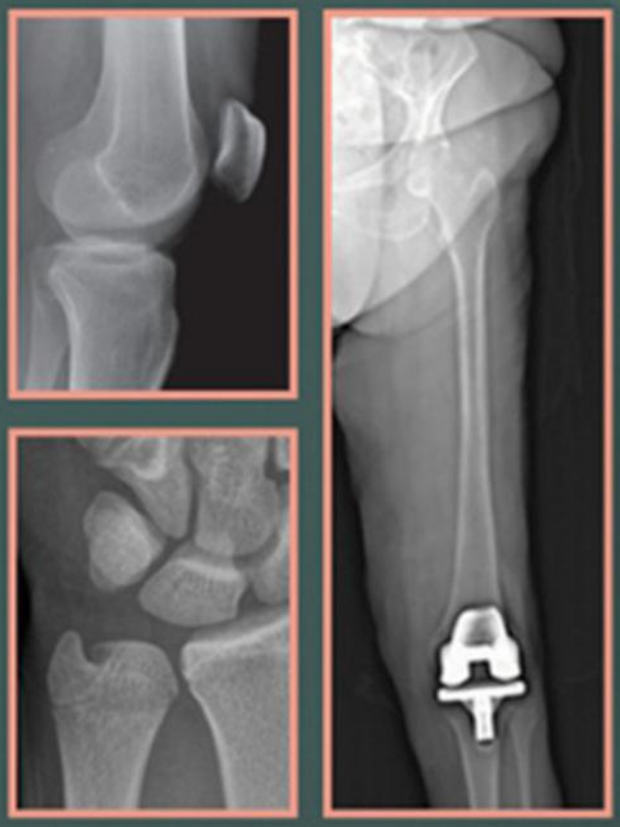
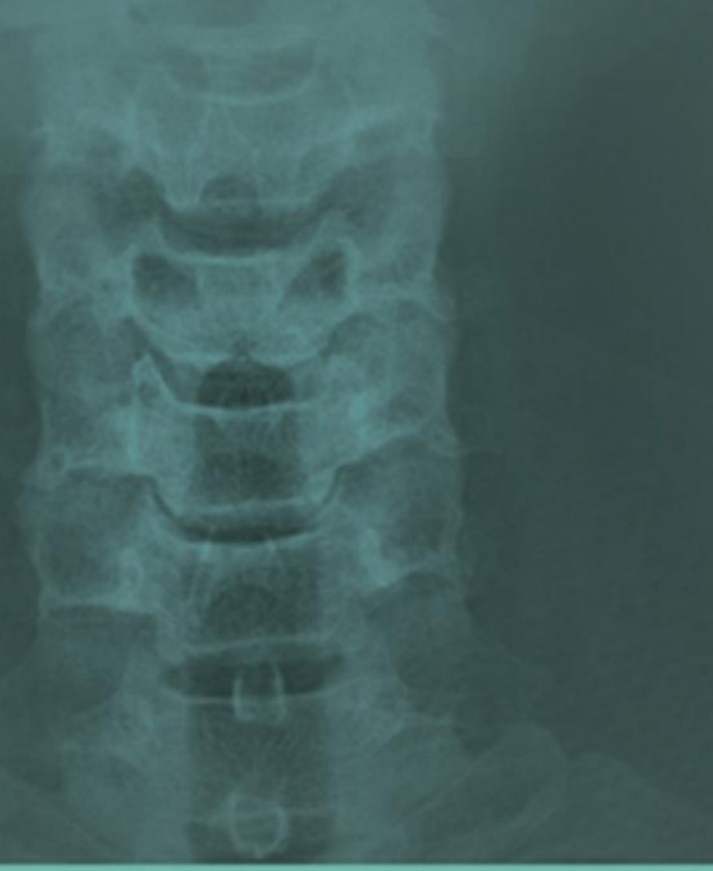
FIFTH EDITION

# Radiographic Image Analysis





Kathy McQuillen Martensen

Evolve®

Student Resources on Evolve
*Details Inside*

ELSEVIER

# Radiographic Image Analysis

This page intentionally left blank

FIFTH EDITION

# Radiographic Image Analysis

Kathy McQuillen Martensen, MA, RT(R)
Associate of Radiology
Roy J. and Lucille A. Carver College of Medicine
University of Iowa
Iowa City, Iowa

ELSEVIER

RADIOGRAPHIC IMAGE ANALYSIS, FIFTH EDITION ISBN: 978-0-323-52281-6



**International Standard Book Number: 978-0-323-52281-6**

*Executive Content Strategist:* Sonya Seigafuse
*Senior Content Development Manager:* Luke Held
*Content Development Specialist:* Kathleen Nahm
*Publishing Services Manager:* Julie Eddy
*Book Production Specialist:* Clay S. Broeker
*Design Direction:* Ryan Cook

Printed in the United States of America

Last digit is the print number: 9 8 7 6 5 4 3 2 1

ELSEVIER

3251 Riverport Lane
St. Louis, Missouri 63043

*My lasting appreciation to Marilyn Holland,*
*who believed in an idea*
*and jump-started this journey for me,*
*and to my friend Stephanie Harris,*
*who again gave her time*
*and talent to Radiographic Image Analysis.*

# REVIEWERS

**Stephanie Harris, BS, RT(R)(M)(CT)**
Diagnostic Imaging Manager
Mercy Medical Center
Cedar Rapids, Iowa

# PREFACE

This textbook serves as a practical image analysis and procedure reference for radiography educators, students, and technologists by providing information to correlate the technical and positioning procedures with the image analysis guidelines for common projections; adjust the procedural setup for patient condition variations, for nonroutine situations, and when a less-than-optimal projection is obtained; develop a high degree of radiography problem-solving ability; and prepare for the radiography ARRT examination.

## THIS EDITION

The organization of the procedures for this edition has continued with the changes introduced in the last edition to reduce repeatable information and provide efficient access to specific data. The new format includes additional quick, accessible tables that summarize important details and can be used for easy reference. This edition also includes many new and updated projections with improved resolution.

Chapters 1 and 2 lay the foundation for evaluating all projections, outlining the technical and digital imaging concepts that are to be considered when studying the procedures presented in the subsequent chapters.

Chapters 3 through 12 detail the image analysis guidelines for commonly performed radiographic procedures. For each procedure presented, this edition provides the following:

- Accurately positioned projections with labeled anatomy.
- Photographs of accurately positioned models.
- Tables that provide a detailed one-to-one correlation between the positioning procedures and the image analysis guidelines.
- Discussions, with correlating projections, on identifying how the patient, central ray, or image receptor was poorly positioned if the projection does not demonstrate an image analysis guideline.
- Discussions of topics relating to positioning for patient condition variations and nonroutine situations.
- Illustrations and photographs of bones and models, positioned to clarify information and demonstrate anatomy alignment when distortion makes it difficult.
- Practice projections that demonstrate common procedural errors.

# ACKNOWLEDGMENTS

I would like to thank the following individuals who have helped with this edition.

The University of Iowa Hospitals and Clinics' Radiologic Technology Classes of 1988 to 2019, who have been my best teachers because they have challenged me with their questions and insights.

Sonya Seigafuse, Luke Held, Kathleen Nahm, and the entire Elsevier team for their support, assistance, and expertise in planning and developing this project.

The professional colleagues, book reviewers, educators, and technologists who have evaluated the book, sent me compliments and suggestions, and questioned concepts in the previous editions.

**Kathy**

# CONTENTS

This page intentionally left blank

CHAPTER

# 1

# Guidelines for Image Analysis

## OUTLINE



## OBJECTIVES

*After completion of this chapter, you should be able to do the following:*

- State the characteristics of an optimal projection.
- Properly display projections of all body structures.
- State how the patient is associated with the projections and explain what to do if there is a misassociation.
- Discuss how to mark projections accurately and explain the procedure to be followed if a projection has been mismarked or the marker is only faintly seen.
- Discuss why good collimation practices are necessary and list the guidelines to follow to ensure good collimation.
- Describe how positioning of anatomic structures in reference to the central ray (CR) and image receptor (IR) affects how they are visualized on the resulting projection.
- State how similarly appearing structures can be identified on projections.
- Determine the amount of patient or CR adjustment required when poorly positioned projections are obtained.
- Discuss the factors that affect the spatial resolution in a projection.
- Describe the radiation protection practices that are followed to limit patient and personnel dose and discuss how to identify whether adequate shielding was used.

## KEY TERMS

**ALARA**
**annotation**
**anterior**
**backup timer**
**contrast mask**
**decubitus**
**detector element (DEL)**
**distortion**
**dose creep**
**dose equivalent limit**
**double exposure**
**elongation**
**exposure maintenance formula**
**field of view (FOV)**
**flexion**
**focal spot**
**foreshortening**
**geometric factors**
**grid**
**grid cutoff**
**image receptor (IR)**
**inverse square law**
**involuntary motion**
**lateral**
**magnification formula**
**matrix**
**medial**
**midcoronal plane**
**midsagittal plane**
**motion unsharpness**
**nonstochastic effects**
**object–image receptor distance (OID)**
**picture archival and communication system (PACS)**
**pixel**
**posterior**
**profile**
**project**
**radiolucent**
**radiopaque**
**recorded detail**
**scatter radiation**
**size distortion**
**source–image receptor distance (SID)**
**source-skin distance (SSD)**
**spatial frequency**
**spatial resolution**
**stochastic effects**
**values of interest (VOI)**
**voluntary motion**

## WHY IMAGE ANALYSIS?

Radiographic projections are such that slight differences in quality do not necessarily rule out their diagnostic value. Reviewers can ordinarily make satisfactory adjustments by reason of their experience and knowledge, although passing less than optimal projections may compromise the diagnosis and treatment and result in additional projections at a higher expense and radiation dose to the patient. The purpose of image analysis is to explore how to evaluate projections for acceptability, determine how to improve positioning and technical skills before repeating a projection, and continually improve skills.

Why does a technologist care about creating optimal projections and studying all the small details relating to image analysis? The most important answer to this question lies in why most technologists join the profession—to help people. From the patient's point of view, it provides the reviewer with projections that contain optimal diagnostic value, prevents the anxiety that occurs when additional projections or studies need to be performed, and prevents the radiation dosage that might be caused by additional imaging. From a societal point of view, it helps to prevent additional increases in health care costs that could result because of the need for additional, more expensive imaging procedures and because of the malpractice cases that might result from a poor or missed diagnosis. From a technologist's point of view, it would be the preventable financial burden and stress that arise from legal actions, a means of protecting professional interest as more diagnostic procedures are being replaced with other modalities, and the personal satisfaction gained when our patients, employer, and ourselves benefit from and are recognized for our expertise.

Consider how accuracy in positioning and technical factors affect the diagnostic value of a projection. Chest procedures are one of the most commonly performed projections each year. They are completed to evaluate the lungs, heart, and thoracic viscera, as well as disease processes such as pneumonia, heart failure, pleurisy, and lung cancer. The reviewer must consider all the normal variations that exist in areas such as the mediastinum, hila, diaphragm, and lungs. Should they also have to consider how the appearance of these structures is different with preventable positioning and technical errors? It takes only 2 or 3 degrees of rotation to affect the appearance of the lungs, causing differences in brightness values along the lateral borders of the chest projection (Fig. 1.1). Similarly, certain conditions such as mediastinal widening or cardiac size cannot be evaluated properly on a rotated posteroanterior (PA) chest projection. The normal heart shadow on such a projection will occupy slightly less than 50% of the transverse dimension of the thorax (Fig. 1.2). This is evaluated by measuring the largest transverse diameter of the heart on the PA or anteroposterior (AP) projection and relating that to the largest transverse measurement of the internal dimension of the chest. When the PA chest projection is rotated, bringing a different heart plane into profile, this diagnosis becomes compromised.

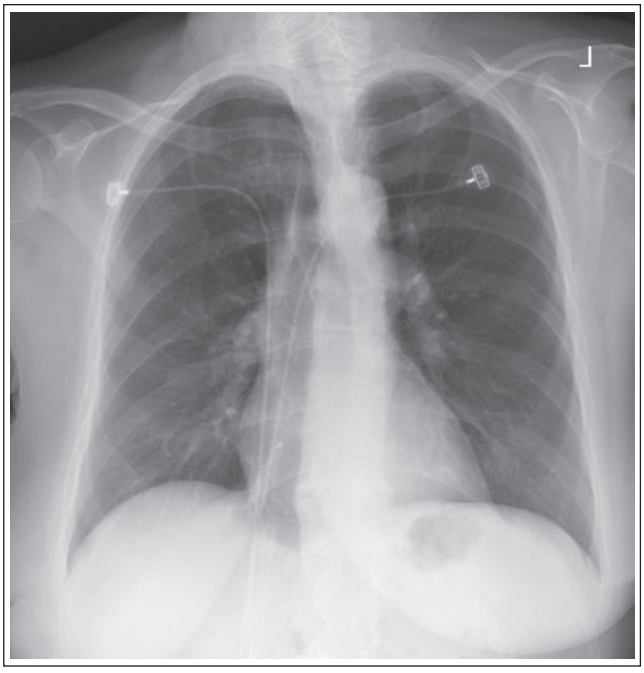


**FIGURE 1.1** Rotated PA chest projection.

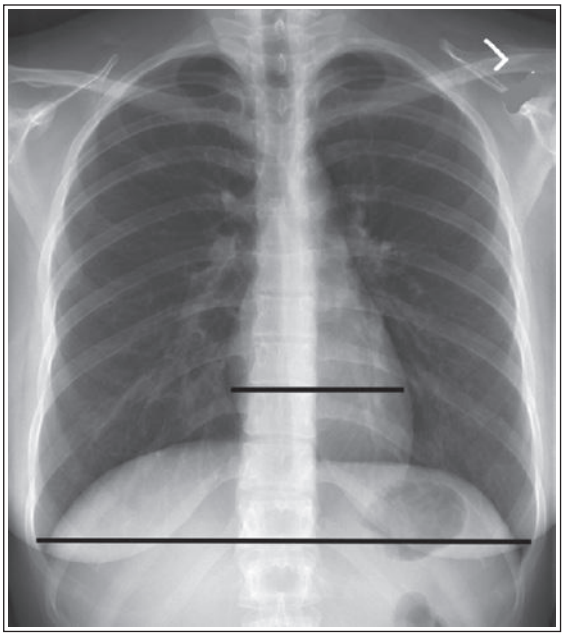


**FIGURE 1.2** Evaluating a PA chest projection for mediastinal widening.

If instead of being evaluated for acceptability, projections are evaluated for optimalism, could more consistent and improved diagnoses be made from diagnostic projections? Figs. 1.3 and 1.4 demonstrate three lateral and PA wrist projections, all of which were determined to be acceptable and sent to the reviewer for diagnosis. Note how the trapezium is visualized only on the first lateral wrist projection but is not demonstrated on the other

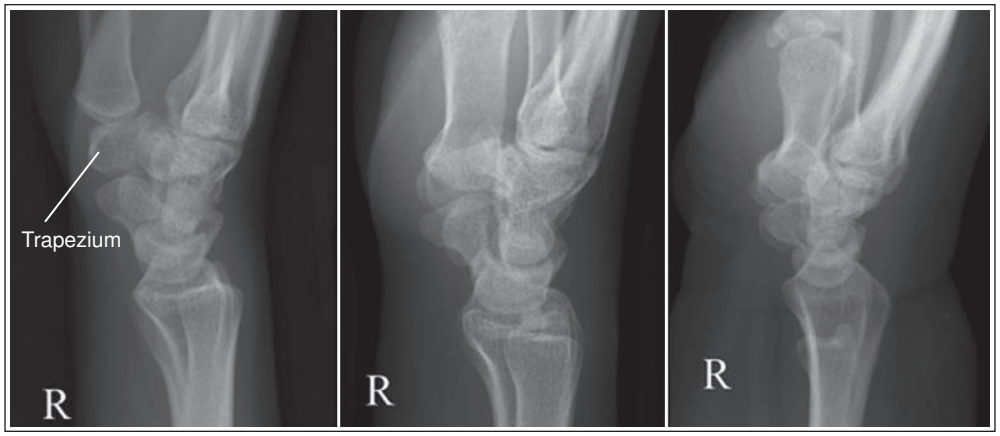



**FIGURE 1.3** Lateral wrist projections demonstrating the difference in trapezium visualization with thumb depression and elevation.

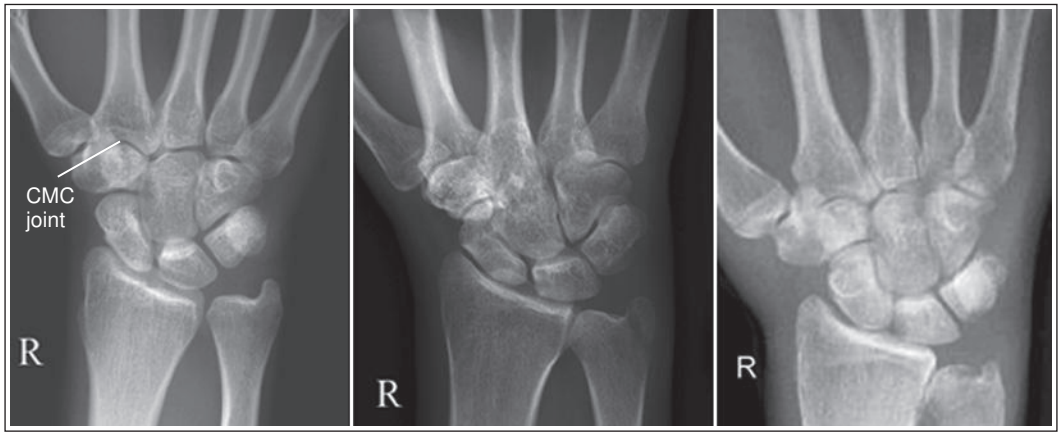



**FIGURE 1.4** PA wrist projections demonstrating the difference in carpometacarpal (CMC) joint visualization with variations in metacarpal alignment with the IR.

two, and observe how the carpometacarpal joints and distal carpal bones are well visualized on the first PA wrist projection but are not seen on the other two projections. The first lateral wrist projection was obtained with the thumb depressed until the first metacarpal (MC) was aligned with the second MC, whereas the other lateral wrist projections were obtained with the first MC elevated. The first PA wrist projection was obtained with the MCs aligned at a 10- to 15-degree angle with the IR, the second PA wrist projection was taken with the MCs aligned at an angle greater than 15 degrees, and the third projection was taken with the MCs aligned at an angle less than 10 degrees. If the radiologist cannot arrive at a conclusive diagnosis from the projections that the technologist provides, he or she must recommend other imaging procedures or follow-up projections.

## TERMINOLOGY

At the beginning of most chapters there is a list of key chapter terms. The glossary at the end of this text provides definitions of these terms.

## CHARACTERISTICS OF THE OPTIMAL PROJECTION

An optimal image of each projection demonstrates all of the most desired features, as described in Box 1.1.

Because of a patient's condition, equipment malfunction, or technologist error, such perfection is not obtained for every projection that is produced. A less than optimal projection is thoroughly evaluated to determine the reason for error so that the problem can be corrected before the examination is repeated. A projection that is not optimal but is still acceptable according to a facility's standards is carefully studied to determine whether skills can be improved before the next similar examination; continuous improvement is sought.

This text cannot begin to identify the variations in the standards of acceptability in all the different imaging facilities. What might be an acceptable standard in one facility may not be what is desired in another. As you study the projections in Chapters 3 to 12, you may find that many of them are accepted in your facility even though they do not meet the guidelines as written. You

**BOX 1.1 Characteristics of the Optimal Projection**

- Projection is accurately displayed
- Demographic information (e.g., patient and facility name, time, date) is visualized
- Correct marker(s) is in the appropriate position without superimposing the VOI
- Desired anatomic structures are in the exposure field and are in accurate alignment with each other
- There is maximum spatial resolution
- Radiation protection is present and was accurately used during the exposure
- Image histogram was accurately produced without errors
- Adequate exposure reached the IR based on ideal EI
- Contrast resolution identifies the subject contrast
- Noise is minimal (including scatter and preventable artifacts)

*EI*, Exposure index; *IR*, image receptor; *VOI*, values of interest.

may also find that a guideline that is listed is not desired in your facility. The goal of this text is not to dictate what an acceptable or unacceptable projection is, because that is determined by the needs of the reviewer. The most common radiography positioning and exposure practices were used when deciding the positioning and image analysis guidelines that are listed in the tables for each projection.

## IMAGE ANALYSIS PROCESS

After a projection is correctly displayed, it is evaluated for positioning and technical accuracy. Table 1.1 provides a systematic approach that is designed to be used when evaluating projections to ensure that all aspects of the projection are analyzed. Under each item in Table 1.1 there is a list of questions to explore while evaluating

**TABLE 1.1 Image Analysis Process**

| Topics to Analyze | Questions to Consider When Analyzing Projections |
|---|---|
| Demographic requirements are visualized on the projection | • Was the x-ray order associated with the correct patient?<br>• Are the patient's name and age or birthdate, and patient identification number visible, and are they accurate?<br>• Are the examination time and date visible? |
| Projection is accurately displayed on the workstation monitor (Table 1.2) | • Was the correct procedure algorithm selected on the workstation prior to starting the exam?<br>• Is the correct aspect of the structure positioned at the top and the right and left sides of the displayed projection?<br>• Is the marker face-up or reversed, as expected?<br>• If projection was flipped or rotated to improve display, does marker still indicate correct side as displayed? |
| Correct marker (e.g., R/L, arrow) is visualized on projection and demonstrates accurate placement (Table 1.3) | • Is the marker visualized within the exposure field, and is it positioned as far away from the center of field as possible?<br>• Have specialty markers been added and correctly placed if applicable?<br>• Is the marker clearly seen without distortion, and is it positioned so it does not superimpose the VOI?<br>• Does the R or L marker correspond to the correct side of the patient?<br>• If more than one projection is on IR, have they both been marked if they are different sides of the patient?<br>• Are annotated markings correct? |
| Appropriate collimation practices are evident (Table 1.4) | • Are all of the required anatomic structures visible?<br>• Does the VOI fill the workstation screen?<br>• Was the long axis of the part aligned with the long axis of the IR?<br>• Was the CR centered to the center of the VOI?<br>• Is only the required VOI and 0.5–1 inches (1.25–2.5 cm) of the surrounding anatomy demonstrated on the projection?<br>• Is the collimated border present on all four sides of the projection when applicable?<br>• Is collimation within 0.5 inch (1.25 cm) of the skin line when applicable?<br>• Is collimation to the specific anatomy desired on projections requiring collimation within the skin line?<br>• Does the contrast mask align with the edges of the exposure field? |
| Relationships between the anatomic structures are accurate for the projection demonstrated (Tables 1.5–1.7) | • Are the relationships between the anatomic structures demonstrated as indicated in the procedural analysis sections of this textbook or defined by your imaging facility?<br>• Is the anatomic VOI in the center of the projection, or was the CR centered in the VOI?<br>• Does the projection demonstrate the least possible amount of size distortion?<br>• Does the projection demonstrate undesirable shape distortion?<br>• Are the joints of interest and/or fracture lines seen as open spaces? |
| Projection demonstrates maximum spatial resolution (Table 1.8) | • Was a small focal spot used when indicated?<br>• Was the appropriate SID used?<br>• Was the part positioned with the least amount of OID possible?<br>• Does the projection demonstrate signs of undesirable patient motion or unhalted respiration?<br>• Computed radiography: Was the smallest possible IR cassette used?<br>• Computed radiography: Are there signs of a double exposure? |

**TABLE 1.1 Image Analysis Process—cont'd**

| Topics to Analyze | Questions to Consider When Analyzing Projections |
|---|---|
| Radiation protection is present on projection when indicated, and good radiation protection practices are used during the procedure (Table 1.9) | • Was the exam explained to the patient, and were clear, concise instructions given during the procedure?<br>• Were immobilization devices used to prevent patient motion when needed?<br>• Was the minimal SSD of at least 12 inches (30 cm) maintained for mobile radiography?<br>• Was the possibility of pregnancy determined of all females of childbearing age?<br>• Is gonadal shielding evident and accurately positioned when the gonads are within the primary beam and shielding will not cover the VOI?<br>• Were radiation protection measures used for patients whose radiosensitive cells were positioned within 2 inches (5 cm) of the primary beam?<br>• Was the field size tightly collimated?<br>• Were exposure factors (kV, mA, and time) set to minimize patient exposure?<br>• If the AEC was used, was the backup time set to prevent overexposure to the patient?<br>• Are there anatomic artifacts demonstrated on the projection?<br>• Were personnel or family who remained in the room during the exposure given protective attire, positioned as far from the radiation source as possible, and present only when absolutely necessary and for the shortest possible time? |
| Image histogram was accurately produced (see Tables 2.1 and 2.4) | • Is the exposure indicator within the acceptable parameters for the system?<br>• Was the correct body part and projection chosen from the workstation menu?<br>• Was the CR centered to the VOI?<br>• Was collimation as close to the VOI as possible, leaving minimal background in the exposure field?<br>• Was scatter controlled with lead sheets, grids, tight collimation, etc.?<br>• If collimated smaller than the IR, is the VOI in the center of the projection and are all four collimation borders seen?<br>• Computed radiography: Was at least 30% of the IR covered?<br>• Computed radiography: If multiple projections are on one IR, is collimation parallel and equidistant from the edges of the IR and are they separated by at least 1 inch (2.5 cm)?<br>• Computed radiography: Was the IR left in the imaging room while other exposures were made and was the IR read shortly after the exposure?<br>• Computed radiography: Was the IR erased if not used within a few days? |
| Adequate exposure reached the IR (see Tables 2.5–2.9) | • Were the technical factors of mAs and kV set appropriately for the projection?<br>• Is the required subject contrast in the VOI fully demonstrated?<br>• Is the EI number obtained at the ideal level or within the acceptable parameters for the digital system?<br>• Is the brightness level adequate to demonstrate the VOI?<br>• Does the projection demonstrate quantum noise?<br>• Does any VOI structure demonstrate saturation?<br>• Is there a decrease in contrast and detail visibility caused by scatter radiation fogging?<br>• Was a grid used if recommended, and if so, was the appropriate grid ratio and technique used for the grid?<br>• Are there grid line artifacts demonstrated?<br>• Was the correct SID used for the exposure set?<br>• Was the OID kept to a minimum, and if not, were the exposure factors adjusted for the reduction in scatter radiation when applicable?<br>• If collimation was significantly reduced, were the technical factors adjusted for the reduction in scatter radiation when applicable?<br>• If a 17-inch field size was used, was the thinnest end of a long bone or vertebral column positioned at the anode end of the tube?<br>• Was exposure adjusted for additive and destructive patient conditions?<br>• If the AEC was used, was the mA station set to prevent exposure times less than the minimum response time?<br>• If the AEC was used, was the backup time set at 150%–200% of the expected manual exposure time for the exam?<br>• If the AEC was used, was the activated ionization chamber(s) completely covered by the VOI?<br>• If the AEC was used, is there any radiopaque hardware or prosthetic devices positioned in the activated chamber(s)?<br>• If the AEC was used, was the exposure (density) control on zero? |
| Contrast resolution is optimal for demonstrating the VOI | • If projection is less than optimal but acceptable, does windowing allow the VOI to be fully demonstrated?<br>• If projection is less than optimal but acceptable, does an alternate procedural algorithm improve contrast resolution enough to make the projection acceptable? |

*Continued*

**TABLE 1.1 Image Analysis Process—cont'd**

| Topics to Analyze | Questions to Consider When Analyzing Projections |
|---|---|
| No preventable artifacts are present on the projection (see Table 2.10) | • Are any artifacts visible on the projection?<br>• Can the artifact be removed?<br>• What is the location of any present artifact with respect to a palpable anatomic structure?<br>• Have you asked the patient about the nonremovable artifact's origin (surgical implant, foreign body)?<br>• Does the projection have to be repeated because of the artifact?<br>• Can the artifact be removed?<br>• Have you asked the patient about any nonremovable artifact's origin? |
| Ordered procedure and the indication for the exam have been fulfilled | • Has the routine series for the body structure ordered been completed as determined by your facility?<br>• Do the projections in the routine series fulfilled the indication for the examination, or must additional projections be obtained?<br>• Projection is:<br>_____ optimal<br>_____ acceptable, but not optimal<br>_____ unacceptable<br>If projection is acceptable but not optimal, or is unacceptable, describe what measures should be taken to produce an optimal projection. |

*AEC*, Automatic exposure control; *CR*, central ray; *EI*, exposure index; *IR*, image receptor; *L*, left; *OID*, object–image receptor distance; *SID*, source–image receptor distance; *R*, right; *SSD*, source-skin distance; *VOI*, values of interest.

a projection. The discussions in Chapters 1 and 2 will explore these question areas. The answers to all the questions, taken together, will determine whether the projection is optimal, is acceptable, or needs repeating based on professional or departmental standards.

## 1. Demographic Requirements Are Visualized on the Projection

Projections are evaluated to be certain that the correct patient has been associated with the projections obtained on that patient before they are sent to a picture archival and communication system (PACS). This is accomplished with computed radiography when the cassette's barcode label is scanned and associated with the patient's identification barcode and examination request and with DR when the patient and examination order is pulled up on the workstation before the examination is obtained. It is when the projection being obtained is selected from the workstation that the algorithms used to display and rescale the projection are also selected.

Once a projection is sent to the PACS, it is immediately available to whoever has access, and it will make it difficult to retrieve. If the projection is allocated with the wrong patient, the projection may be seen or evaluated by a physician before the misassociation is noticed.

If incorrect patient information is assigned to a projection, the technologist can reassociate the examination to the correct patient as long as the projection has not been sent to the PACS. If the projections are sent to the PACS with the incorrect patient assigned to the examination, the PACS coordinator must be immediately notified to correct the error before the projections are viewed.

## 2. Projection Is Accurately Displayed on the Workstation Screen

Digital images are displayed on the workstation screen in the manner that they were obtained or after a preprocessing algorithm has been applied that changes how the projection is to be displayed to meet the facilities' desires (e.g., a left lateral chest projection may be transversely flipped to be displayed as a right lateral).

How the patient is oriented on the IR during the procedure determines if a projection will be displayed accurately on the workstation or if it will require postprocessing manipulation. Each digital system's IR has a "top" and "right" or "left" side orientation. These orientation indicators align the image orientation with the computer algorithm of a patient in the anatomic position (AP projection). As long as the top indicator is placed under the portion of the anatomy that is to be up when the projection is displayed, the projection will be displayed with the correct anatomy at the top. On AP projections where the right and left sides of the patient are included (torso, skull, etc.), the patient's right side is aligned with the right orientation indicator on the IR to accurately display the patient's left side on the viewer's right side. For PA projections, where the patient's left side will be oriented with the right side of the IR during the procedure, the associated algorithm will request that the computer transversely flip the projection obtained before it is displayed. Table 1.2 lists display guidelines to explore when analyzing the display acceptability.

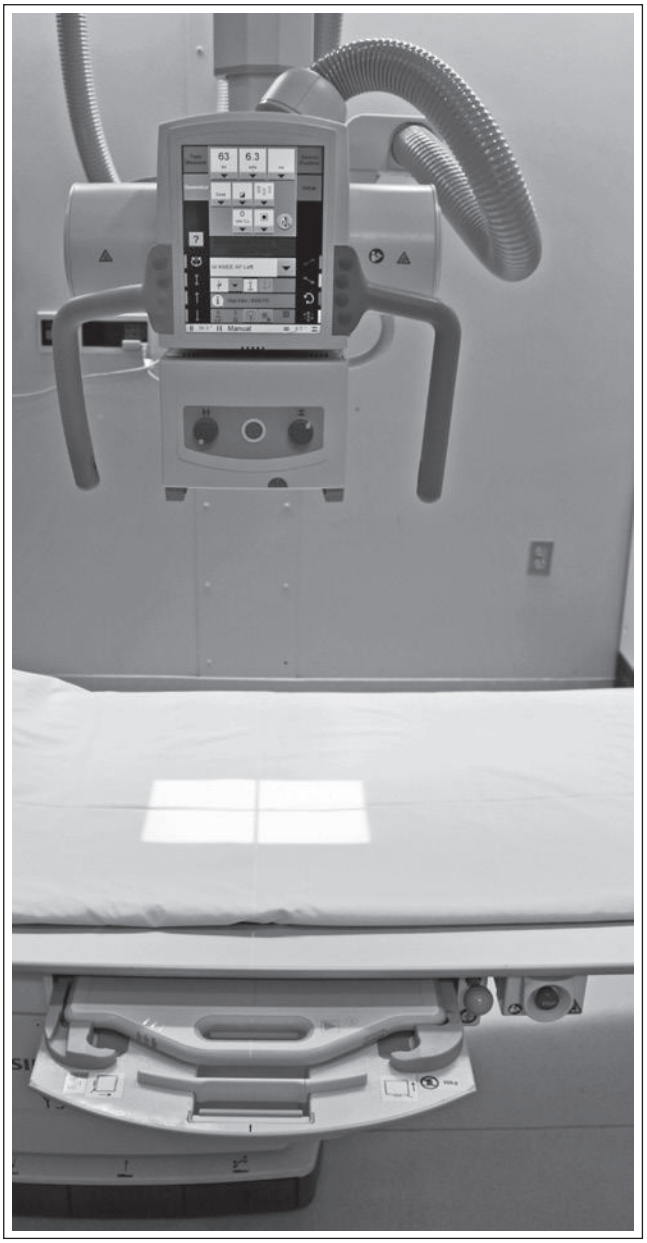


**FIGURE 1.5** Orientation of patient with IR for proper display.

The quality of a projection may appear different depending on where it is displayed in the facility. Display station resolution refers to the maximum number of pixels that the screen can demonstrate. To display projections at full resolution, the display screen must be able to display the same number of pixels as those at which the digital system acquired the projection. If the digital system's matrix size is smaller than the display station's matrix size, the values of surrounding pixels are rounded up or down as needed to display the whole projection. The technologist's workstation display screens typically do not demonstrate resolution as high as that of the radiologist's display screens.

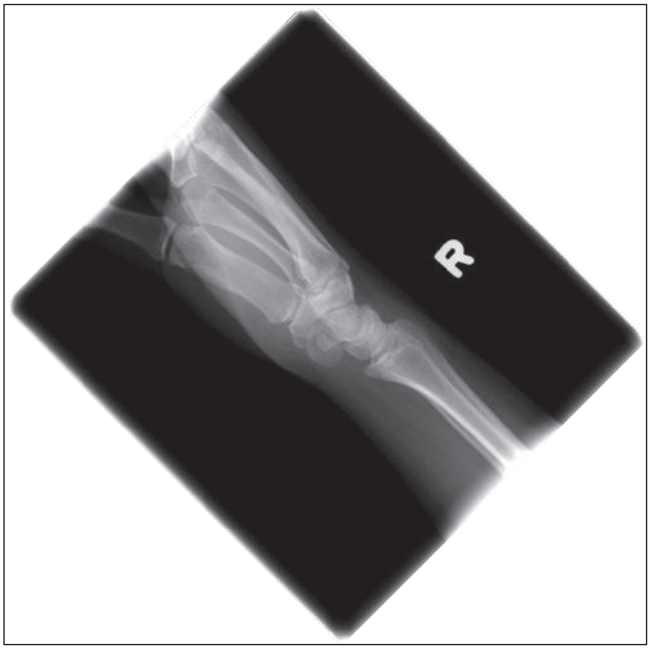



**FIGURE 1.6** Diagonally displayed right lateral wrist projection. When possible, avoid positioning extremities diagonally on the IR if the projection cannot be rotated to be in degree increments on the workstation display or if when rotated, the projection does not adjust to fill the display monitor. Aligning the long axis of extremities with the longitudinal or transverse axis of the IR will prevent both issues.

**TABLE 1.2 Projection Displaying Guidelines**

| | |
|---|---|
| Patient and IR orientation | • Choose the correct procedural algorithm (projection) on the workstation prior to the exam so the correct algorithm is used to display the projection after the exposure.<br>• Orient the aspect of the projection that should be on the top when the projection is displayed to the "top" on the IR when obtaining projection (Fig. 1.5).<br>• Avoid placing extremities diagonally on IR when possible (Fig. 1.6). |
| AP, PA, and AP/PA oblique projections of chest, abdomen, shoulder, nip, vertebrae, and cranium | • Display as if the patient were standing in an upright position, with the viewer and the patient facing one another. The right side of the patient on the projection is on the viewer's left side.<br>• AP or AP oblique: R or L marker appears correct when the projection is accurately displayed if it was placed on the IR face-up (Fig. 1.7).<br>• PA or PA oblique: R or L marker appears reversed if it was placed on the IR face-up (Fig. 1.8). |
| Lateral projections | • Display in the same manner as the technologist viewed the patient when obtaining the projection.<br>• Right lateral: Patient faces the viewer's left side. Marker is correct if it was placed on the IR face-up.<br>• Left lateral: Patient faces the viewer's right side. Marker is correct if it was placed on the IR face-up (Fig. 1.9). |

*Continued*

**TABLE 1.2 Projection Displaying Guidelines—cont'd**

| | |
|---|---|
| AP/PA (lateral decubitus) projections of chest and abdomen | • Display as if the viewer and patient are facing one another, with the side of the patient that was positioned upward when the projection was taken placed upward on the displayed projection (Fig. 1.10).<br>• AP: R or L marker is correct.<br>• PA: R or L marker is reversed. |
| Inferosuperior (axial) shoulder and axiolateral hip projections | • Display so the anterior surface is up and the posterior surface is down (Fig. 1.11).<br>• Marker is placed anteriorly. |
| Extremity projections | • Display as if the viewer's eyes were going through the projection in the same manner the CR went through the extremity when the projection was taken. A right PA hand projection is displayed with the thumb positioned toward the viewer's left side and a right lateral hand projection is displayed so the palmar side of the hand is positioned toward the viewer's left side (Fig. 1.12).<br>• Finger, wrist, and forearm: Display as if the patient were hanging from the fingertips.<br>• Elbow and humerus: Display as if they were hanging from the shoulder.<br>• Toes(s) and AP and AP oblique foot: Display as if they were hanging from the toes.<br>• Lateral foot, ankle, lower leg, knee, and femur: Display as if they were hanging from the hip |
| Adjusting for poor display | • Digital projections that have been displayed inaccurately can be flipped horizontally and vertically and rotated before being saved to the PACS (Fig. 1.13). |

*AP,* Anteroposterior; *CR,* central ray; *IR,* image receptor; *L,* left; *PA,* posteroanterior; *PACS,* picture archival and communication system; *R,* right.

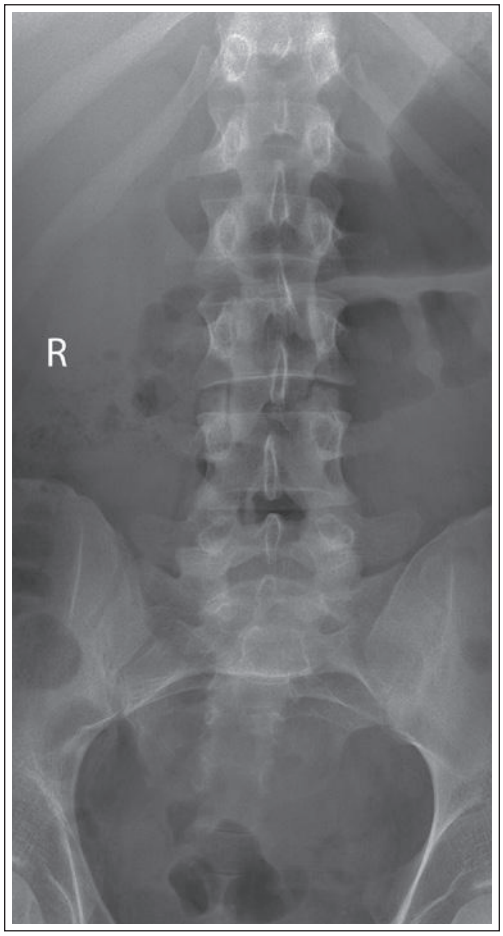



**FIGURE 1.7** Accurately displayed and marked AP lumbar vertebrae projection.

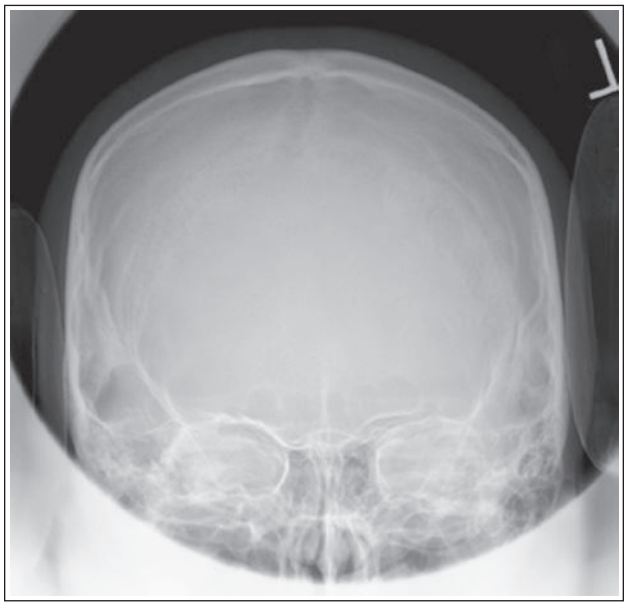


**FIGURE 1.8** Accurately displayed PA cranium projection.

## 3. Correct Marker Is Visualized on Projection and Demonstrates Accurate Placement

Lead markers are used to identify the patient's right and left sides, indicate variations in the standard procedure, or show the amount of time that has elapsed in timed procedures, such as small bowel studies. The markers are constructed of lead so they are radiopaque. Each projection must include a correctly placed marker. Table 1.3 lists guidelines to follow when marking and evaluating marker accuracy on projections.

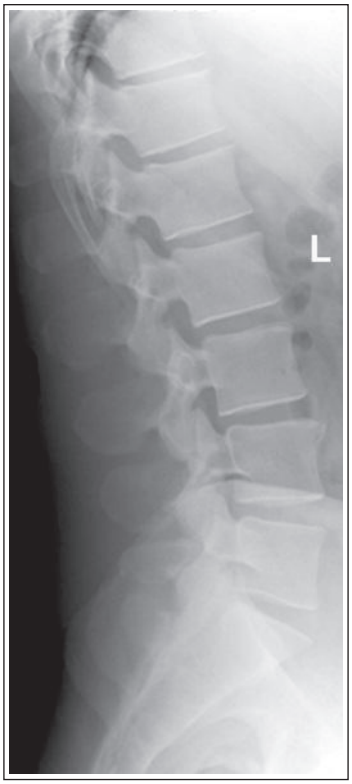



**FIGURE 1.9** Accurately displayed left lateral lumbar vertebrae projection.

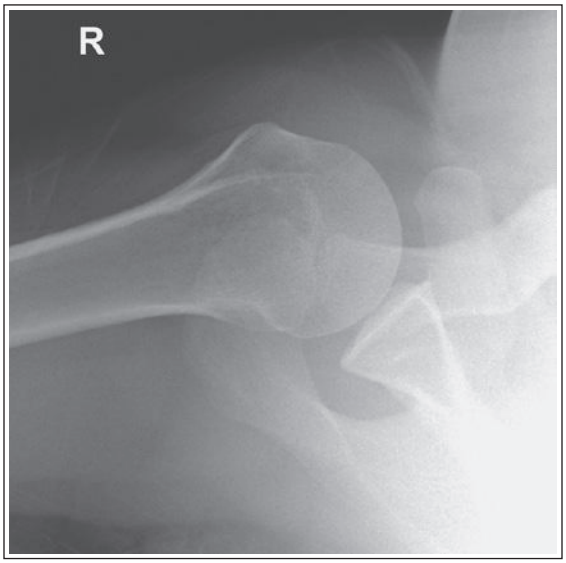



**FIGURE 1.11** Accurately displayed and marked inferosuperior (axial) shoulder projection.

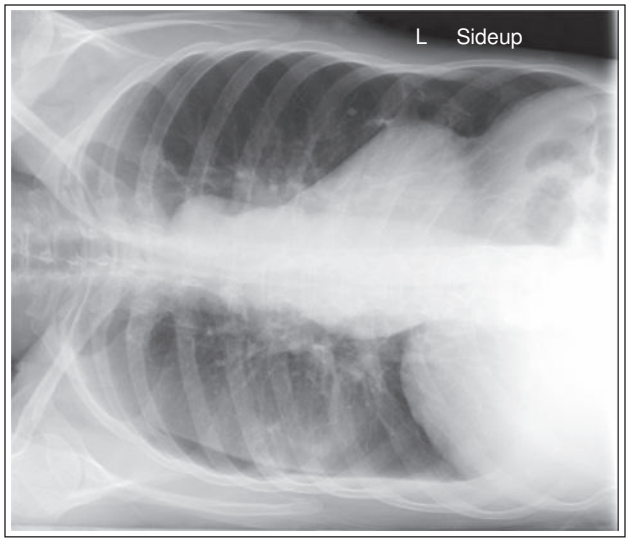



**FIGURE 1.10** Accurately displayed and marked AP (right lateral decubitus) chest projection.

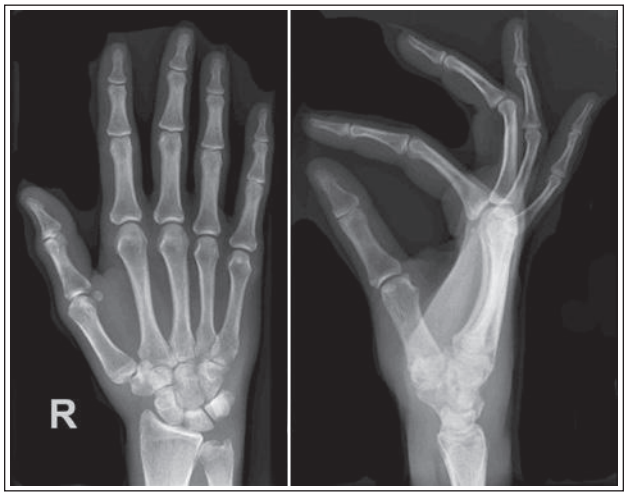



**FIGURE 1.12** Accurately displayed right PA and lateral hand projections.

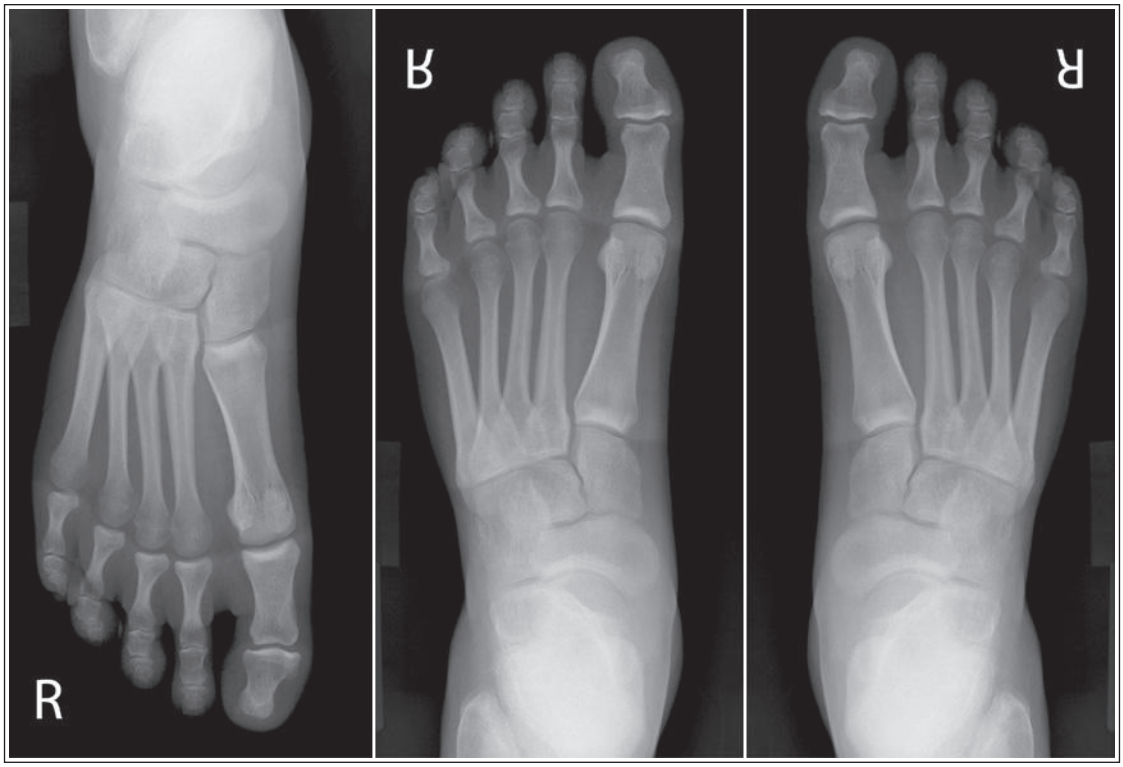



**FIGURE 1.13** An AP foot projection that has been displayed upside down, vertically flipped for poor display, and rotated for accurate display. The first AP foot projection was obtained using DR and with the patient seated on the imaging table with the toes pointing toward the foot end of the table. A face-up R marker was placed in the exposure field. Because the patient was not oriented on the IR to have the toes at the top when displayed, the projection was displayed upside down on the workstation monitor. If the projection was vertically flipped to accurately display it, the marker will be reversed and the foot displayed as if it were a left foot instead of a right, as demonstrated in the second foot projection. If the first foot projection was rotated instead of being flipped, the marker will remain face-up and the foot will be displayed accurately, as demonstrated on the third foot projection.

**TABLE 1.3 Marker Placement**

| | |
|---|---|
| General guidelines | • Position marker within the exposure field as far away from the center of the field as possible.<br>• Avoid placing marker in an area that will cover up the VOI (Fig. 1.14) or be hidden by a shield. If tape is used to secure the marker in place, it should also not cover up the VOI, because it may be seen as an artifact.<br>• Place marker directly on the IR or imaging tabletop whenever possible in a face-up position. This placement avoids marker distortion and magnification, prevents scatter radiation from undercutting the marker, and ensures that the marker will not be projected off the IR (Fig. 1.15).<br>• Do not place the marker directly on the skin.<br>• Replace the tape on markers regularly to prevent transmission of bacteria from patient to patient. |
| AP/PA projections of torso, vertebrae, and cranium | • Place the R or L marker laterally on the side being marked.<br>• Vertebral column is the dividing plane for the right and left sides. If marking the right side, position the R marker to the right of the vertebral column; if marking the left side, position the L marker to the left of the vertebral column (Fig. 1.7). |
| Lateral projections of torso, vertebrae, and cranium | • Marker indicates the side of the patient positioned closer to the IR. If the left side is positioned closer to the IR, place an L marker on the IR (Fig. 1.16).<br>• Whether the marker is placed anteriorly or posteriorly to the torso or vertebrae does not affect the accuracy of the marking, although the projections of markers placed posteriorly are often obscured by scatter (Fig. 1.17). |
| AP/PA oblique projections of torso, vertebrae, and cranium | • Marker identifies the side of the patient positioned closer to the IR and is placed on the correct side of the patient (Fig. 1.18).<br>• Vertebral column is the plane used to divide the right and left sides of the body. |

*Continued*

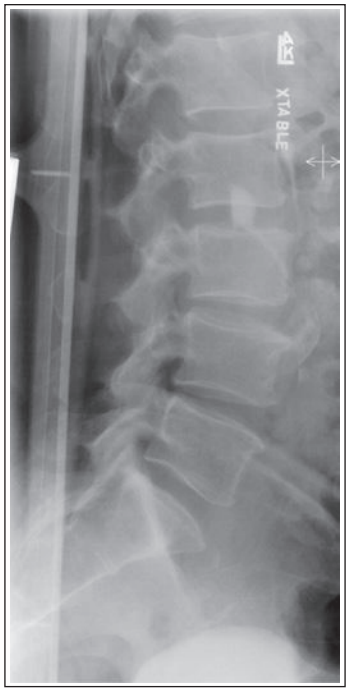



**FIGURE 1.14** Left lateral lumbar vertebrae projection with marker superimposing VOI.


**FIGURE 1.15** Markers that have been magnified, distorted, and undercut with scatter radiation.

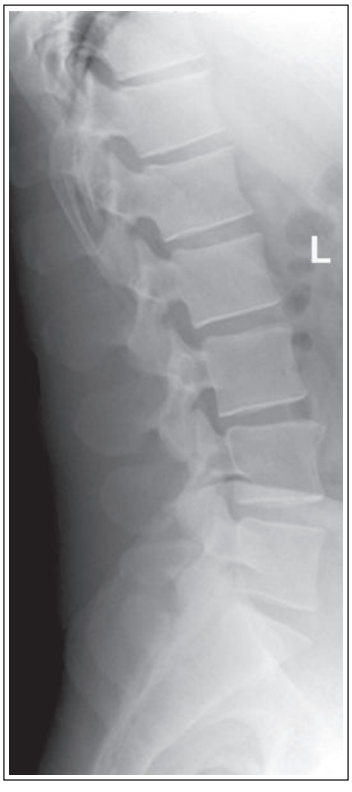



**FIGURE 1.16** Marker placement for lateral lumbar vertebrae projection.

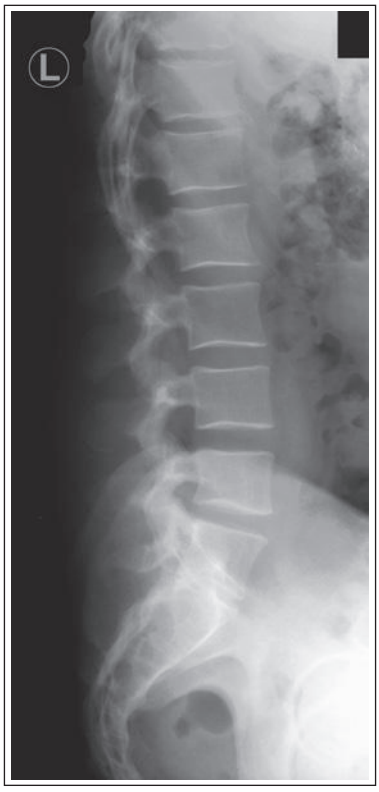



**FIGURE 1.17** Markers placed posteriorly on lateral torso or vertebrae projections often have to be annotated because they are obscured by scatter.

**TABLE 1.3 Marker Placement—cont'd**

| | |
|---|---|
| AP/PA (lateral decubitus) projections of torso | • Place the R or L marker laterally on the side being marked. The vertebral column is the dividing plane for the right and left sides.<br>• Marker is less likely to obscure the VOI if the side of the patient that is positioned up, away from the cart or imaging table on which the patient is lying is the side marked.<br>• Place an arrow marker pointing up toward the ceiling or lead lettering to indicate which side of the patient is positioned away from the cart or imaging table (Fig. 1.10). |
| Extremity projections | • Mark the right or left side of the patient being imaged.<br>• When multiple projections of the same anatomic structure are placed on the same IR, mark only one of the projections (Fig. 1.19).<br>• If projections of a right and a left anatomic structure are placed on the same IR, mark both projections with the correct R or L marker (Fig. 1.20). |
| AP and AP oblique projections of shoulder and hip | • Marker used indicates the side of the patient being imaged (Fig. 1.21).<br>• Place marker laterally to prevent it from obscuring medial anatomic structures and to eliminate possible confusion about which side is being imaged (Fig. 1.22) |
| Cross-table lateral projections | • Marker used indicates the right or left side of the patient when the extremities, shoulder, or hip is imaged (Fig. 1.11) and the side of the patient positioned closer to the IR when the torso, vertebrae, or cranium is imaged (Fig. 1.9).<br>• Place the marker anteriorly to prevent superimposition of structures that are at the posterior edge of the IR. |
| Postexam annotation | • Facilities may allow postexam annotation when a marker is missing or only partially visualized on the resulting projection. Position any annotated markings as described above.<br>• If marker is only partially demonstrated, place the annotated marker next to the partial one without covering it up (Fig. 1.23). |

*AP*, Anteroposterior; *IR*, image receptor; *L*, left; *PA*, posteroanterior; *R*, right; *VOI*, values of interest.

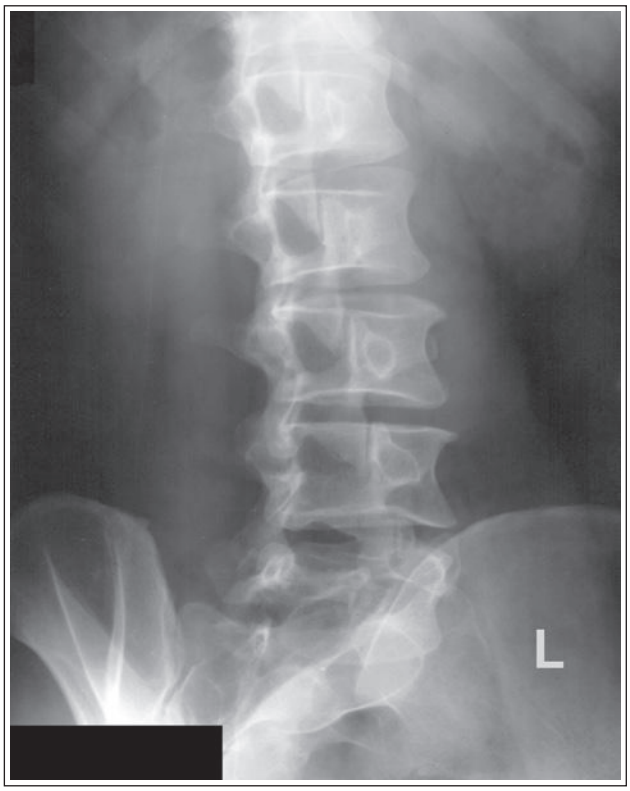



**FIGURE 1.18** Marker placement for AP oblique lumbar vertebrae projection.

## 4. Appropriate Collimation Practices Are Evident

Good collimation practices:

- Clearly delineate the values of interest (VOI).
- Decrease radiation dosage by limiting the amount of patient tissue exposed.
- Improve the visibility of recorded details by reducing the amount of scatter radiation that is produced.
- Reduce histogram analysis errors.

Each projection requires that the CR be centered to a particular location and that it is collimated to a particular VOI. For example, all wrist projections require that one-fourth of the distal forearm be included because radiating wrist pain may be a result of a distal forearm fracture, and a lateral ankle projection includes 1 inch (2.5 cm) of the fifth metatarsal base to rule out a Jones fracture. For each projection presented in Chapters 3 to 12 there are guidelines on what makes up the VOI on the projection and a description of how to collimate to include the VOI (Table 1.4).

## 5. Relationships Between the Anatomic Structures Are Accurate for the Projection Demonstrated

Each projection is to demonstrate specific bony relationships that will best facilitate diagnosis as defined in the

*Text continued on p. 18*

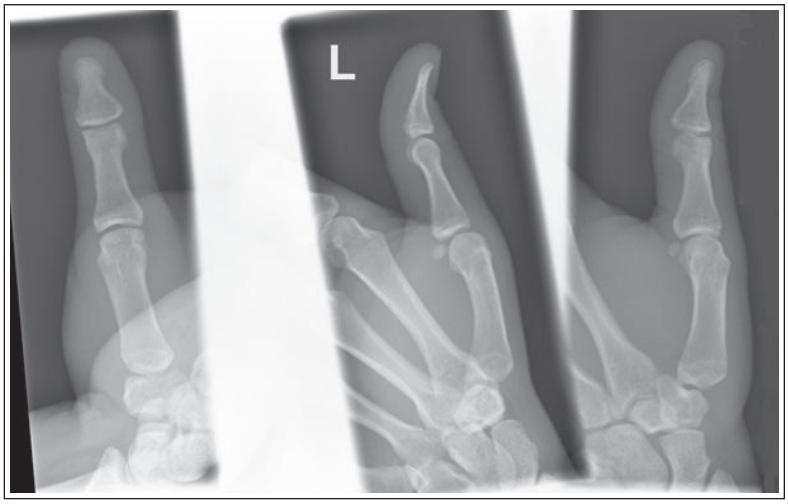



**FIGURE 1.19** Marker placement for unilateral finger projections on one IR.

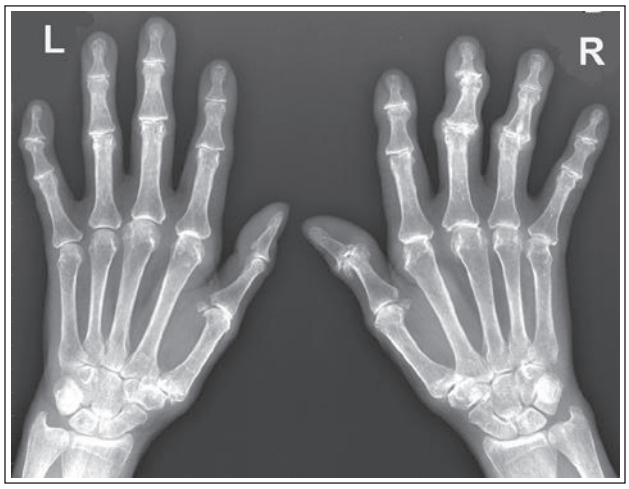



**FIGURE 1.20** Marker placement for bilateral PA hand projections.

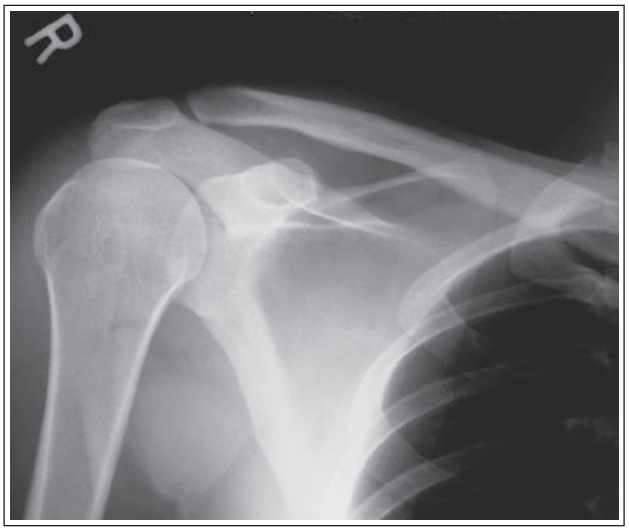



**FIGURE 1.21** Marker placement for an AP projection of shoulder.

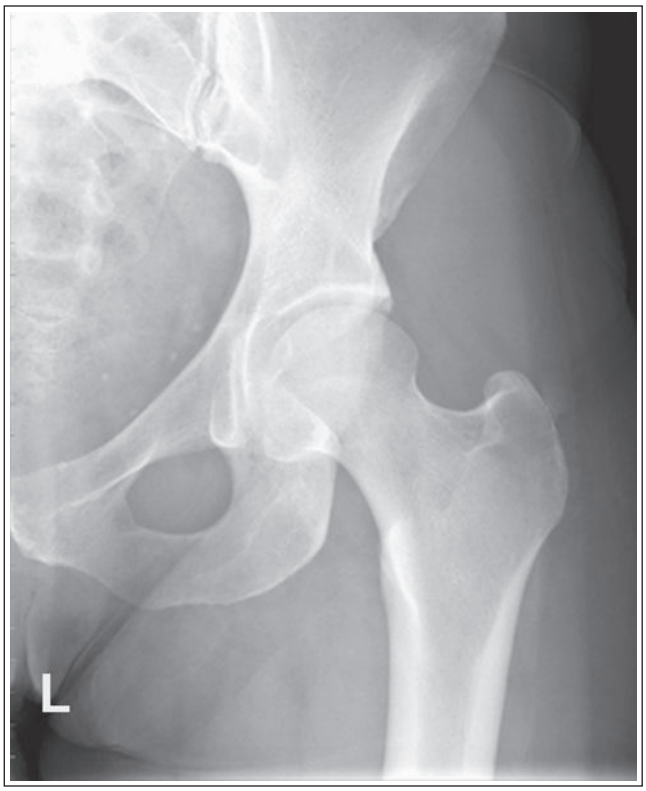



**FIGURE 1.22** Poor marker placement on an AP projection of hip.

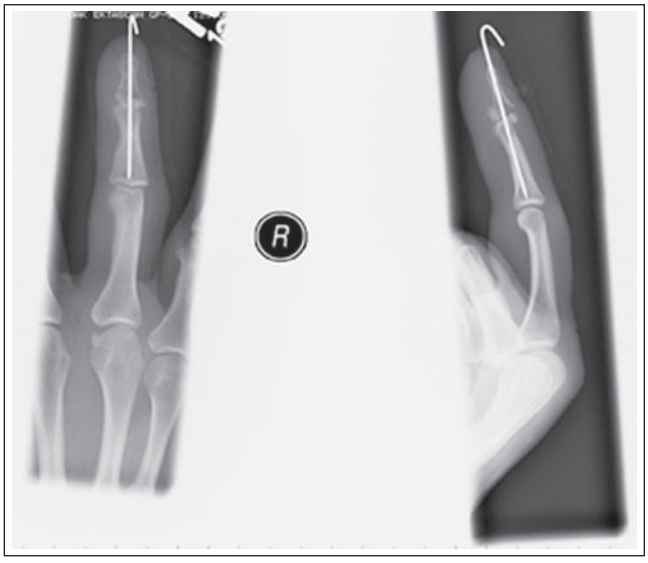



**FIGURE 1.23** Partially visible marker and annotation.

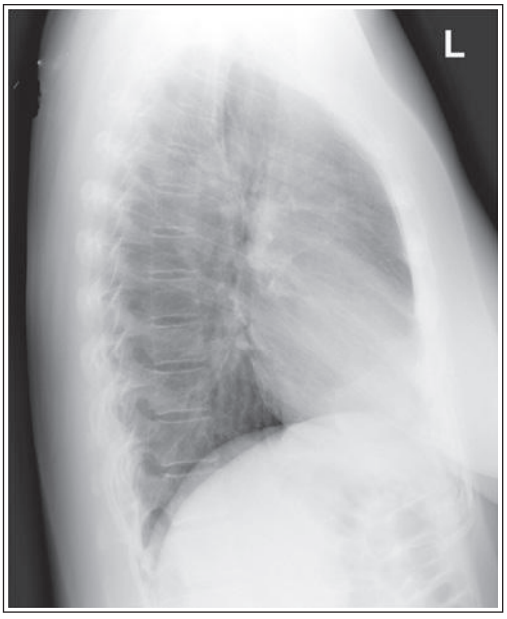



**FIGURE 1.25** Proper "to skin line" collimation on a lateral chest projection.

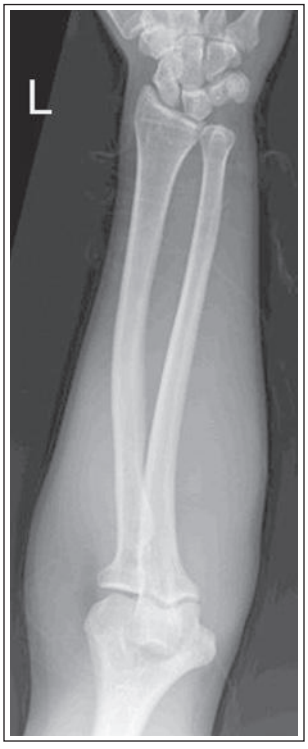



**FIGURE 1.24** Proper "to skin line" collimation on an AP forearm projection.

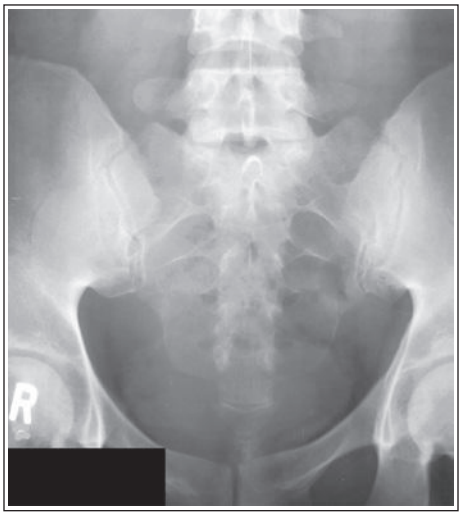



**FIGURE 1.26** Proper collimation on an AP sacral projection

**TABLE 1.4 Collimation Best Practices**

| | |
|---|---|
| General guidelines | • To allow for even collimation on all sides, obtain the tightest collimation and provide the best positioning for good exposure field recognition, align the long axis of the part to the long axis of the IR, center the CR to the center of the VOI, and narrow the radiation beam on all sides to include only the required VOI and 0.5–1 inch (1.25–2.5 cm) of the surrounding anatomy (Figs. 1.24–1.26).<br>• When the structure being imaged is smaller than the IR, collimation is brought to within 0.5 inch (1.25 cm) of the closest skin line.<br>• VOI fills the display screen demonstrating tight collimation (Fig. 1.27)<br>• Each projection should demonstrate a small collimated border around the entire VOI, unless the entire IR is covered. |

**TABLE 1.4 Collimation Best Practices—cont'd**

| | |
|---|---|
| Rotating the collimator | • Rotate the collimator to align it with anatomic structures that are not aligned with the longitudinal or transverse axis of the IR (Fig. 1.28).<br>• Collimator rotation does not affect the alignment of the beam with the grid because this alignment is affected only when the tube column is rotated and is demonstrated on the projection by visualization of grid line artifacts and grid cutoff. |
| Overcollimation | • Results in the clipping of required anatomy on the projection (Fig. 1.29).<br>• To prevent clipping of extremity structures that are positioned at a greater OID, view the shadow of the magnified structure that is projected onto the IR by the collimator light and allow the collimated field to remain open enough to include the shadow (Fig. 1.30). |
| Using the collimation borders to determine CR placement | • Collimated borders on a projection can be used to determine the exact location of CR placement by making an imaginary X on the projection by diagonally connecting the corners of the collimated border (Fig. 1.31). The center of the X indicates the CR placement for the projection. |
| Long bones | • When imaging long bones that require both joints to be included on the projection, choose a large enough IR and open the collimation field so it extends 1–2 inches (2.5–5 cm) beyond each joint space. This prevents the off-centered joints from being projected off the IR when they are projected in the direction of the diverged x-ray beams that are used to record them (Fig. 1.32).<br>• Place long bones diagonally on IR only when both joints are required and can only fit on IR when placed diagonally (Fig. 1.33). |
| Collimator guide | • The collimation guide can be used to determine the actual IR coverage (Fig. 1.34). |
| Collimator light field on patient versus actual coverage on IR | • When the collimator's CR indicator is positioned on the torso and the collimator is set to a predetermined width and length, the light field demonstrated on the torso does not represent the true width and length of the field set on the collimator. This is because the x-rays will continue to diverge as they move through the torso to the IR, increasing the field's size as they do so (Fig. 1.35).<br>• The thicker the body part being imaged, the smaller the collimator's light field that appears on the skin surface. |
| Contrast masking versus good collimation | • Postprocessing contrast masking adds a black background around the VOI, providing a perceived enhancement of image contrast.<br>• Contrast masking is to only extend to the exposed areas, matching the collimation borders.<br>• Contrast masking does not replace good collimation practices and should not be used to present a perceived radiation dose savings to the patient by moving one or more of the sides into the exposed region (Fig. 1.36). If done unevenly, the perceived location of the CR is changed on the masked projection.<br>• A projection that has been masked and sent to the PACS cannot be unmasked. |

*CR*, Central ray; *IR*, image receptor; *OID*, object–image receptor distance; *PACS*, picture archival and communication system; *VOI*, values of interest.

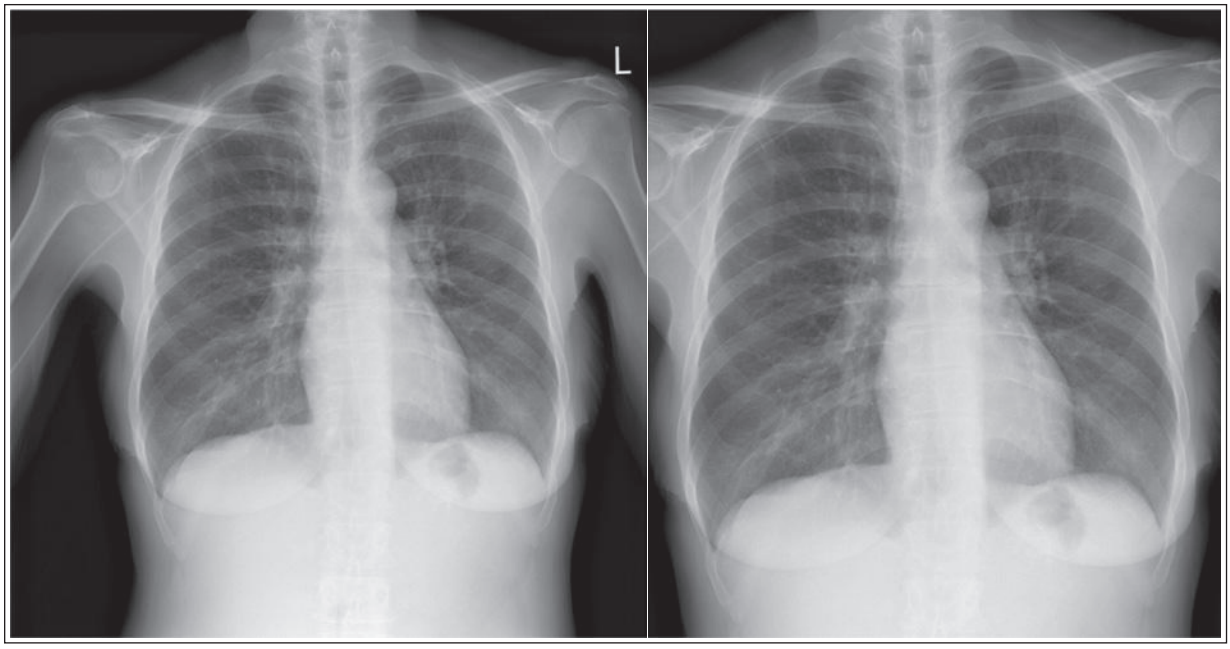



**FIGURE 1.27** Collimation determines how the VOI will fill the workstation screen. The first AP chest projection was obtained with less collimation than the second. Note how collimation determines how the display screen will be filled.

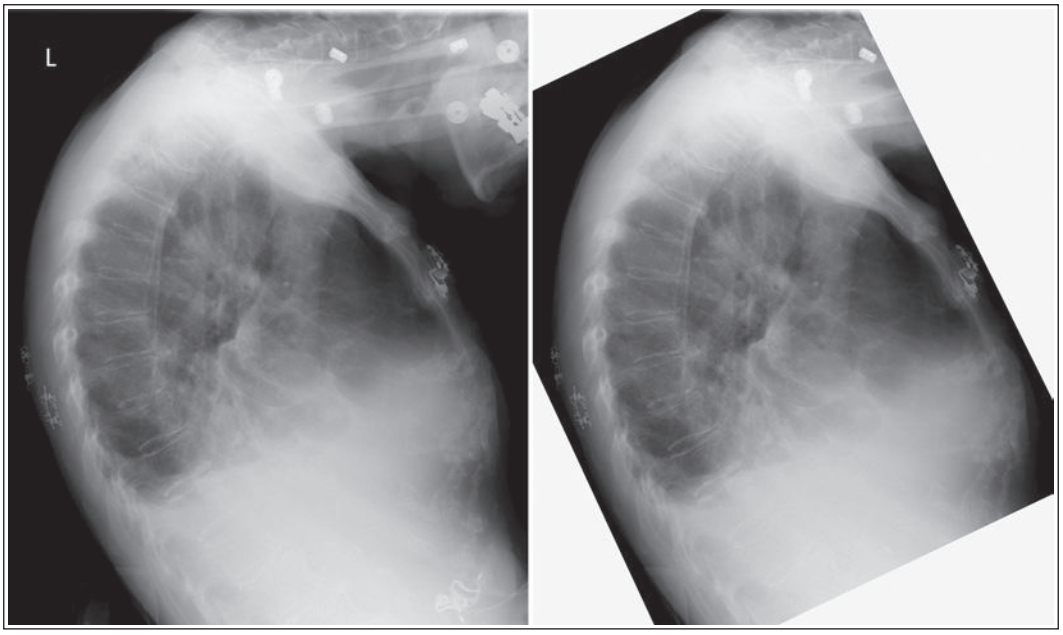



**FIGURE 1.28** Nonrotated and rotated collimator head on tilted lateral chest projection to obtain tighter collimation.

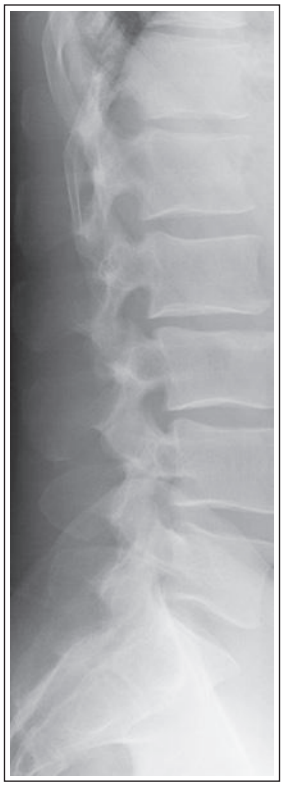


**FIGURE 1.29** Overcollimation on a lateral lumbar vertebral projection.


**FIGURE 1.30** Viewing the hand's shadow to determine proper collimation.

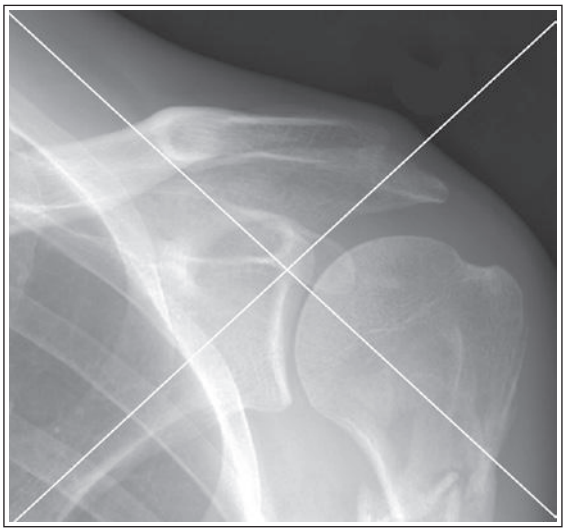


**FIGURE 1.31** Using collimated borders to locate CR placement.

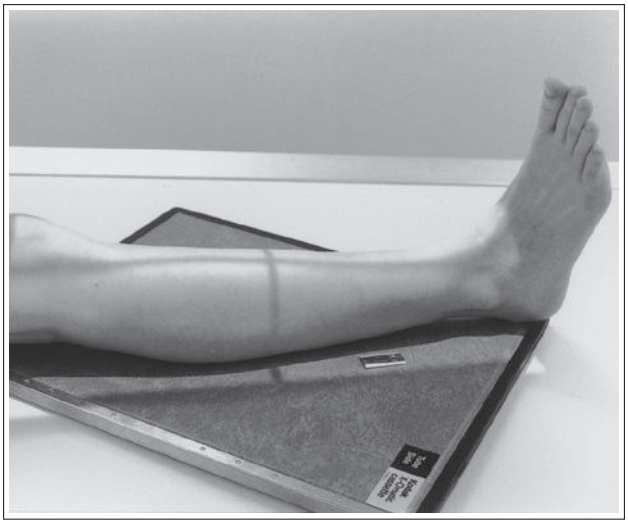


**FIGURE 1.33** Diagonally positioning long bones on the IR to include both joints.

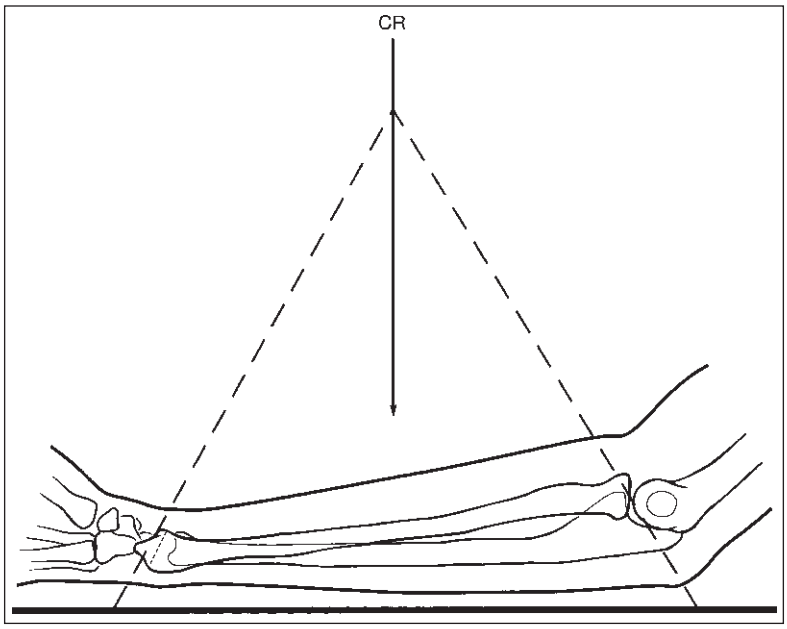



**FIGURE 1.32** Proper positioning of long bones with diverged x-ray beam.

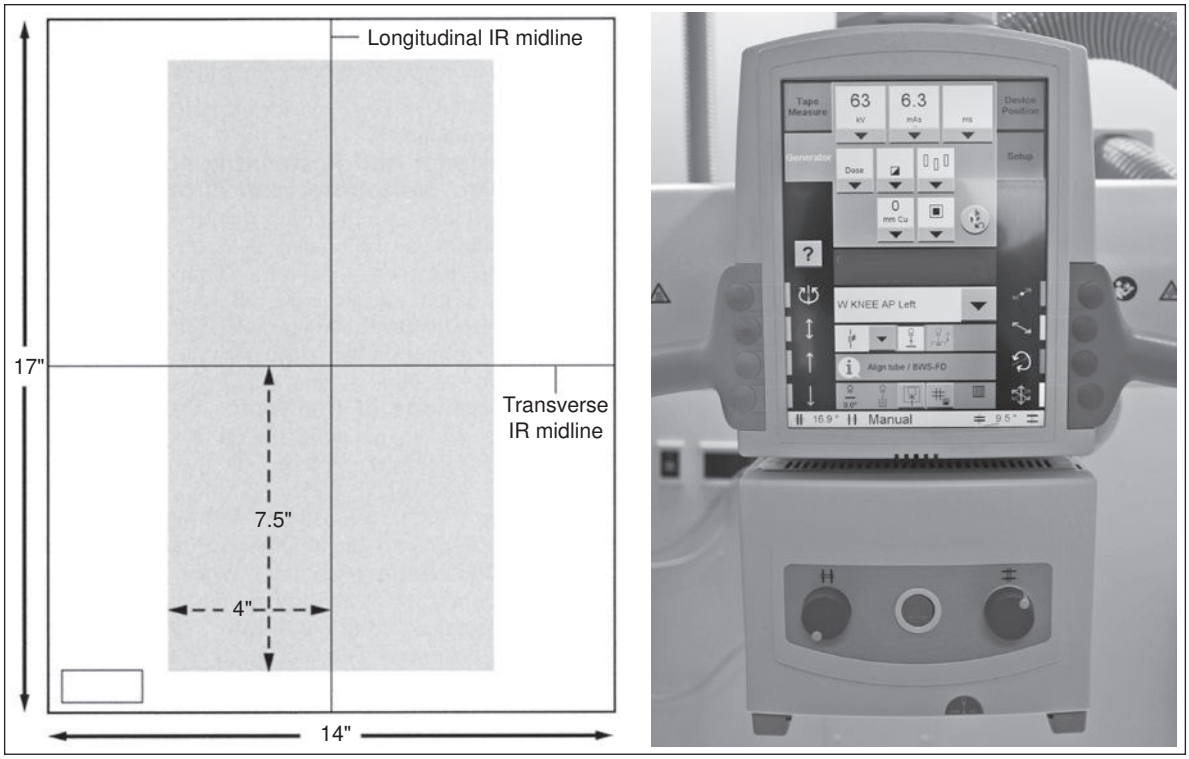



**FIGURE 1.34** Marker placement for tightly collimated image.

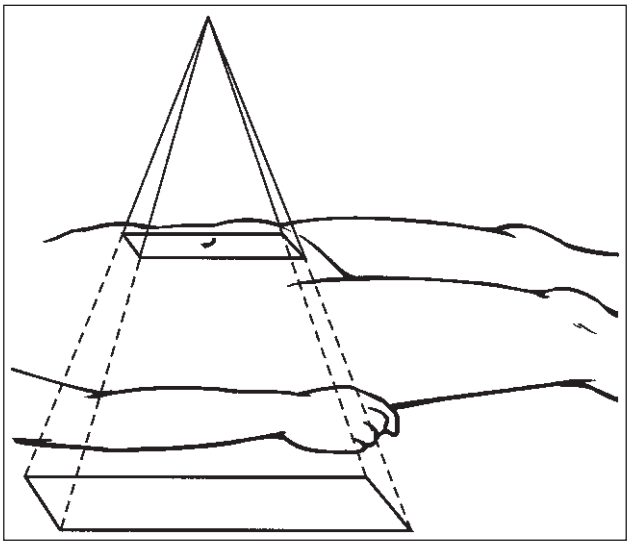


**FIGURE 1.35** Collimator light field versus IR coverage.

procedural analysis sections of this text. Most positioning routines require AP-PA and lateral projections to be taken to demonstrate superimposed anatomic structures, localize lesions or foreign bodies (Fig. 1.37), and determine alignment of fractures (Fig. 1.38). When joints are of interest, oblique projections are also added to this routine to visualize obscured areas better. In addition to these, special projections may be requested for more precise demonstration of specific anatomic structures and pathologic conditions.

To appreciate the importance of the anatomic relationships on a projection, one must understand the clinical reason for what the procedure is to demonstrate for the reviewer. An optimally positioned tangential (supraspinatus outlet) shoulder projection (Fig. 1.39) demonstrates the supraspinatus outlet (opening formed between acromion and humeral head) and the posterior aspects of the acromion and acromioclavicular (AC) joint in profile. The technologist produces these anatomic relationships when the midcoronal plane is positioned vertically and it can be ensured that the proper positioning was obtained when the superior scapular angle is positioned at the level of the coracoid tip on the projection. From this optimal projection the radiologist can evaluate the supraspinatus outlet for narrowing caused by variations in the shape (spur) or slope of the acromion or AC joint, which has been found to be the primary cause of shoulder impingements and rotator cuff tears. If instead of being vertical, the upper midcoronal plane was tilted toward the IR, the resulting projection would demonstrate the superior scapular angle positioned above the coracoid tip, preventing clear visualization of the acromion and AC joint deformities, because their posterior surfaces would no longer be in profile and would narrow or close the supraspinatus outlet (Fig. 1.40). Because the reviewer would be unable to diagnose outlet narrowing that results from variations in the shape or slope of the

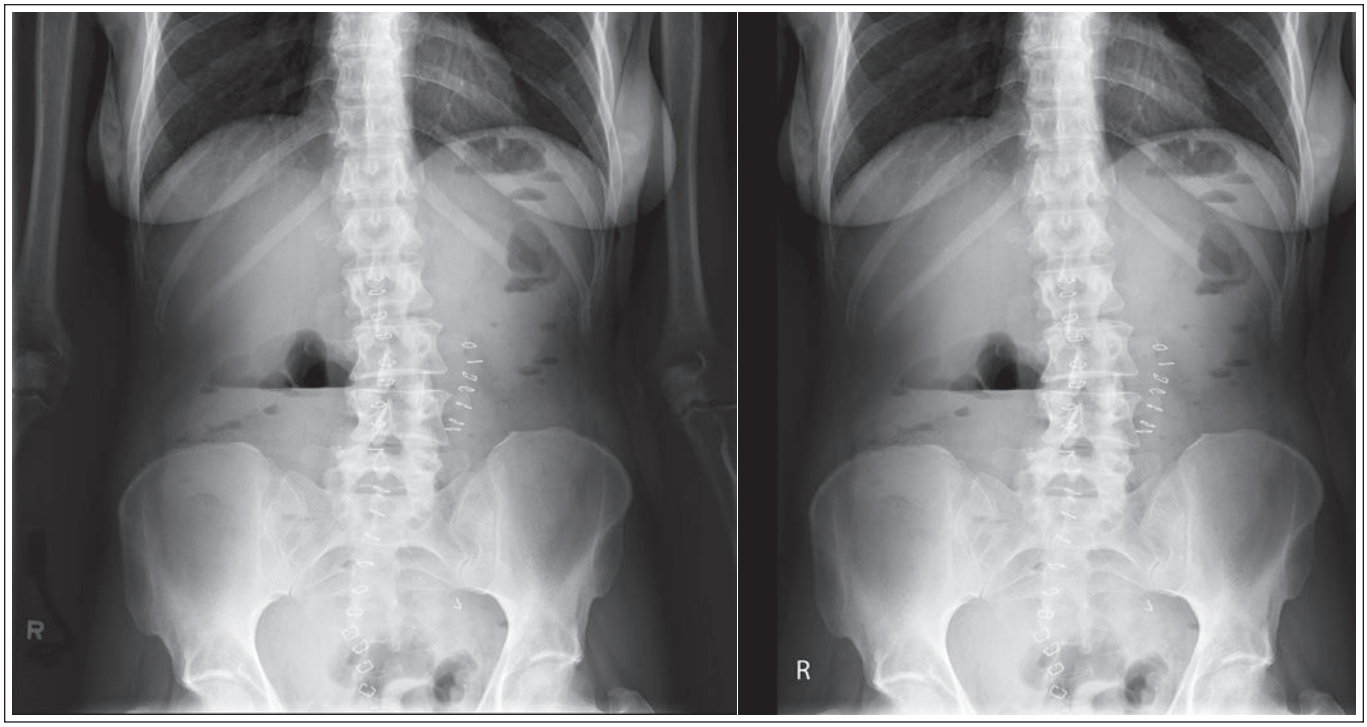



**FIGURE 1.36** AP abdomen projections with and without contrast masking. The first projection shows that the arms were included along the sides of the torso. The second projection has the contrast mask exceeding into the exposure field, excluding the arms and hiding that they were included in the exposure. Because the second projection was equally masked on both sides, the perceived placement of the CR is the same as the original projection. If the contrast mask exceeded into the exposure field on only one side, the perceived location of the CR placement will move in the same direction.

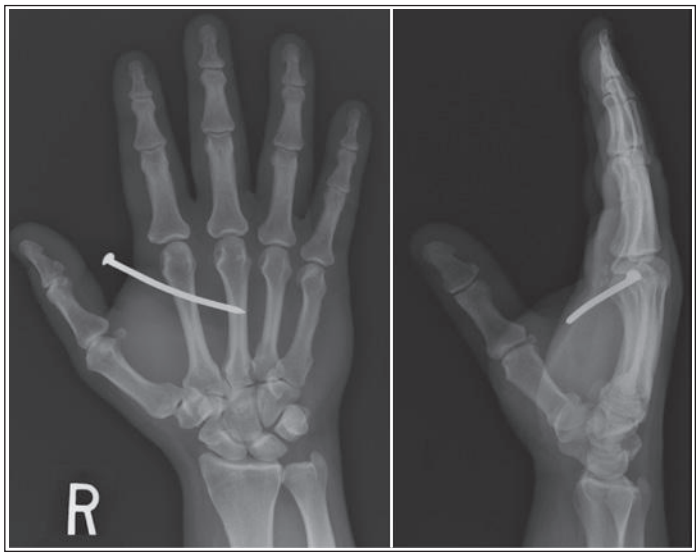



**FIGURE 1.37** PA and lateral hand projections to identify location of foreign body (nail).

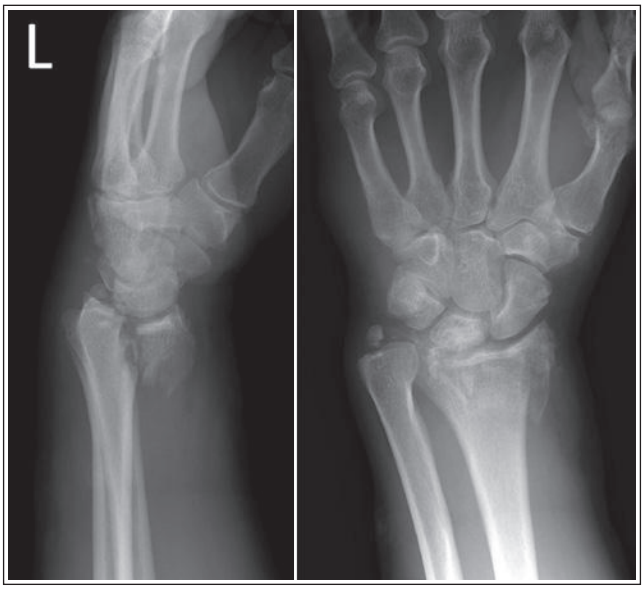



**FIGURE 1.38** Lateral and PA wrist projection to demonstrate distal forearm fracture alignment.

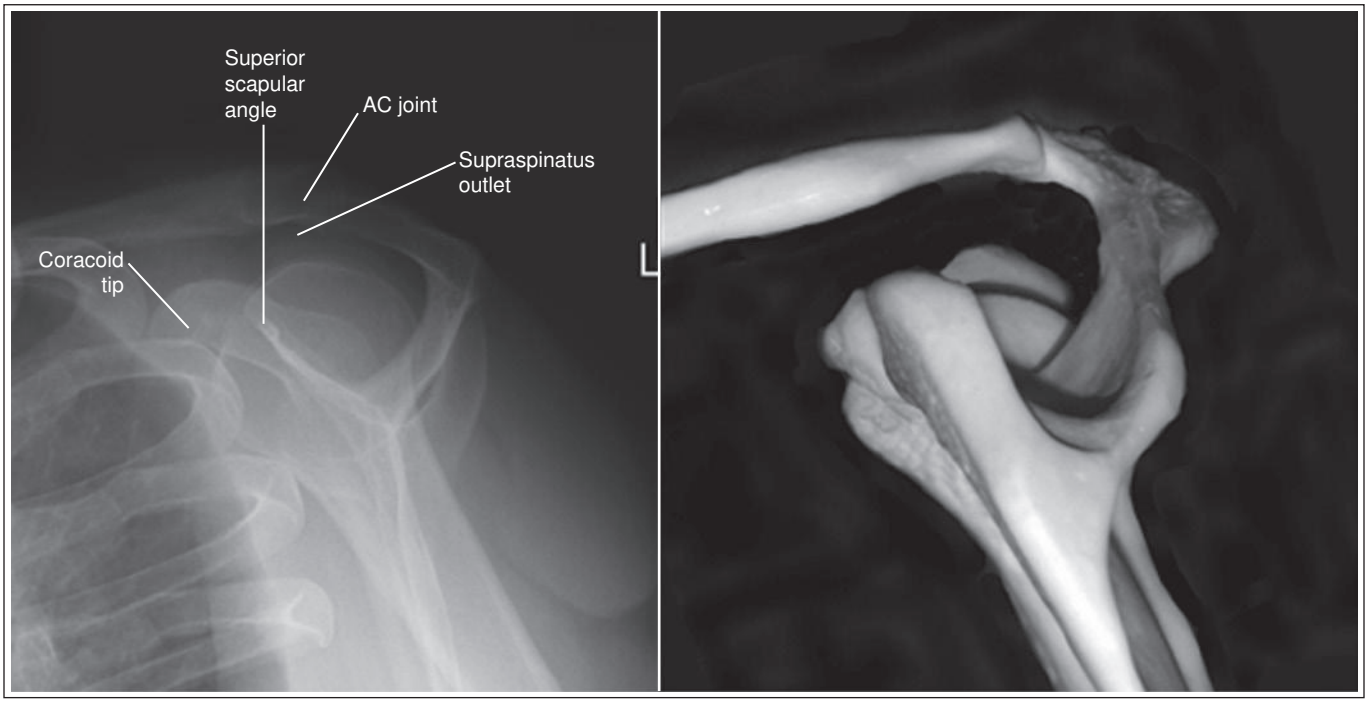



**FIGURE 1.39** Properly positioned skeletal bones and shoulder in the tangential (supraspinatus outlet) projection.

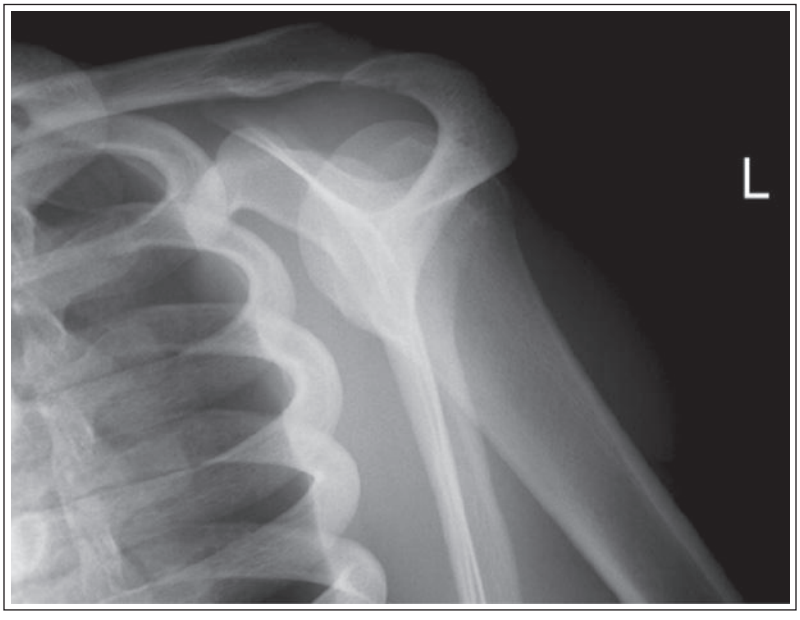



**FIGURE 1.40** Poorly positioned tangential (supraspinatus outlet) shoulder projection.

acromion or AC joint, this projection would not be of diagnostic value.

For each projection in the procedural analysis sections of this book, there is a list of:

- Image analysis guidelines to use when evaluating the anatomic relationships that are seen on an optimal projection
- An explanation that correlates the anatomic relationships with the specific positioning procedure(s)
- A description, with correlating projections, of related positioning errors to use to properly reposition the patient if an unacceptable projection is obtained and needs repeating

An optimal projection appears as much like the real object as possible, but because of unavoidable distortion that results from the shape, thickness, and position of the object and beam, part, and IR alignment, this is not always feasible, resulting in some anatomic structures appearing different from the real object. Using skeletal bones positioned in the same manner as the projection will greatly aid in identification of the anatomic structures on a projection. Closely compare the visualization of the anatomic structures on the skeletal scapular bone photograph and tangential shoulder projection shown in Fig. 1.39. Note that the superior scapular angle and lateral borders of this surface on the skeletal image are well demonstrated, obscuring the coracoid, but on the tangential projection the superior scapular angle is seen as a thin cortical line, its lateral borders are not demonstrated, and the coracoid can be clearly visualized. Also note that the superior surface of the spine is visualized on the skeletal bone image between the lateral and medial scapular spine borders but is not seen on the x-ray projection.

When identifying anatomic structures, one must consider how anatomy may appear different from the real object. Table 1.5 lists imaging concepts and guidelines that when understood and applied to how the procedure was obtained, can help with identification of the anatomic structures on the projection.

*Text continued on p. 29*

**TABLE 1.5 Identifying Anatomic Structures**

| | |
|---|---|
| CR centering | • Center the CR to the center of the VOI. Because straight x-rays record the anatomy at the CR, it is here that the anatomy is the truest.<br>• As one moves away from the CR in all directions, the x-rays used to record the anatomy diverge and expose the IR at an angle (Fig. 1.41). The farther one moves away from CR, the larger is the angle of divergence (Fig. 1.42).<br>• At a 40-inch SID, the divergence of x-rays is 2 degrees per inch the anatomy is off-centered in any direction from the CR; at a 72-inch SID, it is 1 degree per inch.<br>• Bilateral hand, feet, or knee projections that require the CR to be centered between the structures may require slight variations in positioning of the reference plane to align it with the divergence of the x-ray and obtain optimal projections (Fig. 1.43). |
| Angled CR | • When an angled CR or diverged x-rays are used the anatomy will move in the direction that the x-ray beams travel. Anatomy positioned farthest from the IR move at greater distances than those positioned closer to the IR (Figs. 1.44 and 1.45).<br>• As CR angulation or x-ray divergence increases, the degree of anatomy movement also increases. |
| Size distortion | • Size distortion is represented when all axes of the structure demonstrate an equal percentage of increase in size over the real object (Figs. 1.46 and 1.47).<br>• All projections demonstrate some degree of size distortion because none are taken with the structure situated directly on the IR detector, no structure is flat, and not all of the structure is recorded with a perpendicular beam.<br>• To keep size distortion at a minimum, use the shortest possible OID and the longest feasible SID. |
| Shape distortion | • Elongation has occurred when one of the structure's axes appears disproportionately longer on the projection than the opposite axis (Fig. 1.48). The least amount of elongation occurs when the CR is aligned perpendicular to the part and IR, and the part and IR are parallel with each other as demonstrated in Fig. 1.49A. For causes of elongation, see Fig. 1.49B–D.<br>• Foreshortening has occurred when one of the structure's axes appears disproportionately shorter on the projection than the opposite axis (Fig. 1.50). For cause of foreshortening, see Fig. 1.49E. |
| Patient obliquity | • All procedural protocols define reference planes (e.g., midsagittal or midcoronal) within the patient that are to be aligned with the IR in some manner to produce optimal projections. Technologists need to estimate the degree of patient obliquity when positioning the patient and when evaluating projections (Fig. 1.51).<br>• Always use the reference plane to determine the amount of obliquity. Do not assume a sponge of a set angle will always position the patient at the same angle. A 45-degree sponge may turn the patient more or less than 45 degrees, depending on how far under the patient the sponge was placed. |

*Continued*

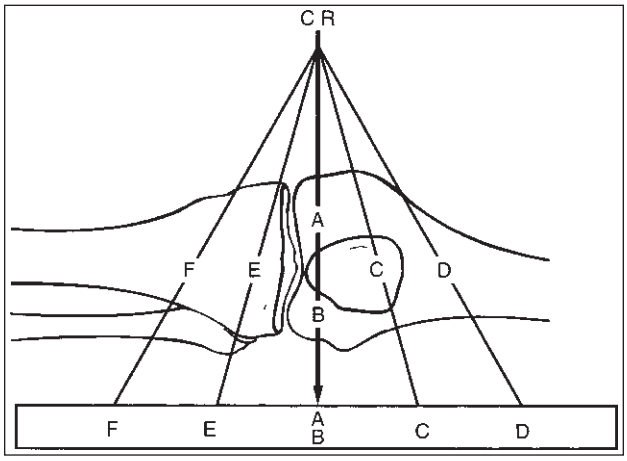



**FIGURE 1.41** Effect of CR placement on anatomic alignment.

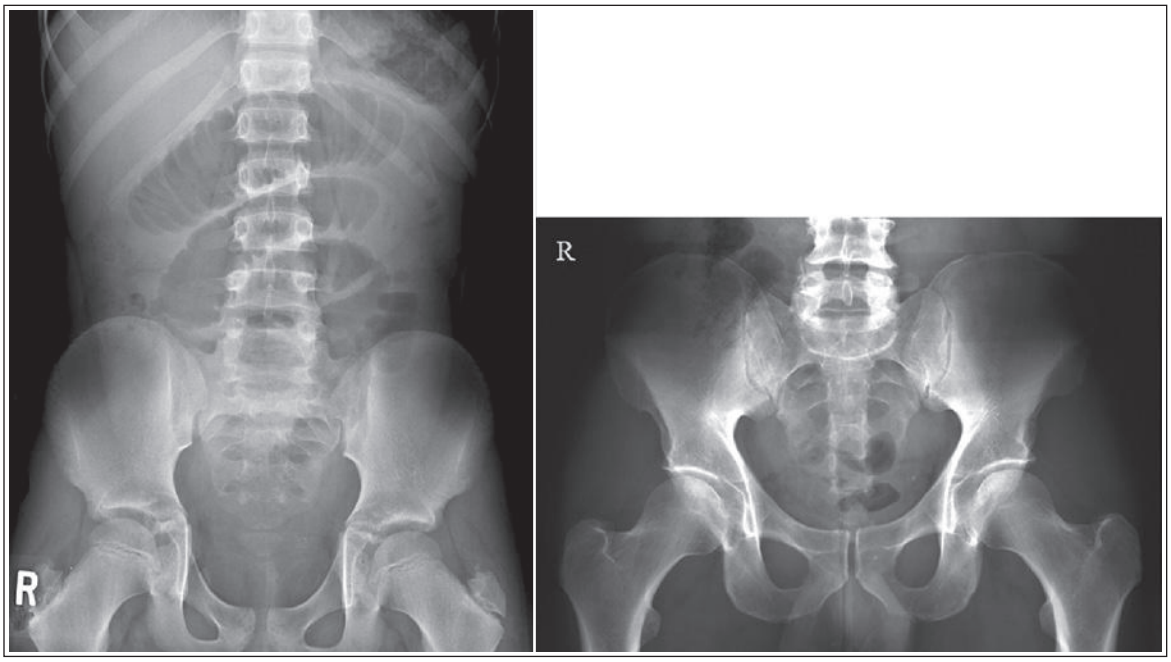



**FIGURE 1.42** Properly positioned AP abdomen and pelvis projections demonstrating the effect of CR placement. Compare the relationship of the symphysis pubis and coccyx and how differently the sacrum is visualized. Both projections are taken with a perpendicular CR, but the CR is centered to the midsagittal plane at the level of the iliac crest for the abdomen projection and is centered at the inferior sacrum for the pelvis projection. The symphysis pubis and coccyx on both projections were recorded using diverged beams, but because the CR is centered more superiorly and beams with greater angles of divergence were used to record the symphysis pubis and coccyx on the abdomen projection, the symphysis pubis is moved more inferiorly to the coccyx on this projection when compared with its alignment with the coccyx on the pelvis projection. Also compare sacral visualization on these two projections. Because of the more inferior centering used in the pelvis projection, the x-rays recording the sacrum are angled cephalically into the curve of the sacrum and those recording the sacrum for the abdomen projection are angled caudally, against the sacral curve. This results in decreased sacral foreshortening on the pelvis projection and increased sacral foreshortening on the abdomen projection. The off-centered diverged beams will affect structures in the same manner that an angled CR will.

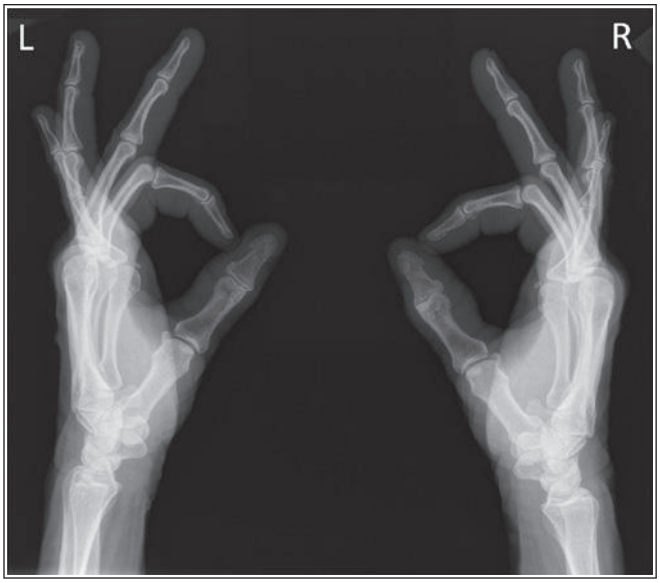



**FIGURE 1.43** Bilateral projections. It is not uncommon for bilateral projections of the hands, feet, or knees to be ordered for a comparison diagnosis. This off-centering of the CR between the hands results in posteriorly diverged x-rays recording the MCs, which caused the second through fourth MC to be projected posterior to the fifth MC on the hands, producing less than optimal lateral hands because the MCs should be superimposed on lateral hand projections, and they are not on these projections. The farther apart the hands are positioned from each other, the greater will be the amount of lateral divergence and the more supinated the hands will appear. This appearance can be offset by estimating the degree of x-ray divergence (2 degrees for every 1 inch of off-center) and increasing the degree of internal rotation of the hands from the standard positioning by the same degree.

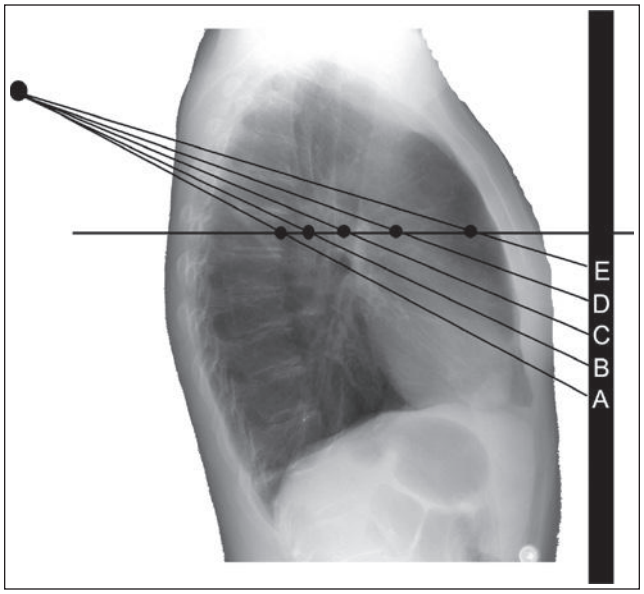



**FIGURE 1.44** Using an angled beam. When an angled CR or diverged beam is used to record an object, the object will move in the direction in which the beams are traveling. The more the CR is angled, the more the object will move. Also, note that objects positioned on the same plane but at different distances from the IR, which would have been superimposed if a perpendicular CR were used, will be moved different amounts. In the figure, point A is farther away from the IR than point C, and even though these two points are horizontally aligned, if a caudally angled CR were used to record these two structures, point A would project farther inferiorly than point C on the resulting projection. If the two structures were closer together (points A and B), the amount of separation between the structures when an angled CR is used would be less, and if the two structures were farther apart (points A and E), the separation between the structures on the resulting projection would be greater.

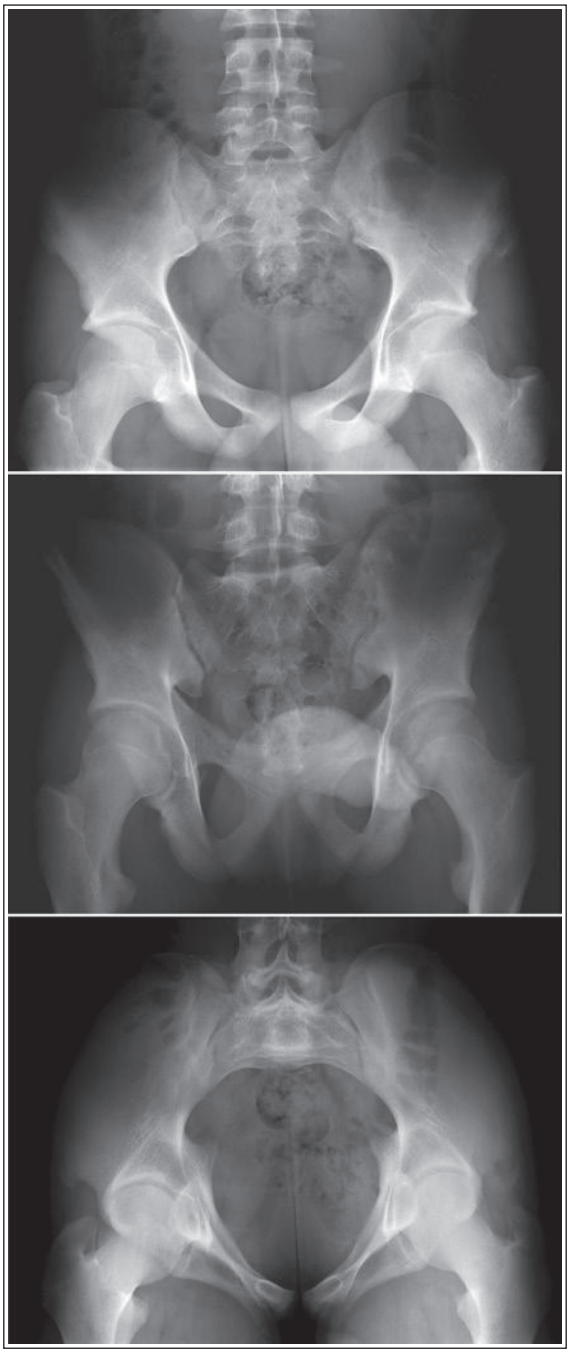


**FIGURE 1.45** AP pelvis projections demonstrating the effect of CR angulation: CR perpendicular *(top)*, CR angled cephalically *(center)*, and CR angled caudally *(bottom)*. Note how the structures situated farther from the IR (ASISs, symphysis pubis, and obturator foramen) have moved the direction that the CR was angled and how the same anatomic structures demonstrate different distortion.

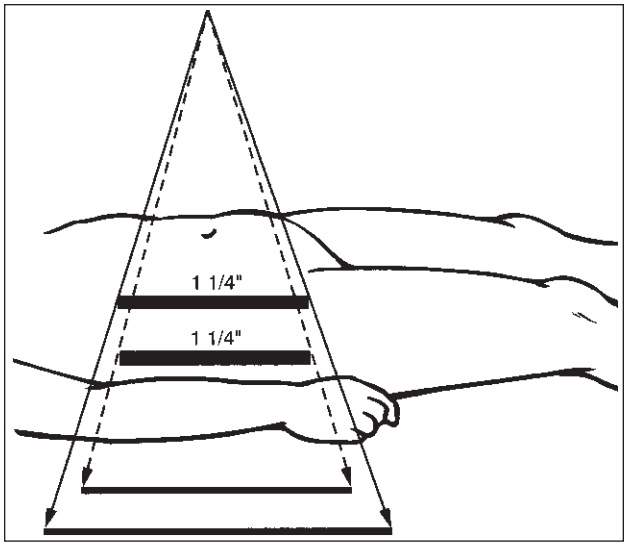



**FIGURE 1.46** The part farthest from the IR will be magnified the most. The amount of magnification demonstrated on a projection is dependent on how far each structure is from the IR at a set source–image receptor distance (SID). The farther away the part is situated from the IR, the more magnified the structure will be. Magnification also results when the same structure, situated at the same OID, is imaged at a different SID, with the longer SID resulting in the least magnification.

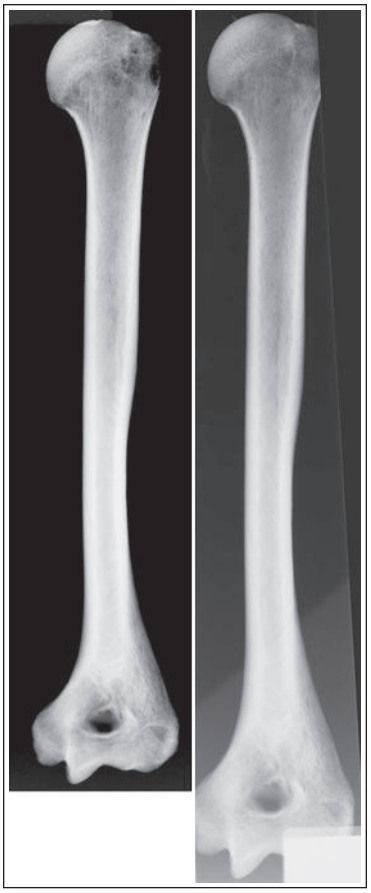


**FIGURE 1.48** Humerus bones in AP projection without and with elongation.

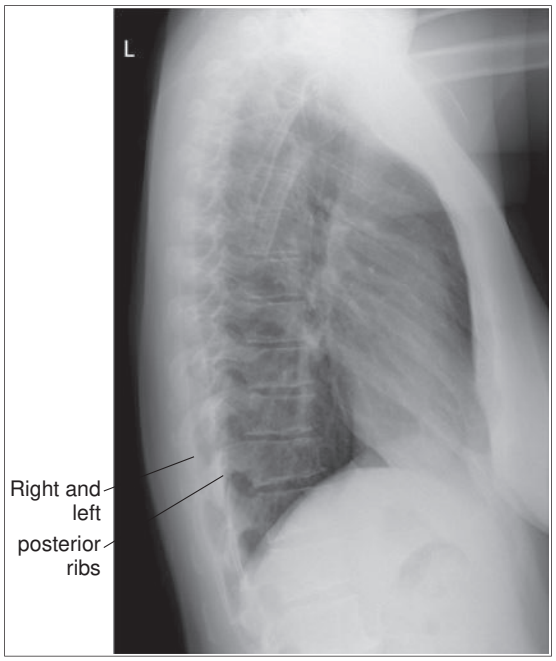



**FIGURE 1.47** Left lateral chest projection showing increased magnification of right lung field due to increased OID. Differences in magnification can be noticed between one side of a structure when compared with the opposite side if they are at significantly different OIDs. This can be seen on an accurately positioned lateral chest projection, which demonstrates approximately 0.5 inch (1 cm) of space between the right and left posterior ribs, even though both sides of the thorax are of equal size. Because the right lung field and ribs are positioned at a greater OID than the left lung field and ribs on a left lateral projection, the right lung field and ribs are more magnified.

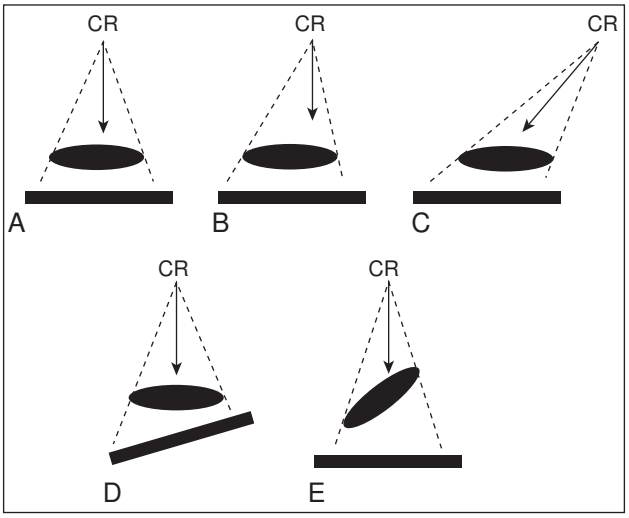



**FIGURE 1.49** Best CR, part, and IR alignment for the least distortion (A). Causes of anatomic distortion: 1. The CR is perpendicular to the part and the image receptor (IR) is parallel with the part (B), but the part is not centered to the CR (off-centered). The greater the off-centering, the greater the elongation. 2. The CR is angled and is not aligned perpendicular to the part, but the IR and the part are parallel with each other (C). The greater the CR angulation, the greater the elongation. 3. The CR and part are aligned perpendicular to each other, but the IR is not aligned parallel with the part (D). The greater the angle of the IR, the greater the elongation. 4. Foreshortening occurs when the CR and IR are perpendicular to each other, but the part is inclined (E). The greater the incline, the greater will be the foreshortening.

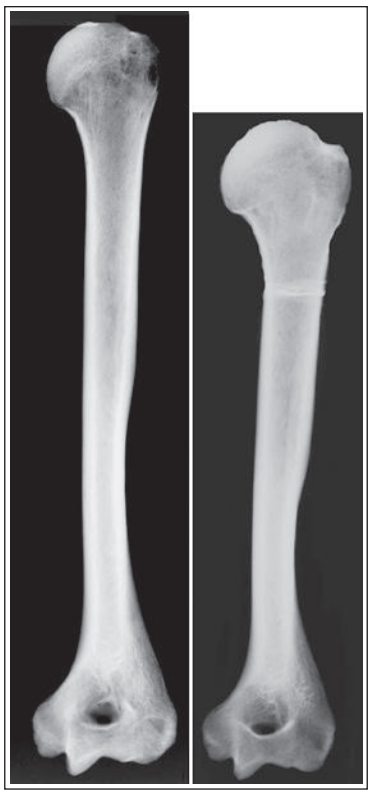


**FIGURE 1.50** Humerus bones in AP projection without and with foreshortening.

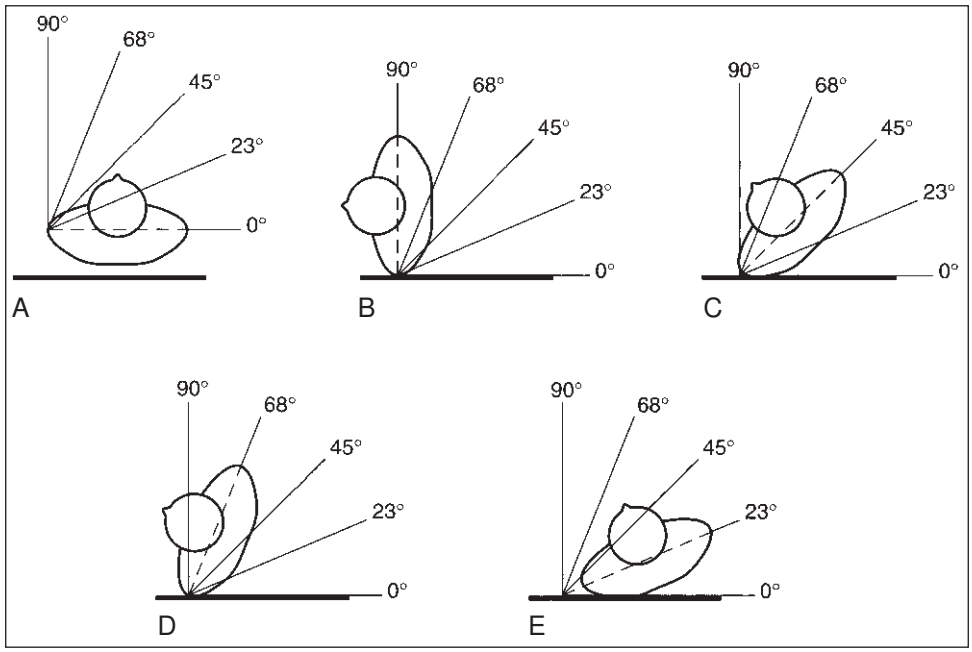



**FIGURE 1.51** Estimating the degree of patient obliquity, viewing the patient's body from the top of the patient's head. When the patient is in an AP-PA projection, the reference plane is aligned parallel (0-degree angle) with the IR (A) and, when the patient is in a lateral projection, the reference plane is aligned perpendicular (90-degree angle) to the IR (B). For a 45-degree AP-PA oblique projection, place the reference plane halfway between the AP-PA projection and the lateral projection (C). For a 68-degree AP-PA oblique projection, place the reference plane halfway between the 45- and 90-degree angles (D). For a 23-degree AP-PA oblique projection, place the reference plane halfway between the 0- and 45-degree angles (E). Even though these five angles are not the only angles used when a patient is positioned for projection, they are easy to locate and can be used to estimate almost any other angle. For example, if a 60-degree AP-PA oblique projection is required, rotate the patient until the reference plane is positioned at an angle slightly less than the 68-degree mark. The torso has been used to demonstrate this obliquity principle, but it can also be used for extremities.

**TABLE 1.5 Identifying Anatomic Structures—cont'd**

| | |
|---|---|
| Extremity flexion | • Extremity projections often require a precise degree of structure flexion to adequately demonstrate the desired information. Technologists need to estimate the degree that the extremity is flexed when positioning the patient and when evaluating projections (Fig. 1.52) |
| Joint spaces and fractures | • For an open joint space or fracture to be demonstrated, the CR or diverged rays recording the joint or fracture line must be aligned parallel with it (Figs. 1.53 and 1.54). Failure to accomplish this alignment will result in a closed joint or poor fracture visualization (Figs. 1.55–1.57). |
| Distinguishing between structures of similar shape and size | • Use known structures that surround the structures being identified (Fig. 1.58).<br>• Use specific bony projections such as tubercles located on or near the structure (Fig. 1.59).<br>• Identify the more magnified of the two structures. The anatomic structure situated farthest from the IR is magnified the most (Fig. 1.47) |

*CR*, Central ray; *IR*, image receptor; *OID*, object–image receptor distance; *SID*, source–image receptor distance; *VOI*, values of interest.

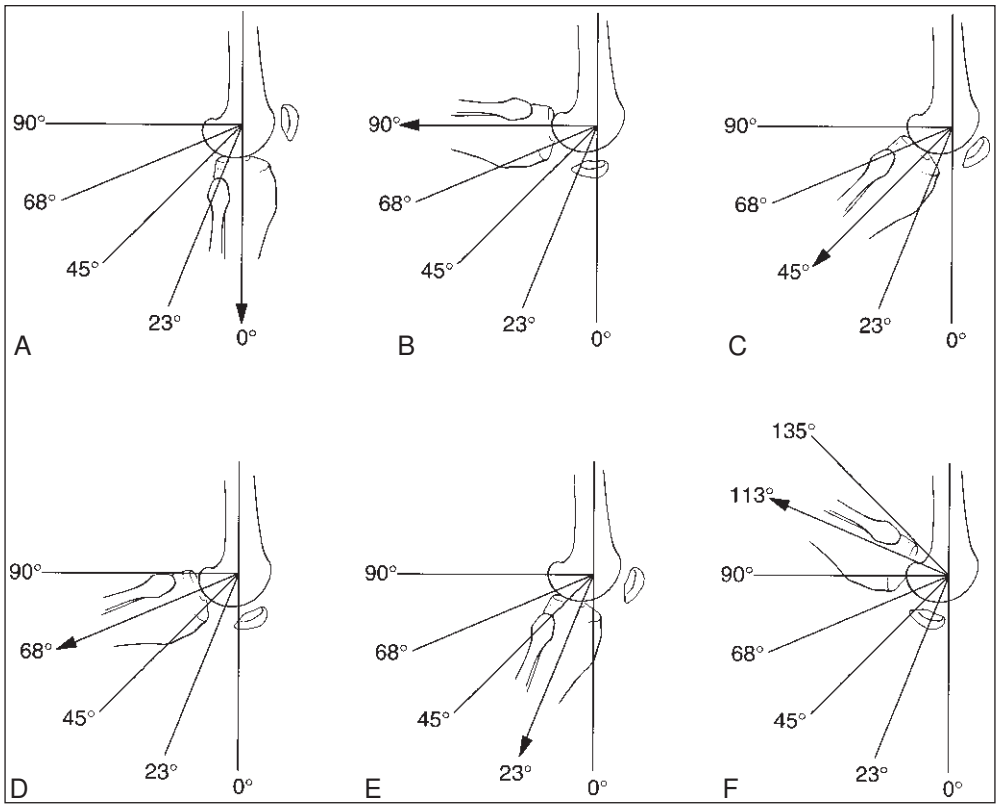



**FIGURE 1.52** Estimating the degree of joint or extremity flexion. When an extremity is in full extension, the degree of flexion is 0 (A), and when the two adjoining bones are aligned perpendicular to each other, the degree of flexion is 90 degrees (B). As described in the preceding discussion, the angle found halfway between full extension and 90 degrees is 45 degrees (C). The angle found halfway between the 45- and 90-degree angles is 68 degrees (D), and the angle found halfway between full extension and a 45-degree angle is 23 degrees (E). Because most flexible extremities flex beyond 90 degrees, the 113- and 135-degree angles (F) should also be known.

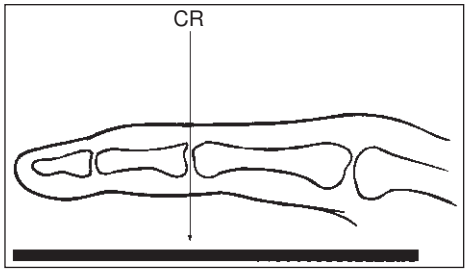



**FIGURE 1.53** Accurate alignment of joint space and CR.

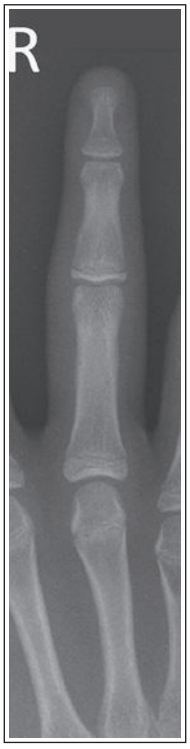



**FIGURE 1.54** AP finger projection with open joints.

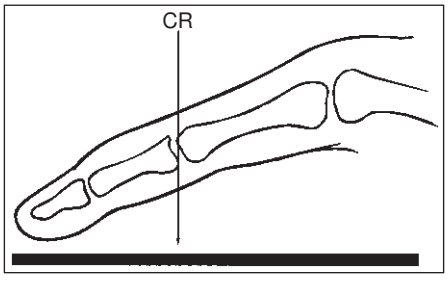



**FIGURE 1.55** Poor alignment of joint space and CR.

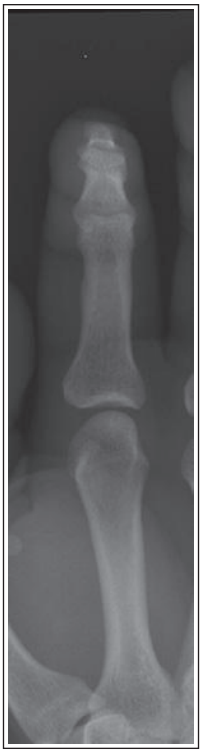


**FIGURE 1.56** PA finger projection with closed joints.

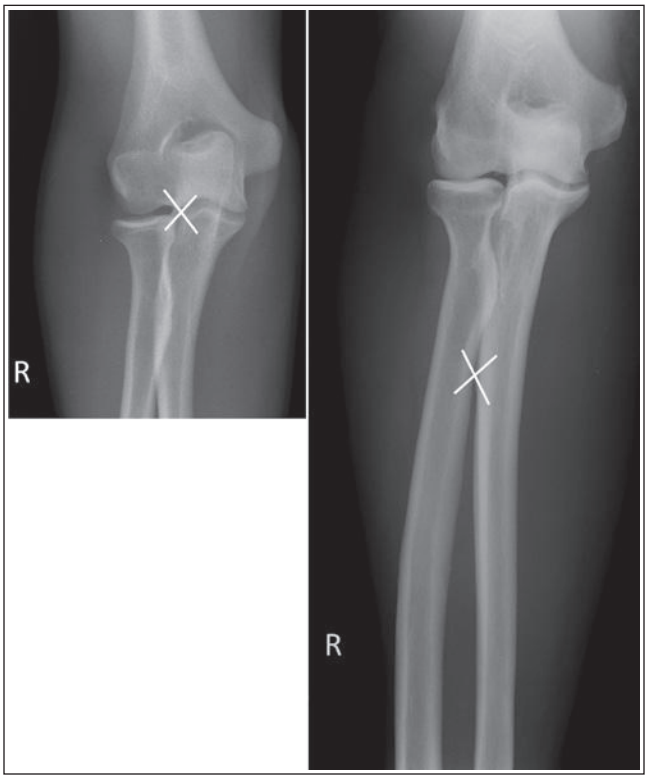



**FIGURE 1.57** AP elbow projections comparing the effects of CR centering on joint visualization.

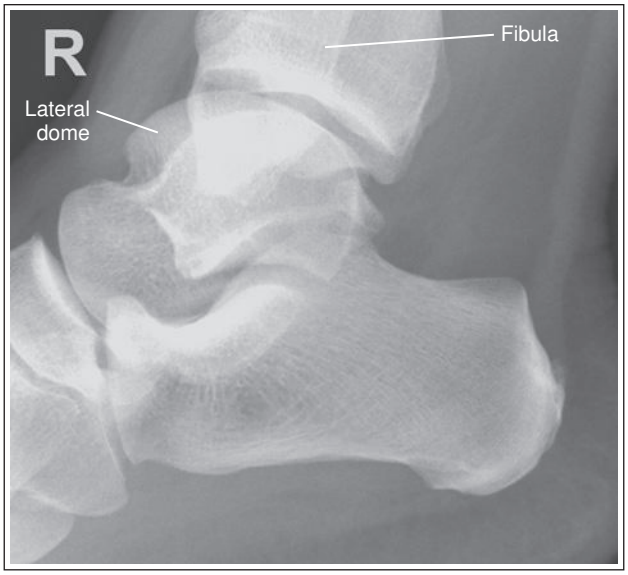



**FIGURE 1.58** Poorly positioned right lateral ankle projection. A lateral ankle projection demonstrates inaccurate anterior alignment of the talar domes and a closed tibiotalar joint space. One cannot view the joint space or distinguish between the talar domes to determine which talar dome is the more anterior, but the relationship of the tibia and fibula can easily be used to deduce this information. An accurately positioned lateral ankle projection demonstrates superimposed talar domes and the fibula demonstrated in the posterior half of the tibia. If a lateral ankle is obtained that demonstrates the talar domes without superimposition and the fibula too anterior on the tibia, the anterior talar dome will be the lateral dome because the lateral dome will move in the same direction as the fibula.

**TABLE 1.6 Steps for Repositioning the Patient for Repeat Projections (Figs. 1.59 and 1.60)**

1. Identify the two structures that are mispositioned.
2. Determine the number of inches (cm) that the two mispositioned structures are "off."
3. Determine if the two structures will move toward or away from each other when the main structure is adjusted.
4. Begin the repositioning process by first positioning the patient as he or she was positioned for the poorly positioned projection. From this positioning, move the patient as needed for proper positioning.
5. If the structures move in opposite directions from each other when the patient is repositioned, adjust the patient half of the distance that the structures are off.
6. If only one structure moves when the patient is repositioned, adjust the patient so that the structure that moves is adjusted the full amount.

**Steps for Repositioning the Patient and CR for Repeat Projections.** Tables 1.6 and 1.7 list the steps to take when repositioning the patient or the CR after a projection has been obtained that does not meet the required anatomic relationships.

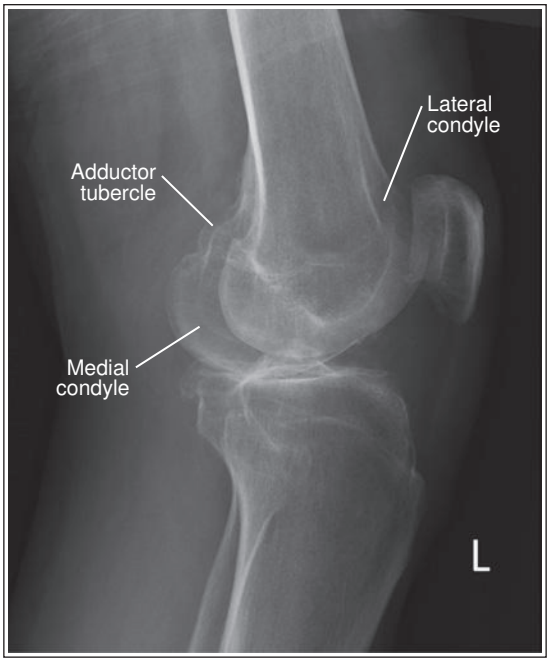



**FIGURE 1.59** Poorly positioned left lateral knee projection. The medial femoral condyle can be distinguished from the lateral condyle on a lateral knee projection by locating the adductor tubercle which is situated on the posterior aspect of the medial condyle. The anterior and the posterior surfaces of the medial and lateral femoral condyles should be superimposed on an accurately positioned lateral knee projection. This projection demonstrates that a 0.5-inch (1.25-cm) gap is between them, with the medial condyle positioned more posteriorly. To obtain an optimal lateral knee projection using patient positioning in this situation (see Table 1.6), the medial condyle is rotated anteriorly 0.25 inch (0.6 cm). As the medial condyle is rotated anteriorly the lateral condyle will rotate posteriorly by an equal distance so the amount of repositioning movement needed is only half of the distance between the two rotated structures.

## 6. Projection Demonstrates Maximum Spatial Resolution

Spatial resolution refers to the ability of an imaging system to record sharp detail edges and distinguish small adjacent details from each other in a projection. The sharpness of the recorded detail on a projection refers to how many pixels the detail's edge will spread across because of blur. Low blur indicates that the spread is minimal, involving fewer pixels and indicating high detail sharpness. The geometric factors that affect blur are the focal spot size and distances. The greatest edge sharpness is obtained by using a small focal spot, the longest possible source–image receptor distance (SID), the shortest possible object–image receptor distance (OID), and controlling motion. It is also greatest in computed radiography when the smallest possible IR cassette is chosen.

It is the digital system's pixel size that determines the minimum size a detail can be and still be resolved and how far adjacent details have to be from each other for them both to be resolved. The term *spatial frequency* is used to describe the expected quality of the spatial resolution that is obtained by a digital system at a set focal

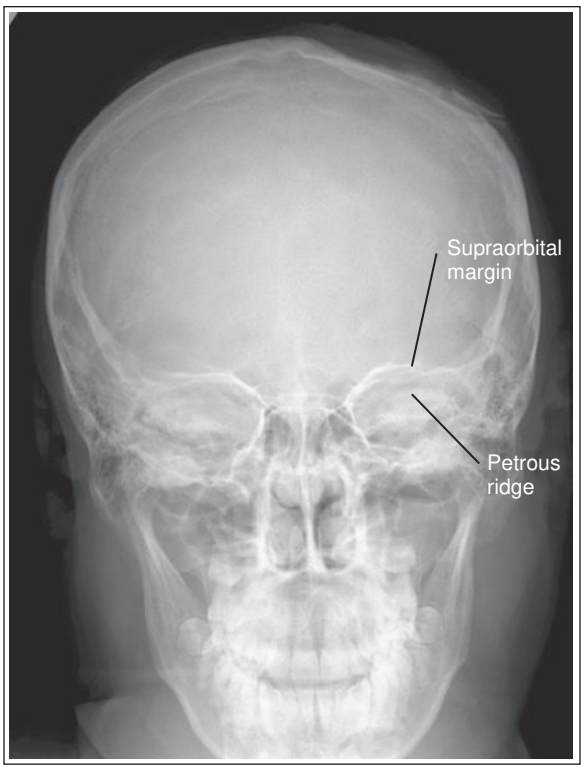



**FIGURE 1.60** Poorly positioned AP axial (Caldwell method) cranial projection. An accurately positioned AP axial cranial projection demonstrates the supraorbital margins 1 inch (2.5 cm) superior to the petrous ridges. This AP axial cranial projection demonstrates superimposition of the supraorbital margins and petrous ridges. When the chin is elevated away from the chest, the supraorbital margins move superiorly, whereas the petrous ridges, being located at the central pivoting point in the cranium, do not move. To obtain an optimal projection by repositioning the patient, the chin is adjusted 1 inch (2.5 cm) away from the chest, moving the supraorbital margins superiorly and 1 inch (2.5 cm) above the petrous ridges. To obtain an optimal projection by adjusting the CR, determine that the supraorbital margins are the farthest from the IR and that they will need to be moved 1 inch (2.5 cm) superiorly to obtain optimal alignment with the petrous ridges. Measure the physical distance between the petrous ridges and supraorbital margins on a skeletal structure, which will be found to be approximately 3 inches (7.5 cm), and then use the chart in Table 1.7, step 5, to determine the degree of angulation adjustment that is needed to move the supraorbital margins 1 inch (2.5 cm) superiorly, and adjust the CR angulation by 10 degrees cephalically before repeating the projection.

**TABLE 1.7 Steps for Repositioning the Central Ray for Repeat Projections (Figs. 1.60 and 1.61)**

1. Identify the two structures that are mispositioned.
2. Determine which of the identified structures is positioned farthest from the IR. This is the structure that will move the most when the CR angle is adjusted.
3. Determine the direction that the structure situated farthest from the IR must move to be positioned accurately with respect to the other structure.
4. Determine the number of inches (cm) that the two mispositioned structures are off on the projection.
5. Estimate how much the structure situated farthest from the IR will move per 5 degrees of angle adjustment placed on the CR. How much the CR angulation projects two structures away from each other depends on the difference in the physical distance of the structures from each other, as measured on the skeletal bone.
   - If the identified physical structure (actual bone, not as seen on radiographic image) is separated by 0.5–1.25 inches (0.16–3.2 cm), a 5-degree CR angle adjustment will move the structure situated farthest from the IR by approximately 0.125 inch (0.3 cm).
   - If the identified physical structures are separated by 1.5–2.25 inches (3.75–6 cm), a 5-degree CR angle adjustment will move the structure situated farthest from the IR approximately 0.25 in (0.6 cm).
   - If the identified physical structures are separated by 2.5–3.25 inches (6.25–8 cm), a 5-degree CR angle adjustment will move the structure situated farthest from the IR approximately 0.5 inch (1.25 cm).
   - If the identified physical structures are separated by 3.5–4.5 inches (8.75–11 cm), a 5-degree CR angle adjustment will move the structure situated farthest from the IR approximately 0.75 inch (1.9 cm).
6. Place the needed angulation on the CR, as determined by steps 4 and 5, and direct the CR in the direction indicated in step 3.

*CR*, Central ray; *IR*, image receptor.

spot size and using a set SID and OID. Spatial frequency is defined in terms of the number of details that can clearly be visualized in a set amount of space (distance). This change is not expressed as the size of the object but in terms of the largest number of line pairs per millimeter (lp/mm) that can be seen when a resolution line pair test tool is imaged using the system. As the geometry is improved by using a small focal spot, increasing the SID, or decreasing the OID, the spatial frequency number will become larger and the ability of the system to resolve smaller details increases. Spatial frequency is directly related to pixel size because each pixel can only visualize one gray shade, distinguishing only one detail, and two pixels are needed to make up a line pair. If the frequency of change in the projection from detail to detail is closer together than the width or height of the pixel, the details will not be resolved (Table 1.8).

## 7. Radiation Protection Is Present on Projection When Indicated, and Good Radiation Protection Practices Are Used During the Procedure

Diagnostic imaging professionals have a responsibility to adhere to effective radiation protection practices for the following reasons: (1) to prevent the occurrence of radiation-induced nonstochastic effects by adhering to dose-equivalent limits that are below the threshold dose-equivalent levels and (2) to limit the risk of stochastic effects to a reasonable level compared with nonradiation risks and in relation to society's needs, benefits gained, and economic factors.

*Text continued on p. 37*

**TABLE 1.8 Spatial Resolution**

| | |
|---|---|
| Systems matrix and pixel sizes | • **Computed radiography:** Choose the smallest possible IR (Fig. 1.62). Computed radiography systems have resolution capabilities between 2.55 and 5 lp/mm, with the 14 × 17 inch FOV providing approximately 3 lp/mm and the 8 × 10 inch FOV providing approximately 5 lp/mm.<br>• **Direct/indirect capture radiography:** Systems have a set matrix and pixel size, determined by the size of the detector DELs and the spacing between them. Pixel size is the same regardless of the degree of collimation. Spatial resolution capabilities of approximately 3.7 lp/mm. |
| Focal spot size | • Smaller focal spot sizes produce better spatial resolution (Figs. 1.63 and 1.64).<br>• Use the small focal spot for extremity projections.<br>• A detail that is smaller than the focal spot size used to produce the projection will be entirely blurred and blend with the surrounding details.<br>• Using a small focal spot is only feasible when imaging structures that can be obtained using a milliamperage (mA) setting of 300 mA or less.<br>• If the thickness measurement is large or if the patient's ability to hold still is not reliable, a large focal spot is recommended. These two factors will require a longer exposure time to obtain the needed IR exposure, and if a small focal spot is used, patient motion may result. |
| SID and OID | • Longer SID produces better spatial resolution (Fig. 1.65).<br>• Shorter OID produces better spatial resolution (Fig. 1.66).<br>• As a general practice, the SID is set at the facility's standard to match the technique charts and preprogrammed settings and the OID is kept as low as possible.<br>• To offset magnification when the part cannot be placed at an acceptable OID, the SID can be increased to greater than the standard used. The ratio between the OID and SID must remain the same for equal magnification results, and because this requires unacceptable SIDs, equal magnification is seldom obtained. This should not be done on projections that are obtained for specific reasons where it would not be recommended, to include assessing enlargement.<br>• If the SID is increased to offset magnification blur, it is also necessary to increase the mAs using the (Fig. 1.67):<br>  • Exposure maintenance formula *([new mAs]/[old mAs] = [new distance squared]/[old distance squared])*. This formula is used to adjust the mAs the needed amount to maintain the required exposure to the IR and prevent quantum noise. |
| Motion | • Motion unsharpness refers to lack of detail sharpness in a projection that is caused by patient movement during the exposure. Because the projection is actually recorded in more than one location when movement and the exposure are happening at the same time, the details get spread over many pixels.<br>• Voluntary motion refers to the patient's breathing or otherwise moving during the exposure. It can be controlled by explaining to the patient the importance of holding still, making the patient as comfortable as possible on the imaging table, using the shortest possible exposure time, and using positioning devices (Fig. 1.68).<br>• Involuntary motion is movement that the patient cannot control. Its effects will appear the same as those of voluntary motion in most situations, with the exception of within the abdomen (Fig. 1.69). In the abdomen, peristaltic activity of the stomach and intestines can be identified on a projection by sharp bony cortices and blurry gases (see Fig. 1.69). The technologist's only means of decreasing the blur caused by involuntary motion is to use the shortest possible exposure time.<br>• Normal voluntary motions such as breathing or shaking can become involuntary motions (e.g., an unconscious patient is unable to control breathing and a patient with severe trauma may be unable to control shivering). |
| Double exposure | • A double-exposed image may occur with computed radiography when two projections are exposed on the same IR cassette without processing having been done between the exposures. The projections exposed on the IR can be totally different and easy to identify (Fig. 1.70), or they may be the same projection, with almost identical overlap (Fig. 1.70). Double-exposures of the same projections typically appear blurry and can easily be mistaken for patient motion (Fig. 1.71). When evaluating a blurry projection, look at the cortical outlines of bony structures that are lying longitudinally and transversely to see if you can find more than one representing the same structure. If one outline is demonstrated, the patient moved during the exposure, but if two are demonstrated, the projection was exposed twice and the patient was in a slightly different position for the second exposure.<br>• A double-exposed computed radiography image will demonstrate adequate brightness because it will be rescaled during processing. |

*CR*, Central ray; *DEL*, detector element; *FOV*, field of view; *IR*, image receptor; *OID*, object–image receptor distance; *SID*, source–image receptor distance.

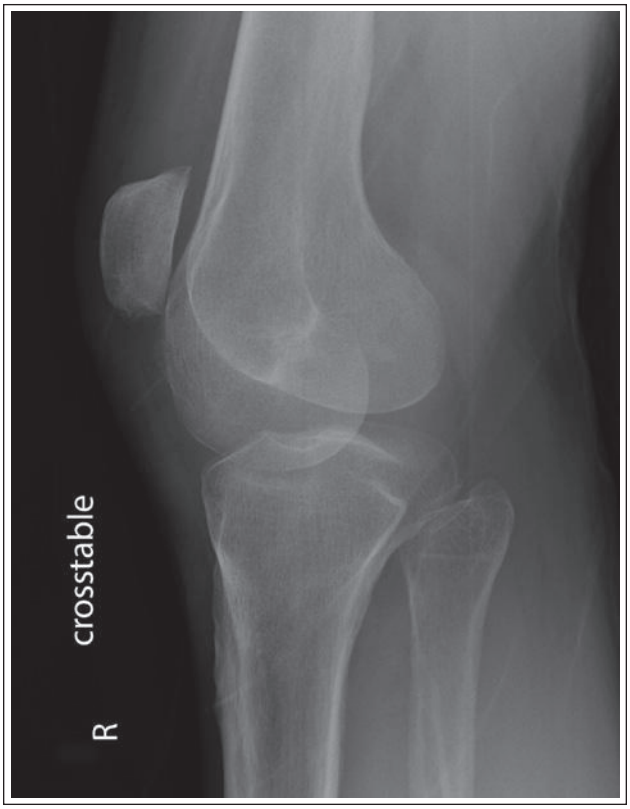



**FIGURE 1.61** Poorly positioned cross-table lateromedial knee projection. The cross-table lateral knee projection demonstrates the medial femoral condyle anterior and distal to the lateral femoral condyle. An optimally positioned lateral knee projection should demonstrate superimposition of the femoral condyles. Because the patient is unable to rotate or move the leg for this projection, the CR needs to be adjusted to obtain an optimal projection. The physical space between the femoral condyles of the knee, as measured on a skeletal bone, is approximately 2 inches (5 cm). Using the CR adjustment guidelines in Table 1.7, step 5, we find that structures that are 2 inches apart will require a 5-degree CR angle adjustment to move the part situated farthest from the IR 0.25 inch (0.6 cm) more than the structure situated closer to the IR. The medial condyle is situated closer to the IR so the lateral condyle is the one that will be moved with a CR adjustment. Because the anterior and distal femoral separation is 1 inch (2.5 cm), the CR will need to be angled 20 degrees cephalically to move the lateral condyle anteriorly to align with the anterior surface of the medial condyle and the x-ray tube will need to be rotated 20 degrees caudally to move the lateral condyle distally to align with the medial condyle.

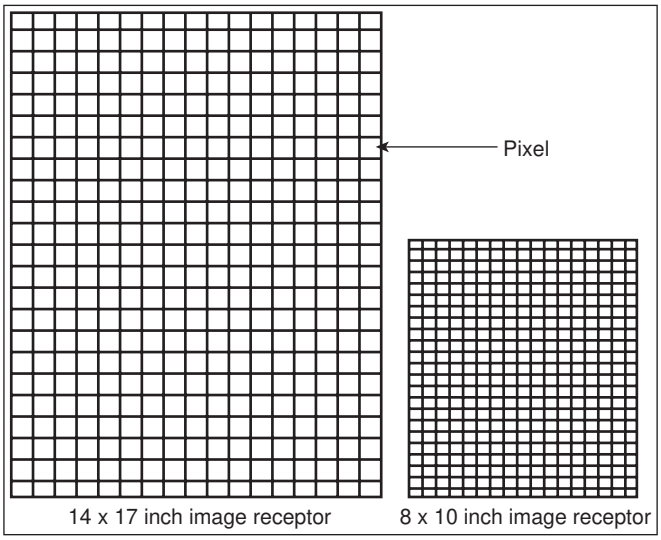



**FIGURE 1.62** Computed radiography systems have a set matrix size. The image matrix refers to the layout of pixels in rows and columns and is determined by the system's manufacturer. A larger matrix size will provide a higher number of pixels. The size of the pixels in the matrix is determined by the field of view (FOV). The FOV defines the area on the IR from which data are collected. Because the entire IR is scanned for data during processing, the FOV is the entire IR cassette (imaging plate) and because different cassette sizes are used, the size of the IR chosen influences the size of the FOV, size of pixels, and resulting spatial resolution. A computed radiography system using a matrix size of 1024 × 1024 will divide the image into 1,048,576 pixels. Spreading this matrix over a 14 × 17 inch FOV will result in larger pixel sizes than spreading the matrix over an 8 × 10 inch FOV. Because the 8 × 10 inch IR will contain pixels of smaller size, it will provide superior spatial resolution.

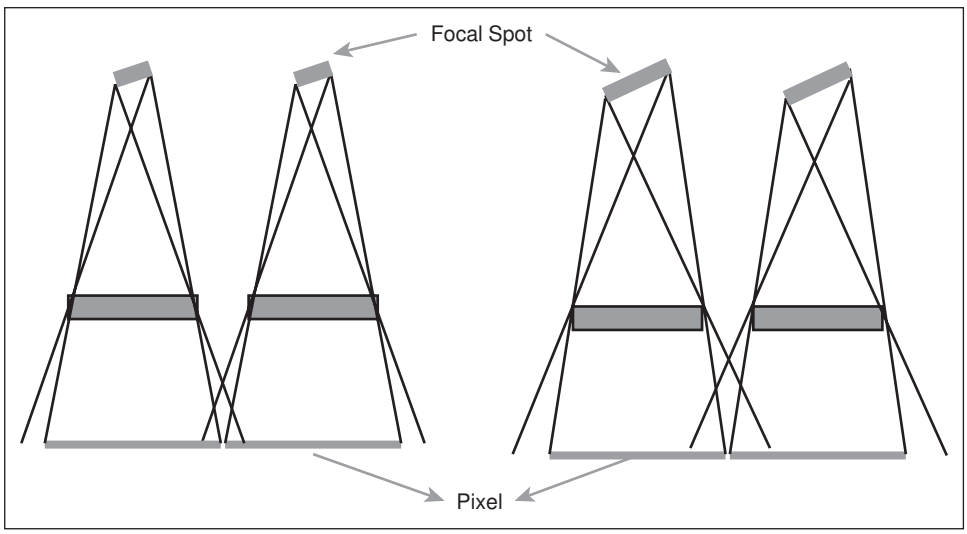



**FIGURE 1.63** Focal spot size. The smaller the focal spot size used, the better will be the spatial resolution on the projection because less blur will be spread to the adjacent pixel.

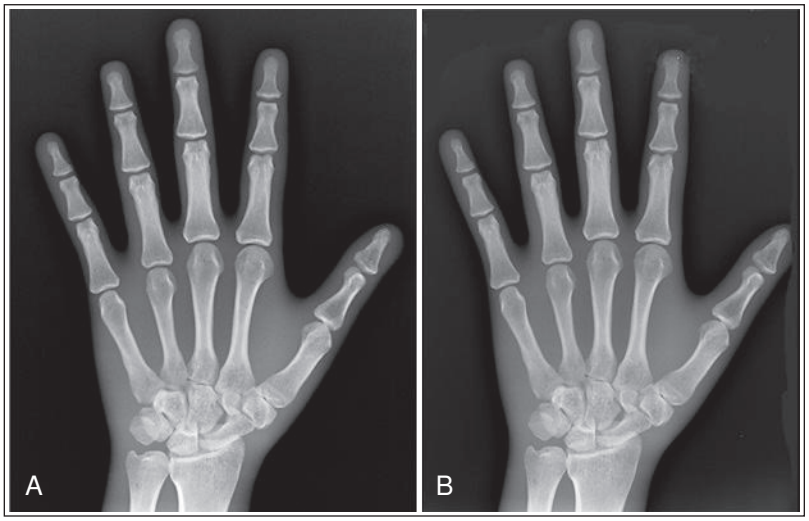



**FIGURE 1.64** Comparing sharpness of recorded detail between (A) small and (B) large focal spot. Compare the trabecular patterns and cortical outlines on these PA hand projections. (A) was obtained using a small focal spot, and (B) was obtained using a large focal spot. Note how the use of a small focal spot increases the spatial resolution.

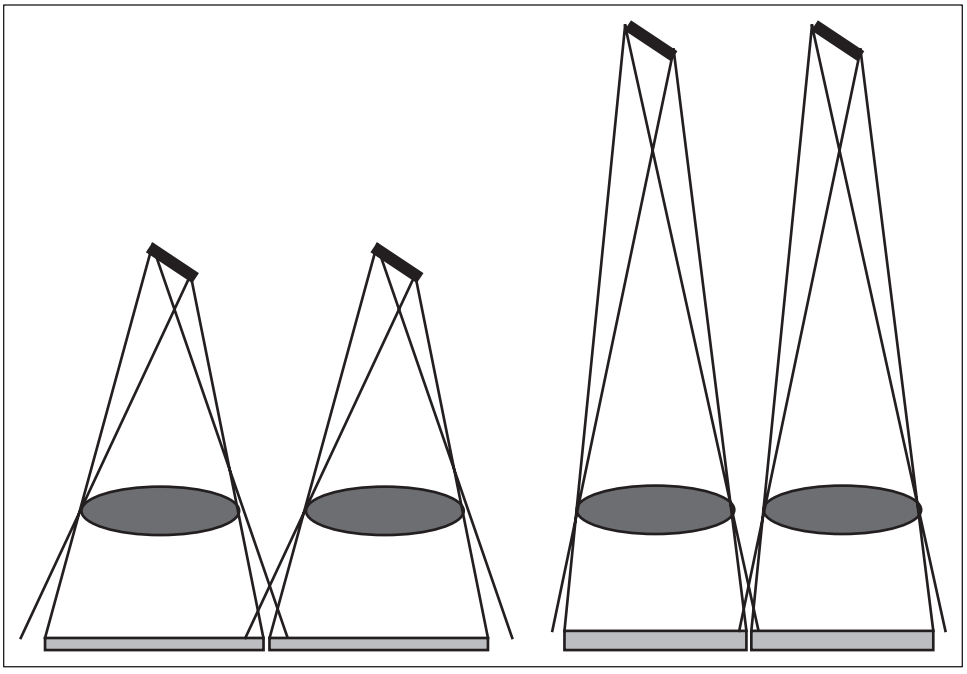


**FIGURE 1.65** SID and spatial resolution. The longer the SID, the sharper the recorded details because the beams recording the detail edges are nearer to the CR and recorded with straighter x-rays.

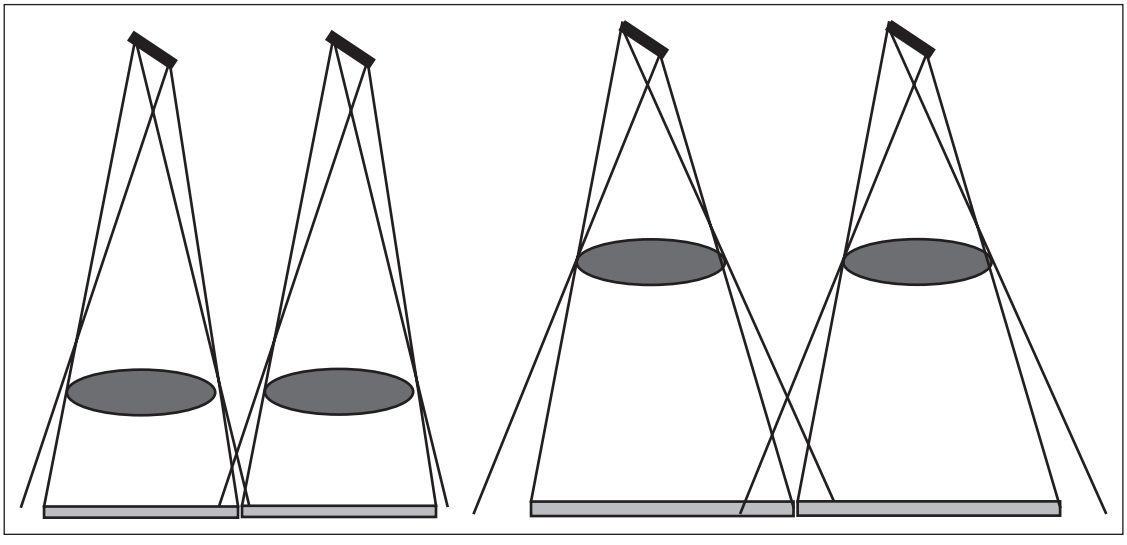


**FIGURE 1.66** OID and spatial resolution. The shorter the OID, the better the spatial resolution.

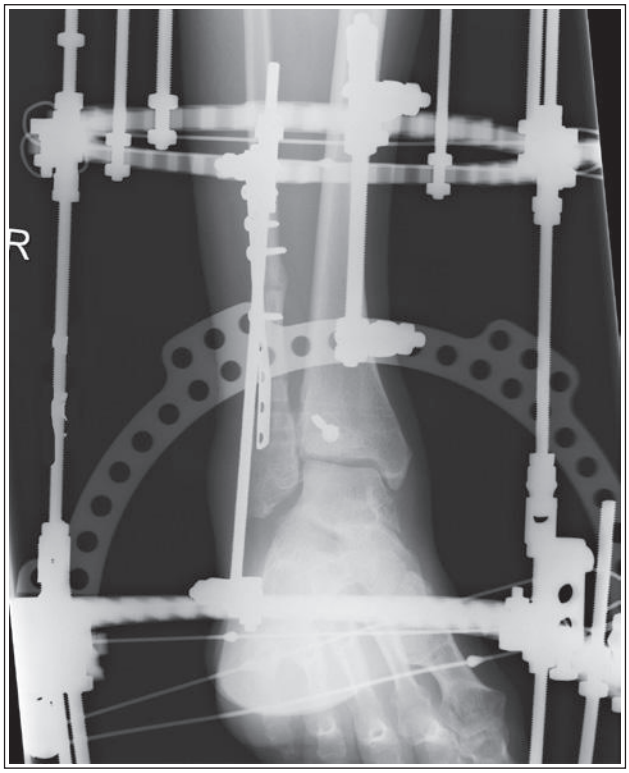



**FIGURE 1.67** AP ankle projection obtained at a long OID because of traction device. In nonroutine clinical situations, the technologist may be unable to get the part as close to the IR as possible. One example of this is a patient who is unable to straighten the knee for an AP projection or is in traction as demonstrated in the AP ankle projection. For this situation the ankle would be at an increased OID that could not be avoided. To offset magnification the SID can be elevated above the standard, and equal magnification will result if the ratio between the SID and OID remain the same. A projection taken at a 1-inch OID and 40-inch SID would demonstrate the same magnification as one taken at a 4-inch OID and 160-inch SID because both have a 1:40 ratio. It is often not feasible to increase the SID the full amount needed to offset the magnification completely because the SID cannot be raised that high.

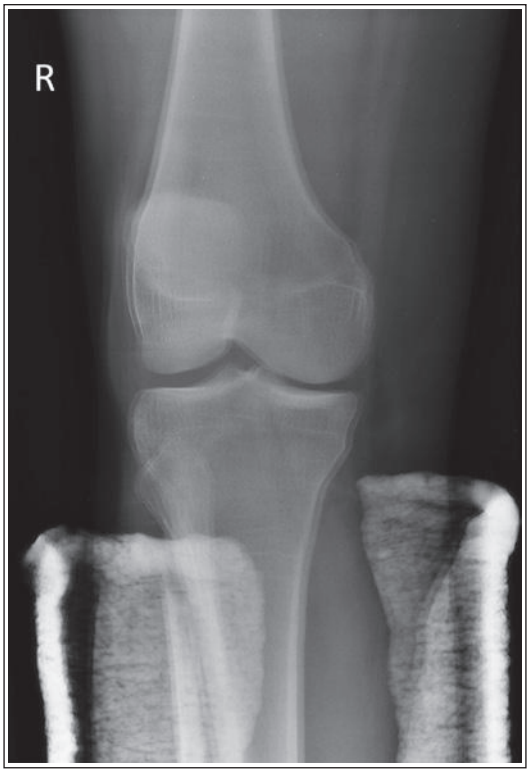



**FIGURE 1.68** Anteroposterior oblique knee projection demonstrating voluntary patient motion.

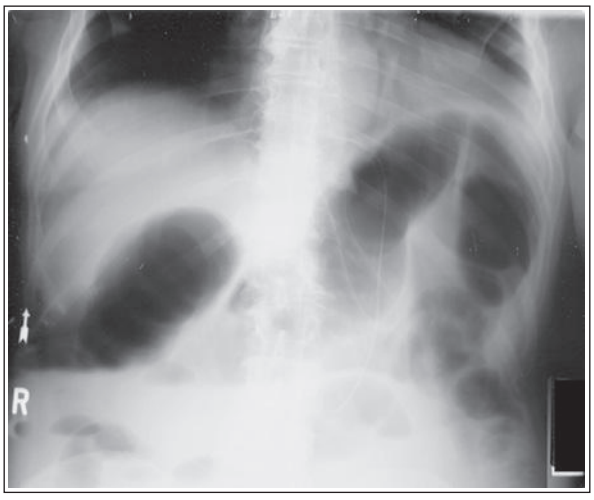



**FIGURE 1.69** Involuntary patient motion on AP abdomen projection.

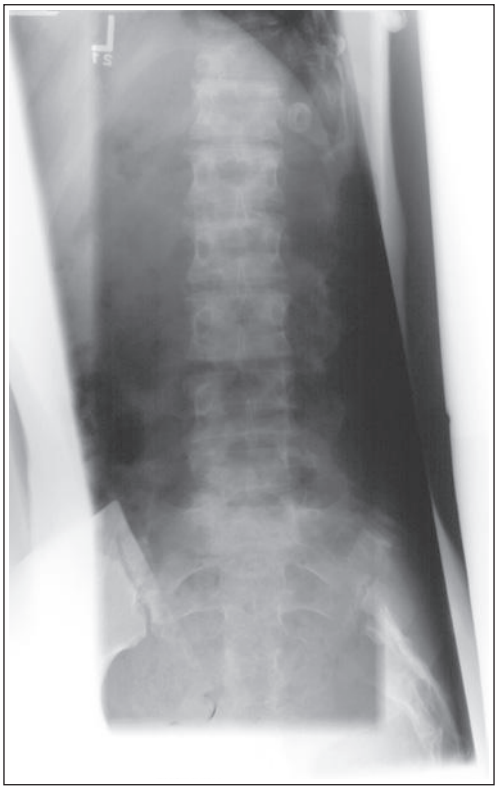


**FIGURE 1.70** Double-exposed AP and lateral vertebral projections.

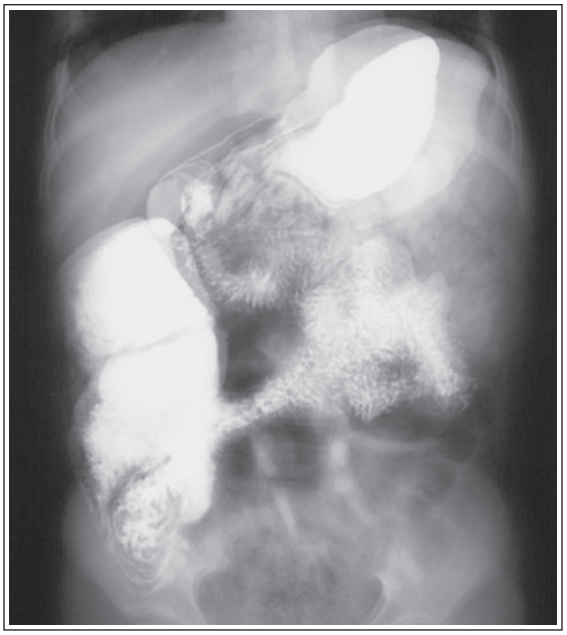


**FIGURE 1.71** Double-exposed AP abdomen projections with barium in stomach and intestines.

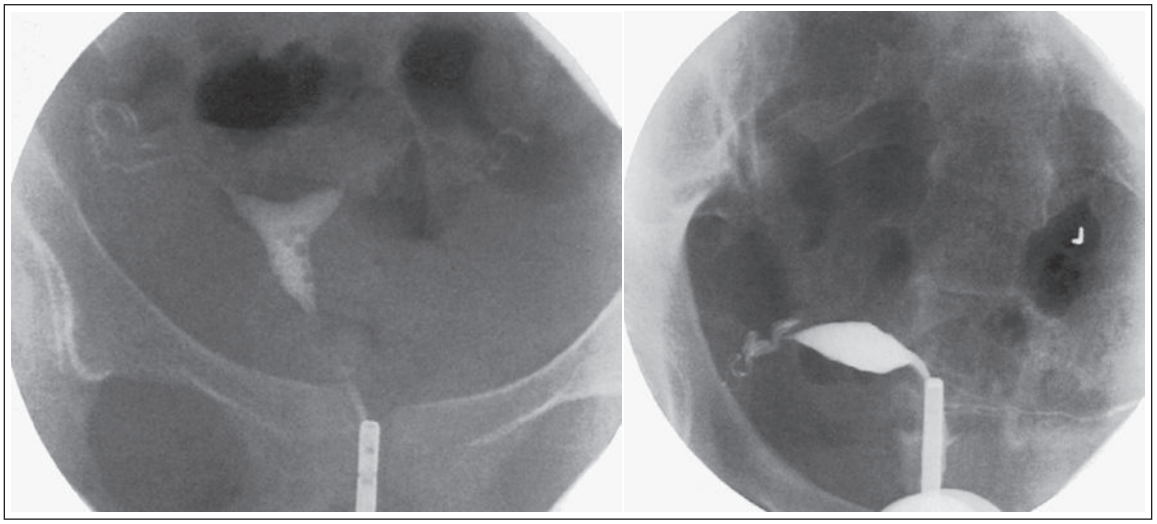


**FIGURE 1.72** Hysterosalpingogram. The uterus is found at the midline, superior to the bladder. It is approximately 3 inches (7.5 cm) long; its inferior aspect begins at the level of the symphysis pubis and it extends anterosuperiorly. The uterine tubes are bilateral, beginning at the superolateral angles of the uterus and extending to the lateral sides of the pelvis. Tucked between the lateral side of the pelvis and the uterus and inferior to the uterine tubes are the ovaries. The exact level at which the uterus, uterine tubes, and ovaries are found varies from patient to patient. Note the variation in the location of these structures in these two patients. Because the location of these organs within the inlet pelvis cannot be determined with certainty, the entire inlet pelvis is shielded.

**TABLE 1.9 Radiation Protection Best Practices**

| | |
|---|---|
| Effective communication | • Explain procedure to patient prior to beginning exam. Express the importance of holding still and maintaining position.<br>• Give clear, concise instructions and watch that patient follows them. |
| Immobilization devices | • Use immobilization devices when needed to prevent motion blur. |
| SSD | • Maintain an SSD of at least 12 inches (30 cm) to prevent an unacceptable entrance skin dose.<br>• As SSD increases, radiation exposure decreases.<br>• Calculate amount of exposure decrease by using the inverse square law *([new mAs]/[old mAs] = [old distance squared]/[new distance squared]).* |
| Pregnancy | • Question females of childbearing age if there is a chance of pregnancy.<br>  • If there is hesitancy rather than denial, complete additional questioning and a pregnancy test.<br>• Avoid radiation exposure or limit it during embryonic stage of development as the cells are extremely radiosensitive and easily damaged by radiation. |
| Shield gonads | • When they are within 2 inches (5 cm) of the primary x-ray beam.<br>• If the patient is of reproductive age and the shield does not cover the VOI.<br>• Shields are to be made of a minimum of 1 mm of lead. |
| AP torso projections female gonadal shielding | • Shield the ovaries, uterine (fallopian) tubes, and uterus (Fig. 1.72).<br>• Use a flat contact shield cut to the shape of the inlet pelvis (Figs. 1.73 and 1.74).<br>  • The dimensions of the shield used is varied according to the amount of magnification that the shield will demonstrate, which is determined by the OID and SID and by the size of the pelvis, which increases from infancy to adulthood. Calculate the % of magnification using the formula: *% of magnification = SID/SOD or image size/object size.*<br>• Before palpating for shield placement, explain the reason why you are palpating and ask permission to do so.<br>• Place the narrower end of the shield just superior to the symphysis pubis and allow the wider end of the shield to lie superiorly over the reproductive organs.<br>• Move shield side-to-side, centering it between the anterior superior iliac spines (ASISs).<br>• When using radiation protection on children, do not palpate for the pubic symphysis, because it is not full formed and they are taught that no one should touch their "private areas." Instead, use the greater trochanters to position the shield because they are at the level of the superior border of the pubic symphysis.<br>• Having the patient suspend respiration can help to keep the shield from moving after positioning. |
| AP torso projections male gonadal shielding | • Shield the testes (Fig. 1.75).<br>• Use a flat contact shield, cut in the shape of an isosceles triangle with rounded corners.<br>• Place one of the shield's rounded corners approximately 1–1.5 inches (2.5–4 cm) inferior to the symphysis pubis. The shield frames the inferior outlines of the pubic symphysis and inferior ramus and extends inferiorly until the entire scrotum is covered. |
| Lateral projection female and male gonadal shielding | • Lay a flat contact shield along an imaginary plane that connects the coccyx and a point 1-inch (1.5 cm) posterior to the ASIS (Figs. 1.76 and 1.77). |
| Radiosensitive cells | • Shield the eyes, thyroid, breasts, and gonads whenever they lie within 2 inches (5 cm) of the primary beam. |
| Collimation | • Tightly collimate to within 0.5–1 inches (1.25–2.5 cm) of the VOI. |
| Exposure factors | • Select the highest practical kV and the lowest mAs that will produce an EI number that is at the ideal level. |
| AEC backup timer | • Set the AEC backup timer at 150%–200% of the expected manual exposure time to prevent overexposure to the patient when the AEC is not properly functioning or the workstation is not set correctly. Once this time is reached, the exposure will automatically terminate. |
| Dose creep | • Avoid dose (technique) creep by using higher technical factors (kV or mAs) than necessary because of fear of producing projections with quantum noise. |
| Anatomic artifacts | • Do not allow the patient or x-ray personnel to hold the VOI in position without lead gloves if his/her hand will be within the exposure field (Fig. 1.78).<br>• Use positioning and immobilization tools to help the patient to maintain the appropriate positioning. |
| Personnel and family members in x-ray room during exposure | • Whenever possible, no one other than the patient is in the room during the exposure.<br>• If anyone remains in the room during the exposure:<br>  • Lead protection attire such as aprons, thyroid shields, glasses, and gloves are worn.<br>  • He/she stands out of the path of the radiation source and as far from it as possible. |

*AEC*, Automatic exposure control; *EI*, exposure index; *OID*, object–image receptor distance; *SID*, source–image receptor distance; *SSD*, source-skin distance; *VOI*, values of interest.

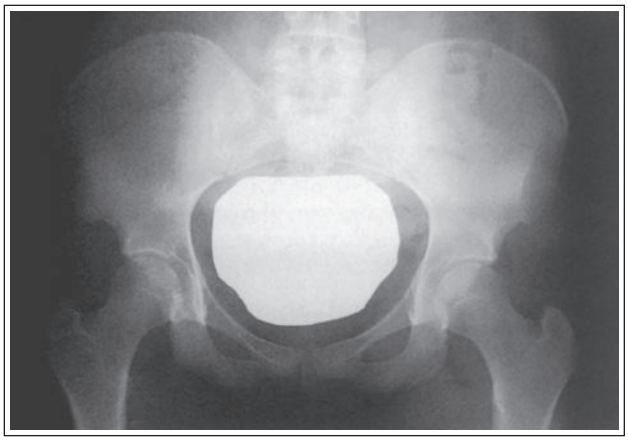


**FIGURE 1.73** Proper gonadal shielding in the female.

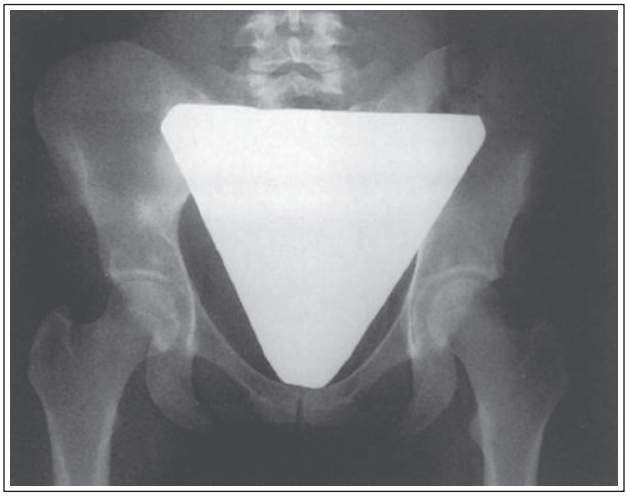


**FIGURE 1.74** Poor gonadal shielding in the female. Oddly shaped and male (triangular) shields do not effectively protect the female patient. The dimensions of the shield used should be varied according to the amount of magnification that the shield will demonstrate, which is determined by the OID and SID used and by the size of the pelvis, which increases from infancy to adulthood.

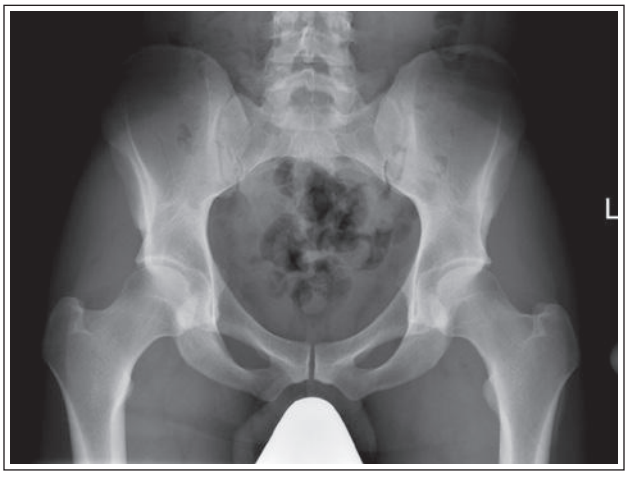



**FIGURE 1.75** Proper gonadal shielding in the male. The reproductive organs that are to be shielded on the male are the testes, which are found within the scrotal pouch. They are located along the midsagittal plane, inferior to the symphysis pubis.

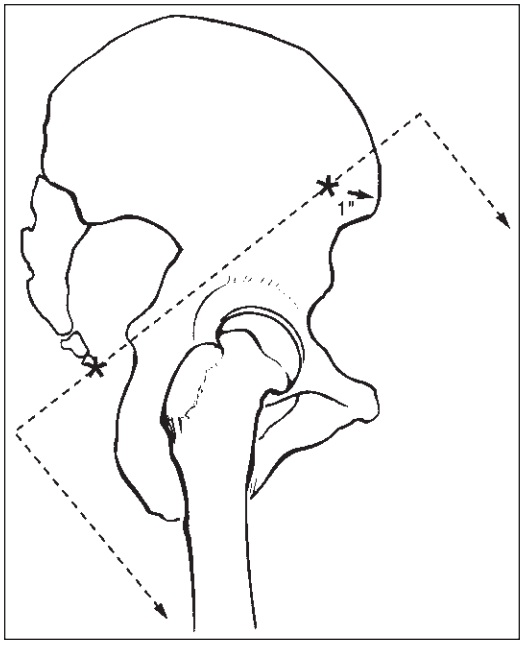



**FIGURE 1.76** Gonadal shielding for the lateral projection in both the male and female. This shielding method can be safely used for lateral vertebral, sacral, or coccygeal projections without fear of obscuring the VOI.

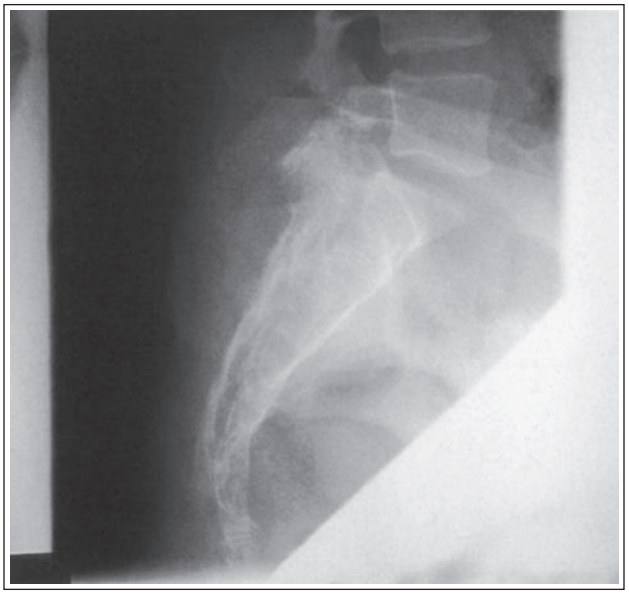


**FIGURE 1.77** Proper gonadal shielding in the lateral projection.

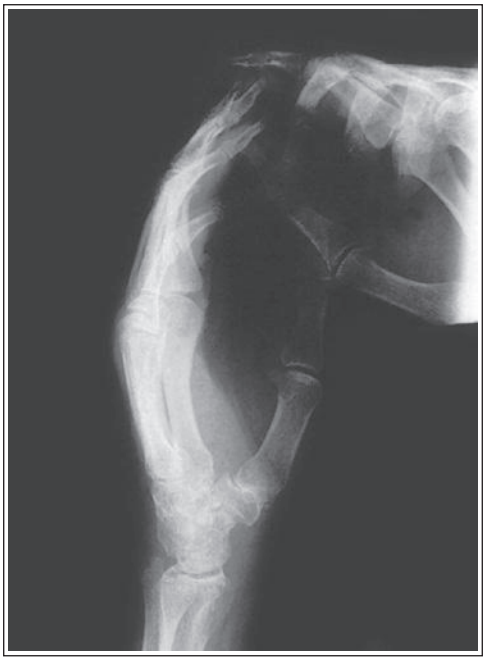


**FIGURE 1.78** Lateral hand projection with an anatomic artifact. Anatomic artifacts are structures other than what is required that are demonstrated on the projection. Note in the figure how the patient's other hand was used to help maintain the lateral hand position. This is not an acceptable practice. Many sponges and other positioning tools are available to aid in positioning and immobilization of the patient. Whenever the hands of the patient, x-ray personnel, or others must be within the radiation field, they must be properly attired with lead gloves.

More than adults, children are susceptible to low levels of radiation because they possess many rapidly dividing cells and have a longer life expectancy. In rapidly dividing cells, the repair of mutations is less efficient than in resting cells. When radiation causes DNA mutations in a rapidly dividing cell, the cell cannot repair the damaged DNA sufficiently and continues to divide; therefore the DNA remains in disrepair. The risk of cancer from radiologic examinations accumulates over a lifetime, and because children have a longer life expectancy, they have more time to manifest radiation-related cancers. This is particularly concerning because many childhood diseases require follow-up imaging into adulthood.

Continually evaluating one's radiation protection practices is necessary because radiation protection guidelines for diagnostic radiology assume a linear, nonthreshold, dose-risk relationship. Therefore any radiation dose, whether small or large, is expected to produce a response. Even when radiation protection efforts are not seen on the resulting projection itself, good patient care standards dictate their use. Table 1.9 lists radiation protection practices that, when followed, fulfill the ALARA (as low as reasonably achievable) philosophy.

CHAPTER

# 2

# Visibility of Details

## OUTLINE



## OBJECTIVES

*After completion of this chapter, you should be able to do the following:*

- Describe the processing steps completed in computed radiography and direct-indirect digital radiography (DR).
- State why the exposure field recognition process is completed in computed radiography and is not needed in DR.
- Identify the areas of an image histogram and list the guidelines to follow to produce an optimal histogram.
- Explain the relationship between the image histogram and the chosen lookup table in the automatic rescaling process.
- Discuss the causes of a histogram analysis error.
- List the exposure indicator parameters for the digital systems used in your facility, and discuss how to use them to evaluate and improve the quality of projections.
- Describe how to identify when a projection has been overexposed and underexposed.
- State the causes of overexposure and underexposure in digital radiography and the effect that each has on image quality.
- Describe the factors that affect contrast resolution.
- List the different artifacts found in radiography, and discuss how they can be prevented, when applicable.
- Discuss the difference between an optimal and an acceptable projection.
- List the guidelines for obtaining mobile and trauma projections, and state how technical factors should be adjusted to adapt for different mobile and trauma-related conditions.
- Describe the differences to consider when performing procedures and evaluating pediatric and obese patient projections.

## KEY TERMS

**additive condition**
**algorithm**
**anode heel effect**
**artifact**
**automatic exposure control**
**automatic rescaling**
**backup timer**
**bit depth**
**brightness**
**contrast resolution**
**destructive condition**
**differential absorption**
**dynamic range**
**exposure field recognition**
**exposure indicator**
**gray scale**
**histogram**
**histogram analysis error**
**image acquisition**
**imaging plate**
**lookup table**
**moiré grid artifact**
**phantom image**
**postprocessing**
**procedural algorithm**
**quantum noise**
**radiopaque**
**raw data**
**saturation**
**scatter radiation**
**subject contrast**
**thin-film transistor**
**windowing**

## DIGITAL RADIOGRAPHY

Two types of digital imaging systems are used in radiography to acquire and process the radiographic image, the cassette-based system known as computed radiography, and the cassette-less detector system known as direct-capture digital radiography (DR). The systems are unique in the methods that they use to acquire and process the image before sending it to the computer to be analyzed and manipulated. Understanding the acquisition and processing steps of each system will help the technologist prevent errors that cause poor acquisition and processing, and understand the indicators used to analyze the quality and improve the radiographic projection.

### Image (Data) Acquisition

**Computed Radiography.** Computed radiography uses cassettes that envelope an imaging plate (IP) as the image receptor (IR) that can be placed in the Bucky or on the imaging tabletop to obtain the projections. Prior to the exposure, the computed radiography cassette is associated with the patient, body part, and projection at the workstation. Selecting the correct body part and projection ensures that the correct algorithm type will be used during the histogram analysis process and that the correct lookup table (LUT) is applied when the image is rescaled. During the image acquisition process, the radiographic exposure absorbed by the IP causes ionization and the released electrons to be trapped in the IP's photostimulable phosphor. The number and distribution of the trapped electrons in each area of the IP represent the differential absorption and latent image of the body part being radiographed. Once the IP has been exposed, the cassette is loaded, and the IP is extracted and sent to the reader unit. The IP is divided into a matrix with rows and columns of pixels, and a laser beam is scanned back and forth across the plate, releasing the trapped electrons, resulting in the ionized atoms moving to a neutral state and the extra energy from the photon being released as visible light through a process called photostimulable luminescence. The emitted light is directed through the light channeling guide to the photomultiplier tube (PMT), where it is amplified and converted to an electrical signal and then sent to the analog-to-digital converter (ADC) to be digitized. During digitization, each pixel is assigned a digital value that represents the amount of light that was emitted from that surface of the IP. Pixels that received greater IR exposure are assigned values that represent darker gray shades, whereas the pixels receiving less exposure are assigned values that represent lighter gray shades. All the digital numbers (gray shade values) together make up what is referred to as the *raw data*. Prior to the creation of the histogram, a partitioned pattern recognition (also called *segmentation*) algorithm is applied to the data to identify and count the number of projections that have been obtained using a single photostimulable phosphor plate (PSP) plate so that each can be processed separately.

**Direct-Capture Digital Radiography.** Direct-capture DR uses a cassette-less imaging capture system that is hard-wired to the image processing system and does not require the technologist to physically place the IR into the reader. Prior to the exposure, the technologist must choose the correct patient and projection from the workstation to ensure that the correct histogram analysis and LUT are applied to the image before it is displayed. The IR contains a matrix of pixel-size radiation absorption areas called *detector elements* (DELs), which includes a thin-film transistor (TFT) that captures the electrons which are freed through ionization in the DEL when the remnant radiation strikes it, and the storage capacitor that stores the electrons. The latent image in the remnant radiation is represented by the TFTs collecting varying intensities. After the exposure, the TFT acts as a switching gate, sending the stored signals to the computer in an orderly manner for processing and manipulation where each DEL signal is given a digital number that represents the gray shade value. Only the DELs in the TFT that have received radiation, which is determined when the technologist collimates, collect and send electric signals and are included in the image. This eliminates the need for the partitioned pattern recognition process that is completed in computed radiography and the many histogram errors that poor recognition can cause.

### Histogram Construction

After the raw data have been acquired in both computed radiography and DR, a histogram graph is generated that has the pixel gray shade values on the *x*-axis and the number of pixels with that gray shade value on the *y*-axis (Fig. 2.1). The peaks and valleys in the histogram represent the subject contrast in the remnant radiation and are determined by the total exposure (kV and mAs selected) that is used and the resulting differential absorption that creates the latent image. Gray shade values between white to black are positioned on the histogram from left to right, with the metallic objects and contrast mediums recorded on the left in the graph, followed by bone, soft tissues near the center, fat, and finally gaseous or air values on the right. The tail or high spiked portion on the far right of some histograms represents the pitch black background value that is outside the values of interest (VOI; those that represent the anatomical structures of interest) and in the exposure field. This background value will be the darkest value because this area is exposed to primary radiation that does not go through any part of the patient, such as with extremity and chest projections that have been collimated close to the skin line but not within it (Fig. 2.2). The spike is referred to as the raw exposure area and is not visible on projections in which the entire IR is covered with anatomy, such as abdomen projections or projections in which the collimation field

is within the skin line, such as for an anteroposterior (AP) lumbar vertebrae projection.

When optimal procedure practices are used (Table 2.1), because the subject contrast of a particular anatomic structure (e.g., chest, abdomen, shoulder) is fairly consistent from exposure to exposure, the shape of each procedure's histogram is fairly consistent as well.

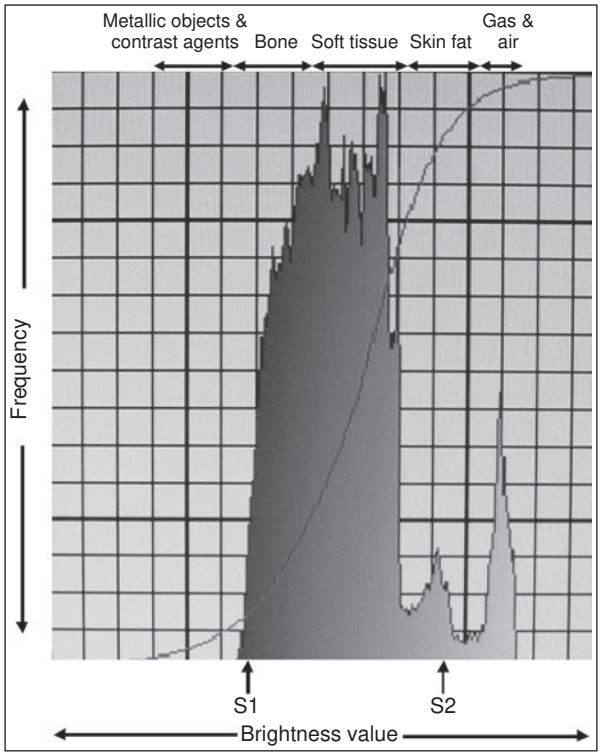



**FIGURE 2.1** Histogram.

## Exposure Field Recognition

Once the image histogram has been created, it is analyzed to identify the data that is part of the VOI from all other data background exposure, positive contrast mediums, nonremovable metallic objects (i.e., prostheses), and

**TABLE 2.1 Guidelines for Producing Optimal Image Histograms**

**Computed and Direct-Capture Radiography**

- Eliminate any removable artifacts.
- Set the correct technique factors for the projection.
- Choose the correct procedural algorithm (body part and projection) from the workstation menu.
- Center the CR to the center of the VOI.
- Collimate as closely as possible to the VOI, leaving minimum background in the exposure field.
- Control the amount of scatter reaching the IR (grids, collimation, lead sheets).

**Computed Radiography Only**

- Use the smallest possible IR, covering at least 30% of the IR.
- Erase the IP if the IR has not been used within 48 h.
- If collimating smaller than the IR, center the VOI and show all four collimation borders.
- When placing multiple projections on one IR, all of the collimation borders must be parallel and equidistant from the edges of the IR, and at equal distance from each other.
- Do not leave the IR cassette in the imaging room while other exposures are being made and read the IP shortly after the exposure.
- Process the IR promptly.

*CR*, Central ray; *IP*, imaging plate; *IR*, image receptor; *VOI*, values of interest.

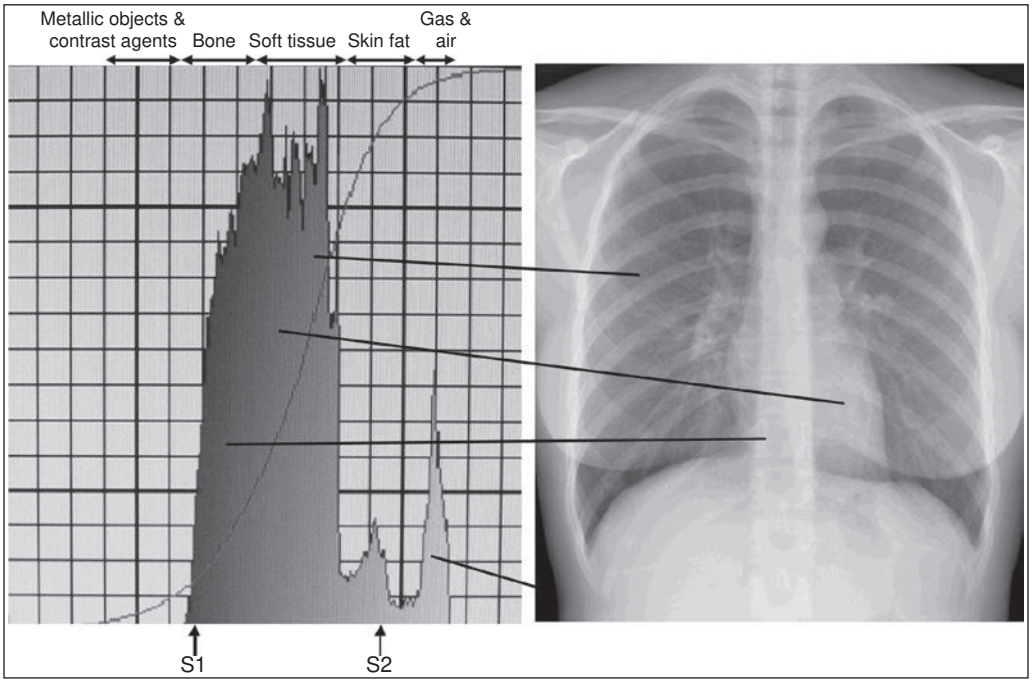



**FIGURE 2.2** Histogram of PA chest projection.

radiopaque artifacts, so that only the range of pixel data from the anatomical VOI is sent to the LUT for rescaling. This is accomplished by applying an exposure field recognition algorithm. During this process, the computer scans inward from both ends of the image histogram until it identifies the first gray shades that contain a pixel count or a threshold number (a specific number of pixels in the column is reached) of pixels on each end (Fig. 2.3). The shade value that is identified on the left is labeled $S_{min}$ and represents the minimum useful gray shade value (brightest shade), and the shade value identified on the right is labeled $S_{max}$ and represents the maximum useful gray shade value (least brightness). The analysis will also identify $S_{ave}$, which is the average pixel value (usually soft tissue) and is located halfway between $S_{min}$ and $S_{max}$. $S_{ave}$ is used to calculate the exposure index (EI) readings and can be used to determine the accuracy of the IR exposure if there is no exposure field recognition error.

Q. B. Carroll in "Radiography in the Digital Age" describes three general types of histogram analysis that are applied to the image histogram. The type that is associated with a particular projection is based on the expected shape of the acquired image histogram and is set when the technologist selects the procedure algorithm (body part and projection) on the workstation. These algorithms are designed to inform the computer to expect certain nonanatomical structures on the histogram, and when they are identified to exclude them from the VOI (Fig. 2.4).

Type 1 is associated with procedures (i.e., extremities) that will have raw exposure area between the anatomical structure and the collimation border. The image histogram on these procedures is expected to demonstrate a tail or high spiked area on the far right, and because this tail does not represent an anatomical structure, it should not be included in the VOI. The type 1 applied algorithm will instruct the computer to skip over the dark values that represent this tail when it is scanning inward from the right side to label $S_{max}$.

Type 2 is associated with procedures (i.e., lumbar spine procedures) that will not have the raw exposure tail on the far right of the image histogram because the procedure requires the technologist to collimate within the skin border of the anatomical structure, excluding any raw exposure area. When this algorithm type is set, the computer does not search for a tail and does not exclude the data on the far right from the VOI.

Type 3 is associated with a procedure when a large radiopaque area is present in the exposure field, such as a positive contrast medium or nonremovable metallic object (i.e., prosthesis), and the image histogram is expected to demonstrate these nearly white values on the

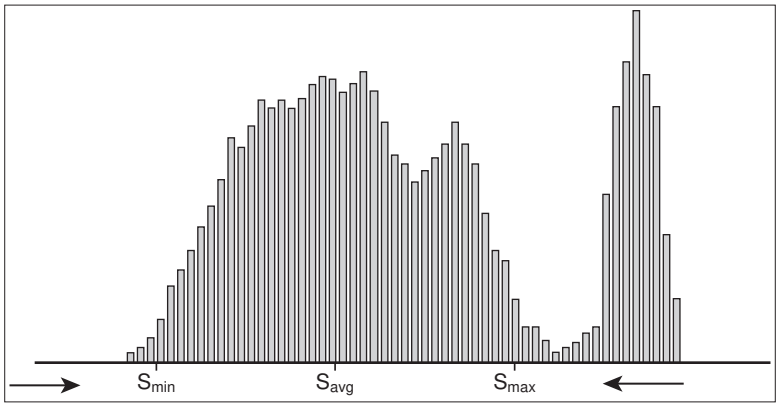



**FIGURE 2.3** Identifying the VOI on the image histogram.

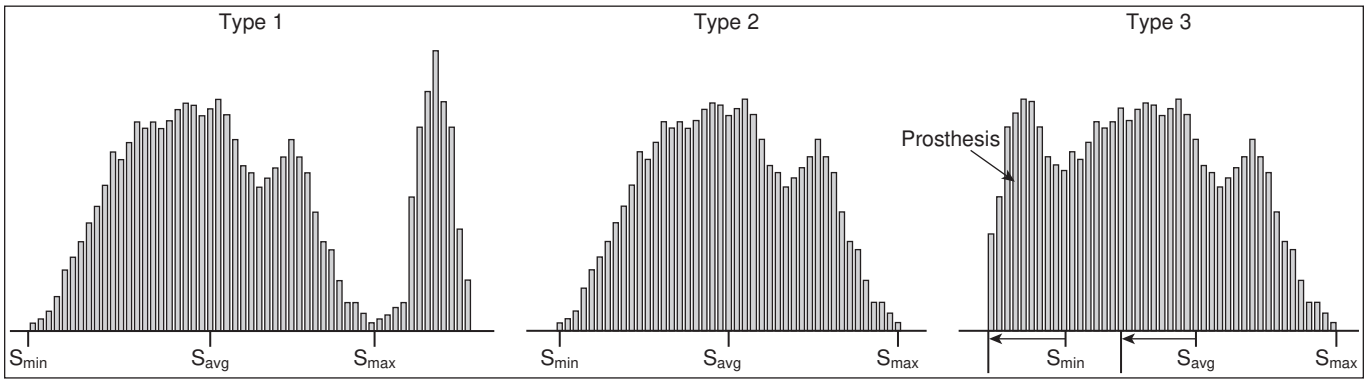



**FIGURE 2.4** Histogram analysis types.

far left. The type 3 applied algorithm will instruct the computer to skip over these white values when it is scanning inward from the left to label $S_{min}$.

## Automatic Rescaling

Included in the computer software is an LUT, or "ideal," histogram for every radiographic projection. These LUTs provide the standard for $S_{min}$, $S_{ave}$, and $S_{max}$ that the image histogram is compared and rescaled to. The LUT that is used for a projection is determined when the procedure algorithm is chosen on the workstation. After the histogram analysis is completed and the VOI identified, the pixel values that represent the VOI are sent to the computer for rescaling to the appropriate LUT (also called gradation processing and normalization). Rescaling involves aligning the brightness and somewhat the gray scale range of the image histogram's VOI with that of the selected LUT by applying algorithms to the data.

To rescale for brightness, the computer finds the difference in the $S_{ave}$ values between the image histogram and the LUT, and then makes this adjustment difference to all values in the VOI, aligning the image histogram values with the LUT values (Fig. 2.5). The values in the image histogram are always changed to the standard values in the LUT. If the image histogram was positioned farther to the right than the LUT's histogram, representing a projection in which the remnant beam had more IR exposure than is desired, the algorithm applied to the data would move the obtained values of each pixel toward the left, aligning them with the values in the LUT and brightening up the pixel values before they are displayed. If the image histogram was positioned farther to the left than the LUT's histogram, representing a projection in which the remnant beam had less IR exposure than is desired, the algorithm applied would move the obtained values of each pixel toward the right, aligning them with the values on the LUT and decreasing the brightness of the pixel values before they are displayed.

To rescale the image histogram to the LUT's gray scale, the number of gray shades between $S_{min}$ and $S_{max}$ are adjusted by rounding the values found in the image histogram up or down as needed to align them with the gray scale values in the LUT (Fig. 2.6). If the image histogram is wider than the LUT's histogram, representing a projection in which the remnant beam demonstrated lower subject contrast than desired, the algorithm applied to the data would narrow the histogram, decreasing the

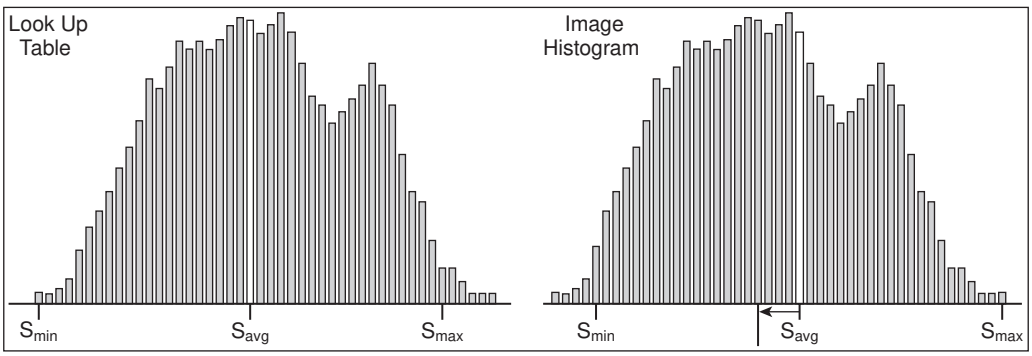



**FIGURE 2.5** When rescaling for brightness the image histogram's values are adjusted toward brighter or darker *gray shades* the needed amount to align it with the LUT. The figure demonstrates this occurring for overexposure. The number of *gray shades* between $S_{min}$ and $S_{max}$ has not changed between the two illustrations.

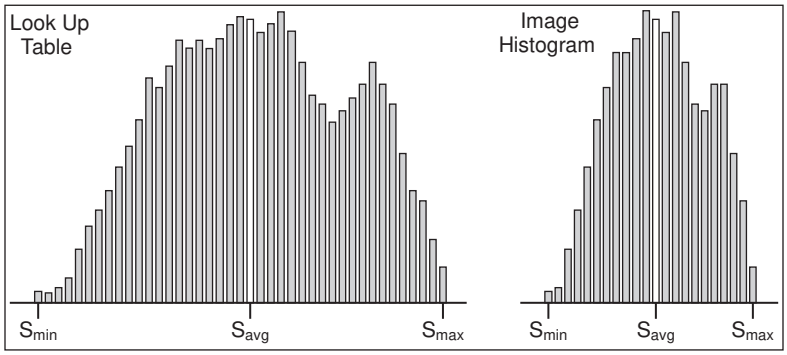



**FIGURE 2.6** When rescaling for gray scale the image histogram's values are rounded up or down as needed to align with the number of gray scales in the LUT. The figure demonstrates how the image histogram would change after rescaling to the lower contrast LUT. There will be a widening of the histogram, increasing the number of gray scales used.

number of gray scales, which increases the degree of difference between each gray scale and increases the contrast between details. If the image histogram was narrower than the LUT's histogram, representing a projection in which the remnant beam demonstrated higher subject contrast than desired, the algorithm applied to the data would widen the histogram, increasing the number of gray scales, which decreases the degree of difference between each gray scale, decreasing the contrast between details. This process aligns the gray scale values, but it does not adjust the number of pixels in each gray scale (represented by the *y*-axis on the histogram) to match the LUT. This explains why displayed projections obtained using inadequate kV will demonstrate so many light gray pixels and those obtained without appropriate scatter radiation control practices will demonstrate excessive dark gray pixels even after rescaling.

## Exposure Indicators

EIs are readings that denote the amount of radiation intensity that struck the IR. Although they give an indication of the amount of radiation that the patient was exposed to, they are not measures of dose to the patient because they do not take into account the energy level of the photons or attenuation. Each digital manufacturer has a method of determining the acceptable EI range and the ideal EI number for their system and provides these numbers to a technologist to use when determining the accuracy of the IR exposure. Table 2.2 lists different manufacturers' EIs for acceptable exposure for some of the computed radiography and DR systems available. Note that each provides an ideal or average EI and an EI range of acceptable exposures. The ideal EI represents a medium gray value, which usually indicates soft tissue, and because digital systems can successfully rescale a projection that was obtained using two times higher and lower IR exposure than is needed for the ideal EI, the EI acceptable exposure ranges listed will be what the readings would be if the exposure were doubled or cut in half from the ideal (Fig. 2.7). The EI expression varies from one manufacturer to another, and technologists are to be aware of those in the facilities where they work.

After the image histogram has been created and analyzed, the EI is read by the computer at the midpoint ($S_{ave}$) of the defined VOI, and it is displayed on the digital projection. To produce optimally exposed projections, the technologist's goal is to obtain EI readings that are as close to the ideal EI as possible for the digital system used. Projections in which the EI reading is not at the ideal level but within the acceptable range do not require repeating but are evaluated to determine why this has occurred and what technical changes to consider in future projections to bring the EI closer to the ideal. The technical factors are also be adjusted when a series of projections are obtained on the same body part and the first projection

**TABLE 2.2 Exposure Indicator Parameters**

| Digital System | Exposure Indicator | Acceptable Range | Ideal Exposure | Insufficient Exposure | Excessive Exposure |
|---|---|---|---|---|---|
| CareStream CR | Exposure index (EI) | 1700–2300 | 2000 | <1700 | >2300 |
| Fuji CR and Konica | Sensitivity (S) number | 100–400 | 200 | >400 | <100 |
| Agfa CR | Log median value (LgM) | 2.2–2.8 | 2.5 | <2.2 | >2.8 |
| Phillips DR | Exposure index (EI) | 55–220 | 110 | >220 | >55 |
| Siemens DR | Exposure index (EI) | 500–2000 | 1000 | <500 | >2000 |
| Siemens YSIO DR | Exposure index (EI) | 125–500 | 250 | <125 | >500 |

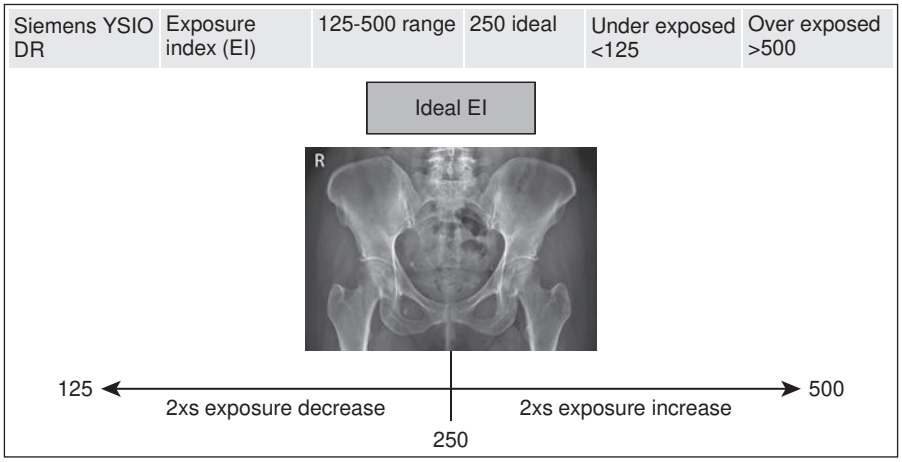



**FIGURE 2.7** Exposure indicator parameters for the Siemens YSIO DR system.