Radiology Fundamentals

Introduction to Imaging & Technology

Jennifer Kissane
Janet A. Neutze
Harjit Singh
Editors

Sixth Edition

Springer

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Thank you to the sixth edition team.
I couldn't have done it without you. I am in awe of the energy and effort put into this project by so many, past and present—it is what makes this such a remarkable textbook.

To my family, thank you for the love, support, and encouragement.
To my Dad, thanks for watching over me.

– Harjit Singh

Thank you learners for giving us the opportunity to share our passions. Thank you family for your patience; now it's your turn.

– Janet A. Neutze

JN and HS, thank you for the guidance.
Contributors, thank you for the hard work.
SP, thanks for making it pretty!

To my husband, thank you for being awesome; to my parents, thank you for my work ethic; to my crazy kids, keep reading! Remember, "N" is for the knowledge cause I'm very, very smart.

– Jennifer Kissane

Thank you to my family and to the entire RadFun team, specifically JK for the opportunity.

– Shalin Patel

Preface

The sixth edition of the *Radiology Fundamentals: Introduction to Imaging & Technology* is directed toward medical students, non-radiology house staff, physician assistants, nurse practitioners, radiologist assistants, and other allied health professionals as a curriculum guide to supplement their radiology education. This book serves only as an introduction to the dynamic field of radiology. The goal of this text is to provide the reader with examples and brief discussions of the basic radiographic principles that should serve as the foundation for further learning. We hope that it will foster and further stimulate the process at the heart of medical education: self-directed learning.

Each edition continues to expand upon the first edition of the photocopied pages and films, written and organized by the original authors, Dr. William Hendrick and Dr. Carlton "Tad" Phelps. As mentors, Dr. Hendrick and Dr. Phelps of Albany Medical Center wanted a curriculum guide to reinforce the teaching concepts of their radiology elective. Dr. Harjit Singh, editor and author of much of the text of the first print edition, formalized the material in 1988. Our third edition, updated by the faculty and students at Penn State Hershey, was a first effort at organizing and digitizing the information for publication. The fourth edition expanded and reinforced the original authors' work. The fifth edition expanded on the positive aspects of the fourth edition, including a pediatrics imaging section. The fifth edition wouldn't have been possible without the hard work of Jonathan Enterline, MD.

Our sixth edition introduces SAFE radiology, an exciting new way to approach the application of imaging to patient care. Easy to learn and easy to remember, SAFE reminds us all that safety and appropriateness should precede any imaging testing and that all results should be applied expeditiously and thoughtfully. Dr. Jennifer Kissane joins us as a new editor and brings both her diagnostic and interventional radiology expertise to those chapters.

Radiology continues to expand in breadth and depth. As consultants to our clinician colleagues and from both cost and safety standpoints, radiologists are poised to be the navigators for clinical imaging well into the future. We hope this book, used in conjunction with lectures, electives, and discussions, is a start.

Hershey, Pennsylvania

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Part I
Introduction

1 Practicing SAFE Radiology

It is no longer good enough to just know how to interpret imaging studies. All imaging modalities have bioeffects on tissue. Many imaging examinations ordered today are unnecessary or inappropriate, inflating healthcare costs. Imaging reports reflect the complexity of the image information and may be difficult to interpret by the ordering providers. Patients are now able to access their imaging information via electronic portals and are holding clinicians and radiologists accountable for the information in those reports.

In response to these new requirements, medical student educators in the Department of Radiology at Penn State College of Medicine created an educational program to improve patient care and increase value, utilizing a new scaffold curriculum for medical students and learners of all levels.

We created the acronym **SAFE – S**afety-**A**ppropriateness-(interpreting) **F**ilms-**E**xpedite and **E**xecute – as a way to remember the order in which safely, timely and appropriately ordered, interpreted, and implemented imaging should be provided. Without safety and appropriateness practiced *first*, even the best imaging interpretation may not provide the desired imaging results a patient deserves. We designed this program to align with the American College of Radiology's (ACR) Imaging 3.0 goals of providing safe, appropriate, timely, and value-based imaging to all patients and clinicians. It will also give students some insight into Centers for Medicare and Medicaid Services' (CMS) Qualified Provider Led Entity (QPLE)/Appropriate Use Criteria (AUC) programs, due to be fully implemented by 2021.

The description that follows elaborates on the concepts in each part of the SAFE program. In addition, in each of the chapters which follow, we have noted key SAFE points that relate to the modality and/or the image interpretation.

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We hope you will find the SAFE radiology concept valuable to your learning, your teaching, and your practice of applying the best imaging to the care of all patients.

S: Safety: Discuss patient and physician safety considerations in the use of ionizing radiation, magnetic resonance imaging, ultrasound, and radiology contrast materials. Describe radiology safety applicable to the pediatric, pregnant, and elderly patient. List resources available to accomplish these goals including the role of Health Physics personnel available at your practice.

A: Appropriateness: Utilize resources such as radiologists, ACR Appropriateness Criteria™, Image Gently™, Image Wisely™, and Choosing Wisely™ to order appropriate studies while managing resources and maximizing safety. Observe the role that radiology studies and radiologists play in the overall care and management of the patient.

F: Films: Use a systemic approach when evaluating chest and abdominal radiographs. Discuss core concepts in advanced imaging such as Hounsfield units (CT), T1 and T2 weighting on MRI, and fluid on ultrasound exams. Describe patient preparation for radiology studies. Observe how imaging studies are obtained.

E: Expedite and Execute: Expedite patient management by recognizing common emergent findings. Execute the knowledge you have learned about safety, appropriateness, and image interpretation to provide safe and effective patient-centered care.

2 Patient Radiation Safety and Risk

Objectives:
1. Understand the difference between nonionizing and ionizing radiation.
2. Understand the difference between stochastic and non-stochastic effects.
3. Be able to discuss the concept of ALARA.

Everyone is concerned about patient radiation dose. From 1993 through 2008, radiation dose attributed to medical radiation rose from 0.54 to 3 mSv per capita. The largest component of the medical patient radiation dose was CT scanning (49%). This is despite the fact that CT scanning makes up only 17% of the total medical procedures that contributes to a patient's radiation dose.

The radiation dose for all diagnostic exams should be minimized to the lowest amount of radiation needed to produce a diagnostic quality exam [1].

What Is Radiation?

Radiation is emitted from unstable atoms. Unstable atoms are said to be "radioactive" because they release energy (radiation). The radiation emitted may be electromagnetic energy (x-rays and gamma rays) or particles such as alpha or beta particles. Radiation can also be produced by high-voltage devices, such as x-ray machines. X-rays are a form of electromagnetic energy with a wavelength that places it into an ionizing radiation category. In a diagnostic exam, these photons can penetrate the body and are recorded on digital or film medium to produce an image of various densities that show details inside the body.

Light, radio, and microwaves are nonionizing types of electromagnetic radiation. Radio waves are used to generate MR images. X-rays and gamma rays are *ionizing*

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forms of electromagnetic radiation and can produce charged particles (ions) in matter. When ionizations occur in tissue, they can lead to cellular damage. Most damage is repaired by natural processes. In some cases, the damage cannot be repaired or is not repaired correctly which can lead to biological effects.

There are two categories of biological effects related to radiation exposure:

Non-stochastic (also called deterministic)
Stochastic (also called probabilistic)

- *Non-stochastic* effects can occur when the amount of radiation energy imparted to tissue (dose) exceeds a threshold value. Below the threshold, no effect is observed. Above the threshold, the effect is certain.

  Examples:

  - Skin injury
  - Cataracts

- Stochastic effects can manifest at any dose, meaning there is no threshold below which the effect cannot occur. In reality, the probability of a stochastic effect increases as radiation dose imparted to the tissue increases.

  Examples:

  - Cancer
  - Leukemia

Where Do We Use Radiation in a Hospital?

- Radiography:
  - Fluoroscopy
  - Mammography
  - Cardiac catheterization
  - Computed tomography
  - Radiation therapy (linear accelerator)
- Radioactive material:
  - Nuclear medicine
  - Radiation therapy

Listed below are three tables – they provide an estimate of effective radiation dose from common diagnostic exams and interventional procedures (Tables 2.1, 2.2, and 2.3). As a reference standard, the average annual background radiation we all receive from the sun and soil is 3 mSv.

Table 2.1 Typical effective radiation dose from diagnostic x-ray-single exposure

Exam [1]	Effective dose mSv (mrem)
Chest	0.1 (10)
Cervical spine	0.2 (20)
Thoracic spine	1.0 (100)
Lumbar spine	1.5 (150)
Pelvis	0.7 (70)
Abdomen or hip	0.6 (60)
Mammogram (2 views)	0.36 (36)
Dental bitewing	0.005 (0.5)
Dental (panoramic)	0.01 (1)
DEXA (whole body)	0.001 (0.1)
Skull	0.1 (10)
Hand or foot	0.005 (0.5)

Adapted with permission from Mettler et al. [2]

Table 2.2 The dose a patient could receive if undergoing an entire procedure that may be diagnostic or interventional. For example, a lumbar spine series usually consists of five x-ray exams

Examinations and procedures	Effective dose mSv (mrem)
Intravenous pyelogram	3.0 (300)
Upper GI	6.0 (600)
Barium enema	7.0 (700)
Abdomen, kidney, ureter, bladder (KUB)	0.7 (70)
CT head	2.0 (200)
CT chest	7.0 (700)
CT abdomen/pelvis	10.0 (1000)
Whole-body CT screening	10.0 (1000)
CT biopsy	1.0 (100)
Calcium scoring	2.0 (200)
Coronary angiography	20.0 (2000)
Cardiac diagnostic and intervention	30.0 (3000)
Pacemaker placement	1.0 (100)
Peripheral vascular angioplasties	5.0 (500)
Noncardiac embolization	55.0 (5500)
Vertebroplasty	16.0 (1600)

Adapted with permission from Mettler et al. [2]

Table 2.3 Typical effective radiation dose from nuclear medicine examinations

Nuclear medicine scan radiopharmaceutical (common trade name)	Effective dose mSv (mrem)
Brain (PET) 18F FDG	14.1 (1410)
Brain (perfusion) 99mTc HMPAO	6.9 (690)
Hepatobiliary (liver flow) 99mTc sulfur colloid	2.1 (210)
Bone 99mTc MDP	6.3 (630)
Lung perfusion/ventilation 99mTc MAA & 133Xe	2.5 (250)
Kidney (filtration rate) 99mTc DTPA	1.8 (180)
Kidney (tubular function) 99mTc MAG3	2.2 (220)
Tumor/infection 67Ga	2.5 (250)
Heart (stress-rest) 99mTc sestamibi (Cardiolite)	9.4 (940)
Heart (stress-rest) 201Tl chloride	41.0 (4100)
Heart (stress-rest) 99mTc tetrofosmin (Myoview)	11.0 (1100)
Various PET studies 18F FDG	14.0 (1400)

Adapted with permission from Mettler et al. [2]

What Are the Risks?

There is no threshold for stochastic effects so any imaging procedure or therapy that involves the use of radiation involves some risk. When performed properly, the risk is usually very small and is far outweighed by the medical benefit of having the procedure. Regardless, the concept of ALARA (keeping the radiation dose **a**s **l**ow **a**s **r**easonably **a**chievable) should always be employed to minimize the risk.

A small percentage of imaging and therapy studies performed in the hospital can potentially exceed threshold values for non-stochastic effects.

Radiation therapy and interventional fluoroscopy procedures may result in radiation doses that exceed the threshold dose for skin injuries, and less frequently for cataract induction. The procedures performed in these areas are often lifesaving, and every effort to minimize the magnitude of these effects is taken.

Resources

As you continue your career in medicine, you will specialize. Part of medicine, in virtually all areas of specialization, involves ordering x-rays or nuclear medicine based procedures for your patients.

In the news media, great attention has been paid to the increase in medical radiation dose to members of the public. Currently, there are discussions and debates over the appropriateness of ordering certain exams without need. This will become a health system financial restraint (CMS' QPLE/AUC program) as well as a public health question.

Some Resources to Look into:

- ACR Appropriateness Criteria
  http://www.acr.org/secondarymainmenucategories/quality_safety/app_criteria.aspx
- Image Wisely Campaign (adult)
  http://www.rsna.org/Media/rsna/upload/Wisely_525.pdf
- Image Gently Campaign (pediatrics)
  http://www.pedrad.org/associations/5364/ig/
- Health Physics Society
  http://hps.org/physicians/blog/
  http://hps.org/publicinformation/asktheexperts.cfm

S: Ionizing radiation is the first thing we think about when we think about safety in imaging. In addition to radiologists, cardiologists, orthopedic surgeons, emergency physicians, podiatrists as well as medical professionals with office "x-ray" machines need radiation safety education and support. Know about and use these resources such as your health physicists.

A: Resources such as health physicists, radiologists, ACR Appropriateness Criteria™, Image Gently™, Image Wisely™, and Choosing Wisely™ will help you to order appropriate studies while managing resources and maximizing safety.

F: Be aware that your imaging specialists are using techniques such as collimation of the examined area, reducing fluoroscopy time, and selecting appropriate number of images to answer the clinical question asked.

E: Resources such as health physicists and radiologists can help to advise and manage inappropriate or excessive radiation exposure to patients such as pediatric and pregnant patients. The ALARA principle is key to the SAFE use of ionizing radiation and, as we shall see, other imaging modalities such as MRI and ultrasound.

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3 Introduction to Radiology Concepts

Objectives:
1. Identify the four (4) naturally occurring densities visible on a conventional radiograph in order from the highest to lowest density.
2. Define and give two examples of the silhouette sign on a frontal chest radiograph.

Radiographic Densities

Let us disregard the anatomy seen on the radiograph for now and concentrate on basic radiographic principles. In Fig. 3.1, you can see examples of the four basic densities, bone, soft tissue, fat, and air, which are visible on a conventional radiograph.

Main Radiographic Densities

1. *Bone* – this is the densest of the four basic densities and appears white or “radiodense” as radiologists prefer to say.
2. *Soft Tissue* – all fluids and soft tissues have the same density on a conventional radiograph. This density is slightly less than the bone but slightly greater than fat. One advantage of CT scanning is that various soft tissues and fluids can be discriminated as different radiographic densities to a much greater degree than conventional radiographs.

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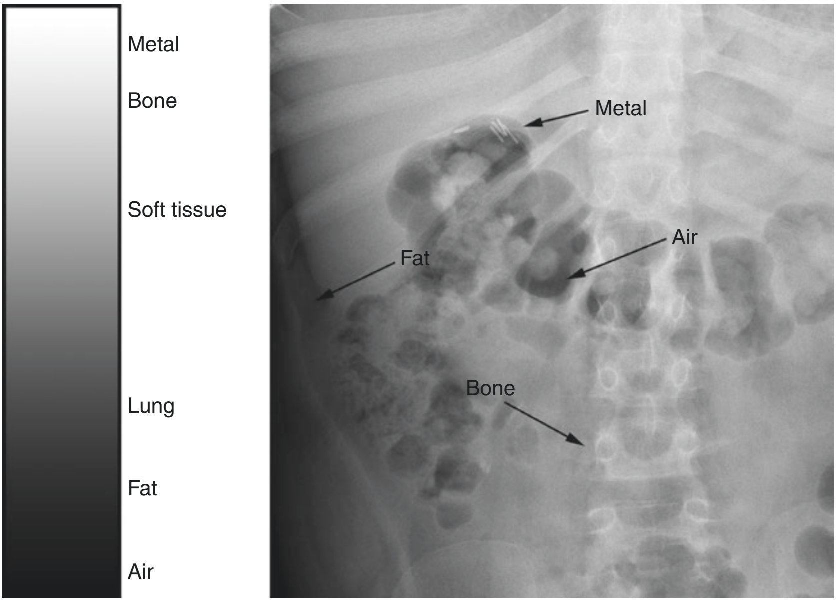

FIGURE 3.1 - RADIOGRAPHIC DENSITIES
Note how the four basic densities are visible on an abdominal radiograph

3. *Fat* – this density may seem the least obvious to you. Fat can be seen interposed between various soft tissue and fluid densities. Abdominal fat allows us to see the edges of various soft tissue structures since the fat is slightly less dense than the organs themselves.
4. *Air* – the lungs, “bowel gas,” and the air surrounding the patient are examples of air densities. Air densities are generally quite dark, almost black, on the radiograph. Thus, the lungs are not radiodense but are instead said to be “radiolucent.” Why does the air in the lungs appear less black (more radiodense) than the air around the patient? This is because the air density in the lungs is added to the densities of the superimposed chest wall structures.

There is an additional density on some radiographs which may be denser than bone: metal density. This is not included in the above classification because it is not a naturally occurring density. Examples of metallic density on the radiograph include orthopedic hardware, wire sutures in the sternum in patients who have undergone cardiac surgery, and wire leads seen in a pacemaker.

Radiographic densities are normally additive in an arithmetic way. This means that a soft tissue density which is twice as thick as an adjacent soft tissue structure will be twice as white. Conversely, a structure which is half as dense as an adjacent structure but twice as thick will demonstrate an identical radiographic density.

The Silhouette Sign

What is the effect of juxtaposition of structures of varying density upon each other? When two structures of *different densities* are adjacent (i.e., abutting each other), the interface between them will be clearly delineated on the radiograph. For example, the soft tissue density of the heart is clearly delineated from the air density of the lung along the cardiac border. However, when two structures of the *same density* are adjacent or overlapping, their margins cannot be distinguished. For example, when pneumonia fills the alveoli of the right lung with fluid, the lung becomes fluid density, and the normal interface between the right heart border (soft tissue density) and the lung (air) may become invisible; the right heart border can no longer be seen (Fig. 3.2).

This is called the silhouette sign and is one of the most useful principles in radiology.

Other examples of the silhouette sign include the following:

1. The heart cannot be distinguished separately from the blood within the cardiac chambers because both have soft tissue/fluid density.
2. The dome of the liver and the inferior aspect of the right hemidiaphragm cannot be distinguished radiographically since both have soft tissue density. You would

FIGURE 3.2 - THE SILHOUETTE SIGN
Right middle lobe pneumonia illustrates silhouetting of the right heart border by the area of consolidation. Compare to the crisp left heart border

only see the dome of the liver and the right hemidiaphragm separately when free intraperitoneal air is present. This is because the air density is interposed between the two soft tissue densities.

The silhouette sign will be used repeatedly in many sections of this course and in interpreting radiographs clinically. It is very important that you have a clear understanding of this principle.

S: Recognizing densities on conventional imaging may result in cancelling advanced imaging that could cause harm. For example, recognizing metal within the eye on an x-ray would result in cancellation of a brain MRI as the strong magnetic field of the MRI can cause the metal to heat up or migrate, causing blindness.
A: Conventional imaging, such as x-rays of chest, abdomen, and bones, is often the first-line modality to decide if further imaging is needed. ACR Appropriateness Criteria is a good place to start learning about the appropriate order of imaging or if imaging is even necessary.
F: Conventional radiography is dependent on experts such as radiology technologists to acquire images with techniques that allow different densities to be displayed. Improper techniques, large and small patients, or uncooperative patients may contribute to images that are difficult to interpret.
E: Identifying unexpected densities such as air outside of an expected location (pneumothorax or pneumoperitoneum) or metal density such as bullet fragments or foreign bodies will result in appropriate identification and management.

4 Conventional Radiology

> **Objectives:**
> 1. State the convention for describing standard radiographic projections.
> 2. Explain why cardiac size differs on AP versus PA radiographs.
> 3. Define the “lordotic projection” view and two indications for its use.
> 4. Discuss how the following variables and techniques may alter the appearance of a conventional chest radiograph: underexposure, rotation, inspiration, and expiration.

Many technical factors impact the appearance of conventional radiographs. This chapter will introduce the main factors you should be aware of when interpreting radiographs.

The Radiographic Projection

The radiographic projection is named according to the direction in which the x-ray beam passes through the body of the patient when the radiograph is taken (Fig. 4.1).

In other words, if the x-ray detector was placed behind the patient and the x-ray tube was placed in front of the patient, the x-rays would pass from the front of the patient through the back of the patient onto the x-ray detector in an anteroposterior (AP) radiograph. In a posterior-anterior (PA) radiograph, the detector is located along the anterior aspect of the patient’s body with the x-ray tube posterior to the patient. In this situation, the x-ray beam passes through the patient from posterior to anterior.

Note the difference in the size of the heart shadow between the AP and PA radiograph in Fig. 4.1. Because x-rays diverge from a point source, objects that are situ-

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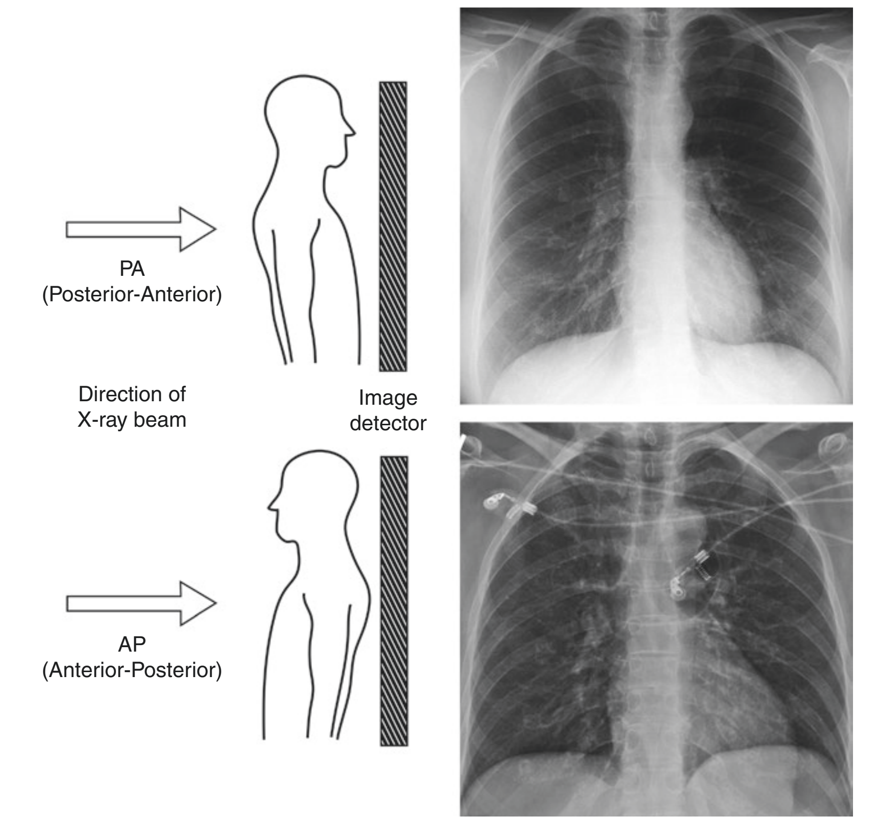

FIGURE 4.1 - THE AP AND PA VIEWS
How does this affect the appearance of various anatomical structures in the chest?

ated farther from the detector will cast a larger shadow. Since the heart is an anterior structure, it is magnified more on the AP radiograph because the anterior structures are farther from the radiographic detector. Demonstrate this principle for yourself by shining a flashlight on your hand so that it casts a shadow on the wall. The farther your hand is from the wall (which in this case acts like the x-ray detector), the more magnified and fuzzy the shadow becomes. Portable radiographs are most commonly performed AP, because the patient can be imaged in a semi-upright or supine position. The radiographic trade-off is that image quality may not be as good, as the supine patient's chest x-ray is often underinflated.

Next, look at Fig. 4.2. This is the "lordotic projection." With this projection, the x-ray source is angled toward the head, and the clavicles project superior to the lung apex on the radiograph. This view is used to detect possible apical abnormalities such as tuberculosis or a lung tumor in the apex, called a Pancoast tumor. CT scans are now more commonly used because of increased sensitivity and specificity relative to the apical lordotic chest x-ray.

Look at Fig. 4.3. The heads of the clavicles and the spinous processes have been drawn on the diagram on the left. Since the clavicular heads are anterior structures

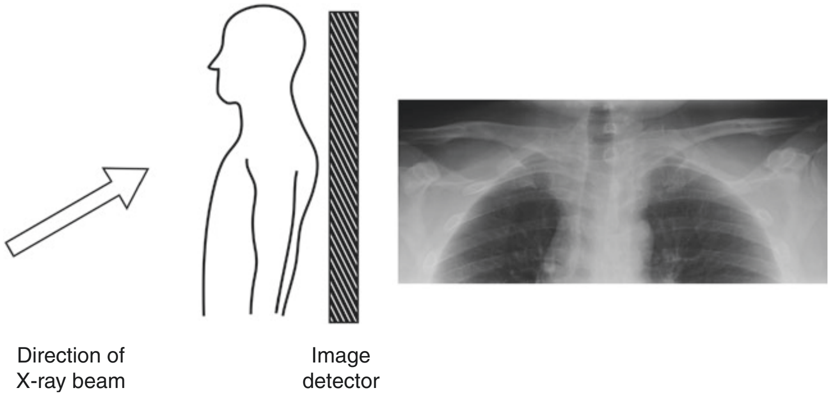

FIGURE 4.2 - THE LORDOTIC PROJECTION
The lordotic view is especially useful for visualizing the lung apices. The clavicles are projected cephalad, allowing a clear view of the lung apices

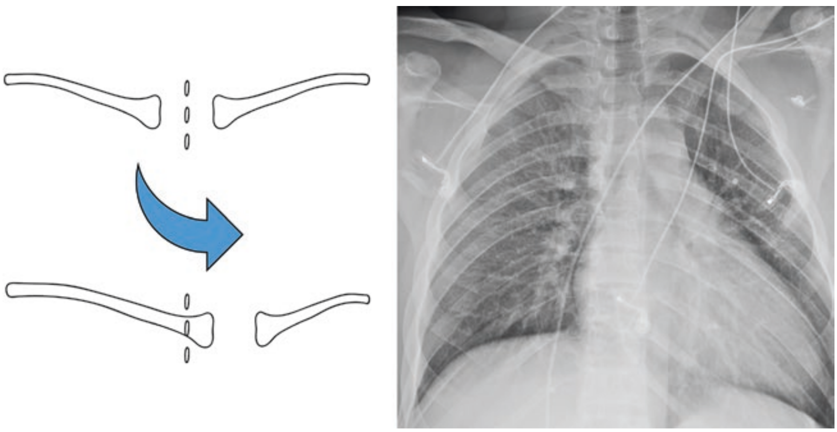

FIGURE 4.3 - ROTATION OF THE CHEST
In this illustration, note how the clavicular heads and spinous processes of the vertebral bodies appear in the AP position and with the rotation of the chest to the left. On the chest x-ray, the right clavicular head has rotated past the spinous processes, indicating that the patient is rotated to the left

and the spinous processes are quite posterior, they will move in opposite directions on the radiographs relative to a central axis of rotation. Using this principle of rotation, acquiring two radiographs, one in straight PA and one in slight rotation, may help to determine the position of an abnormality in the lung.

Finally, note Fig. 4.4. The two radiographs were obtained within minutes of each other. Although this is an extreme example, it is important to realize that radiographs exposed at less than full inspiration produce artifactual crowding of the pulmonary vasculature which can simulate pulmonary edema.

In some situations, expiratory radiographs are intentionally obtained. The most common situation is when looking for a small pneumothorax. In this situation, the pneumothorax will become slightly larger relative to the lung as air is expired.

Next, examine Fig. 4.5. Can you find examples of the four basic densities? Can you find examples of summation of radiographic densities due to superimposition of structures? Superimposed kidneys and stool-filled colon will be denser than each structure by itself. Examples of the silhouette sign? Kidneys adjacent to the liver or spleen will silhouette and obscure each other's margins.

And last, but certainly not the least, Fig. 4.6 is an image from a normal air contrast barium enema. This demonstrates how certain substances such as barium can be used to make certain anatomic structures more visible on the radiograph (in this case, white barium and dark air in the large bowel).

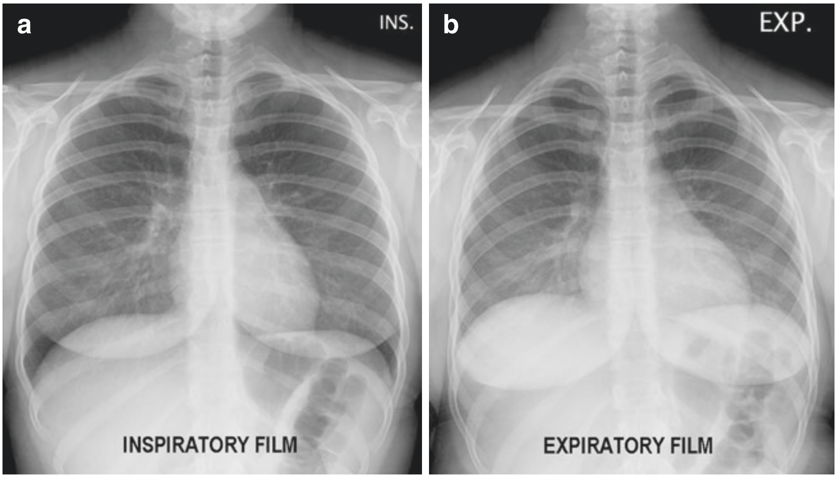

FIGURE 4.4 - INSPIRATORY AND EXPIRATORY FILMS
The radiographs here are those of inspiration (**a**) and expiration (**b**). Note the difference in the size of the lungs and their apparent difference in densities