motion
long-scale contrast
low-contrast
magnification
object-image receptor distance (OID)
overexposed
penetrometer
penumbra
prime factors
quality
quantity
quantum mottle
radiographic contrast
shape distortion
short-scale contrast
size distortion
source-image receptor distance (SID)
spatial resolution
subject contrast
tissue density
umbra
underexposed
voluntary motion
window level
window width

This chapter explains the prime factors of radiographic exposure and their radiographic effects, some of which you have already been introduced to. In addition, it introduces the four primary factors of radiographic quality and the principal methods for controlling them. You will begin to observe the effects of exposure on radiographs and to understand how the various factors controlled by the limited operator affect the final image.

### Prime Factors of Radiographic Exposure

**Milliamperes (mA)**

- Controls radiographic density
- Controls quantity of x-rays produced
- Controlled by adjusting the mA
- Quantity of exposure is directly proportional to mA

**Exposure Time (Seconds)**

- Controls radiographic density
- Controls quantity of x-rays produced
- Controlled by adjusting the timer in x-ray circuit
- Controls duration of exposure
- Quantity of exposure is directly proportional to exposure time

**Kilovolts (kVp)**

- Controls radiographic contrast
- Controls x-ray penetration
- Controls the quantity and quality of the x-ray beam
- Increased kVp results in increased quantity of photons
- Increased kVp results in increased penetration of the body part

**Source-Image Receptor Distance (SID)**

- Affects the density and intensity of the x-ray beam
- Quantity of exposure is inversely proportional to the square of the distance

Each dimension of the radiation field is proportional to the SID. Therefore, the field area is proportional to the square of the SID and the radiation intensity is inversely proportional to the square of the SID.

## PRIME FACTORS OF RADIOGRAPHIC EXPOSURE

Exposure is a broad term used to describe the x-rays that the patient is exposed to, the amount of x-rays in the primary beam, and also the amount of x-rays that reach the image receptor (IR). The x-ray beam is often described in terms of its quantity and its quality. The principle factors that affect x-ray **quantity** are *milliamperage-seconds* (mAs), *kilovoltage* (kVp), **source-image receptor distance (SID)**, and *filtration*. The factors that affect x-ray **quality** are kVp and filtration. Note that kilovoltage and filtration affect both quantity and quality (Box 7.1). Filtration was discussed in Chapter 5.

The quantity and quality of the x-ray beam are controlled by four **prime factors.** *These factors are under the direct control of the limited operator*. The prime factors of exposure are milliamperage (mA), exposure time (S), kVp, and SID.

Box 7.1

### X-Ray Beam Quantity and Quality

| Quantity Factors | Quality Factors |
|---|---|
| mA | |
| Exposure time | |
| mAs | |
| kVp | kVp |
| SID | |
| Filtration | Filtration |

*kVp,* Kilovoltage; *mA,* milliamperage; *mAs,* milliampere-seconds; *SID,* source-image receptor distance.

### Milliamperage

As explained in Chapter 5, changes in mA affect the rate of exposure, that is, the number of photons produced per second during an exposure. For this reason, a change in mA will alter the quantity of exposure to the IR. An increase in mA will increase the quantity of exposure; decreased mA will reduce the quantity of exposure. Exposure is *directly proportional* to mA; that is, if the mA doubles, the quantity of exposure also doubles. Technically, when the mA is doubled, the number of electrons at the filament doubles. During the exposure, the number of photons emitted from the tube doubles as well. The opposite is true if the mA decreases by 50%. The electrons at the filament and the photons emitted will be halved. The dose given to the patient is also directly proportional; for example, if the mA is doubled, the dose to the patient is doubled.

### Exposure Time

Exposure time also controls the exposure to the IR. This factor affects the exposure by determining how long the exposure will last. Obviously a longer exposure time will increase the exposure to the IR, and a decrease in exposure time will reduce the IR exposure. Like the mA described earlier, the quantity of exposure is also *directly proportional* to the exposure time. The dose to the patient is also directly proportional; for example, if the exposure time is doubled, the dose to the patient is doubled.

### Milliampere-Seconds

As stated in Chapter 5, the unit used to indicate the total quantity of x-rays in an exposure is milliampere-seconds, abbreviated mAs. This unit is the product of mA and exposure time (mA × time = mAs). For example, if the control panel were set at 200 mA and 0.2 second, the mAs would equal 200 × 0.2:

$$200 \text{ mA} \times 0.2 \text{ second} = 40 \text{ mAs}$$

A desired quantity of exposure may be obtained by any combination of mA and time that, multiplied together, equals the desired mAs. For example, 40 mAs could be obtained using any of the following combinations:

50 mA, 0.80 seconds = 40 mAs
100 mA, 0.40 seconds = 40 mAs
200 mA, 0.20 seconds = 40 mAs
400 mA, 0.10 seconds = 40 mAs

*The quantity of exposure and the patient dose are directly proportional to the mAs.* For each of the four exposure techniques listed earlier, the volume of photons emitted and the dose to the patient will be equal. The density or blackening effect on the image will also be equal. *The unit mAs is the primary controller of radiographic density.*

It is important to understand that the mA, exposure time, or the equivalent, mAs, all follow the same directly proportional rule in terms of exposure and dose. If any of these three factors are doubled, both the exposure and the dose are doubled. If any of the three are cut in half, the exposure and dose are cut in half.

## Kilovoltage

The kVp controls both the quality and the quantity of the x-ray beam. As the kVp is increased, the energy of the photons in the beam is increased, changing its quality. As the photon energy increases, the *penetrating ability* of the photons increases. When larger or denser body parts are x-rayed, the kVp is increased so that the photons can get through the part and reach the IR. If the kVp is set too low, the photons may not all get through the body part to form the image. Setting the correct kVp for each body part is very important so that the correct number of photons reach the IR. *The kVp is the primary controller of the penetration of x-rays.*

The kVp also has an effect on the quantity of exposure to the IR. When the kVp is increased, the electrons from the filament reach the anode with more energy. More interactions then occur in the anode and more x-rays are emitted. When kVp is increased, density is increased; however, mAs is the primary controller of density. Unlike the effects of mA, exposure time, or mAs, changes in exposure are *not* directly proportional to kVp. *The kVp is never doubled* owing to the fact that doubling of the kVp would result in four times more photons being emitted! Conversely, the kVp would never be halved owing to the fact that four times fewer photons would result. These would be extreme changes in exposure. Although kVp will affect density, kVp should not be used to control radiographic density.

The **contrast** of the image is directly affected by kVp. High kVp produces a **low-contrast** image and low kVp produces a **high-contrast** image. Each body part that is radiographed will have a kVp assigned to it via the exposure technique chart. This kVp is predetermined based on the penetration required for the part and the contrast required. Often, the physician may request that an additional radiograph be taken at a different contrast level to see the anatomy differently. *Therefore kVp is the primary controller of radiographic contrast.*

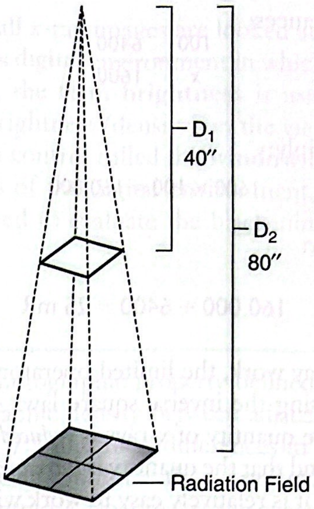

**Fig. 7.1** Source-image receptor distance affects both maximum field size and radiation intensity. At 80 inches the field size is four times as large and the x-ray intensity is four times less than at 40 inches.

## Source–Image Receptor Distance

The distance between the tube target and the IR is called the source-image receptor distance, abbreviated SID. Because the x-ray beam diverges, forming the shape of a cone, the photons get farther apart as they get farther from the target (Fig. 7.1); thus, the SID affects the *intensity* of the x-ray beam and the quantity of x-rays.

The relationship between the SID and the intensity of the beam is expressed by the **inverse square law**, which states that the intensity is *inversely proportional* to the square of the distance. The inverse square law is expressed mathematically as a formula.

$$\frac{I_2}{I_2} = \frac{D_2^2}{D_1^2}$$

In this formula, *I* represents radiation intensity and *D* represents SID. For all SID calculations, the distance is always squared. As the distance increases, the intensity decreases and vice versa. For example, if the distance were doubled, the intensity would decrease to one fourth of the original intensity. If the distance were reduced 50%, the intensity would increase by four times. In Fig. 7.1, suppose $D_1$ is 40 inches and $D_2$ is 80 inches, or twice as great. If the original intensity at $D_1$ had a value of 100 mR, the intensity at $D_2$ would be 25 mR. This value is determined by using the inverse square law formula as follows:

Insert values:

$$\frac{100}{x} = \frac{80^2}{40^2}$$

Square distances:

$$\frac{100}{x} = \frac{6400}{1600}$$

Cross multiply:

$$1600 \times 100 = 160{,}000$$

Divide by $x$:

$$160{,}000 \div 6400 = 25 \text{ mR}$$

In daily x-ray work, the limited operator seldom makes calculations using the inverse square law. As long as it is known that the quantity of x-rays is *reduced 4×* when the SID doubles and that the quantity is *increased 4×* when the SID is halved, it is relatively easy to work with adjustments in the SID. The SID is a prime factor and it must always be set at the correct distance. In practice, the SID is seldom changed and it is most often set at 40 inches. Many departments now use a SID of 48 inches. For chest x-rays done using the upright Bucky, the SID is always set at 72 inches.

It should be evident that the four prime factors are important technical factors in the production of an x-ray image. If the mA, exposure time, mAs, kVp, and SID are not set correctly based on the technique chart, the image of the body part will not have the correct density and contrast.

Chapter 3 contains instructions and practice problems for working with squared numbers and for solving equations of this type.

## PHOTOGRAPHIC AND GEOMETRIC FACTORS

There are four primary factors that directly affect how the x-ray image looks: *density*, *contrast*, *distortion*, and *spatial resolution*. Density and contrast are considered photographic properties, and distortion and recorded detail are considered geometric properties. An understanding of these factors is essential to the discussion and evaluation of x-ray images. Each factor is influenced and controlled differently. Knowledge about these concepts enables the radiographer to identify the nature of problems that relate to film quality and to solve these problems effectively.

### Density

**Density** is a photographic property that refers to the overall blackness or darkness of the radiographic image. An image that is neither too dark nor too light when seen on the viewing monitor is said to have the correct radiographic density. Fig. 7.2 provides examples of varying

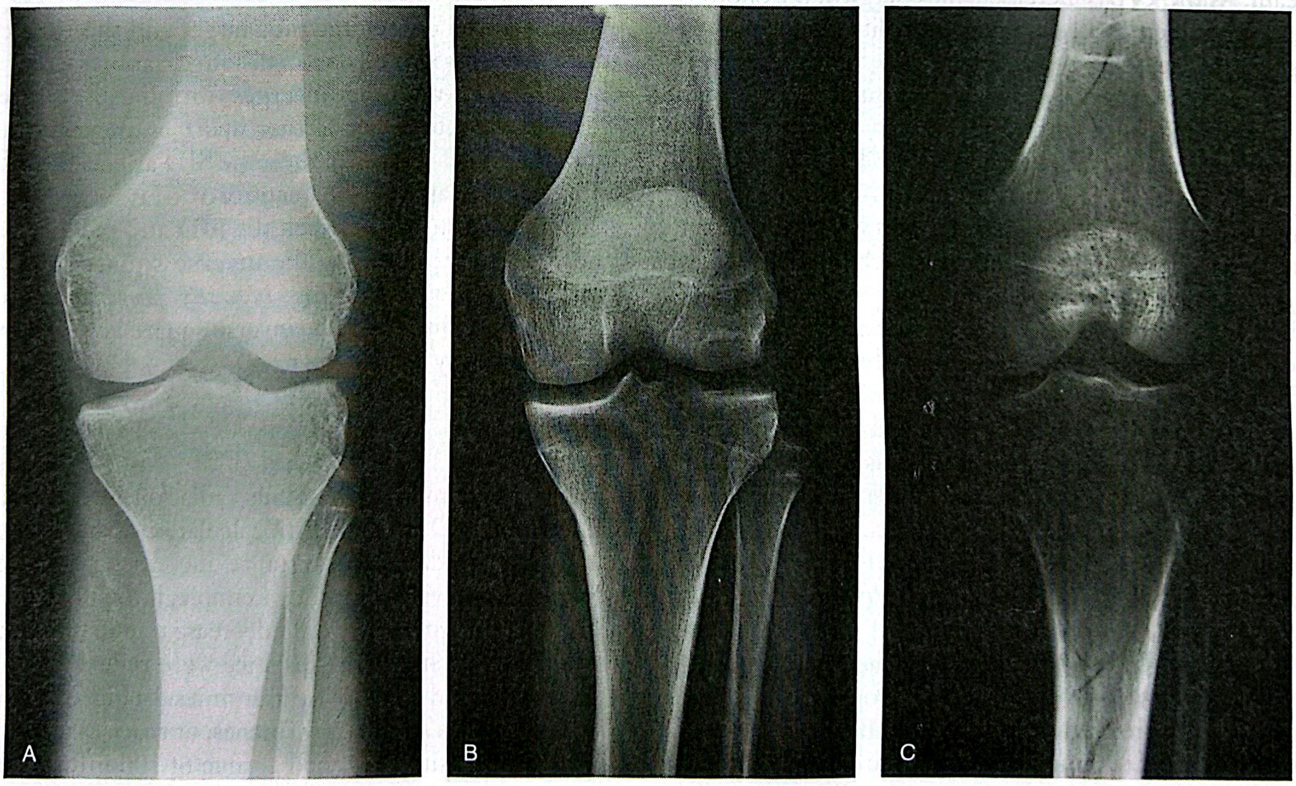

**Fig. 7.2** Sufficient radiographic density is required to make a diagnosis. (A) Radiograph of the knee with insufficient density, 10 milliampere-seconds (mAs), 80 *kilovoltage* (kVp). It is too light to make a diagnosis and a repeat radiograph is required. (B) Radiograph of the knee with proper density, 20 mAs, 80 kVp. All bony aspects of the knee are seen, including soft tissue detail around the bone. (C) Radiograph of the knee with too much density, 40 mAs, 80 kVp. Diagnosis cannot be made and a repeat radiograph is required.

radiographic density. Note that density affects the *visibility of detail.* Some detail in the image is lost when the image is either too dark or too light.

Radiographic density is the result of setting the prime factors of exposure and, therefore, the quantity of exposure to the IR determines the radiographic density. The greater the quantity of exposure, the darker the image will be. An image that is too dark is said to be **over-exposed**, and one that is too light is **underexposed.** *Density is primarily controlled by varying the mAs,* usually by increasing or decreasing the exposure time.

Although kVp and SID also affect radiographic density, they are not used to control it. SID is usually kept constant and kVp is used to control contrast and to penetrate the body part.

Do not confuse tissue density with radiographic density. **Tissue density** refers to the mass density, or atomic number, of the body part. Increased tissue density—as in bone, for example—causes a lighter area on the radiograph because it absorbs more of the primary radiation, leaving less exposure on the IR. Conversely, fat has a much lower tissue density than bone. It will absorb less primary radiation and will produce a darker area on the image. Increased radiographic density means that the image is darker, whereas increased tissue density results in a lighter area on the image. In other words, radiographic density and tissue density are *inversely* related to each other, and this can be quite confusing if the term *density* is used without qualification.

Digital imaging is used predominantly today. Using digital imaging, the x-ray exposure is processed in a computer and all x-ray images are looked at on a viewing monitor. In this digital environment in which there are no longer "films", the term **brightness** is used in place of density. The brightness (density) on the viewing monitor is adjusted by a control called the **window level.** Because of the newness of the digital environment, density continues to be used to evaluate the blackening level of the image.

## Contrast

Contrast is a photographic property defined as the difference in radiographic density between adjacent portions of the image. Fig. 7.3 illustrates differences in **radiographic contrast.** Adequate contrast is also a key factor in the *visibility of detail.* Contrast is what makes the anatomy more visible. Images with contrast that is too low have little density difference between the anatomical structures. They have a flat, gray appearance, and details may be so similar in radiographic density that they are difficult to differentiate from each other. Images with too much contrast have a "black-and-white" appearance. They contain some areas that are very dark and others that are very light. These images have a great difference between the anatomical structures. It is difficult to see detail in areas with extremes of density. Optimum contrast provides sufficient differences in density to easily make out details in all portions of the image.

Optimal contrast can be either high or low depending on the body part. For example, an image of a hand requires a high contrast to be optimal, whereas an image of a chest requires a low contrast to be optimal. Sometimes the

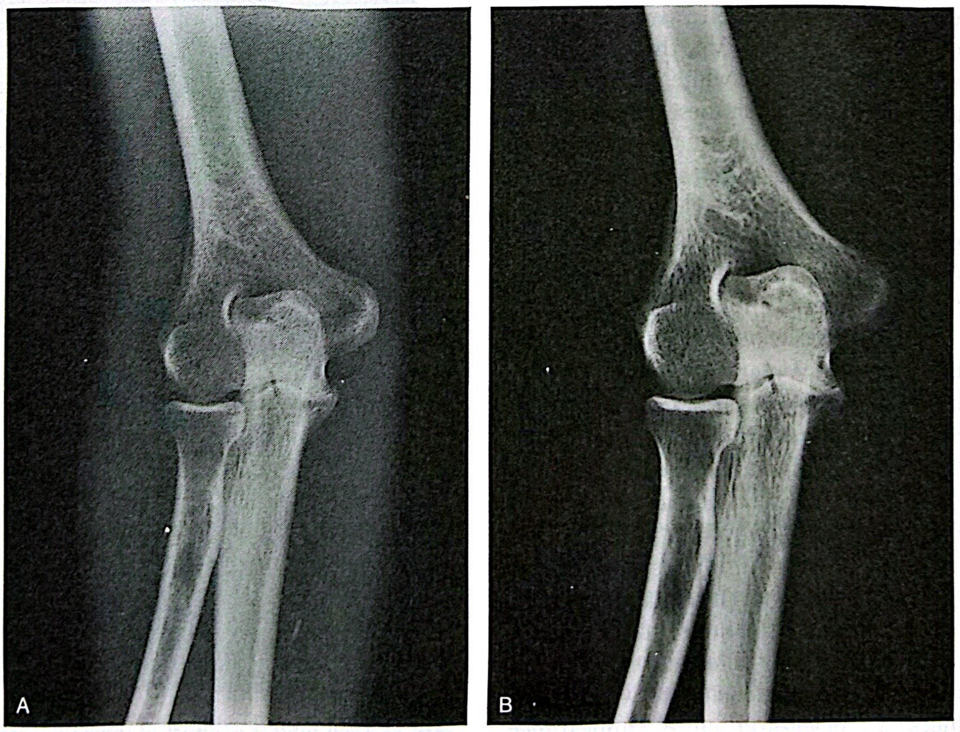

**Fig. 7.3** Sufficient contrast is required to make a diagnosis. Two different scales of contrast are shown on the elbow. (A) Long scale (low contrast). (B) Short scale (high contrast).

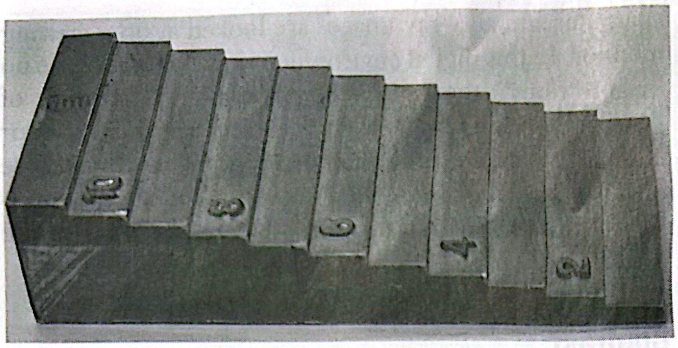

**Fig. 7.4** Aluminum step-wedge–type penetrometer. Its radiographic image is a gray scale, as seen in Fig. 7.5.

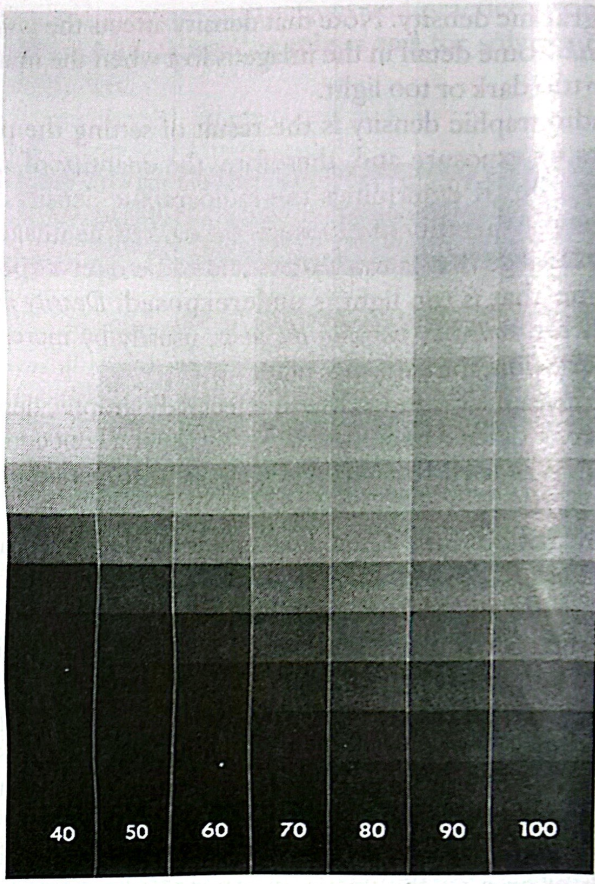

**Fig. 7.5** Radiographs of a penetrometer at seven *kilovoltage* (kVp) levels demonstrate changes in contrast with varying kVp. High contrast is produced at 40 kVp and low contrast is produced at 100 kVp. As kVp is increased, more steps are seen.

radiologist may request that an additional image be done on a body part at a different contrast level to visualize different anatomy.

*Contrast is primarily controlled by kVp*. A decrease in kVp produces increased contrast; increased kVp reduces contrast.

Fig. 7.4 illustrates a tool called a **penetrometer**. It is a solid piece of aluminum with steps of varying thickness. A penetrometer is often referred to as *step-wedge* because of its shape. A radiographic image of a penetrometer is a gray scale that shows the amount of penetration of each step. It simulates the different densities that would be seen on a patient's radiograph. Fig. 7.5 illustrates the gray scales produced by radiography of a penetrometer at different kVp settings. At 40 kVp, the number of gray tones between black and white is five. Note that there is considerable difference in radiographic density between each of these steps. This would be considered high contrast; high contrast is also called **short-scale contrast** because the range of densities is short. At 100 kVp, there are more than 15 gray tones between black and white, but the difference in radiographic density between these steps is slight. This would be considered low contrast; low contrast is called **long-scale contrast** because the range of densities is long.

Contrast is significantly influenced by the tissue densities within the patient, referred to as **subject contrast**. Subject contrast is the range of differences in the intensity of the x-ray beam after it has been attenuated by the patient. It is affected by the kVp and the tissue density. For example, the abdomen has many structures with similar tissue density and therefore displays low subject contrast. Abdominal structures, such as the liver and the kidneys, will appear similar, so abdominal radiographs tend to have a gray appearance (Fig. 7.6). On the other hand, the chest organs display a high degree of subject contrast. The tissues are very dense in the center, where the x-ray beam must penetrate the sternum, the spine, and the heart, but the lungs are air-filled and easily penetrated. The contrast in tissue density between these structures produces a "black-and-white" appearance (Fig. 7.7). A long scale of contrast is desirable for

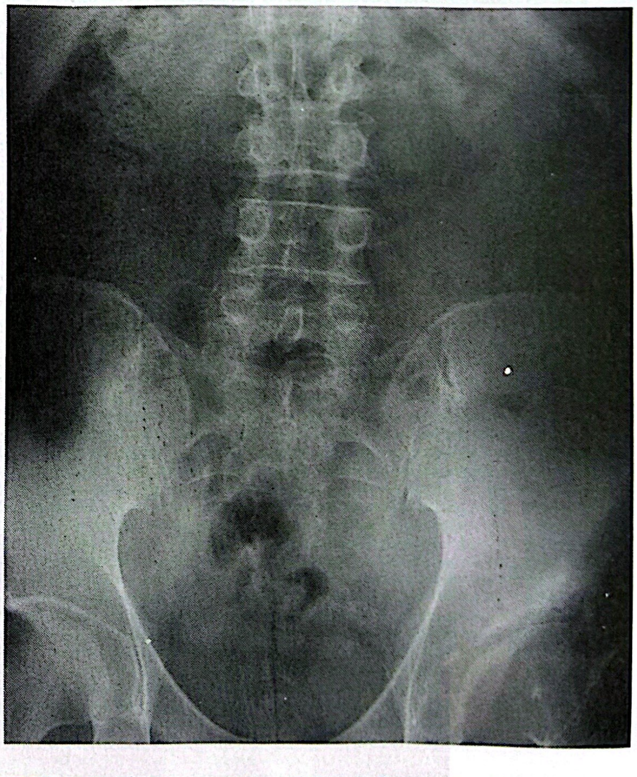

**Fig. 7.6** Low subject contrast of the abdominal structures produces relatively low radiographic contrast.

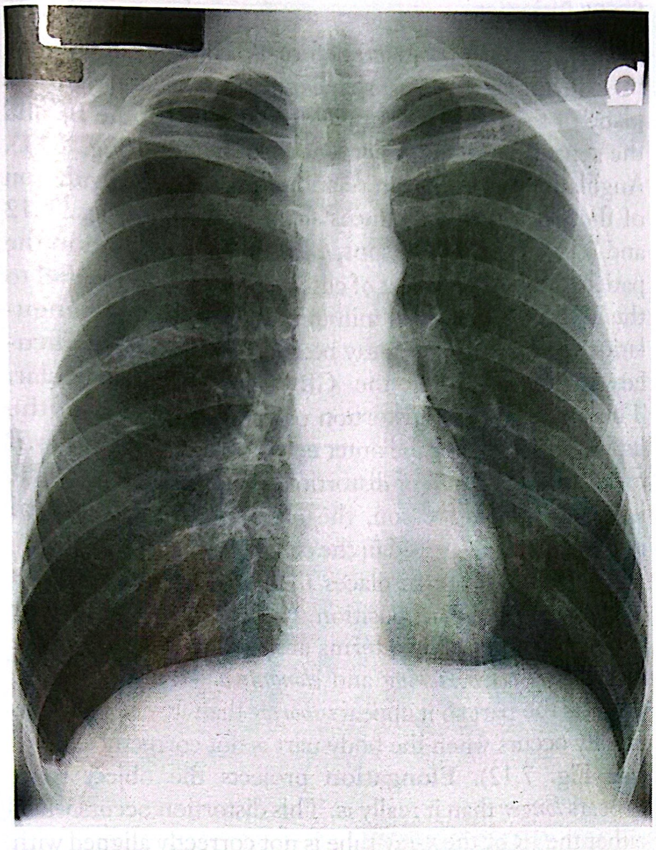

**Fig. 7.7** High subject contrast of the chest produces relatively high radiographic contrast.

structures such as the chest that have a high degree of subject contrast. To achieve this, a high kVp (100 to 120) is typically used. Conversely, when the subject contrast is low, such as in the abdomen, a short scale of contrast produces a better image. To achieve this, a lower kVp (75 to 90) is typically used.

Contrast is directly influenced by the presence of fog and collimation. **Fog** is a general, unwanted exposure to the radiographic image. Fog produces an overall increase in density that causes all parts of the image to appear as though seen through a gray veil. It causes areas that would otherwise be bright or white to appear gray. Fog is primarily caused by scatter radiation. **Collimation** will also affect the contrast in the image. When the collimator is opened too far, scattered x-rays will reach the IR and produce fog. These factors are discussed in Chapter 9. Fog and collimation that is too wide decreases contrast.

In the new digital environment, the term contrast continues to be used. The contrast on the viewing monitor is adjusted by a control called the **window width.**

## Radiographic Distortion

**Distortion** is a geometric property and refers to differences between the actual subject and its radiographic image. Because the subject is three-dimensional and the image is flat (two-dimensional), all radiographic images have some degree of distortion. Distortion is unequal magnification of different portions of the same object. Radiographic distortion may be categorized by whether it primarily affects the size of the object or its shape. **Size distortion** is always in the form of magnification enlargement. **Shape distortion** is the result of unequal magnification of the actual shape of the structure.

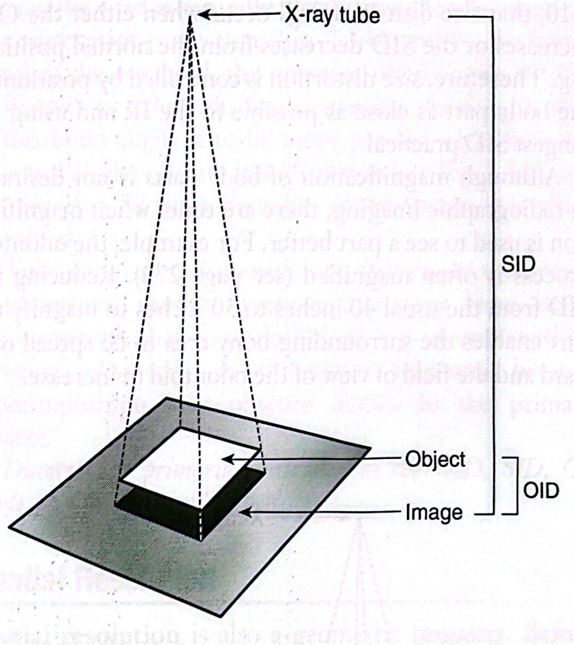

**Fig. 7.8** When the object is near the image receptor, the object and its image are nearly the same size. *OID*, Object-image receptor distance; *SID*, source-image receptor distance.

### Size Distortion

Size distortion occurs when the part is magnified. **Magnification** is a result of the geometry of the imaging setup. It is a function of the relationship between the SID and the distance between the subject and the IR. This distance is called the **object–image receptor distance (OID)**. As you can see in Fig. 7.8, when the SID is great and the OID is minimal, there is little magnification distortion. The object and its image are almost the same size.

As the OID is increased, the magnification increases and distortion of the part occurs (Fig. 7.9). You can demonstrate this principle by using a flashlight to project a shadow of your hand on a flat surface. The farther your hand is from the surface, the greater the size of its shadow. Fig. 7.10 illustrates the increased magnification caused by a decrease in SID.

Radiographic images can never be smaller than their actual size in the body. All images are magnified slightly because the body part is always above the IR. For the great majority of images, the goal is to keep magnification as low as possible to prevent size distortion. The limited operator should recognize, from studying Figs. 7.9 and

7.10, that size distortion will occur when either the OID increases or the SID decreases from the normal positioning. Therefore, size distortion is controlled by positioning the body part as close as possible to the IR and using the longest SID practical.

Although magnification of body parts is not desirable in radiographic imaging, there are times when magnification is used to see a part better. For example, the odontoid process is often magnified (see page 276). Reducing the SID from the usual 40 inches to 30 inches to magnify the part enables the surrounding bony area to be spread outward and the field of view of the odontoid to increase.

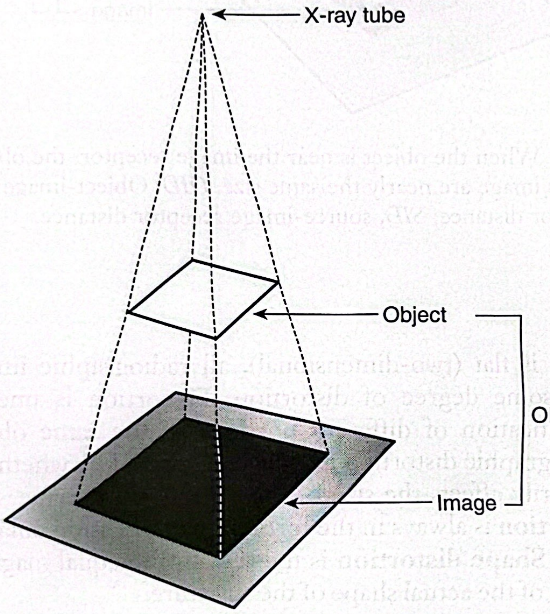

**Fig. 7.9** With increased distance between the object and the image receptor *(OID)*, the image is magnified.

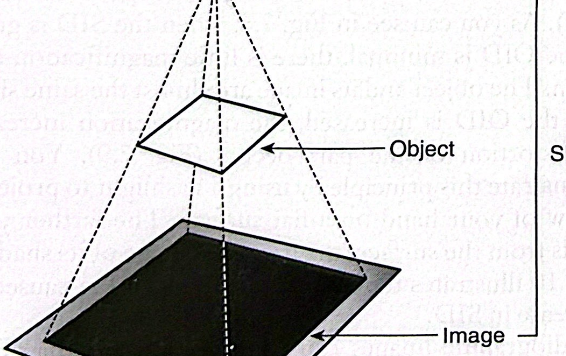

**Fig. 7.10** With decreased distance between the radiation source and the image receptor *(SID)*, magnification increases.

### Shape Distortion

Shape distortion, as stated before, is the result of unequal magnification. The least shape distortion occurs when the plane of the subject is parallel to the plane of the IR and the central ray (CR) is perpendicular to both (Fig. 7.11). Angulation of the part in relation to the IR, or angulation of the x-ray beam, produces shape distortion (Figs. 7.12 and 7.13). For these reasons, effort is made to position the patient so that the object of clinical interest is as parallel to the IR as possible and to minimize the need for tube angulation. Even when the x-ray beam is directed perpendicular to the IR, only the CR is truly perpendicular. Therefore the least distortion occurs at the center of the image. Structures at the outer edges of the radiograph will exhibit some degree of distortion, especially when the IR is large. For this reason, the object of primary clinical interest is usually placed in the center of the field.

Shape distortion displaces the projected image of an object from its actual position. It can be projected either shorter or longer. Two terms are used to describe shape distortion: *foreshortening* and *elongation.* **Foreshortening** projects the part so it appears *shorter* than it really is. This usually occurs when the body part is not correctly aligned (see Fig. 7.12). **Elongation** projects the object so it appears *longer* than it really is. This distortion occurs when either the IR or the x-ray tube is not correctly aligned with the part (see Fig. 7.13).

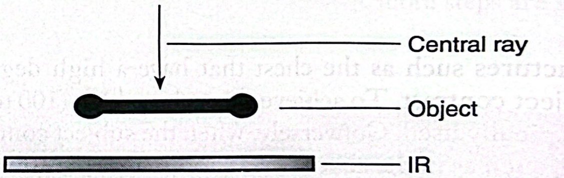

**Fig. 7.11** The least distortion occurs when the object is parallel to the image receptor *(IR)* and the central ray is perpendicular to both.

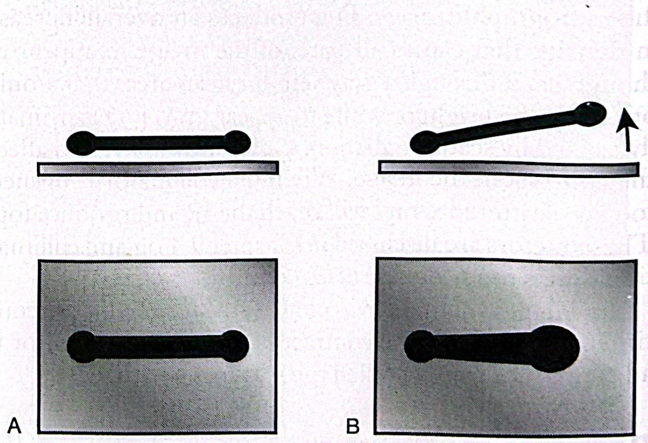

**Fig. 7.12** (A) Object and image receptor (IR) are parallel. (B) When the object is not parallel to the image receptor, unequal magnification creates shape distortion. Note also that the object is foreshortened.

When considering shape distortion, one must also keep in mind that many body parts are distorted by virtue of their position in the body and not because of misalignment of the CR, IR, or body part. For example, the scaphoid bone in the wrist is naturally foreshortened in the standard posteroanterior projection (Fig. 7.14A and B). To better visualize the scaphoid, the operator often angles the CR 20 degrees to reduce the foreshortening. Angling the CR to this bone aligns it to be more parallel with the x-ray tube and displays it with less distortion (see Fig. 7.14C and D). See Box 7.2 for a summary of the factors that affect distortion.

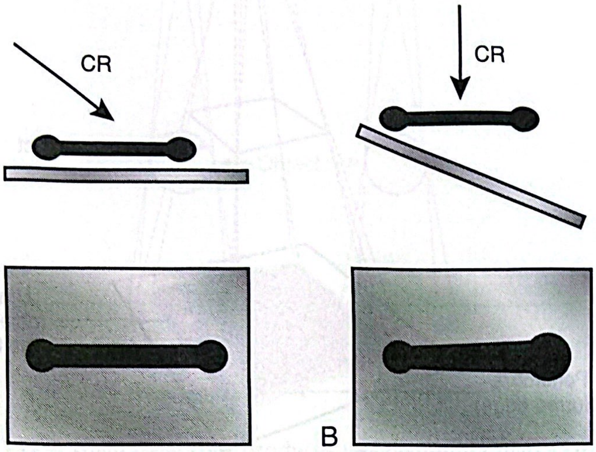

**Fig. 7.13** Shape distortion occurs when the x-ray tube and image receptor (IR) are not aligned (A), or the object and IR are not aligned (B). Note elongation in both of the images. In B, there is both elongation and magnification. *CR*, Central ray.

Tube angulation, or positioning that causes distortion, is sometimes used to prevent structures from being superimposed, that is, projected on top of one another; however, distortion is sometimes tolerated because superimposition may obscure details in the primary subject.

*Distortion is primarily controlled by the OID, SID, CR angle, part position, and IR position.*

## Spatial Resolution

**Spatial resolution** is also a geometric property. Before digital imaging, it was referred to as *recorded detail.* Spatial resolution refers to the sharpness of the image, and is more casually referred to as *resolution, sharpness, definition,*

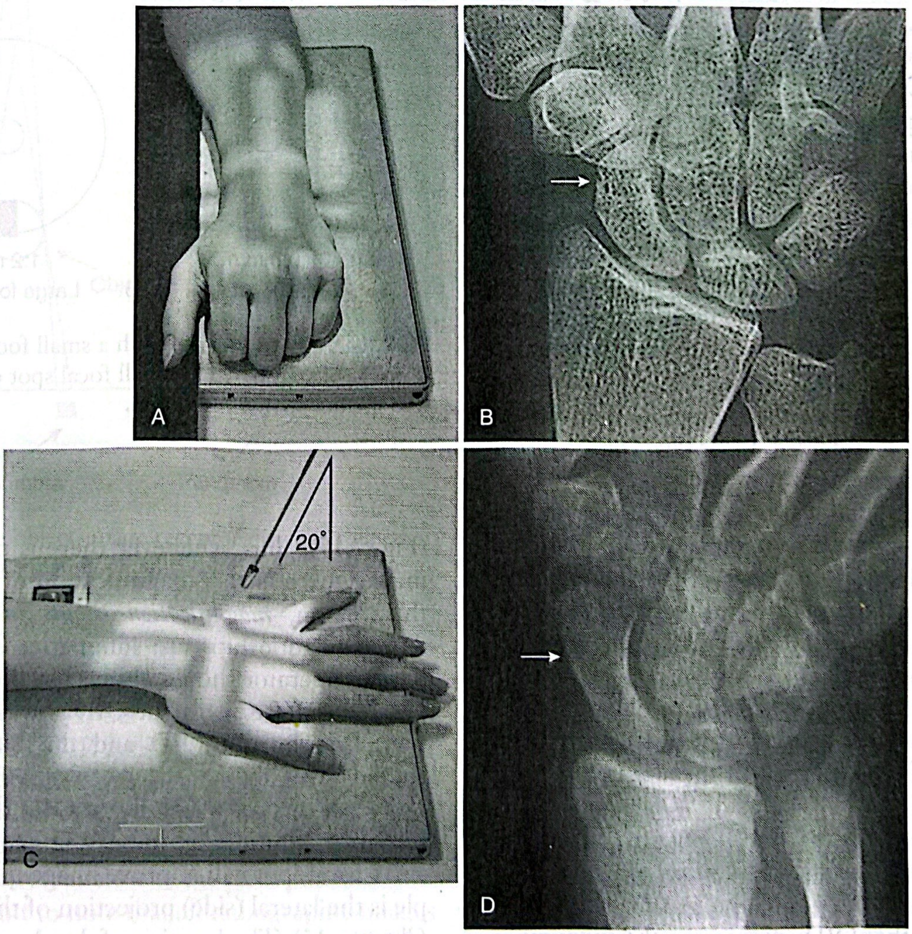

**Fig. 7.14** With normal wrist position (A), the scaphoid bone *(arrow)* is somewhat foreshortened (B) because it does not lie parallel to the image receptor. Angulation of the central ray aligns it more perpendicularly with the scaphoid *(arrow)* (C) and improves visualization (D).

**Box 7.2**

**Factors Affecting Distortion**

**Size**

- Object-image receptor distance
- Source-image receptor distance

**Shape**

- Alignment
  - Central ray (CR)
  - Part
  - Image receptor
- CR angulation
  - Direction
  - Degree

or simply *detail.* It is the edge sharpness of all portions of the image that determines whether the image appears sharp or blurred. When resolution is optimum, the edge sharpness of structures in the image is crisp and accurately rendered. Poor resolution tends to appear "fuzzy" or unclear. Several key factors that affect spatial resolution include patient motion, OID, SID, and the focal spot.

## Geometric Factors

The geometric factors that control the formation of the image are *SID, OID,* and *focal spot size.* If these three factors are controlled properly, maximum spatial resolution will be seen in the image.

To promote understanding of how spatial resolution is maintained or improved, several terms are used. The **umbra** is the actual anatomic area, body part, or structure shown in the radiographic image. The **penumbra** describes the "unsharp edges" of the umbra, or body part (Fig. 7.15). All body parts will have some unsharpness at the edges in the radiographic image. The goal in radiographic imaging is to reduce the penumbra as much as possible. Penumbra is referred to as *blur* or *geometric unsharpness* in some texts.

X-rays are not emitted from a point source in the target of the x-ray tube. The rectangular area of the target where the electrons strike is called the *focal spot* (Fig. 7.16). The x-ray photons are emitted from this area. Conventional x-ray tubes will have two focal spots, generally termed a *small focal spot,* which is usually approximately 0.6 mm, and a *large focal spot,* which is usually approximately 1.2 mm. When the small focal spot is activated, the x-rays are emitted from an area half the size of the large focal spot.

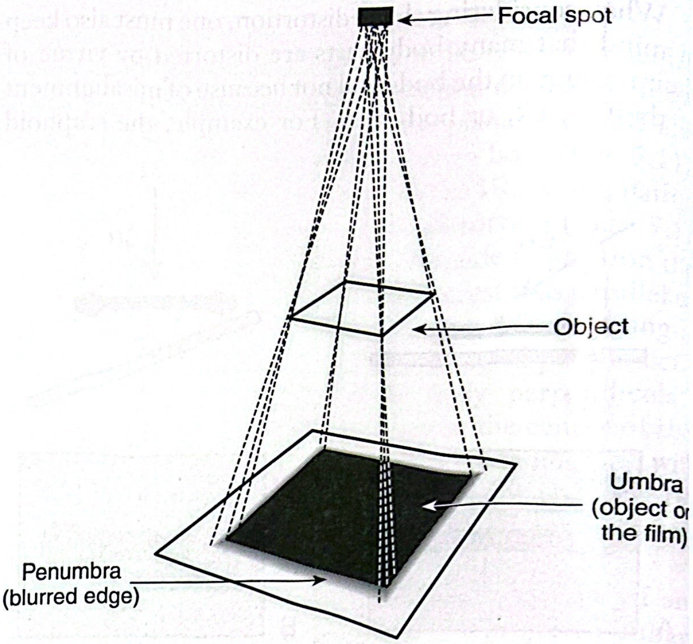

**Fig. 7.15** X-rays are emitted from several points on the focal spot of the x-ray tube. This creates unsharp edges of objects called *penumbra.*

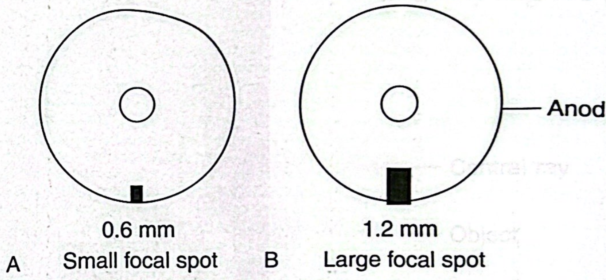

**Fig. 7.16** X-ray tubes have both a small focal spot (A) and a large focal spot (B). The small focal spot creates less penumbra and greater spatial resolution.

Fig. 7.17 demonstrates that focal spot size affects the size of the penumbra, and the smaller the effective focal spot, the less the penumbra and the greater the spatial resolution. When the OID decreases, the penumbra decreases, prompting greater spatial resolution (Fig. 7.18). When the SID increases, the magnification and penumbra decrease, also prompting greater recorded detail (Fig. 7.19); thus, whenever there is magnification of the image, there is also magnification of the penumbra. For this reason, *magnification results in image unsharpness.* These relationships are summarized in Table 7.1. The limited operator should always use the smallest focal spot possible. Because only the OID and SID affect magnification, the shortest OID and the longest SID possible should be used.

When there is a significant OID that cannot be minimized by positioning, increasing the SID and using the small focal spot will improve image quality. A good example is the lateral (side) projection of the cervical spine (see Chapter 15). The location of the shoulder prevents placement of the neck close to the IR. To avoid undue loss of detail, the projection is done at a 72 inch SID using the small focal spot.

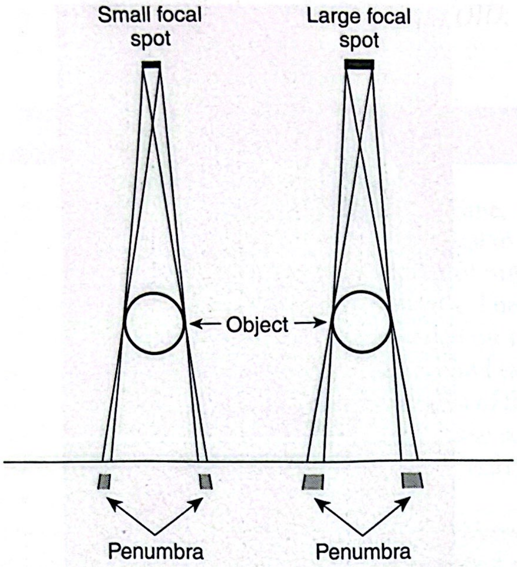

**Fig. 7.17** A small focal spot produces less penumbra than a large focal spot. The small focal spot produces greater spatial resolution.

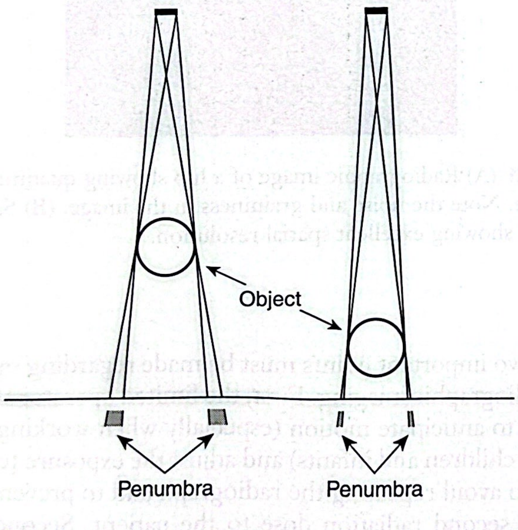

**Fig. 7.18** Reducing the object-image receptor distance reduces penumbra and creates greater spatial resolution.

It is important to remember that the distance between the patient's skin and the IR does not necessarily represent the OID. It is the distance between the IR and the object of clinical interest within the patient that matters. For this reason, an effort is made to perform radiography with the object of clinical interest as close to the IR as possible.

It is also important to note that all radiographic images have less resolution than the anatomic part itself. The challenge in radiography is to control the degree of unsharpness so that it does not interfere with image diagnosis.

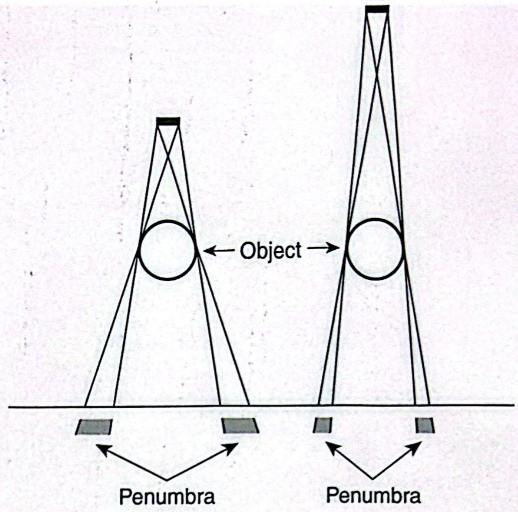

**Fig. 7.19** Increasing the source-image receptor distance reduces penumbra and creates greater spatial resolution.

## TABLE 7.1
## Effects of Image Geometry on Spatial Resolution

| Factor | Direction of Change | Effect on Resolution |
|---|---|---|
| Focal spot size | Decrease | Increase |
| Object-image receptor distance | Decrease | Increase |
| Source-image receptor distance | Increase | Increase |

### Motion

Any movement during radiography will cause blurring of the radiographic image (Fig. 7.20), reducing spatial resolution. This applies to patient motion, of course, but also to movement of the IR or the x-ray tube. To prevent motion, the IR is placed in a firm, stable location and the tube is locked in position. The discussion that follows is intended to assist you in avoiding patient motion.

Patient motion may be categorized as either voluntary or involuntary. **Involuntary motion** involves movements over which the patient has no control, such as tremors, peristalsis, and heartbeats. **Voluntary motion** is normally controllable, although certain patients may be unable to control them (e.g., unconscious patients or small babies who cannot hold their breath for a few seconds; patients who are in severe pain; or those who are unable to cooperate).

The first step in avoiding motion is to make every effort to ensure that the patient understands what is expected and is willing to cooperate. *Effective communications with*

**Fig. 7.20** Movement of the patient, tube, or image receptor during exposure causes image unsharpness called *motion blur.*

*both adults and children are key in avoiding motion.* Try to place the patient in a position that is as stable and comfortable as possible. When patients are standing for radiography, have them space their feet shoulder-width apart for a broad base of support and position them firmly against the film holder for stability. Minimize the time that a patient must maintain an awkward or uncomfortable position. Instructions should be clear and complete, with time allowed for the patient to comply.

Immobilization devices are used to minimize motion in certain cases. For example, a sandbag placed strategically over the arm may aid in immobilization of the hand. Devices and methods for pediatric immobilization are discussed in Chapter 18.

*The principal means of controlling involuntary motion is to use a short exposure time.* This is especially important for chest radiography, in which heart motion tends to blur the lung image, and for radiography of children. If motion is anticipated, or if motion is seen on the image and it has to be repeated, the standard mA and exposure time must be changed. A reduction in exposure time, with a corresponding increase in mA to maintain mAs and density, will reduce motion. For example, if 200 mA and 0.20 second (40 mAs) was used for a projection and motion was seen, adjusting the technique to 800 mA and 0.05 second (40 mAs) would significantly reduce motion in the image.

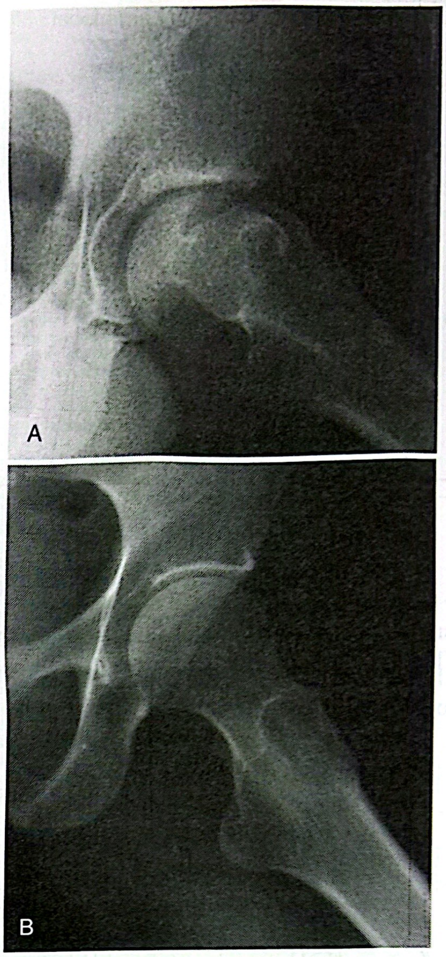

**Fig. 7.21** (A) Radiographic image of a hip showing quantum mottle. Note the noise and graininess in the image. (B) Same image showing excellent spatial resolution.

Two important points must be made regarding motion in radiographic imaging. First, the limited operator should learn to anticipate motion (especially when working with small children and infants) and adjust the exposure technique to avoid repeating the radiograph and to prevent giving a second radiation dose to the patient. Second, the great majority of patients will be able to cooperate and hold their breath. Therefore, the standard exposure technique should not be adjusted to a high mA and short exposure time for every patient. Use of a high mA (usually more than 200 mA) will reduce recorded detail because a high mA requires that the large focal spot be used.

## Quantum Mottle

**Quantum mottle** is a term used to describe the situation in which a grainy or mottled (spotty) image is created. It occurs when the imaging system does not record the anatomic densities, usually because of lack of photons. Quantum mottle will occur when either the mAs or the kVp is set too low. This results in a blotchy, grainy, or noisy image (Fig. 7.21). The result is decreased spatial resolution.

*Spatial resolution is primarily controlled by the OID, SID, focal spot, motion, and quantum mottle.*

## SUMMARY

The four prime factors of exposure are mA, time, kVp, and SID. The quantity of exposure is proportional to both the mA and the time. The mAs is the product of mA and time and indicates the total quantity of exposure. The kVp affects the quantity of exposure by determining how much of the primary beam will penetrate the subject and expose the film. The quantity of exposure in a given area of the IR is influenced by the SID according to the inverse square law, which states that radiation intensity is inversely proportional to the square of the distance.

*Radiographic density* refers to the overall blackness of a radiograph. It is influenced by all factors that affect exposure and is primarily controlled by mAs. An increase in exposure produces a darker image.

*Radiographic contrast.* The kVp is used to control the penetration of the x-ray beam and the contrast on the radiograph. High kVp produces a long scale of contrast, providing the latitude required to make radiographs of subjects with a wide range of tissue densities. A short scale of contrast, produced by low kVp, results in greater density differences between portions of the subject that are similar in tissue density.

*Distortion* refers to both magnification and changes in the shape of the image as compared with the object. Magnification is enlargement of the image as a result of the relationship between the OID and the SID. Shape distortion is caused by unequal magnification. Shape distortion is controlled by alignment of the object to the IR and by the alignment of the x-ray beam.

*Spatial resolution* refers to the sharpness of the radiographic image. It is affected by geometric factors (SID, OID, and focal spot size), motion, and quantum mottle.