Introduction to Imaging

Learning Objectives

1. Identify major types of imaging studies and the principles of the machines used to obtain the examinations, including radiography, CT, MRI, ultrasound, nuclear medicine, and angiography.
2. Identify the relative benefits and drawbacks of each imaging modality.
3. Discuss specific safety issues: Compare the relative radiation doses of imaging modalities. Describe necessary precautions with MRI.
4. Compare the relative radiation doses of imaging modalities.
5. Describe what a patient experiences when undergoing CT scanning, MRI, a barium study, and an angiogram.
6. List some ways that imaging can reduce costs when used appropriately and increase costs when used inappropriately.
7. Identify how social determinants of health can affect imaging services and lead to health disparities.

Introduction

Imaging has revolutionized medical care over the past century, and Nobel Prizes have been awarded for the discovery and investigation of the x-ray, radioactivity, and radium and polonium, as well as the development of computed tomography (CT) and magnetic resonance imaging (MRI). Of note, Marie Curie overcame misogyny, xenophobia, and anti-Semitism (though she was not in fact Jewish) to become the first woman to be awarded the Nobel Prize, the first person to receive two such Prizes, and the only person ever to have been bestowed Prizes in different scientific disciplines (physics and chemistry). We should recognize and celebrate the contributions of those brilliant people who have had to overcome barriers and those whose work has been overlooked.

Imaging is often an important aspect of patient diagnosis, and it is important for physicians to be aware of the various imaging modalities, as well as their advantages and disadvantages. The major imaging modalities are:

- Radiography (x-ray), including mammography
- Fluoroscopy
- Computed tomography (CT)
- Magnetic resonance imaging (MRI)
- Ultrasound
- Nuclear Medicine including SPECT and PET

The following sub-sections briefly describe these modalities including their basic advantages and disadvantages. The lecture material provides additional information and images—including videos—that may help you understand the utility of these specific modalities more thoroughly.

Radiography, Mammography, and Fluoroscopy

Radiography, mammography, and fluoroscopy are projection modalities that rely on x-ray energy to produce the images (Figure 1). Examples of the use of radiography include imaging the chest in a patient with fever to assess the possibility of pneumonia or imaging the foot in a patient who had trauma. Mammography is used to screen for breast cancer in asymptomatic individuals and to diagnose abnormalities in symptomatic patients. Fluoroscopy is used to observe movement, primarily in the gastrointestinal (GI) tract, or to guide procedures such as angiography (imaging of the vessels) and interventional therapy.

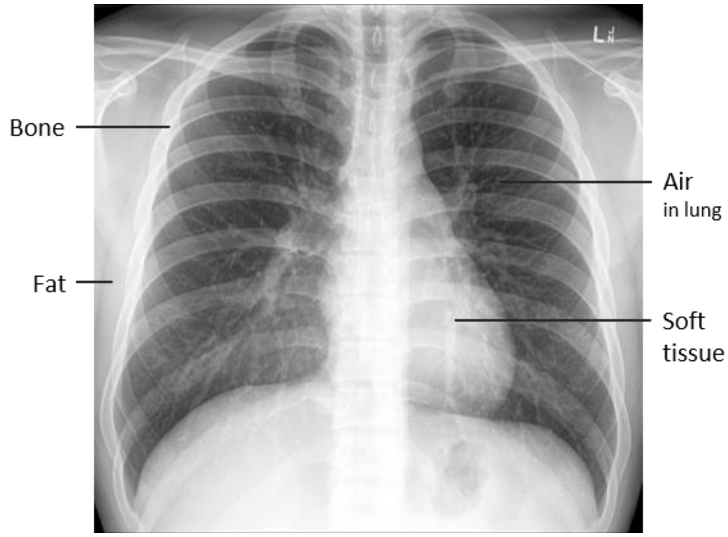

Figure 1. Radiograph of the chest. Radiographs differentiate structures of varying densities. Air is radiolucent (least dense, darker) where bone is radiopaque (most dense, brighter).

Advantages of radiography include the relative ease of performing the study, a modest radiation dose, and a modest cost. *Disadvantages* include the difficulty of differentiating soft tissues. In addition, organs and structures are superimposed so that spatial relationships can be difficult to discern. Fluoroscopy can impart a high radiation dose if the operator is not careful or if the procedure is time-consuming. In addition, angiography is invasive and can be expensive. Patients can experience discomfort with the unpleasant taste of barium for upper GI fluoroscopy, needles and catheter placements for angiography, and breast compression for mammography.

Computed Tomography

Computed tomography (CT) is a cross-sectional, or tomographic, imaging modality that relies on x-rays to obtain data that is reconstructed by a computer to produce images. CT is used for a number of applications, including the identification of bleeding in the brain (Figure 2), the assessment of traumatic injury, and staging of cancer.

Advantages of this cross-sectional approach include easy visualization of structures, more precise spatial relationships of organs and structures relative to radiographs, and good differentiation of soft tissues. This can be further improved with the use of

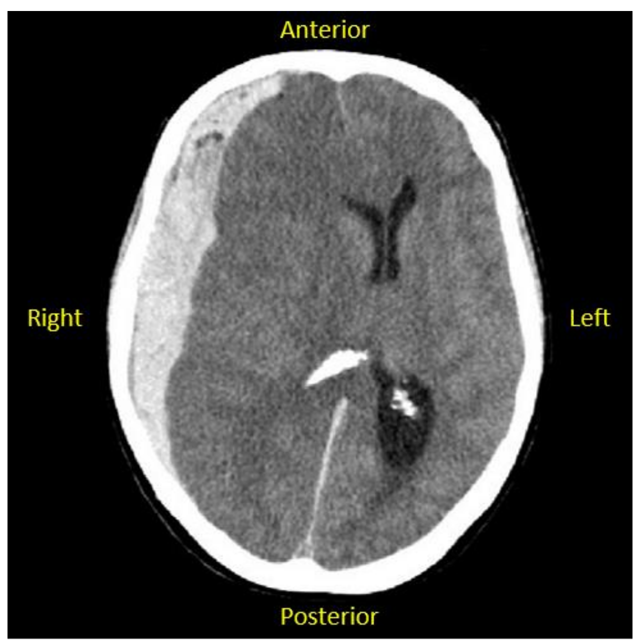

Figure 2. CT of the head. This CT shows a subdural hematoma on the patient's right (get used to orienting yourself). Also note the differentiation of gray and white matter in the brain.

contrast agents. *Disadvantages* of CT include a relatively high radiation dose, though recent years have brought a major emphasis on reducing the dose. When used inappropriately or indiscriminately, CT can add substantial costs to health, but it can also help control costs if used for early diagnosis of an abnormality such as lung cancer or if the diagnosis can be made without more invasive procedures such as surgery (e.g., appendicitis). Patients can experience anxiety because they must lie in a large CT scanner and contrast agents can produce an uncomfortable sensation of heat.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is another cross-sectional imaging modality, based on nuclear magnetic resonance (NMR), and it can produce images in any imaging plane, including transaxial, coronal, sagittal, or oblique. The MRI unit incorporates a powerful electromagnet, and it detects perturbations in the magnetic field. The computer uses the magnetic field data to produce images. MRI is most often used for detailed evaluation of the brain and musculoskeletal system, but it is also used to assess the heart, vessels, and organs of the abdomen and pelvis. MRI contrast agents can be used to improve the delineation of abnormalities such as tumors.

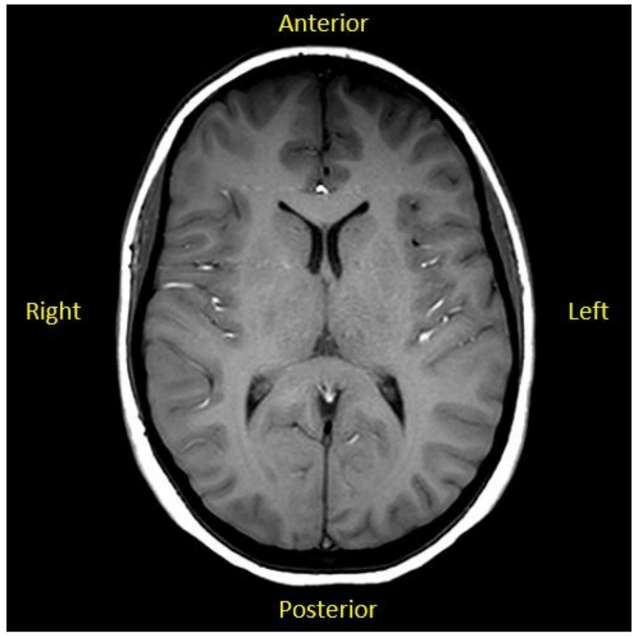

Figure 3. MRI of the head. This is a T1 MRI showing excellent differentiation of the soft tissue of the brain (compare to the head CT in Figure 2).

Advantages of MRI include cross-sectional capability in multiple planes, excellent differentiation of soft tissues, evaluation of function (brain and cardiovascular system), and absence of ionizing radiation that can cause damage to DNA, leading to cell death or cancer. *Disadvantages*, as with CT, include a relatively high cost if used inappropriately, but MRI can be used for early diagnosis of disease and to avert more expensive invasive procedures. For example, brain MRI can be used for the early diagnosis of multiple sclerosis, a neurological disease. MRI of the heart can be applied to determine whether bypass surgery is warranted, and to avoid surgery when not helpful. Because of the constricted space inside the scanner bore, some patients experience claustrophobia. MRI is sensitive to motion, and patients have to lie still for several minutes at a time. (MRI of the heart relies on electrocardiographic (ECG) gating to account for cardiac motion.) In addition, the electromagnet produces a great deal of noise. Because of the strong magnetic field, MRI has special safety considerations. Although most patients with metal in their bodies can undergo MRI, they usually should not have an MRI if they have brain aneurysm clips or metallic fragments in the eyes (which can move) or implanted devices such as pacemakers (which can malfunction).

ULTRASOUND

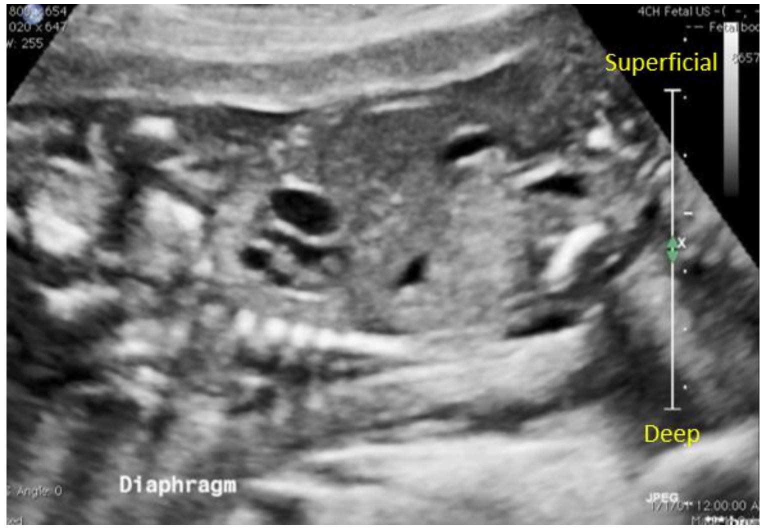

Figure 4. Fetal ultrasound **in utero.** Ultrasound allows you to visualize structures in real time based on echogenicity. This fetal ultrasound includes examples of hyperechoic ribs and anechoic heart chambers.

Ultrasound relies on reflection and transmission of high-frequency sound waves and computer processing to produce images. _Advantages_ of ultrasound include real time performance, permitting dynamic visualization of structures. The lack of ionizing radiation makes it ideal for fetal and pediatric imaging (Figure 4). _Disadvantages_ include a relatively low spatial resolution for many applications, although the high frequency transducers allow improved resolution for fetal imaging and for smaller body parts, such as the thyroid gland. To reduce echoes, which can degrade images, ultrasound gel is placed on the anatomic area of interest. The gel can be cold, and use of a gel warmer can be helpful. Many patients prefer to view the images, especially during a fetal scan.

NUCLEAR MEDICINE

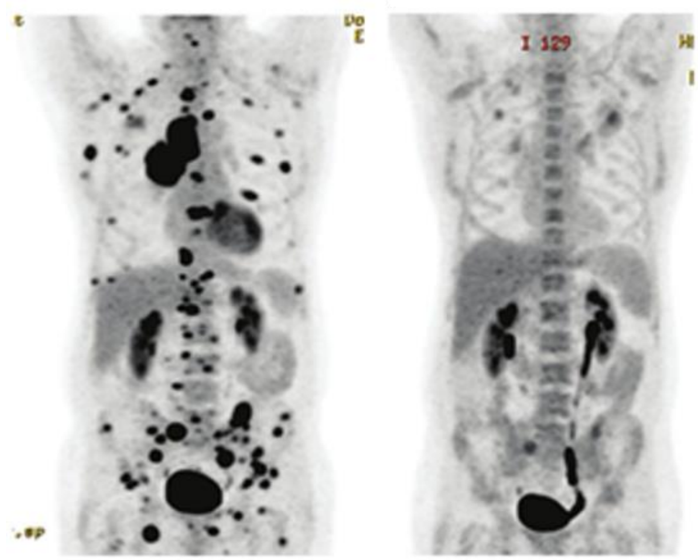

Figure 5. PET. In this PET scan, radioactive isotopes allow visualization of metabolically active cancer metastases before treatment (left) and after treatment (right). Note: isotope in kidneys and bladder is from normal waste removal. Other areas like the heart and brain will also appear “hot” in healthy individuals due to their normally high metabolic activity.

Nuclear medicine examinations use radioactive isotopes and a camera that captures the radioactivity to follow biological molecules to their targets. Exams such as SPECT (single photon emission computed tomography) and PET (positron emission tomography) can be used to produce cross-sectional images. Applications include depiction of cardiac abnormalities; evaluation of brain, endocrine, and renal activity; and detection of cancer and its spread (metastasis), including sentinel lymph node localization (Figure 5).

Advantages of nuclear medicine studies include the ability to assess function and to detect malignant tumors. _Disadvantages_ include a relatively high cost and a relatively low spatial resolution. Radiation exposure is approximately the same as a CT scan (Table 1). SPECT and PET scanners are large and can produce anxiety. The exams can take 30 minutes or longer, and it can be difficult for some patients to stay still during the scan.

Modality	Ionizing radiation (mSv*)	Advantages	Disadvantages
MRI	0	No radiation, high resolution across multiple planes	Moderately high cost, time-consuming and motion sensitive
Ultrasound	0	No radiation, real-time	Low resolution, user dependent
Radiography and Fluoroscopy	Chest radiograph ≈ 0.02; mammogram ≈ 0.4; upper GI ≈ 6	Low cost, easy to obtain, relatively low radiation	Low soft tissue resolution, overlapping structures in 2-D
CT	1-15 depending on region and indication**	Better spatial resolution across multiple planes	Relatively high radiation
Nuclear medicine including PET	1-14 depending on region and indication	Assessment of function	Relatively high radiation/cost and low spatial resolution

Table 1. Summary of imaging modalities. Imaging modalities listed by approximate effective dose of radiation.
* Effective dose is measured in Sieverts (Sv) and takes into account radiation and organ system damage; higher numbers equal a higher health risk. It is important to communicate this to patients in relative terms. For example, a chest radiograph exposes a patient to approximately the same radiation dose as a transcontinental plane ride. You do not need to memorize specific effective doses; they are provided for comparison across modalities.
** Modern CT scanners often use substantially less radiation, in the range of 1-7 mSv.

Social Determinants of Health

It is important to recognize that social determinants of health are associated with differences in the application of imaging, which can lead to health disparities. Missed care opportunities in imaging occur more frequently among black and Hispanic/Latino/Latina patients, those who do not speak English or Spanish, those with non-commercial insurance such as Medicaid and Medicare, and those who live in zip code areas with an average household income under $50,000 per year. Providers should keep this information in mind when ordering imaging studies. A study of pediatric emergency department patients showed that patients of color were less likely to receive imaging studies when there was no standard protocol for management, such as in the setting of upper respiratory infection and fever. However, when there was a standard treatment algorithm, such as in patients with head injury, there were no racial/ethnic differences in the use of imaging. Standard algorithms can ameliorate disparities, but in the absence of such protocols, providers should keep in mind that imaging disparities exist and may be due to implicit bias or other hidden factors.