FOURTH EDITION

Radiographic Image Analysis

KATHY McQUILLEN MARTENSEN

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To my parents, Pat and Dolores McQuillen,
and to my husband, Van,
and to our family, Nicole, Zachary, Adam, Phil, Haley,
Katelynn, and Alexander.

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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, nonroutine situations, or 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 been changed to reduce repeatable information and provide efficient access to specific data. The new format includes additional boxes and tables that summarize important details and can be used for quick reference. This edition also includes many new and updated images, with improved detail resolution.

Chapters 1 and 2 lay the foundations for evaluating all projections, outlining the technical and digital imaging concepts that are to be considered when studying the procedures that are 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 detailed one-to-one correlation between the positioning procedures and image analysis guidelines.
- Discussions, with correlating images, on identifying how the patient, central ray, or image receptor were 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.
- Photographs of bones and models positioned as indicated to clarify information and demonstrate anatomy alignment when distortion makes it difficult.
- Practice images of the projection that demonstrate common procedural errors.

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The professional colleagues, book reviewers, educators, and technologists who have evaluated the book, sent me compliments and suggestions, and questioned concepts in the first three editions. Please continue to do so.

—Kathy

CONTENTS

CHAPTER 1

Image Analysis Guidelines

OUTLINE

OBJECTIVES

After completion of this chapter, you should be able to:

- State the characteristics of an optimal projection.
- Properly display projections of all body structures.
- State the demographic requirements for projections and explain why this information is needed.
- 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 sharpness of recorded details 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
atomic density
backup timer
contrast mask
decubitus
detector element (DEL)
distortion
dose creep
dose equivalent limit
elongation
exposure maintenance formula
field of view (FOV)
flexion
focal spot
foreshortening
grid
grid cutoff
image receptor (IR)
inverse square law
involuntary motion
lateral
law of isometry
manual exposure
matrix
medial
midcoronal plane
midsagittal plane
nonstochastic effects
object–image receptor distance (OID)
picture archival & communication system (PACS)
pixel
posterior
profile
project
radiolucent
radiopaque
recorded detail
scatter radiation
shuttering
source–image receptor distance (SID)
source-skin distance (SSD)
spatial frequency
spatial resolution
stochastic effects
volume of interest (VOI)
voluntary motion

WHY IMAGE ANALYSIS?

Radiographic images are such that slight differences in quality do not necessarily rule out the diagnostic value of a projection. Radiologists 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 teach technologists how to evaluate projections for acceptability, determine how to improve positioning and technical skills before repeating a projection, and continually improve skills.

Why should 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 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 the image. It is estimated that in the United States 68 million chest imaging procedures are performed each year 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 (Figure 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 (Figure 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.

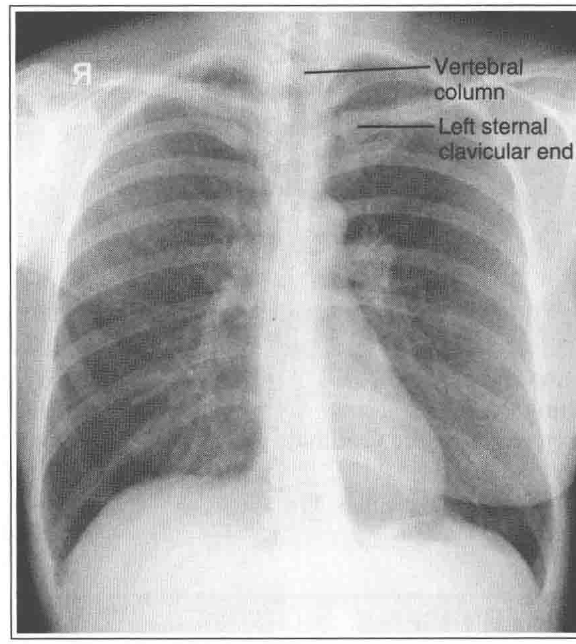

FIGURE 1-1 Rotated PA chest projection.

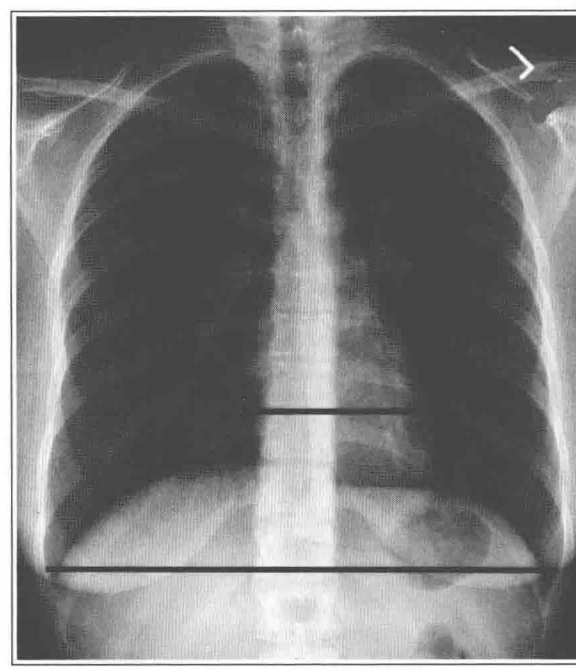

FIGURE 1-2 Evaluating a PA chest projection for mediastinal widening.

If instead of being evaluated for acceptability, projections are evaluated for optimalism, could more consistent and improved diagnoses be made from diagnostic projections? For example, Figures 1-3 and 1-4 demonstrate three lateral and PA wrist projections, all of which were determined to be acceptable and sent to the radiologist for review. Note how the trapezium is visualized only on the first lateral wrist projection but is not

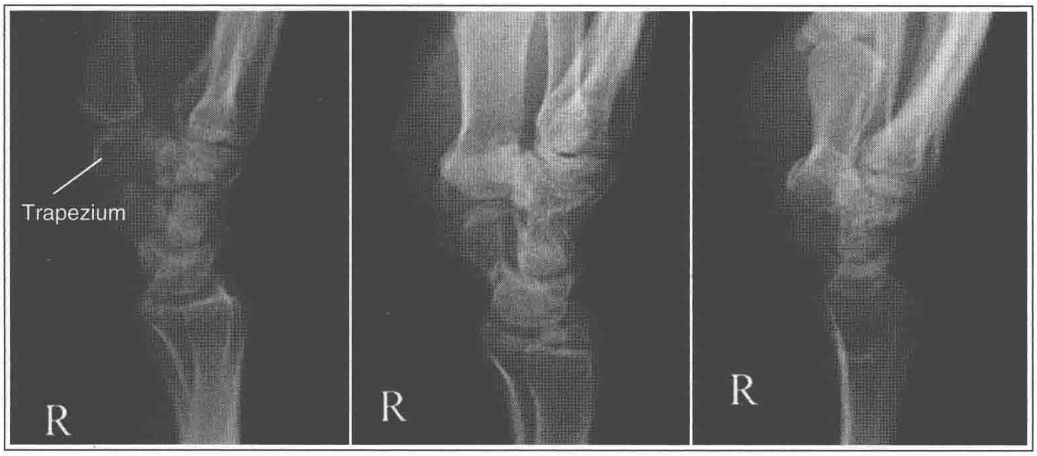

FIGURE 1-3 Lateral wrist projections demonstrating the difference in trapezium visualization with thumb depression and elevation.

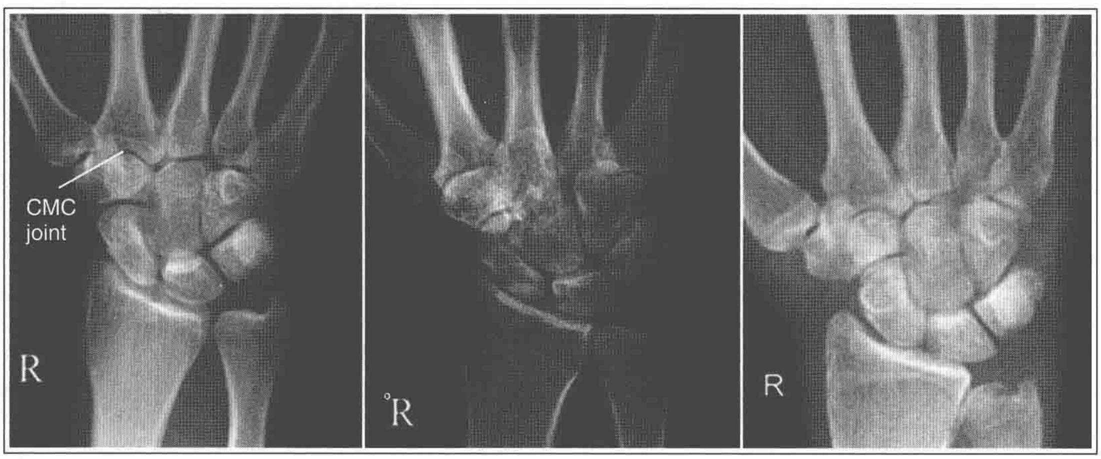

FIGURE 1-4 PA wrist projections demonstrating the difference in carpometacarpal (CMC) joint visualization with variations in metacarpal alignment with the IR.

demonstrated on the other 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 patient's 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 image receptor (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

Different terms are used in radiography to describe the path of the x-ray beam, the patient's position, the precise location of an anatomic structure, the position of one anatomic structure in relation to another, and the way a certain structure will change its position as the patient moves in a predetermined direction. Familiarity with radiography terminology will help you understand statements made throughout this text and converse competently with other medical professionals. At the beginning of most chapters there is a list of key terms that should be reviewed before reading the chapter. The glossary at the end of the textbook provides definitions of these terms.

CHARACTERISTICS OF THE OPTIMAL IMAGE

The guidelines needed to obtain optimal images of all body structures are taught in radiographic procedures, image analysis, radiation protection, and radiographic exposure (imaging) courses.

An optimal image of each projection demonstrates all the most desired features, which includes the following:

- Demographic information (e.g., patient and facility name, time, date)

- Correct markers in the appropriate position without superimposing volume of interest (VOI)
- Desired anatomic structures in accurate alignment with each other
- Maximum geometric integrity
- Appropriate radiation protection
- Best possible contrast resolution, with minimal noise
- No preventable artifacts

Unfortunately, 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 should be 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 should be carefully studied to determine whether skills can be improved before the next similar examination; continuous improvement is sought. A projection should not have to be taken a third time because the error was not accurately identified and the proper adjustment made from the first attempt.

This book cannot begin to identify the standards of acceptability in all the different imaging facilities. What might be an acceptable standard in one facility may not be acceptable in another. As you study the projections in this book, you may find that many of them are acceptable in your facility even though they do not meet optimal standards. You may also find that some of the guidelines listed are not desired in your facility. The goal of this text is not to dictate to your facility what should be acceptable and unacceptable projections. It is to help you focus on improving your image analysis, positioning, radiation protection, and exposure skills and to provide guidelines on how the projection may be improved when a less than optimal image results and a repeat is required.

Displaying Images

Digital images are initially displayed on the computer monitor in the manner in which they have been obtained or after a preprocessing algorithm has been applied that changes how the projection is displayed to meet the facilities' desires. For example, a left lateral chest projection may be transversely flipped to be displayed as a right lateral. Box 1-1 lists the guidelines to follow when evaluating the displaying accuracy.

BOX 1-1 Image Displaying Guidelines

- Display torso, vertebral, cranial, shoulder, and hip projections as if the patient were standing in an upright position.
- AP, PA, and AP-PA oblique projections of the torso, vertebrae, and cranium are displayed as if the viewer and the patient are facing one another. The right side of the patient's image is on the viewer's left, and the left side of the patient's image is on the viewer's right. Whenever AP or AP oblique projections are taken, the R (right) or L (left) marker appears correct when the projection is accurately displayed, as long as the marker was placed on the IR face-up before the projection was taken (Figure 1-5). When PA or PA oblique projections are taken, the R or L marker appears reversed if placed face-up when the projection was taken (Figure 1-6).
- Accurately displayed lateral projections are displayed in the same manner as the technologist viewed the patient when obtaining the projection. For a right lateral the patient faces the viewer's left side and for a left lateral the patient faces the viewer's right side. The marker on these projections is correct as long as it was placed on the IR face-up before the projection was taken (Figure 1-7). One exception to this guideline may be when left lateral chest projections are displayed; often, reviewers prefer the left lateral projection to be displayed as if taken in the right lateral projection.
- AP/PA (lateral decubitus) chest and abdomen projections are oriented as described above in the AP-PA projection and then turned to be displayed so that the side of the patient that was positioned upward when the projection was taken is upward on the displayed projection (Figure 1-8).
- Inferosuperior (axial) shoulder and axiolateral hip projections are displayed so the patient's anterior surface is up and posterior surface is down (Figure 1-9).
- Extremity projections are displayed 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. For example, 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 (Figure 1-10).
- Display finger, wrist, and forearm projections as if the patient were hanging from the fingertips.
- Display elbow and humeral projections as if they were hanging from the patient's shoulder.
- Display toe and AP and AP oblique foot projections as if the patient were hanging from the toes.
- Display lateral foot, ankle, lower leg, knee, and femur projections as if they were hanging from the patient's hip.

Computed Radiography Image Receptor and Patient Orientation. Computed radiography IR cassettes have orientation labels that indicate to the user which end of the cassette is the "top" and which side is the "right" or "left" side. These orientation indicators align the image orientation with the computer algorithm of a patient in the anatomic position (AP projection). The top indicator is placed under the portion of the anatomy that is up when the projection is displayed and for projections of the torso, vertebrae, or cranium the right side of the patient is placed over the right side indicator. When the IR is processed it is read from left to right, starting at the top, and the projection is displayed in the same manner as the IR is read. Thus, if the examination is taken in a position other than just described, the examination chosen (PA) on the workstation must indicate this variation before the projection is read for it to be displayed accurately.

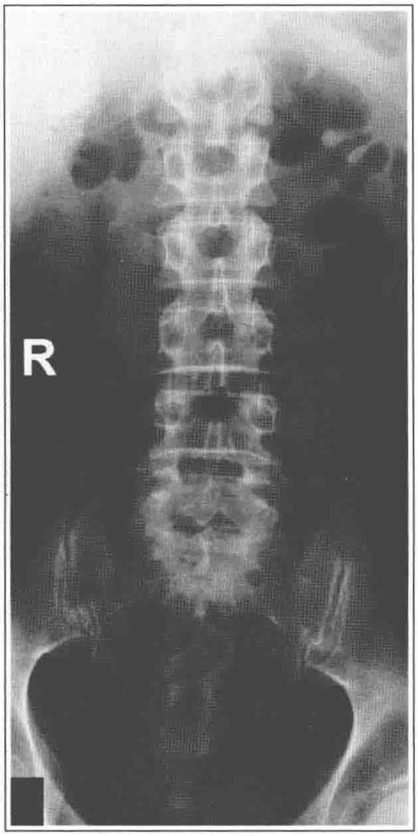

FIGURE 1-5 Accurately displayed and marked AP lumbar vertebrae projection.

FIGURE 1-7 Accurately displayed left lateral lumbar vertebrae projection.

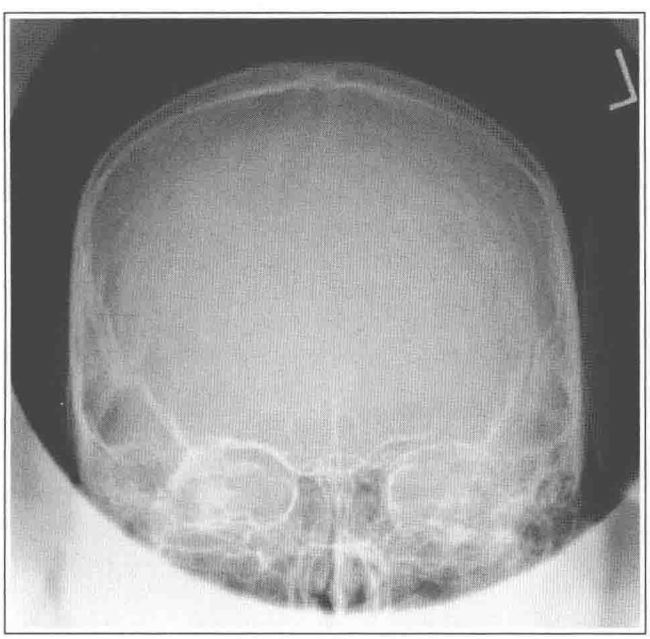

FIGURE 1-6 Accurately displayed PA cranium projection.

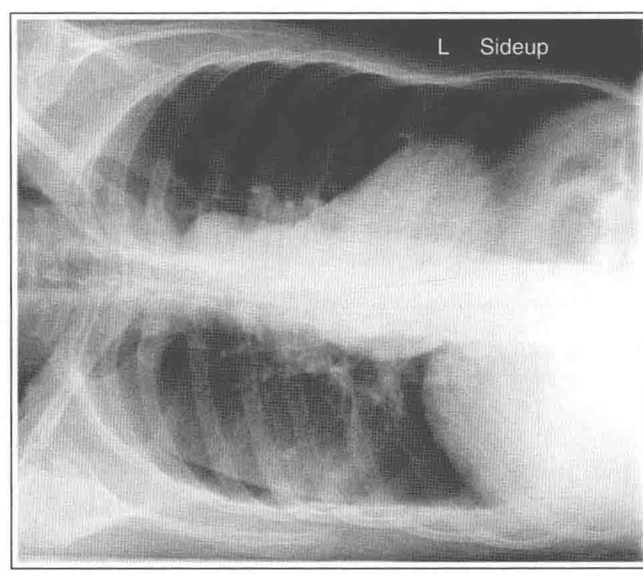

FIGURE 1-8 Accurately displayed and marked AP (right lateral decubitus) chest projection.

Direct-Indirect Capture Digital Radiography. For the digital radiography (DR) system, patient and IR orientation must also be considered when positioning the patient, and the technologist must also choose the correct examination from the workstation before exposing the projection for it to be displayed accurately. When using the table, position the patient's head at the head end of the table, on the technologist's left side, or adjust the patient orientation on the digital system to prevent the projection from being displayed upside down.

When possible avoid positioning extremities diagonally on the IR. Instead, align the long axis of extremities with the longitudinal or transverse axis of the IR (Figure 1-11). Because most digital systems only allow projection to be rotated in increments of 90 degrees, a diagonally obtained projection cannot be aligned vertically on the display computer and will be displayed diagonally.

FIGURE 1-9 Accurately displayed and marked inferosuperior (axial) shoulder projection.

FIGURE 1-10 Accurately displayed right PA and lateral hand projections.

Adjusting for Poor Display. Digital images that have been displayed inaccurately can be flipped horizontally and vertically, and rotated 90 degrees. When poorly displayed projections are obtained, they need adjusting before being saved to the picture archival and communication system (PACS), but this must be done with great care and only if a marker was placed accurately on the projection when it was obtained because inaccurate manipulation can result in the right and left sides getting confused. The marker will provide clues to the patient's orientation with the IR for the projection (see marking images later). The first AP foot projection in Figure 1-12 was obtained using a DR system and with the toes facing the foot end of the table, which causes the foot to be displayed upside down. 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 in Figure 1-12. 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 in Figure 1-12.

FIGURE 1-11 Diagonally displayed right lateral wrist projection.

Contrast Mask

A contrast mask is a postprocessing manipulation that can be added to digital projections as a means of helping the viewer to better evaluate contrast resolution in the selected area. The contrast mask does so by adding a black background over the areas outside the VOI to eliminate them and provide a perceived enhancement of image contrast. *As a rule, the technologist should only mask to the exposed areas, matching the collimation borders, even though it is possible to mask into the exposed areas.* Because it is possible to mask into the exposed areas, some facilities do not allow masking or request that masking be annotated on the projection because of the possibility that the radiologist will not see information that has been included on the original projection. Masking does not replace good collimation practices and should not be used to present a perceived radiation dose savings to the patient. Figure 1-13 demonstrates two abdomen projections taken on the same patient; one that has not been masked and one that has been laterally masked to remove the arms and cover up poor radiation protection practices. Such masking may be construed as altering the patient's medical record because the images are part of the patient's record, lead to misdiagnosis, and carry legal implications. A projection that has been masked and sent to the PACS cannot be unmasked.

FIGURE 1-12 AP foot projection that has been displayed upside down, vertically flipped for poor display, and rotated for accurate display.

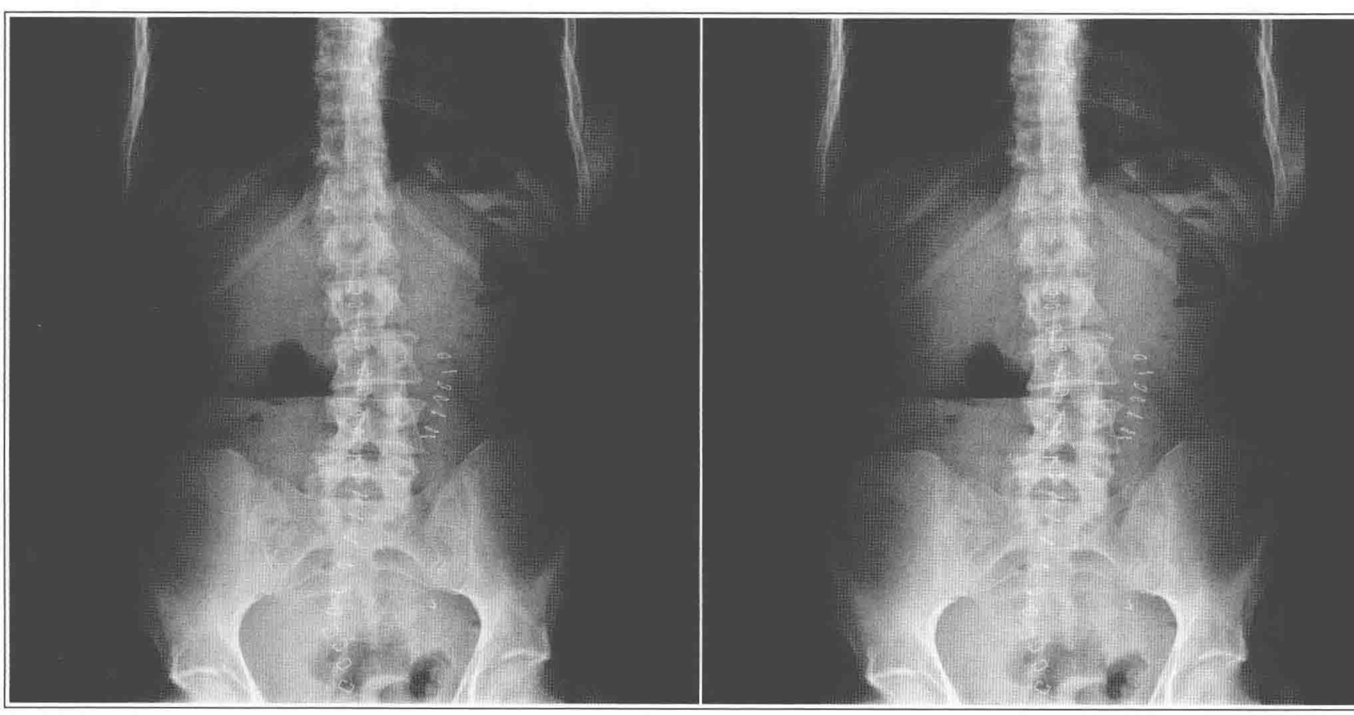

FIGURE 1-13 AP abdomen projections with and without contrast masking and demonstrating poor radiation protection practices.

Display Stations

The resolution ability of the image may be different, depending on where the image is displayed in the department. Display station resolution refers to the maximum number of pixels that the screen can demonstrate. To display images at full resolution, the display monitor must be able to display the same number of pixels as those at which the digital system acquired the image. If the digital system matrix size is smaller than the display station's matrix size, the values of surrounding pixels will be averaged to display the whole image. The technologist's workstation display monitors typically do not demonstrate resolution as high as that of the radiologist's display monitor.

IMAGE ANALYSIS FORM

Once a projection is correctly displayed, it is evaluated for positioning and technical accuracy. This should follow a systematic approach so that all aspects of the analytic process are considered, reducing the chance of missing important details and providing a structured pattern for the evaluator to use in a stressful situation. The image analysis form shown in Box 1-2 is designed to be used when evaluating projections to ensure that all aspects of the projection are evaluated. Under each item in the image analysis form, there is a list of questions to explore while evaluating a projection. The discussion in Chapters 1 and 2 will explore each of these question areas in depth. The answers to all the questions, taken together, will determine whether the projection is optimal, acceptable, or needs repeating.

Demographic Requirements

The correct patient's name and age or birthdate, patient identification number, facility's name, and examination time and date should be displayed on projections.

Computed Radiography. Each computed radiography cassette has a barcode label that is used to match the image data with the patient's identification barcode and examination request. For each examination, the cassette and patient barcodes must be scanned, connecting them with each other and the examination menu.

Direct-Indirect Capture Digital Radiography. With the DR system, the examination and patient are matched when the patient's information is pulled up on the workstation before the examination is obtained. It is important to select the correct patient and order number before

BOX 1-2 Image Analysis Form

_____ Projection is accurately displayed.
- Is the correct aspect of the structure positioned at the top of the displayed projection?
- Is the marker face-up or reversed, as expected?
- If projection was flipped or rotated to improve display, does marker still indicate correct side as displayed?
- Is the long axis of the VOI aligned with the longitudinal axis of the display monitor?

_____ Demographic requirements are visualized on the projection.
- Are the patient's name and age or birthdate, and patient identification number visible and are they accurate?
- Is the facility's name visible?
- Are the examination time and date visible?

_____ Correct marker (e.g., R/L, arrow) is visualized on projection and demonstrates accurate placement.
- Is the marker visualized within the exposure field and is it positioned as far away from the center of field as possible?
- Have specialty markers been added and correctly placed if applicable?
- Is the marker clearly seen without distortion and is it positioned so it does not superimpose the VOI?
- Does the R or L marker correspond to the correct side of the patient?
- If more than one projection is on IR, have they both been marked if they are different sides of the patient?
- Are annotated markings correct?

_____ Required anatomy is present and correctly placed in projection.
- Are all of the required anatomical structures visible?
- Was the field size adequate to demonstrate all the required anatomy?
- Computed radiography: Was the IR cassette positioned crosswise or lengthwise correctly to accommodate the required anatomy and/or patient's body habitus?
- Computed radiography: Was the smallest possible IR cassette used?

_____ Appropriate collimation practices are evident.
- Is the collimated border present on all four sides of the projection when applicable?
- Is collimation within ½ inch (1.25 cm) of the patient's skin line?
- Is collimation to the specific anatomy desired on projections requiring collimation within the skin line?

_____ Relationships between the anatomical structures are accurate for the projection demonstrated.
- Are the relationships between the anatomical structures demonstrated as indicated in the procedural analysis sections of this textbook or defined by your imaging facility?
- Is the anatomical VOI in the center of the projection?
- Does the projection demonstrate the least possible amount of size distortion?
- Does the projection demonstrate undesirable shape distortion?
- Are the joints of interest and/or fracture lines open?
- Was the CR centered to the correct structure?

_____ Projection demonstrates maximum recorded detail sharpness.
- Was a small focal spot used when indicated?
- Was the appropriate SID used?
- Was the part positioned as close to the IR as possible?
- Does the projection demonstrate signs of undesirable patient motion or unhalted respiration?
- Computed radiography: Are there signs of a double exposure?
- Computed radiography: Was the smallest possible IR cassette used?