Chapter 10

Formulating X-Ray Techniques

Learning Objectives

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

- Read and use an x-ray technique chart
- List methods for obtaining and/or creating an x-ray technique chart
- Accurately measure a body part using an x-ray caliper
- Compare fixed kilovolts peak (kVp) technique charts with variable kVp technique charts and state which are preferable
- Explain what is meant by "optimum kVp" and how this value is determined
- Select an appropriate milliamperage station for a given set of circumstances
- Take appropriate steps when the technique chart fails to provide an appropriate exposure
- Calculate exposure adjustments for changes in patient part size
- Determine the technique change required when radiographs are too dark or too light
- Suggest appropriate technique changes for increasing or decreasing the scale of contrast
- Calculate technique changes for variations in source–image receptor distance
- Explain the use of compensating filters for certain body structures
- Select the appropriate compensating filter for given body parts

Key Terms

caliper
compensating filter
exposure maintenance formula
fixed kVp chart
The Joint Commission

latitude
optimum kVp
radiographic phantom
technique chart
variable kVp chart

Most radiography departments have a functional technique chart that provides appropriate exposures for most circumstances. This chapter explores the components of technique charts and explains their limitations. When there is no chart or when the existing chart is inadequate, the limited operator must obtain or create a suitable chart. It is important to remember that no chart meets the requirements for every circumstance. When the planned procedure differs from the chart, the operator must make appropriate changes in the exposure settings. These radiographic examinations might include those involving patients who are larger or smaller than the measurements provided on the chart or patients whose conditions affect the amount of exposure required. Permanent changes in the type of grid, kilovoltage (kVp), milliamperage (mA), or source–image receptor distance (SID) will require a change in technique.

There is no one perfect set of factors that must be used for each exposure. A number of possible combinations may produce a diagnostic radiograph. The limited operator is responsible for ensuring that the technique chart is available, complete, and consistent. It must meet the requirements of the equipment and the preferences of the physician who will interpret the radiographs.

This chapter contains some formulas and mathematical calculations that all limited operators must master. The basic mathematical skills needed to perform these calculations are reviewed in Chapter 3, which also includes additional examples and practice problems to increase your proficiency.

TECHNIQUE CHARTS

A **technique chart** is a listing of the various radiographic examinations performed in the facility. It provides exposure factors for each body part according to its thickness. Table 10.1 is an example of a portion of a manual exposure technique chart. It is called *manual* because each technical factor is set "manually" by the x-ray operator. It includes the following information: type of examination, projection, SID, patient/part measurement (in centimeters), kVp, mA, exposure time, and a grid (Bucky) notation.

X-ray machines that use automatic exposure control (AEC) or anatomically programmed radiography (APR) systems must also have a technique chart. The chart should indicate all the items that a manual technique chart does, except the exposure time (which is automatic). The AEC chart will also have to indicate which of the three detectors to use for each projection. Most of these charts will have a combination of both AEC and manual techniques (Table 10.2).

Some limited operators become so familiar with the operation of their equipment over time that they tend to memorize or estimate exposures and do not feel the need for a technique chart. This practice may result in outdated or unavailable charts and may cause unnecessary exposure errors. Radiation control regulations may require posting of a current technique chart and may also specify the information to be included. In Oregon, for example, regulations require that technique charts include a notation that gonad shielding is required for specific examinations. **The Joint Commission**, the official organization that accredits hospitals and clinics, establishes standards for institutions that receive Medicare payments, and these standards include requirements for x-ray technique charts in radiography departments. Limited operators must be aware of requirements for technique charts and ensure that their charts conform to the regulatory standards.

TABLE 10.1

Example of Portion of a Manual Exposure Radiographic Technique Chart

	Lumbar Spine					
	AP and Oblique 40-Inch SID Bucky			Lateral 40-Inch SID Bucky		
cm	mA	second	kVp	mA	second	kVp
18–19	200	.04	86			
20–21	200	.05	86			
22–23	200	.06	86			
24–25	200	.08	86	200		96
26–27	200	.1	90	200	.15	96
28–29	200	.15	90	200	.2	96
30–31	200	.2	90	200	.25	96
32–33	200	.25	90	200	.37	96
34–35	200	.37	95	200	.5	102
36–37	200	.5	95	200	.65	102
38–39	200	.65	95	200	.85	102
40–41	200	.85	95	200	1.2	102

Measure at levels of anterior superior iliac spine. Use gonad shielding. *AP*, Anteroposterior; *kVp*, kilovoltage; *mA*, milliampere-seconds; *SID*, source–image receptor distance.

Technique charts are unique to each x-ray machine and each facility. The x-ray machine manufacturer cannot supply a definitive chart with the machine because the exposures will vary considerably depending on types of grids, tabletops, and SIDs. When a new chart is necessary, there are several possible sources.

Some of the major x-ray vendors will supply computer-generated charts for their customers. The local technical representative of your x-ray supply company may come to your department on request and do some testing to obtain the necessary data. These data are submitted to the company, and the chart is sent to your facility.

In some communities, experienced radiologic technologists will prepare a technique chart for a fee. This option is often advantageous because the chart can be made specifically for your facility and equipment, using only settings available on your control panel. Exposures may be provided for any procedures unique to your facility. Such a chart is also more likely to conform to local radiation control regulations.

A chart that needs to be changed because *all* of the exposures are too light or too dark can probably be modified easily. When the chart is consistent throughout—that is, all of the exposures are too light or too dark to about the same degree—it is a simple matter of increasing or decreasing all of the exposure times by a specific percentage to correct the

TABLE 10.2

Exposure Technique Chart for Shoulder Girdle Projections

	Shoulder Girdle							
Part	**cm**	**kVp[a]**	**second**	**mA**	**mAs**	**AEC[b]**	**SID**	**IR**
Shoulder—*AP*[c]	18	75		200s		☐☐ ■	48 in	24 × 30 cm
Shoulder—*transthoracic lateral*[c]	40	80		200s		☐☐ ■	48 in	24 × 30 cm
Shoulder—*axillary*[d]	18	75	.08	200s	16		48 in	10 × 12 inch
Shoulder—*PA oblique scapular Y*[c]	24	85	.08	200s	16		48 in	24 × 30 cm
Intertubercular *groove*[d]—	3	55	.01	200s	2		48 in	8 × 10 in
A-C articulation—*AP*[c]	14	70	.15	200s	30		72 in	18 × 43 cm
Clavicle—*AP, PA*[c]	16	70	.06	200s	12		48 in	24 × 30 cm
Scapula—*AP*[c]	18	75		200s		☐☐ ■	48 in	24 × 30 cm
Scapula—*lateral*[c]	24	85	.08	200s	16		48 in	24 × 30 cm

A-C, Acromioclavicular; *AEC*, automatic exposure control; *AP*, anteroposterior; *IR*, image receptor; *PA*, posteroanterior; *s*, small focal spot; SID, source–image receptor distance.
From Frank ED, Long BW, Smith BJ: *Merrill's atlas of radiographic positions and radiologic procedures*, ed 11, vol 1, St Louis, 2007, Mosby.
Note that both manual and AEC techniques are shown.
[a] Kilovoltage values are for a three-phase 12-pulse generator.
[b] Each of these squares represents one of the three detectors in the AEC device.
[c] Bucky, 16:1 grid.
[d] Tabletop, 8:1 grid.

radiographic density for all exposures. If your existing chart is not consistent, the use of a consistent chart borrowed from another facility with the identical equipment or from Appendix D may provide a starting point.

An exposure technique chart should be prepared with a calibrated x-ray machine and the specific type of image receptor (IR) used. After this, correction of a technique chart that is not working will require checking the calibration of the x-ray machine, the digital processor system, or both. Sometimes the problem is an x-ray operator who is not following the techniques posted on the chart. *Technically, a well-prepared exposure technique chart should never be changed.* Also a chart should not be changed because of temporary changes in the calibration of the x-ray machine. Before a chart that has been working well is changed, all potential factors that could affect the techniques should be evaluated. A radiologic technologist with experience in using quality control test tools can easily determine if the x-ray machine is calibrated before calling the service personnel to invasively check the machine.

Finally, if you decide to prepare a chart yourself, products are available to assist you. Supertech Inc.[a] offers both computer software and a handheld slide rule to calculate exposures. Both products are supplied with a small penetrometer and a master density chart (Fig. 10.1A). These are used to test your system and gather the basic data needed to tailor the tool to your x-ray department. Complete instructions are included. The Supertech computer software generates technique charts that conform to The Joint Commission standards.

Regardless of whether you prepare the chart yourself or arrange for its preparation by someone else, some testing is needed to establish baseline data for your system. This testing should be done when the processor is functioning at optimal levels. The same IRs that will be used with the chart should be used for testing. It is helpful to have a record of exposures kept over a period of time that lists the examination, measurement, exposure factors, and an assessment of the images produced.

Before using your technique chart to take radiographs of patients, it is helpful to test some of your exposures using a **radiographic phantom.** A radiographic phantom is a human skeleton, or portion of a skeleton, encased in a plastic material that is similar in density to human tissue. You may already be familiar with phantoms through experience in your radiography education program. A good phantom provides an excellent simulation of radiography of a human patient. It may be possible to borrow one from your film company's technical representative, from your x-ray supply dealer, or from a radiography education program.

Computerized control units with programmed exposure settings or "anatomic programming" such as APR will automatically select the kVp, milliampere-seconds (mAs), and AEC detectors for an examination when the radiographer selects the body part and enters the measurement. To function accurately, these units must first be programmed with exposures that meet the requirements of the facility. In other words, a technique chart must be created and entered into the control's computer. Even with this type of equipment, radiation control agencies may require posting of a printed technique chart.

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[a] Supertech Inc., PO Box 186, Elkhart, IN 46515; www.supertechx-ray.com.

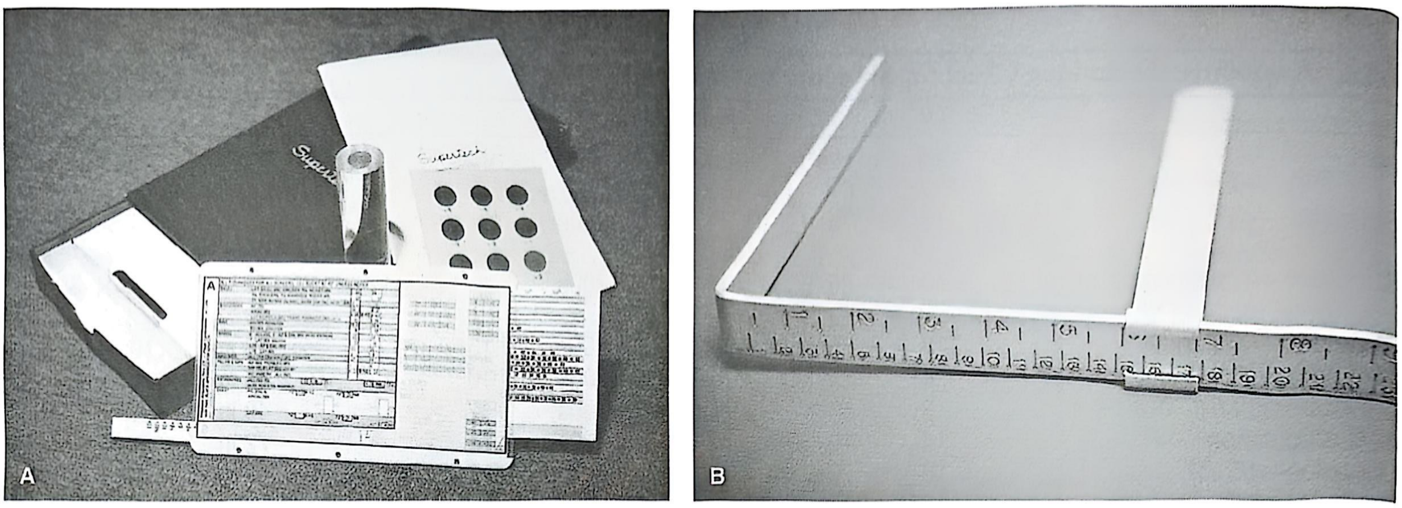

Fig. 10.1 (A) Supertech calculator kit. (B) X-ray caliper for measurement of body parts.

PATIENT MEASUREMENT

Technique charts are based on the measurement of the body part to be radiographed. The radiographer must measure the body part accurately to select the correct exposure from the technique chart or to obtain the correct exposure with a programmable computerized control.

The tool for body part measurement is called a **caliper** (see Fig. 10.1B). The main shaft of the caliper is a flat strip of metal, calibrated in both inches and centimeters. There are two perpendicular extensions from the shaft: one is permanently affixed to one end of the shaft and the other slides up and down the shaft. These two extensions form "jaws" between which the body part is measured.

It is usual for technique charts and computerized controls to specify the part measurement in centimeters. The dimension to be measured is the thickness through which the x-ray beam will pass. Measurements of the trunk of the body should always be made in the same general position as for radiography because measurements may change significantly when the patient changes position. For example, upright measurements of the abdomen are often 4 to 6 cm greater than measurements of the same region when the patient is lying down.

When a body part is measured, the fixed jaw of the caliper is placed under or against the part and the movable jaw is brought snugly and firmly against the patient on the opposite side (Fig. 10.2). You must take care that the jaws of the caliper remain parallel to each other. Pressing the jaws too tightly against the patient may cause them to spread apart at the open end, resulting in an inaccurate measurement. You must also take care that you do not measure air space. For instance, if the patient is lying on the table and you are measuring the thickness of the patient at the waist, the arch of the patient's back may leave a space between the back and the tabletop. Measuring from the tabletop to the surface of the patient's abdomen will give an inaccurate measurement. *Both jaws of the caliper must be firmly in contact with the body part.*

Fig. 10.2 When a body part is measured, the fixed jaw of the caliper is placed under or against the part and the movable jaw is brought snugly and firmly against the patient on the opposite side. Take care that the jaws of the caliper remain parallel to each other.

Body parts are usually measured through the path of the central ray. Some parts, however, may be measured through their thickest portion, or another method may be used. For example, exposures for the anteroposterior (AP) open-mouth projection of the upper cervical spine are usually based on the cervical spine measurement taken in the mid-cervical region. When there is variation in measurement method, it should be stated in the technique chart. The technique chart is designed for a specific measurement method and will not produce accurate results unless the measurement is consistent with the method intended by the chart.

FIXED KILOVOLTAGE VERSUS VARIABLE KILOVOLTAGE

Years ago, it was common to construct technique charts based on a specific mAs value for each projection and to vary the kVp by 2 to 3 kVp/cm for changes in patient/part size. This type of chart is called a **variable kVp chart**. One of the advantages of a variable kVp chart is that overall image contrast is higher, which may provide greater visibility of the spatial resolution. Also, variable kVp enables small incremental changes in exposure techniques that mA and exposure time cannot. Another type of chart is a **fixed kVp chart**. For this method, an optimum kVp value is established for each projection and the mAs is varied according to the patient/part thickness. The advantages of a fixed kVp chart are as follows. When the kVp levels are kept to the high end of the optimum range, exposures will have more **latitude** for exposure error. Latitude means that a wider range of densities, especially grays, are shown on the image. Exposures may be designated for small, medium, large, and extra-large patients, rather than having a separate listing for each centimeter measurement. When this is the case, each size category should state the size range in centimeters. Radiation exposure to patients may be somewhat lower with fixed kVp technique charts. In most departments, there are some charts that are set up as variable kVp and some that are fixed kVp.

An experienced radiologic technologist and a radiologist will usually, together, determine the best type of chart for a particular facility. In most instances, a combination of both is used.

Some control panels do not have a sufficiently wide range of possible mAs combinations to provide ideal exposures at fixed kVp for all patient/part sizes. Small kVp changes can be used to "fine tune" exposures between mAs settings to obtain a proper exposure for each measurement. This results in a modified fixed kVp chart in which mAs is the primary variable but kVp fluctuates within a range of ± 4 kVp from the optimum level.

OPTIMUM KILOVOLTAGE

The kVp setting for any examination must first provide sufficient penetration of the body part to create an image. Kilovoltage settings that are too low will result in both a high-contrast image that may not show all the anatomic parts, and a higher radiation dose to the patient. The best policy is to use the highest kVp setting that will produce sufficient contrast for acceptable image quality. This setting is referred to as **optimum kVp**. This approach will result in the least patient exposure and the greatest exposure latitude.

The optimum kVp for a specific examination may be determined by taking a series of images with a radiographic phantom. Fig. 10.3 illustrates such a series, taken at 15% rule (exposure doubled) increments. In each case, the mAs was reduced 50% to maintain approximately the same radiographic density on all of the radiographs. It is not possible to evaluate the contrast of a radiograph that is too dark or too light. The radiographic density must be in an acceptable range for contrast to be apparent. The mAs must be adjusted to maintain the desired radiographic density when changing kVp. These adjustments are explained later in this chapter. The ideal kVp levels for your facility will depend on the grid ratio and phase of generator and should also correspond with the preferences of the radiologist who will read the radiographs. Useful ranges have been well established by the experience of others. Appendix E provides a listing of suggested optimum kVp ranges that will assist you by providing a starting point.

The kVp for a body part is established for a given room and for each projection in that room. Once established on the technique chart, the kVp should never be changed unless the contrast in the image needs to be adjusted.

CRITERIA FOR MILLIAMPERAGE SELECTION

Many of the exposure changes in this chapter involve changes in the mAs value. Most computerized control panels provide the option of setting the mAs directly. Older units, however, will require you to decide how a given quantity of mAs will be obtained. As explained in Chapters 5 and 7, mAs is the product of mA and time, and several possible combinations of mA and time may be used to achieve the desired quantity of exposure. For example, 10 mAs may be obtained using any of the following combinations:

$$\begin{gathered}50\text{ mA, }0.2\text{ second} = 10\text{ mAs}\\ 100\text{ mA, }0.1\text{ second} = 10\text{ mAs}\\ 200\text{ mA, }0.05\text{ second} = 10\text{ mAs}\end{gathered}$$

When a technique chart is being created or mAs values are being adjusted, the question then becomes which of several possible combinations is best. In choosing an mA setting, the limited operator should consider the tube rating, focal spot size, exposure time requirements, and available mA and time settings.

CALCULATING EXPOSURE TIME

When the desired mAs is known and you have selected an mA setting according to the criteria discussed earlier, the next step is to determine the exposure time. To determine the exposure time, divide the desired mAs by the selected mA. This is a variation of the mAs formula:

$$\frac{\text{mAs}}{\text{mA}} = \text{Time (second)}$$

Example: Suppose the desired mAs is 50, and you have decided to use 200 mA.

Using the formula:

$$\frac{50\text{ mAs}}{200\text{ mAs}} = 0.25\text{ second}$$

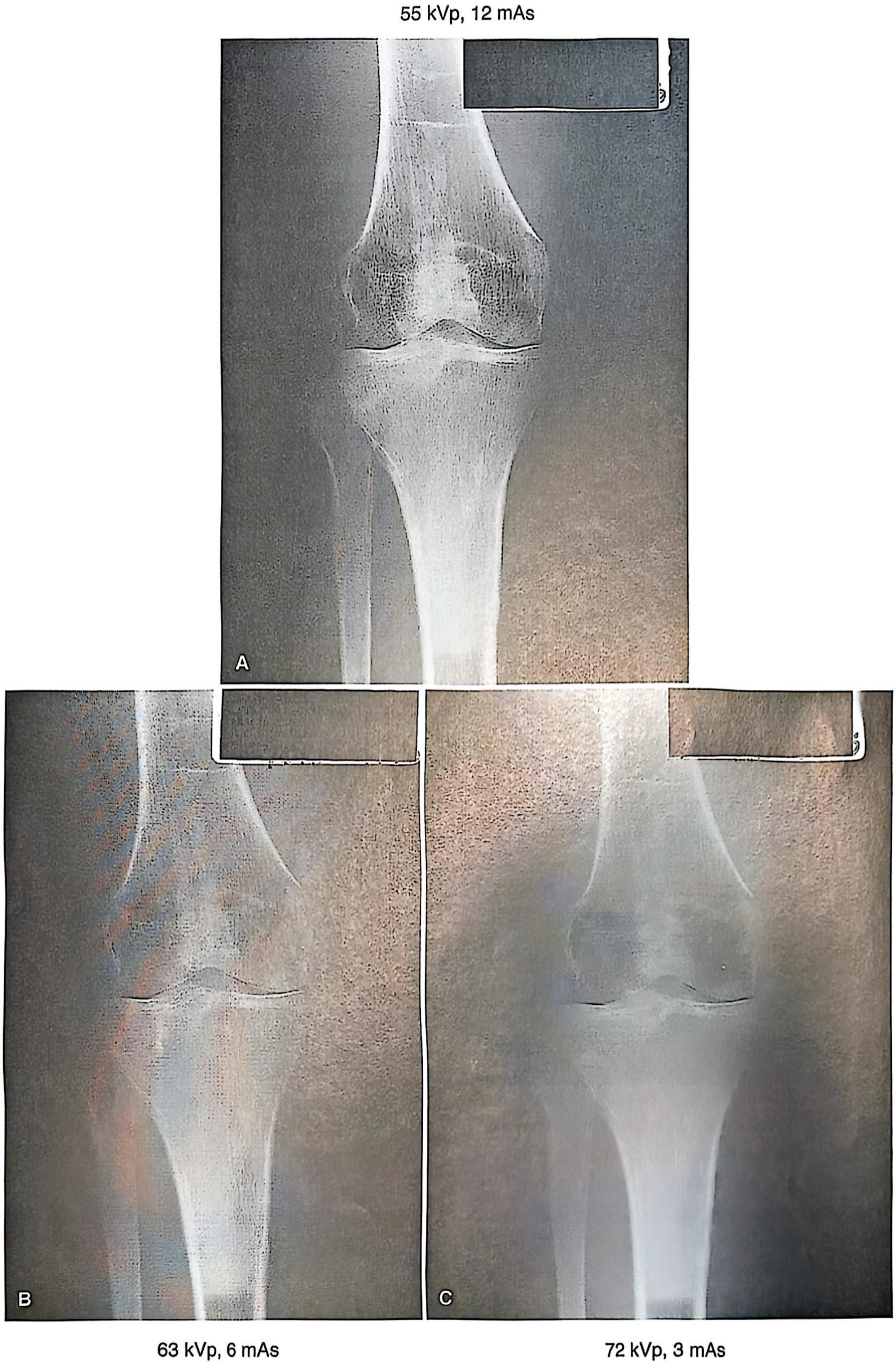

Fig. 10.3 Typical image series using a radiographic phantom to determine adequate kilovoltage. Note that (A) has high contrast, (B) has moderate contrast, and (C) has low contrast. The correct contrast level will be determined by the radiologist. Note that the kilovoltage (kVp) doubled (using the 15% rule) and the milliampere-seconds (mAs) were reduced by 50% to keep image density the same.

It is helpful to make an mAs chart for your machine. Create a column for each mA station and label the rows with the exposure time settings available on your control panel. Then calculate the mAs for all possible combinations and enter them on the chart. An example of such a chart is included in Appendix F. An mAs chart is a helpful reference when creating a technique chart or when departing from the usual exposure for a particular case, such as a patient who is unable to hold still.

TECHNIQUE CHART "FAILURE"

When a technique chart produces inconsistent results, it is often because the kVp levels are not optimal. Too low a kVp range will tend to produce too much contrast for smaller part measurements. For larger part measurements, insufficient penetration will result in films that are too light. When the fixed kVp is too high, radiographs will lack contrast, especially when the part measurement is at the upper end of the size range. These problems are solved by adjusting the level of the fixed kVp for those categories that are causing problems. Changes in kVp will require adjustments in mAs. The calculation of these adjustments is discussed later in this chapter.

Even the best technique charts do not always produce ideal radiographs. One possible cause is variation in generator x-ray output and calibration. When x-ray images are too dark or too light, it is wise to perform a quality control check of the digital system or the generator, or an experienced radiologic technologist can check the kVp, mA, and exposure time using quality control tools before modifying the technique chart. Another possible cause is inconsistency in patient/part measurement, which will produce inconsistent results. It is important that the measurement method conform to the technique chart. Some radiographers always measure body parts through the path of the central ray. Others may measure at the thickest portion of the part for some or all examinations. It is helpful to include measurement instructions on the technique chart. Accurate body part measurement is explained earlier in this chapter.

Technique charts are constructed to meet the requirements of average or normal tissue densities for each body part. Tissue density may vary significantly because of disease, age, or muscle tone. An athlete or laborer may have muscle tissue that is much greater in density than average, requiring more exposure. Elderly patients usually have diminished bone density and muscle tone, requiring less exposure. As you gain experience you will learn to recognize patients whose tissue density requires adjustments to the exposures provided in the technique chart. Box 10.1 lists conditions that require an increase in exposure; Box 10.2 lists conditions that require a decrease in exposure. Some lists of this type suggest a specific amount of exposure change for each condition. The proper adjustment will depend on the severity of the condition. An increase or decrease of 2 to 4 cm from the patient measurement is a convenient method for arriving at a suitable technique.

Box 10.1
Conditions Requiring an Exposure Increase (Hard to Penetrate)

Chest Conditions
- Atelectasis collapse of lung
- Bronchiectasis tubes permanently damaged
- Cardiomegaly enlargement of heart
- Congestive heart failure
- Edema, pulmonary swelling, fluid in lungs
- Empyema pus between lungs & chest wall
- Hemothorax blood between lungs & chest wall
- Hydropneumothorax presence of fluid or air
- Metastases (blastic) malignant growth
- Pleural effusion water in lungs
- Pneumoconiosis diseases lung disease
- Pneumonia
- Tuberculosis (calcific, miliary)

Conditions of Bone
- Acromegaly excess growth
- Arthritis, rheumatoid
- Osteochondroma overgrowth of cartilage
- Osteomyelitis, healed infection of bone
- Osteopetrosis (marble bone)
- Paget disease skeletal disease

Abdomen
- Ascites fluid in peritoneal cavity
- Cirrhosis of liver

Soft Tissue
- Edema

Generalized Conditions
- Heavy musculature
- Large bones

For each of the conditions listed in this box, increase body part measurement by 2–4 cm, depending on severity.

Box 10.2
Conditions Requiring an Exposure Decrease (Easy to Penetrate)

Chest Conditions
- Chronic obstructive pulmonary disease (emphysema)
- Pneumothorax
- Tuberculosis, active

Conditions of Bone
- Arthritis, degenerative
- Gout
- Hyperparathyroidism
- Metastasis, lytic
- Multiple myeloma
- Necrosis
- Osteomyelitis, active
- Osteoporosis
- Sarcoma

Abdomen
- Bowel obstruction
- Pneumoperitoneum

Generalized Conditions
- Advanced age
- Atrophy
- Emaciation

For each of the conditions listed in this box, decrease body part measurement by 2–4 cm, depending on severity.

ADJUSTMENT OF TECHNIQUES

Variations in Patient/Part Size

As the thickness of the subject increases, radiographic density will decrease unless adjustments are made in exposure. This adjustment is usually in the form of a change in mAs. A 30% mAs increase will compensate for a 2-cm increase in part size. This change compounds, like compound interest, and adjustment may require multiple steps. When decreasing technique to compensate for a smaller part size, the mAs is reduced by 20% for each 2 cm of part size reduction.

Example: Your routine technique for a lumbar spine measuring 20 cm is 200 mA, 0.15 second, 80 kVp, 40-inch SID. What technique would you use for a patient whose lumbar spine measured 24 cm?

Adjust for part size by increasing mAs 30% for each 2 cm of additional size.

First, determine the mAs:

$$200 \text{ mA} \times 0.15 \text{ second} = 30 \text{ mAs}$$

To increase to 22 cm, multiply the mAs by 1.3 (100% + 30%):

$$30 \text{ mAs} \times 1.3 = 39 \text{ mAs}$$

To increase to 24 cm, multiply the new mAs (39) by 1.3:

$$39 \text{ mAs} \times 1.3 = 50.7 \text{ mAs (round off to 50 mAs)}$$

In this case, as with others in this chapter, the "ideal" mAs value may be one that is not available on the control panel. Because mAs variations of up to 20% are scarcely noticeable on the radiograph, the ideal mAs can usually be rounded up or down to the nearest available mAs value without any significant effect on radiographic density. If in doubt about which of the available mAs values to select, always select the highest. Now you must select appropriate mA and time settings to produce the calculated mAs, as explained earlier in this chapter.

It is also possible to compensate for part size variations using kVp, but this method should be used only when the size variation is relatively small because a large change in kVp will also alter contrast and may have negative effects on radiographic quality. A change of 2 kVp/cm is sufficient below 85 kVp; above 85 kVp, a 3-kVp change is necessary.

Example: A satisfactory lateral cervical spine radiograph is made on a patient measuring 12 cm using 100 mA, 0.05 second, and 76 kVp at 72-inch SID. Vary the kVp to alter this exposure for a patient measuring 10 cm.

Because the size variation is small, kVp may be used in this instance. Since the original kVp is less than 85, the compensation will be a reduction of 2 kVp/cm. The size difference is 2 cm (12 cm − 10 cm)

$$2 \text{ cm} \times 2 \text{ kVp/cm} = 4 \text{ kVp}$$

$$76 \text{ kVp} - 4 \text{ kVp} = 72 \text{ kVp}$$

Therefore, the new exposure will be 100 mA, 0.05 second, 72 kVp, 72-inch SID. Chapter 3 contains further discussion of these methods of technique adjustment with additional examples and practice problems.

Pediatric Techniques

If babies, small children, youngsters, and small teenagers are having x-ray examinations in your department, a special technique chart will have to be established. In Chapter 11 you will learn that *the rapidly developing tissues of children are much more sensitive to radiation damage than adults*. Therefore careful attention to providing accurate exposure techniques for x-ray of children is crucial. Repeats on children should be kept to a minimum. For babies and very small children, or if motion is anticipated (e.g., crying), use the highest mA setting with the shortest exposure time. Also, your department should provide special training in positioning, restraining, and setting exposure techniques for children. Chapter 18 provides additional information on working with pediatrics.

Obese Patient Techniques

Modified x-ray exposure techniques need to be used on obese patients. The main factors have to be increased, including the mA, kVp, and exposure time. The *major limitation* in obtaining images of obese patients is inadequate penetration of the body part. This situation results in increased quantum mottle (noise) and very low image contrast. The increased exposure time required in these patients can also contribute to motion artifacts in the image. The single most important adjustment that should be made is an increase in the kVp. Increasing the kVp increases the penetration of the x-ray beam. The mA and exposure time (mAs) have to be increased; however, caution should be used in increasing the mA. Greater exposures can be obtained safely by using low mA settings and longer exposure times. (See the tube rating chart in Chapter 6.)

Motion is not a major problem in imaging obese patients because the weight of the patient prevents most body parts from moving, and mA settings of about 320 can be used. This setting may increase the exposure time; however, with an explanation of the importance of holding the breath, most obese patients can comply. With repeated use of high exposure factors, the x-ray tube can become very hot. Limited operators should ensure that adequate cooling of the anode and tube as a whole occurs; this can be accomplished by simply taking more time between exposures. It is also important to point out that obese patients often are not able to have an x-ray done, in particular in the abdominal and pelvic areas. The maximum weight capacity for the x-ray table is 450 lb., but many manufacturers are increasing this to about 700 lb. Ensure that your table can handle the weight of these patients.

Alteration of Radiographic Density

When an image is too light, the best solution is usually an increase in mAs. *The minimum change necessary to cause a visible change in image density is 30% of mAs.* Likewise, when the image is too dark, mAs may be decreased. There are very few instances in which the kVp is changed when images are too light or too dark. Changing mAs by a specific quantity does not always produce the same result. It is the *percentage change* that is significant. Fig. 10.4 illustrates changes in radiographic density produced by various percentages of mAs increase. If an image is so light that it must be repeated to obtain diagnostic quality, at least a *doubling* (100% increase) is usually necessary. When decreasing density, a smaller percentage change is required. That is, a 50% mAs reduction produces the same amount of change as a 100% increase (see Fig. 10.4). *The general rule of thumb for mAs changes is to make adjustments in increments of doubles or halves.*

Although these changes will become much easier for you to estimate with experience, the main lesson here is that you must be bold when making changes. Trying to correct improper density with very small increments of change is ineffective.

Alteration of Contrast Levels

A change in kVp is often used to alter contrast. Because kVp affects the quantity of exposure to the IR, changing kVp will also affect radiographic density. For this reason, when an image of appropriate density requires a change in contrast, it is necessary to change both the kVp and the mAs. Whether working with an entire technique chart or a single exposure, the 15% rule can be used to change the level of contrast while keeping the density constant.

The 15% Rule

The 15% rule is based on the fact that a 15% change in kVp will produce approximately the same change in radiographic density as a doubling or halving of the mAs.

To decrease contrast, increase kVp by 15% and divide the mAs by 2. This application of the 15% rule increases latitude and creates a longer scale of contrast.

Example: A radiograph is made using 20 mAs and 68 kVp. The radiographic density is acceptable, but a longer scale of contrast is desired. To calculate the new exposure, first increase kVp by 15% (100% + 15% = 115%, or 1.15):

68 kVp × 1.15 = 78.2 kVp (round off to 78 kVp)

Next, divide the mAs by 2:

20 mAs ÷ 2 = 10 mAs

Therefore the new exposure is 10 mAs at 78 kVp (Fig. 10.5).

To increase contrast, decrease kVp by 15% and multiply the mAs by 2. This application of the 15% rule decreases latitude and creates a shorter scale of contrast.

Example: A radiograph is made using 10 mAs and 65 kVp. The radiographic density is acceptable, but a shorter scale of contrast (high contrast) is desired. To calculate the new exposure, first decrease kVp by 15%.

65 kVp × 0.15 = 9.75 kVp (round off to 10 kVp)
65 kVp − 10 = 55 kVp

Next, multiply the mAs by 2:

10 mAs × 2 = 20 mAs

Therefore the new exposure is 20 mAs at 55 kVp.

Fig. 10.6 illustrates application of the 15% rule for increasing radiographic contrast. See also Chapter 3.

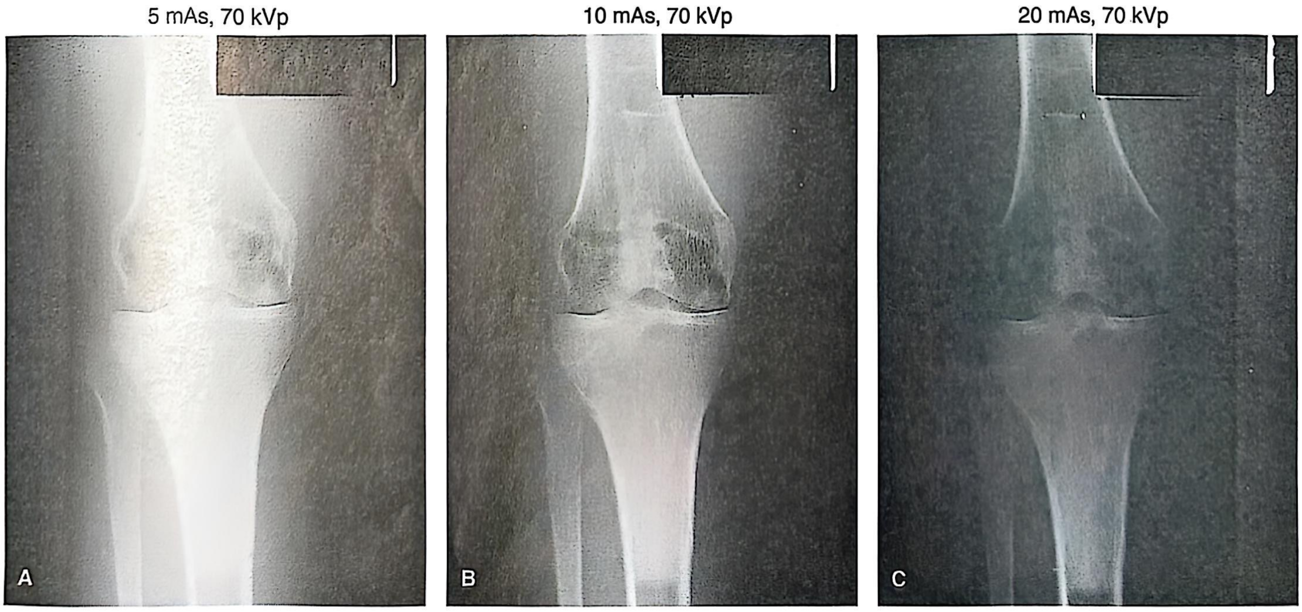

Fig. 10.4 Adjusting milliampere-seconds (mAs) to correct an image that is too light or too dark. Note that the knee in (A) is too light, and doubling the mAs will produce an acceptable density as in (B). Image (C) is too dark, and reducing its mAs by 50% will produce an acceptable density as in (B). Doubling the mAs or cutting the mAs by 50% will have a visible effect on density as shown.

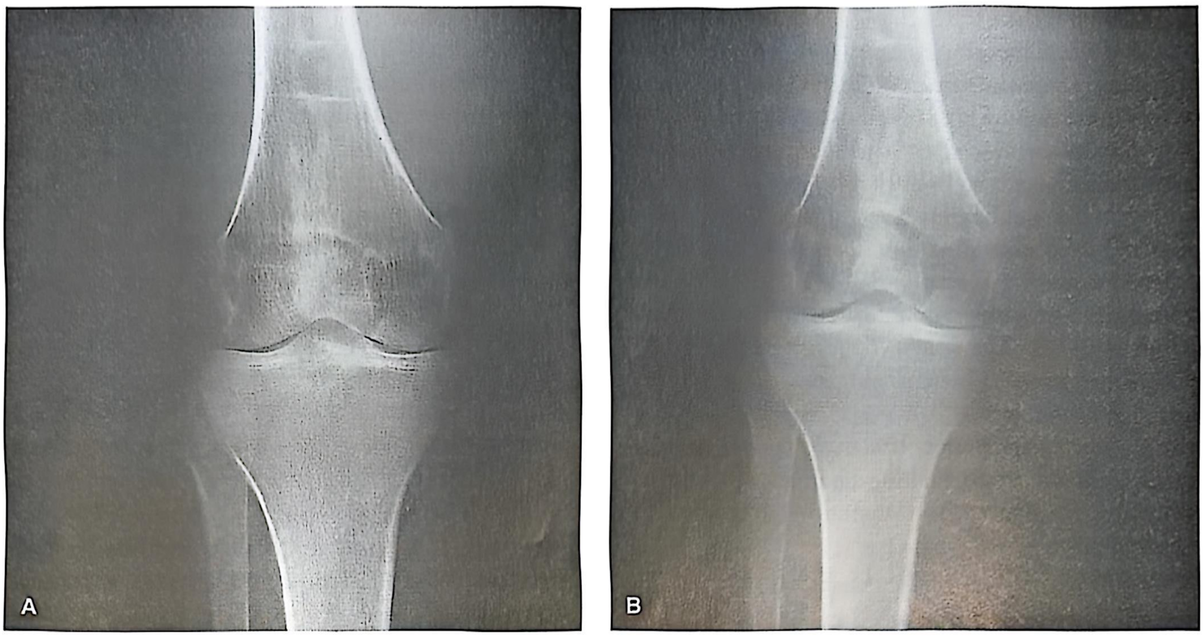

Fig. 10.5 Application of the 15% rule for contrast adjustment. (A) 20 mAs and 68 kVp. (B) 10 mAs and 78 kVp. Note less contrast in (B) because of a higher kilovoltage (kVp).

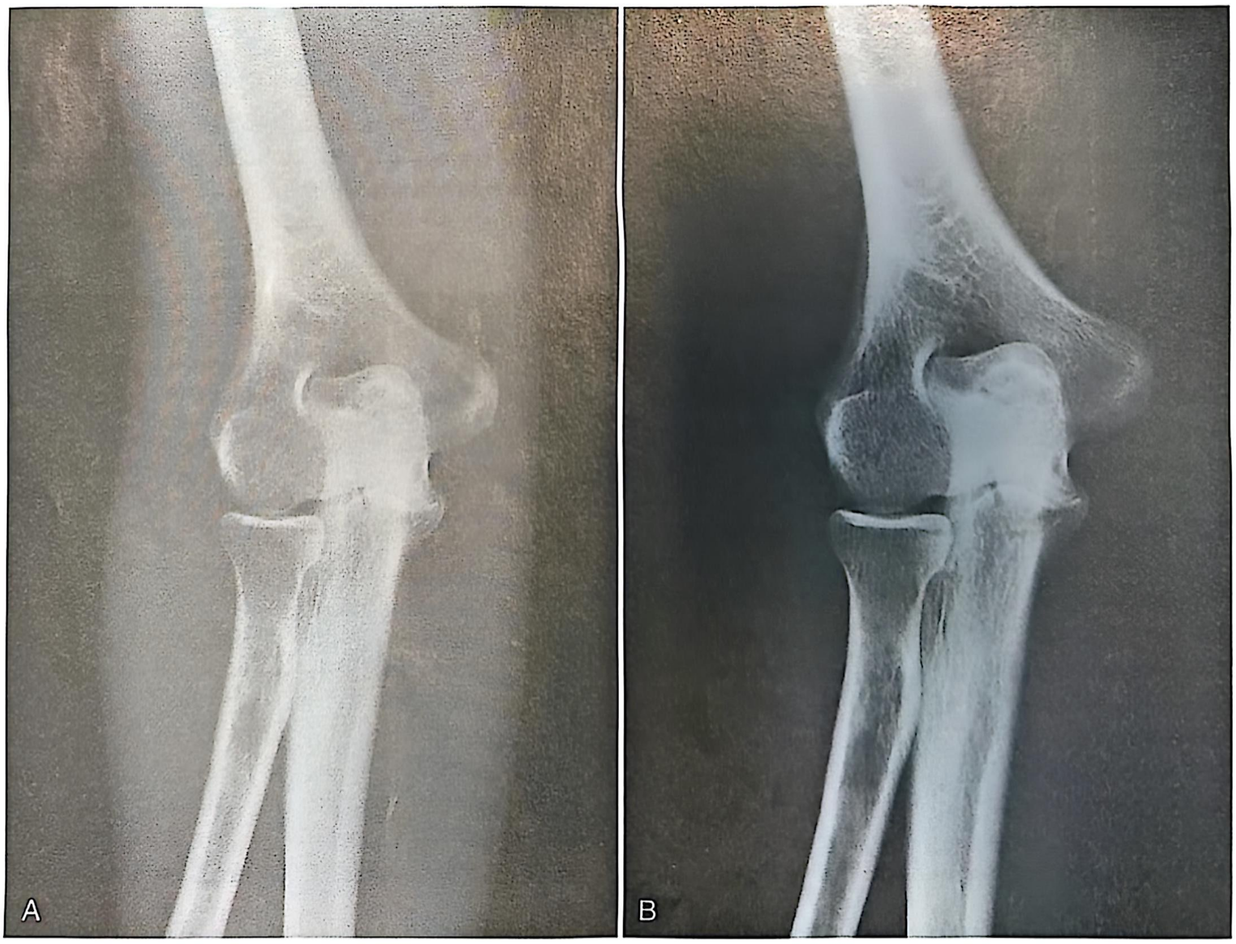

Fig. 10.6 Application of the 15% rule for contrast adjustment. (A) 10 mAs and 65 kVp. (B) 20 mAs and 55 kVp. Note higher contrast in (B) because of lower kilovoltage (kVp).

Variations in Source–Image Receptor Distance

Changes in SID are not routine. A standard distance is established for each procedure, and the technique chart provides the correct exposure for the standard distance. Sometimes it will be necessary to modify exposures for changes in distance. For example, bedside and surgical radiography with mobile equipment may not permit use of the usual distance. An exposure technique for a mobile chest exam may be set with an SID of 40 inches. However, upon entering the patient's room, due to support equipment being in the way, you may only be able to obtain a 36-inch SID.

As explained in Chapter 7, variations in SID result in changes in radiation intensity. If the SID is to be changed without altering radiographic density, the mAs must be modified accordingly. The formula for this change is shown. It is generally referred to as the **exposure maintenance formula**. Because mAs is the primary controller of x-ray intensity and IR exposure, mAs can be adjusted to compensate for changes in distance. The mAs is directly proportional to SID. If the SID is increased, the mAs is increased and vice versa. The SIDs are always squared in this formula.

$$\frac{\text{mAs}_1}{\text{mAs}_2} = \frac{D_1^2}{D_2^2}$$

Example: Suppose that the usual technique for chest radiography of a patient measuring 20 cm is 4 mAs, 110 kVp, at 72-inch SID. In this case it is necessary to perform the examination at a 60-inch SID. How should the technique factors be changed? The solution to this distance problem involves a change in the mAs according to the formula given earlier. To solve it, substitute known values in the equation:

$$\frac{4\ \text{mAs}}{X} = \frac{72^2}{60^2}$$

Square the distances:

$$\frac{4\ \text{mAs}}{X} = \frac{5184}{3600}$$

Cross multiply and divide:

$$4 \times 3600 = 14{,}400$$

and

$$14{,}400 \div 5184 = 2.78$$

Round the mAs:

$$X = 3\ \text{mAs}$$

Table 10.3 provides guidelines for approximate exposure changes for common variations in SID. See also Chapter 3.

TABLE 10.3

Approximate Calculations for Changes in Source–Image Receptor (SID) Distance

From 40-Inch SID to	60 Inch	72 Inch	80 Inch
Multiply mAs by	2	3	4

mAs, Milliampere-seconds.

COMPENSATING FILTERS

Radiography is usually accomplished using a single exposure technique for a given body structure. However, some structures contain areas of significantly varied tissue density that must be shown on one image. These structures present special challenges in demonstrating the anatomic structures with an acceptable range of densities. Often, two exposures must be made on these body structures, which doubles the radiation exposure to the patient. Typically, if one exposure is used, a technique is selected to adequately penetrate the densest area of anatomy. In this case, the radiologist will highlight the dark anatomic area on the image with a "hot light." However, these images often have to be viewed by other physicians who do not have such a light available. With digital radiography systems, the image can be adjusted with the computer to lighten the dark area of anatomy; however, the large difference in transmitted x-rays often exceeds the dynamic range of the software. This can result in images that appear low in contrast, contain high noise, or show processing artifacts.

Examples of x-ray projections that have to demonstrate significantly varied tissue density include the *AP projection of the thoracic spine and the axiolateral projection (Danelius-Miller method) of the hip* (Fig. 10.7), *AP shoulder, lateral C7-T1 cervicothoracic area, AP foot, and AP and lateral scoliosis spine*. Exposure of these structures with a uniformly intense x-ray beam results in the production of an image with areas of underexposed or overexposed anatomy. To compensate for these variations in tissue density, specially designed attenuating devices called **compensating filters** can be placed between the radiographic tube and the IR. The resulting attenuated beam more appropriately exposes the various tissue densities of the anatomy and reveals more anatomic detail. Equally important, the filter will somewhat reduce the entrance skin exposure and therefore the dose to some of the organs in the body (Fig. 10.8).

Fig. 10.9 includes some of the most common filters in use today. These filters can be used with both screen/film and digital imaging systems to improve the image quality of a variety of anatomic areas. With most digital systems, filters are necessary to obtain a diagnostic image of an extreme density-different body part. In addition, radiation exposure to the patient is lowered through elimination of the extra exposures needed to demonstrate all of the anatomy and through the absorption of x-rays in some areas of the filter itself.

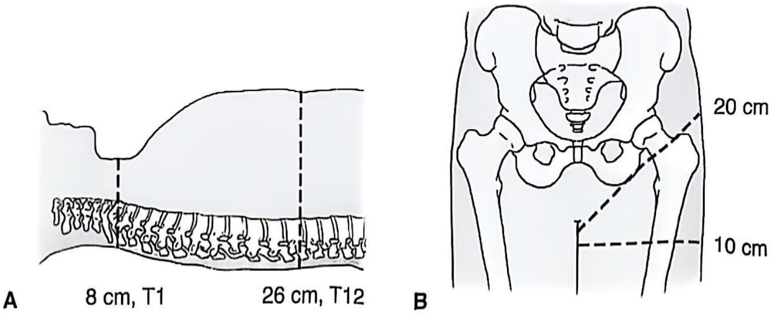

Fig. 10.7 Body structures with significantly varied tissue density include thoracic spine (anteroposterior) (A) and hip (lateral) (B).

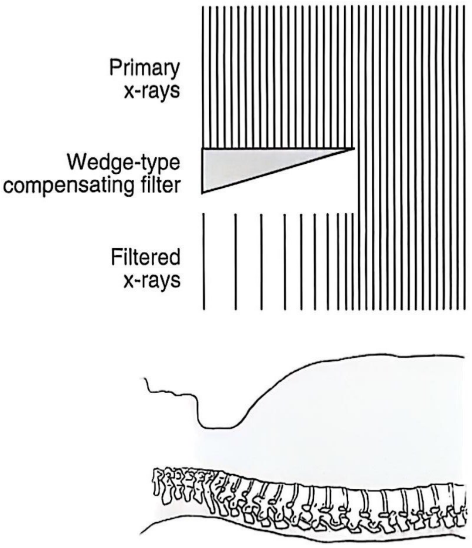

Fig. 10.8 Wedge-type compensating filter in position for an anteroposterior projection of the thoracic spine. Note how the thick portion of the wedge partially attenuates the x-ray beam over the upper thoracic area while the nonfilter area receives the full exposure to penetrate the thick portion of the spine. An even image density results.

The appropriate use of radiographic compensating filters is an important aspect of the work of the limited operator. The operator determines whether or not to use a filter based on an assessment of the patient and then determines the type and exact position of the filter. This is accomplished while positioning the patient. Radiographic projections of the lateral hip and the lateral C7 to T1 cervicothoracic region in most instances will require a filter to demonstrate all the anatomy on one image. Projections such as the AP shoulder and AP thoracic spine may not need a filter on patients with hyposthenic physiques; however, on patients with hypersthenic physiques and patients who are barrel-chested or obese, a filter is necessary. Pediatric patients seldom require a filter, except when AP lateral projections of the full spine are done in cases of spinal curvatures such as scoliosis. The use of compensating filters for full-spine radiography not only allows the entire spine to be imaged with one exposure, it also significantly reduces the radiation exposure to the young age group that requires these images.

Placement

Compensating filters are most often placed in the x-ray beam between the x-ray tube and patient. Broadly, filters fall into two categories based on their location during use: *collimator-mounted* filters and *contact* filters. The collimator-mounted filters are the most common and are mounted on the collimator, either using rails installed on both sides of the window on the collimator housing (Fig. 10.10) or using magnets. Generally, those filters placed between the primary beam and the body will have the added benefit of a reduction in radiation exposure to the patient because of the beam-hardening effect of the filter, whereas those placed between the anatomic part and the IR will have no effect on patient exposure. Measurements provided with the Ferlic filters[b] show radiation exposure reductions of between 50% and 80%, depending on the kVp, in the anatomic area covered by the filter. Measurements by Frank, Stears, Gray, et al.[c] and Gray, Stears, and Frank[d] show exposure reductions of between 20% and 69% to the thyroid, sternum, and breasts for scoliosis radiography. Both types of filters have the same effect on the finished image, which is a more uniform radiographic density, even though the tissue density varies greatly. Filters can be improvised as well, with radiographers creating their own versions of attenuation control devices such as filled bags of saline solution. Bags of solution, however, will increase radiation scattering. Use of improvised filters is not recommended because there is potential for creating unknown artifacts in the image. An example of the improvement in image quality using a compensating filter can be seen in the AP projection of the shoulder in Fig. 10.11.

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[b] Ferlic Filter Company LLC, White Bear Lake, Minnesota.

[c] Frank ED, Stears JG, Gray JE, et al: Use of the posterior-anterior projection as a method of reducing x-ray exposure to specific radiosensitive organs, *Radiol Technol* 54:343, 1983.

[d] Gray JE, Stears JG, Frank ED: Shaped, lead-loaded acrylic filters for patient exposure reduction and image quality improvement, *Radiology* 146:3, 1983.

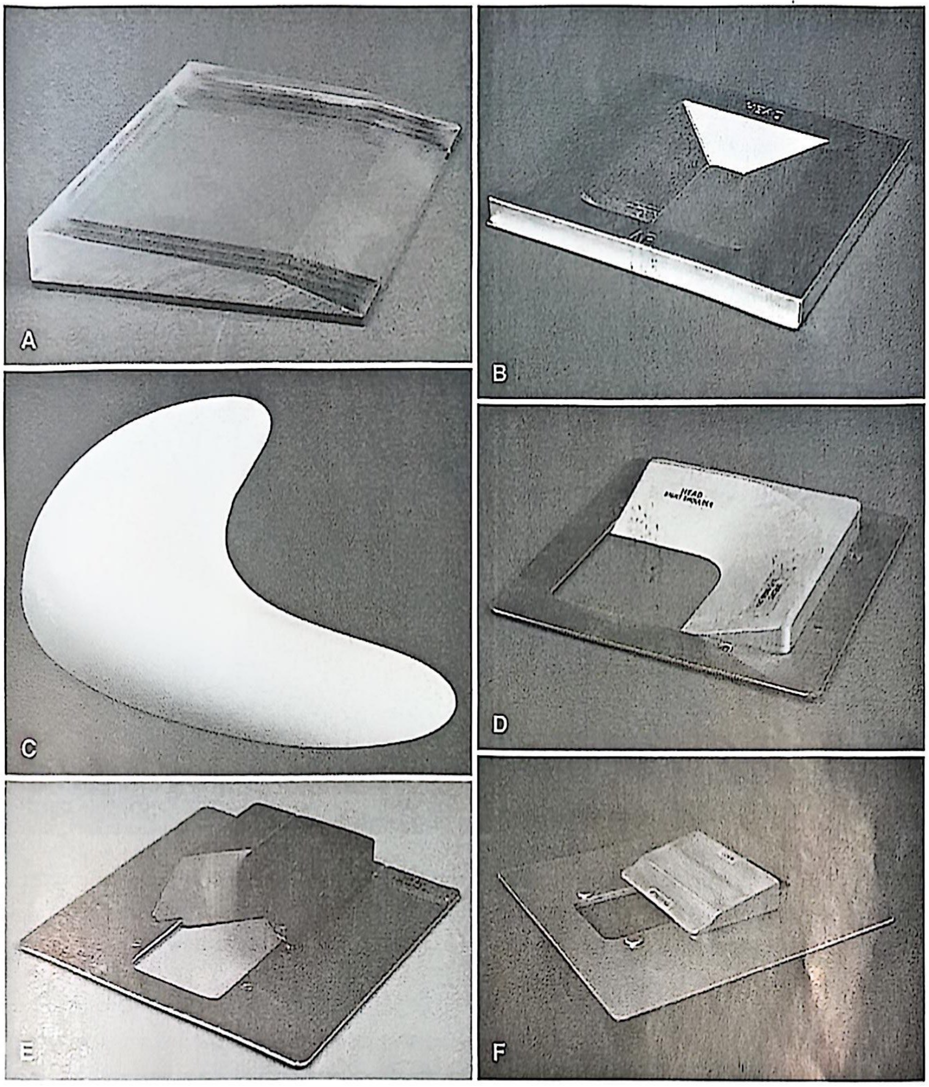

Fig. 10.9 Examples of compensating filters in use today. (A) Supertech wedge, collimator-mounted Clear-Pb filter used for the anteroposterior (AP) projection of the hips, knees, and ankles on long (51-inch) film. (B) Trough, collimator-mounted aluminum filter with a double wedge used for AP projections of the thoracic spine. (C) Boomerang contact filter used for AP projections of the shoulder and facial bones. (D) Ferlic collimator-mounted filter used for AP and posteroanterior oblique (scapular Y) projections of the shoulders. (E) Ferlic collimator-mounted filter used for lateral projections of the cervicothoracic region (swimmer's technique) and axiolateral projections (Danelius-Miller method) of the hip. (F) Ferlic collimator-mounted filter for AP projections of the foot.

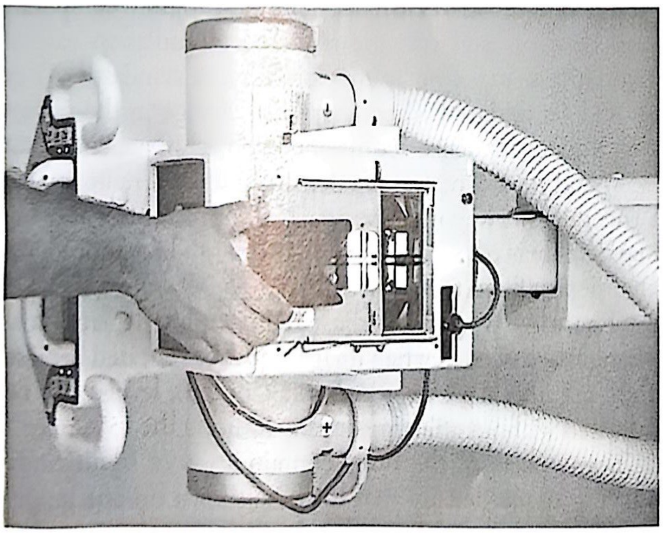

Fig. 10.10 The Ferlic collimator-mounted filter being positioned on the underside collimator for an anteroposterior projection of the shoulder.

Limited operators must use caution when mounting and removing compensating filters on the collimator while the x-ray tube is over the patient. There have been instances in which filters did not attach properly, did not get positioned into the filter track, or were forgotten and fell onto the patient when the tube was moved. All compensating filters, especially the aluminum ones, are moderately heavy with sharp edges; therefore they can cause injury to the patient if dropped. When the filter is positioned to the underside of the collimator and when it is removed, two hands must be used (Fig. 10.12). One hand should attach the filter while the other is positioned to catch the filter if it does not attach properly.

When using compensating filters, the exposure factors on the technique chart may have to be changed, depending specifically on the projection and patient. If compensating filters are new in your department, you may want to refer to a radiographer for appropriate use of the filter and also for accurate exposure techniques.

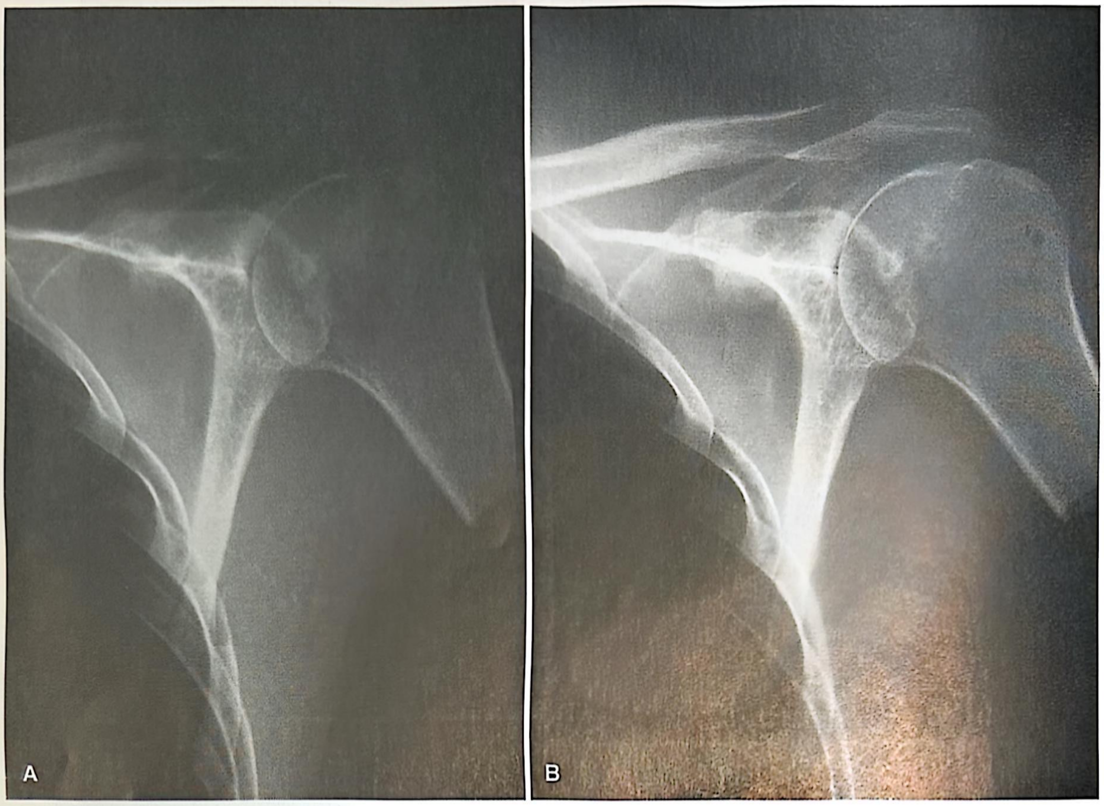

Fig. 10.11 (A) Anteroposterior (AP) projection of the shoulder without a compensating filter. (B) Same projection using the Ferlic shoulder filter, collimator mounted. Note greater visualization of the acromion, acromioclavicular (AC) joint, and humeral head.

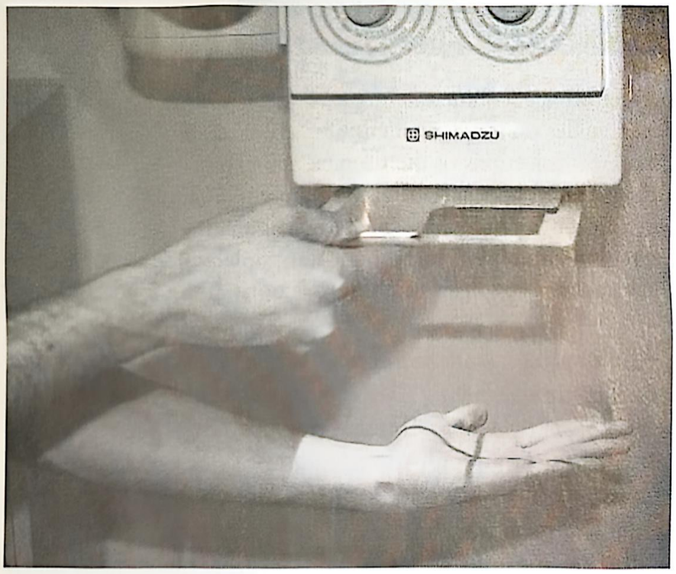

Fig. 10.12 Two hands must be used to attach and remove collimator-mounted filters. Note that one hand is used to catch the filter in case it is dropped.

SUMMARY

A good variable or fixed kVp technique chart is required to produce consistent exposure results. Technique charts are based on body part measurements in centimeters taken using a caliper. Proper measurement according to the method specified by the technique chart is essential. Optimum kVp ranges are established for each body part, and the mAs is varied to adjust the exposure for changes in patient/part thickness. The mA is selected to conform to the requirements of the tube rating chart and to provide the desired focal spot size. The highest mA settings are used when short exposure times are required. Exposure times are determined by calculation, based on the required mAs and the desired mA.

Technique charts are necessary to program computerized controls and may be required by radiation control regulations and The Joint Commission standards. They should be updated when there is a change in the system that affects exposure requirements. Technique charts are designed for normal tissue density and usual radiographic procedures. They must be adjusted for patients whose tissue density is outside the normal range and for procedures that depart from the usual SID, grid, or IR system speed.

The mAs is used to adjust radiographic density. Bold changes are needed when images must be repeated because they are too dark or too light. Contrast levels may be adjusted without affecting density by using the 15% rule.

Some parts of the body contain areas of significantly varying tissue density that must be shown on one image. To compensate for these variations in tissue density, compensating filters should be used and exposure techniques adjusted accordingly.