1 Introduction

AN APPROACH TO IMAGE INTERPRETATION

The first step in medical imaging is to examine the patient and determine the possible cause of his or her problem. Only after this is done can you decide which imaging study is the most appropriate. A vast number of algorithms and guidelines have been developed, but no definite consensus exists on the "right" one for a given symptom or disease because a number of imaging modalities have similar sensitivities and specificities. In this text I provide tables of appropriate initial imaging studies for various clinical situations. When possible, these tables are based on the published literature and recommendations of professional societies. When this is not possible, I give you my opinion based on 45 years of clinical practice.

What should you expect from an imaging examination? Typically one expects to find the exact location of a problem and hopes to make the diagnosis. Although some diseases present a characteristic picture, most can appear in a variety of forms, depending on the stage. As a result, image interpretation will yield a differential diagnosis that must be placed in the context of the clinical findings.

Examination of images requires a logical approach. First you must understand the type of image, the orientation, and the limitations of the technique used. For example, I begin by mentally stating, "I am looking at a coronal computed tomography (CT) scan of the head done with intravenous contrast." This is important, because intravenous contrast can be confused with fresh blood in the brain.

Next I look at the name and age on the image label to avoid mixing up patients, and this allows making a differential diagnosis that applies to a patient of that age and sex. You would not believe the number of times that this seemingly minor step will keep you from making dumb mistakes.

The next step is to determine the abnormal findings on the image. This means that you need to know the normal anatomy and variants of that particular part of the body, as well as their appearance on the imaging technique used. After this, you should describe the abnormal areas, because it will help you mentally order a differential diagnosis. The most common mistake is to look at an abnormal image and immediately name a disease. When you do this, you will find your mind locked on that diagnosis (often the wrong one). It is better to say to yourself something like, "I am going to give a differential diagnosis of generalized cardiac enlargement with normal pulmonary vasculature in a 40-year-old man," rather than to blurt out "viral cardiomyopathy" in a patient who really has a malignant pericardial effusion.

After practicing for 20 years or so, a radiologist knows the spots where pathology most commonly is visualized. Throughout this text, I point out the high-yield areas for the different examinations. Although no absolute rules exist, knowing the pathology and natural history of different diseases will help you. For example, colon cancer typically metastasizes first to the liver rather than the lungs, whereas sarcomas preferentially metastasize to the lungs rather than the liver.

After reviewing the common causes of the imaging findings that you have observed, you should reorder the causes in light of the clinical findings. At this point, you probably think that you are finished. Not so. Often a plethora of information is contained in the patient's image files or in the hospital's computer information system. This comes in the form of previous findings and histories supplied for the patient's other imaging examinations. Reviewing the old reports has directed me to areas of pathology on the current image that I would have missed if I had not looked into the medical information system. A simple example is a pneumonia that has almost but not completely resolved or a pulmonary nodule that, because of inspiratory difference, is hiding behind a rib on the current examination.

You probably think that you are finished now. Wrong again. A certain number of entities could cause the findings on the image, but you just have not thought of them all. After I have finished looking at a case, I try to go through a set sequence of categories in search of other differential possibilities. The categories I use are congenital, physical/chemical, infectious, neoplastic, metabolic, circulatory, and miscellaneous.

X-RAY

Regular x-rays (plain x-rays, also sometimes called *radiographs*) account for about 75% of imaging examinations. X-ray examinations, or plain x-rays, are made by an x-ray beam passing through the patient. The x-rays are absorbed in different amounts by the various tissues or materials in the body. Most of the beam is absorbed or scattered. This represents deposition of energy in the tissue but does not cause the patient to become radioactive or to emit radiation. A small percentage of the incident radiation beam exits the patient and strikes a detector.

The historical imaging receptor was a film/screen combination. The x-ray beam would strike a fluorescent screen, which produced light that exposed the film, and then the film was developed. Newer systems are called *computed radiography* or *digital radiography*. In computed radiography, the x-rays strike a plate that absorbs the x-rays and stores the energy at a specific location. The plate is then scanned by a laser, which releases a point of light from the plate. The location is detected and stored in a computer. In digital radiography detector systems, the x-ray hits a detector and then is converted to light or an electrical charge immediately. Once either type of image is stored in the computer, it can be displayed on a monitor for interpretation or transmitted to remote locations for viewing.

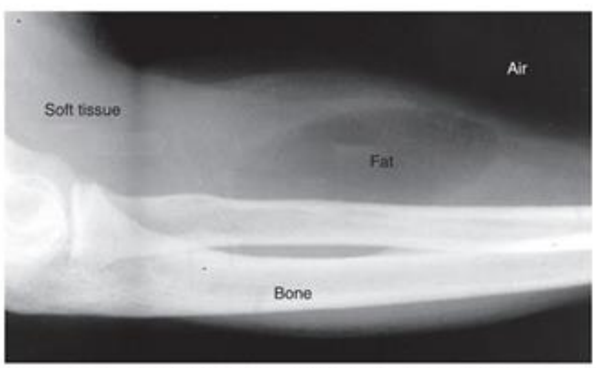
Four basic tissue densities, or shades, are visible on plain x-rays. These are air, fat, water (blood and soft tissue), and bone. Air is black or very dark. On regular x-rays and CT scans, fat is generally gray and darker than muscle or blood (Fig. 1.1). Bone and calcium appear almost white. Items that contain metal (such as prosthetic hips) and contrast agents also appear white. The contrast agents generally used are barium for most gastrointestinal studies and iodine for most intravenously administered agents.

Remember that standard or plain x-rays are two-dimensional presentations of three-dimensional information. That is why frontal and lateral views are often needed. Without these, mistakes can easily be made. You must remember that an object visualized on a specific view is somewhere in the path of the x-ray beam (not necessarily in the patient). If an object projects outside the patient on any view, it is outside the patient. However, even if an object projects within the patient on two orthogonal views, it can still be located outside the patient (Figs. 1.2 and 1.3). Each additional view needed to make a diagnosis requires an additional x-ray exposure and therefore adds to the patient's radiation dose. Radiation doses from various examinations are given in the Appendix.

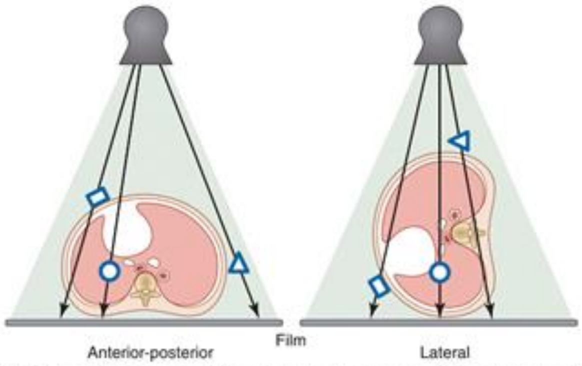
The terminology used to describe images is usually quite straightforward. Chest and abdominal radiographs are referred to as upright or supine, depending on the position of the patient. In addition, chest x-rays are usually described as posteroanterior (PA) or anteroposterior (AP) (Fig. 1.4). These terms indicate the direction in which the x-ray beam traversed the patient on its way to the detector. PA means that the x-ray beam entered the posterior aspect of the patient and exited anteriorly. AP means that the beam direction through the patient was anterior to posterior. A left lateral decubitus view is one taken with the patient's left side down.

Position is important to note, because it can affect magnification, organ position, and blood flow and therefore significantly affect image interpretation. For example, the heart appears larger on AP than on PA images because on an AP projection the heart is farther from the detector and is magnified more by the diverging x-ray beam. It also appears larger on supine than on upright images because the hemidiaphragms are pushed up, making the heart appear wider. Portable chest images are taken not only in the AP projection but also with the tube closer to the patient than on standard upright images. This magnifies the heart even more.

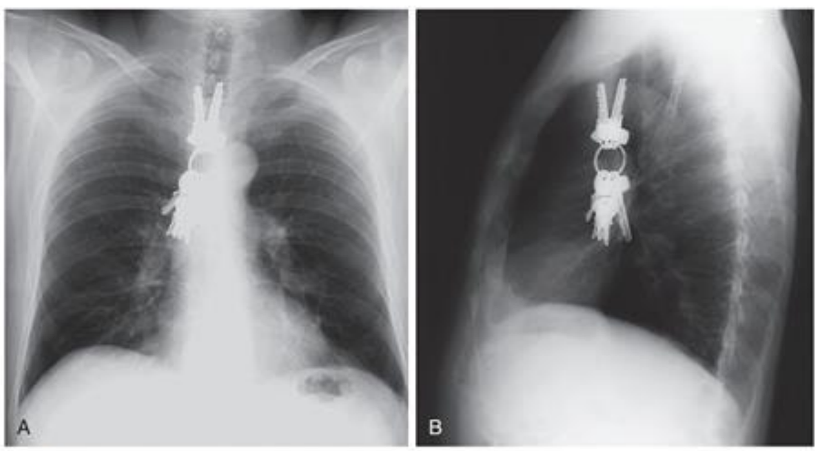
Use of contrast agents permits visualization of anatomic structures that are not normally seen. For example, intravenously or intra-arterially injected agents allow visualization of blood vessels (Fig. 1.5). If imaging is done with standard format, the blood vessels appear white. Digital imaging allows subtraction or removal of unwanted structures, such as the bones, from an image (see Fig. 1.5B). Often the computer manipulation is done in such a way that the



• **Fig. 1.1** The Four Basic Densities on an X-Ray. A lateral view of the forearm shows that the bones are the densest, or white; soft tissue is gray; fat is somewhat dark; and air is very dark. The abnormality in this case is the fat in the soft tissue of the forearm, which is due to a lipoma.



• **Fig. 1.2** Spatial Localization on an X-Ray. On both anteroposterior (AP) and lateral projections, the square and round objects will be seen projecting within the view of the chest, even though the square object is located outside the chest wall. If you can see an object projecting outside the chest wall on at least one view (the triangle), it is outside the chest. If, however, an object looks as though it is inside the chest on both views, it may be either inside or outside.



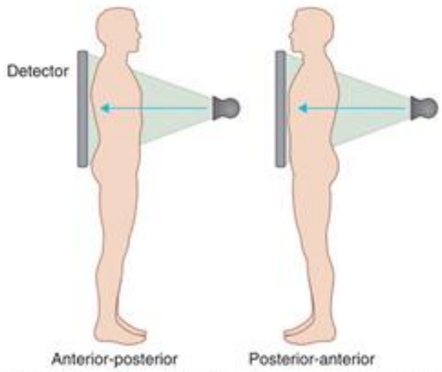
• **Fig. 1.3** What Is the Location of the Keys? On both the posteroanterior (PA) view of the chest (A) and the lateral view (B), the keys seem to be within the center of the chest. Actually, if you look carefully, you will notice that the keys do not change position at all, even though the patient has rotated 90 degrees. The keys are located on the receptor cassette and are not in the patient.

arteries may appear black instead of white, although this usually does not present a problem in interpretation.

Contrast agents are used to fill either a hollow viscus (such as the stomach) or anatomic tubular structures that can be accessed in some way (such as blood vessels, ureter, and common bile duct). When you see an abnormality on one of these studies, you must determine whether the location is intraluminal, mural, or extrinsic. This usually requires seeing the abnormality in perpendicular views (Fig. 1.6). Unless you are careful about this determination, you will make errors in diagnosis.

Contrast agents instilled orally, rectally, or retrograde into the ureter or bladder incur little or no risk unless aspiration or perforation occurs. With the intravenously or intra-arterially administered agents, a small but real risk for contrast reaction exists. This is something that you should consider before ordering a contrast-enhanced CT scan. About 5% of patients will experience an immediate mild reaction, such as a metallic taste or a feeling of warmth; some experience nausea and vomiting, wheeze, or get hives as a result of these contrast agents. Some of these mild reactions can be treated with 50 mg of intramuscular diphenhydramine (Benadryl). Because contrast agents also can reduce renal function, they should not generally be used in patients with compromised renal function (estimated glomerular filtration rate [eGFR] <50 to 60 mL/min).

About 1 in 1000 patients have a severe reaction to intravascular contrast. This may be a vasovagal reaction, laryngeal edema, severe hypotension, an anaphylactic-type reaction, or cardiac arrest. A vasovagal reaction can be treated with 0.5 to 1.0 mg of intravenous atropine. The most important initial therapeutic measures for these severe reactions are to establish an airway, ensure breathing and circulation, and give intravenous fluids. Other drugs obviously also may be necessary. The risk for death from a study using intravenously administered contrast agents is between 1 in 40,000 and 1 in 100,000.



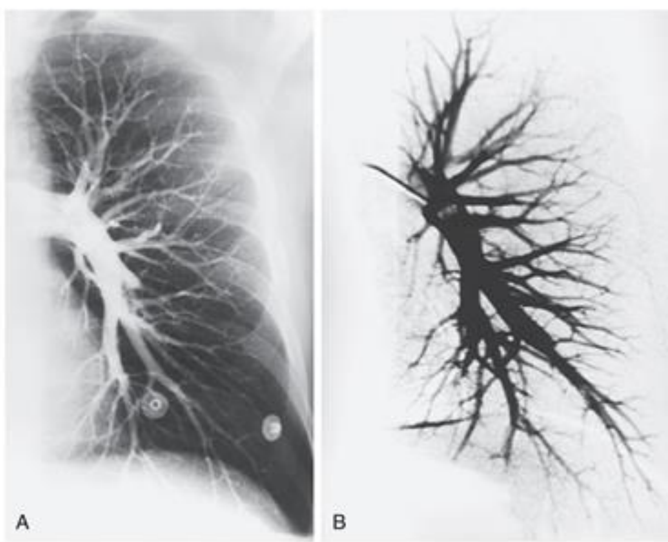
• **Fig. 1.4** Typical X-ray Projections. X-ray projections are typically listed as anteroposterior (AP) or posteroanterior (PA). This depends on whether the x-ray beam passed through the patient from anterior to posterior or the reverse. Lateral (LAT) and oblique (OBL) views also are commonly obtained.

COMPUTED TOMOGRAPHY

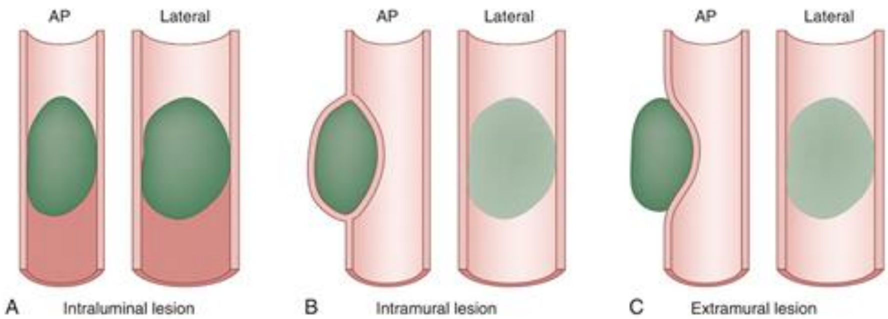
CT is accomplished by passing a rotating fan beam of x-rays through the patient and measuring the transmission at thousands of points. The data are handled by a computer that calculates exactly what the x-ray absorption was at any given spot in the patient. The data can be manipulated in a number of ways, displayed on a screen, or photographed. Because the data points are in the computer memory, it is possible to "window" the data and obtain a number of images without additional radiation exposure (Fig. 1.7). The computers can even display the data as a three-dimensional rotating image, although this is rarely necessary for diagnosis. Compared with plain x-rays, CT uses about 10 to 100 times more radiation.

On early CT scanners the x-ray tube rotated around the patient to obtain a single "slice," and then the table was moved incrementally before another slice was obtained. Newer scanners allow the x-ray tube to stay on and rotate at the same time that the table is moving. This is called a *spiral scanner* or *helical scanner*. The most modern scanners not only have the helical motion but also have multiple rows of detectors and can obtain more than 100 image data slices at once.

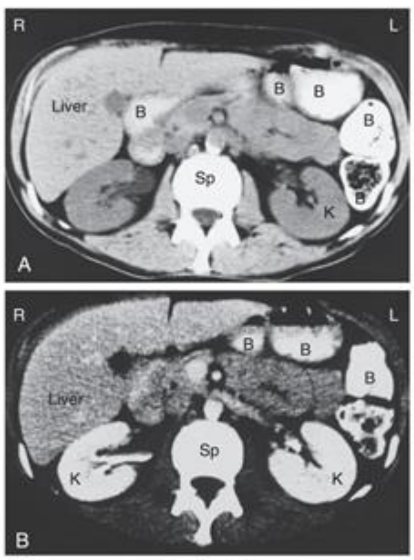
The appearance of tissues on CT scan depends to some extent on the computer manipulation, but in general the



• **Fig. 1.5** Pulmonary Angiogram. (A) A conventional view of blood vessels can be obtained by injecting iodinated contrast material into the vessels. On these images the vessels will appear white and the bones will be seen as you would normally expect (white). A digital subtraction technique with a computer may show the vessels either as black (B) or as white, but the bones will have been subtracted from the image.



• **Fig. 1.6** Appearances of Different Lesions Depending on Their Location When Using Contrast. Contrast medium is used to visualize tubular structures, including the spinal canal, blood vessels, gastrointestinal tract, ureters, and bladder. (A) Intraluminal lesions, such as stones or blood clots within the lumen of the given structure, produce a central defect on both anteroposterior *(AP)* and lateral projections. On the AP and lateral views the contrast will show acute angles on both sides and in both projections. (B) Intramural lesions will produce a defect that indents the column of contrast. When seen tangentially, an acute angle will appear between the normal wall and the beginning of the indentation. (C) Extramural lesions also can indent the wall, but at the point of indentation, the angle will be somewhat blunted as compared with the intramural lesion.



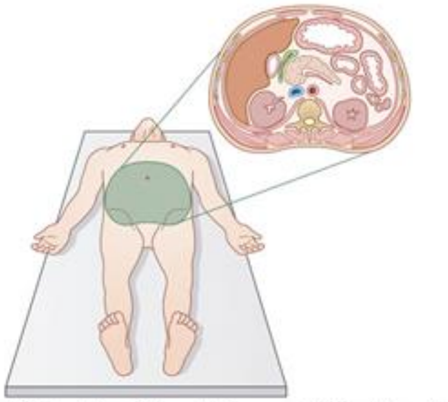
• **Fig. 1.7** Computed Tomography (CT). Images of the abdomen are presented here. (A) The image was made by using relatively wide windows during viewing, and no intravenous contrast was used. (B) The windows have been narrowed, producing a rather grainy image, and intravenous contrast has been administered so that you can see enhancement of the aorta, abdominal vessels, and both kidneys *(K)*. In both images, contrast has been put in the bowel *(B)* to differentiate bowel from solid organs and structures. *L*, Left; *R*, right; *Sp*, spine.

basic four densities on CT images are the same as those in plain x-rays: air is black, fat is dark gray, soft tissue is light gray, and bone or calcium and contrast agents are white. One advantage of CT is that actual x-ray absorption of a specific tissue can be displayed. The units used are Hounsfield units. The Hounsfield density of water is zero. The greater sensitivity of CT compared with plain x-rays allows areas of tiny punctate calcification to be seen.

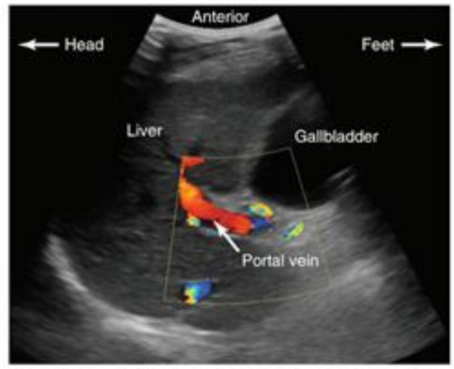
CT scans are presented as a series of slices of tissue. The method is similar in principle to slicing a loaf of bread and pulling up one slice at a time to examine it. Thus CT is a two-dimensional display of two-dimensional information, and objects appear where they really are in space. The scans or slices are shown as if you were viewing the patient from the foot of the patient's bed. Thus the individual's right side is on your left (Fig. 1.8). This also is the convention used for transverse images of ultrasound and magnetic resonance imaging (MRI).

Contrast agents, frequently used in CT scans, are usually the same water-soluble oral, rectal, or intravenous iodinated agents used in other imaging studies. Intravenous contrast agents are common, being used in probably 75% of all CT studies, and obviously carry the risk for contrast reactions discussed previously. Rapid acquisition of images allows the intravenously administered contrast to be displayed and images acquired in arterial, venous, or delayed phases with only a single injection.

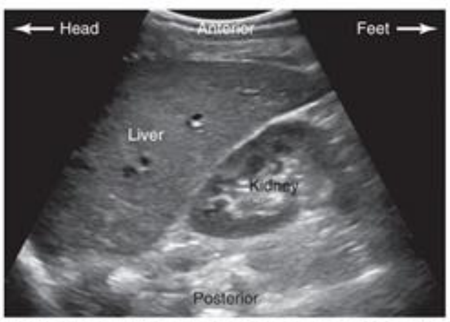
The appeal of CT is that a large number of structures are visualized simultaneously. In a patient with abdominal pain, one CT examination shows the liver, adrenal glands, kidneys, spleen, aorta, pancreas, and other structures. This allows the clinician to identify macroscopic pathology quickly.



• **Fig. 1.8** Orientation of Computed Tomography (CT) and Magnetic Resonance (MR) Images. CT and MR usually present images as transverse (axial) slices of the body. As you stand and look at the patient from the foot of the bed, if you think of these images as slices lifted out of the body, you will have the orientation correct.



• **Fig. 1.10** Color Doppler Ultrasound. In addition to displaying anatomy, ultrasound can analyze blood flow direction and velocity. In this longitudinal image of the liver, the red is blood in the portal vein flowing toward the transducer (located on the anterior aspect of the abdomen) and the blue represents blood flowing away from the transducer.



• **Fig. 1.9** Ultrasound Examination of the Liver and Kidney. This is a longitudinal image, and you are essentially looking at the patient from the right side. The patient's head is to your left. The liver has rather homogeneous echoes, and the kidney is easily seen as a bean-shaped object posterior to the right lobe of the liver.

ULTRASOUND

Ultrasound examination uses high-frequency sound waves to make images. The technology is that of sonar or a glorified fish finder used by fishermen. The image is made by sending high-frequency sound into the patient and assessing the magnitude and time of returning echoes. Echoes are the result of interfaces or changes in density. Typically a cyst has few if any echoes, because it is mostly water. Tissues such as liver and spleen give a picture with rather homogeneous small echoes caused by the fibrous interstitial tissue (Fig. 1.9). High-intensity echoes are caused by calcification, fat, and air.

The technology of ultrasound is attractive because it does not use ionizing radiation and the machines are relatively inexpensive. For these reasons, ultrasound has found widespread use in obstetrics. The use of so-called real-time ultrasound allows the images to be seen in sequential frames just as in a movie. This capability has proved popular for imaging rapidly moving structures, such as the heart. Ultrasound images can be quite dependent on operator-set parameters, and the field of view within the patient is limited. Thus unless clear labels are placed relative to orientation, the images can be difficult or impossible for the novice to interpret. Ultrasound images are usually presented as white echoes on a black background. In addition to using echoes to generate images, the ultrasound equipment can analyze the returning echo frequencies. This Doppler analysis allows for identification of moving blood, as well as its direction and velocity. Examples of its use are to identify and quantitate stenoses of the carotid arteries or the direction of blood flow in the portal vein (Fig. 1.10).

NUCLEAR MEDICINE

Nuclear medicine images are made by giving the patient a short-lived radioactive material. The most commonly used radionuclides decay rapidly and have half-lives of only minutes or hours. Most materials administered are not detectable within a day or so after administration. With the attachment of a radionuclide (such as technetium 99m) to specific carrier compounds, concentration of the radioactivity can be imaged and measured in a chosen organ or tissue, such as the thyroid, bone, lung, heart, abscess, or tumor. Few, if any, significant patient reactions are found to radiopharmaceuticals used for diagnosis.

Nuclear medicine images are made by a gamma camera or positron emission scanner that records radiation emanating from the patient and makes an image of the distribution