# Diagnostic Patient Studies in Surgery

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# Preface

How we make a diagnosis in surgical practice has changed radically in recent years. The basic history and physical examination have remained essentially the same, but newer methods of assessment that complement the history and physical examination have transformed the practice of medicine. These methods are patient and laboratory studies. Although such studies have increased our ability to detect and to diagnose disease, they also present problems characteristic of other technologic advances. Such problems relate to the appropriate uses of new technology. Appropriate uses can only follow an understanding of the basics and application of diagnostic procedures employed in surgery.

The term "patient studies" refers to one of the two major types of diagnostic techniques. Patient studies are diagnostic procedures that require the presence of the patient. These studies are different from laboratory studies, which are performed on specimens, such as blood, urine, or tissue, obtained from patients and processed later in a laboratory prepared to do chemical, immunologic, microbiologic, morphometric, or some other type of analysis. Some diagnoses require a combined use of patient and laboratory studies. For example, imaging or endoscopy, both of which are patient studies, may be used to guide placement of a biopsy needle to obtain a specimen for tissue analysis. Basically, three types of patient studies are performed. All have evolved since the nineteenth century, although many may be traced to antiquity. The three types of patient studies are imaging procedures, endoscopy, and function analyses.

Much of the growth and development of modern medical science and technology can be attributed to advances in patient studies. The use of these studies in surgical practice has had a significant impact on the management of patients. Patient studies have become an indispensable aspect of the management of many conditions treated by surgical means; however, they have also become numerous and sometimes risky, complex, and expensive. This book is intended to help surgeons to understand the commoner patient studies available to them in the management of their patients. This help is provided as a short reference about patient studies and a guide to their use.

A number of technologic advances, occurring mostly since World War II, have given rise to the many patient studies available today. These advances are largely related to rapid developments in science and technology as a whole and include such developments as new energy sources for imaging (ultrasound, nuclear products, magnetic resonance), new materials (fiber optics), and new computational abilities brought about by integrated circuits. Many patient studies have recently undergone rapid change. A means of evaluating this progress is to consider the many branches of medicine and the types of physicians active in the performance of each major type of patient studies.

The field of medical imaging has grown extensively and has given rise to the specialty of diagnostic radiology, which provides physicians skilled in the performance and interpretation of radiographic images. This field has been enriched by advances in nuclear medicine, ultrasound, computer tomography, magnetic resonance imaging, and specialized procedures employing the injection of contrast material. Although some specialists perform their own imaging procedures, the specialists in diagnostic radiology have largely become the main providers of imaging expertise.

The situation is different wtih endoscopy. Endoscopic procedures are performed by physicians and surgeons specializing in diseases of certain systems, such as the genitourinary, gastrointestinal, and respiratory tracts. Not all specialists perform endoscopic studies, however, and many rely on colleagues to perform requisite endoscopic examinations.

Function analyses do not provide an image or an endoscopic view, but rather information about physiologic processes and how they may be deranged. Many function tests began as physiologic investigation. Function analyses are as diverse as the organs and systems that they evaluate. Consequently, these tests are usually supervised and interpreted by physicians in a variety of medical specialties. Function analyses range from the commonplace electrocardiogram to the less-common 24-hour monitoring of esophageal hydrogen ion concentration.

The point about patient studies in surgery is the extensive number and wide assortment of tests that usually require the involvement of other physicians in a variety of specialties. Surgeons who request patient studies have increasing difficulty in deciding which procedures to order and how to respond to their results. Indeed, the errors that may occur in the diagnostic workup of a patient are often related to which tests to perform and when. Although much is now known about patient studies used in surgical diagnosis, this knowledge is available in a multiplicity of sources such as separate textbooks on the various forms of imaging, endoscopy, and function analysis. These sources are usually directed to physicians within a specialty such as radiology or gastrointestinal endoscopy. On the other hand, the standard textbooks of surgery can devote little space to patient studies. This book attempts to follow a middle course by providing information about diverse types of patient studies for surgeons. We have tried to bring together a number of topics related to the surgical applications of the three types of patient studies into a single volume that can be used by the general and subspecialty surgeon as a reference and guide. Because of limits relating to the nature and quantity of material that may be presented in a reasonable manner, much selectivity was necessary in defining the scope and content of this book. This can be best expressed in terms of what we emphasized and what we restricted.

Our approach has been to present topics that relate to general as well as some specialty applications of patient studies. These topics include all major imaging modes in use today, the commoner endoscopic procedures, and function analyses applicable to most workups of the cardiac, genitourinary, respiratory, gastrointestinal, and neurologic systems. Space has prevented us from including other topics such as otolaryngologic and ophthalmologic procedures. We feel justified in excluding these examinations because a surgeon undertaking a diagnostic workup seldom requests specific otolaryngologic or ophthalmologic procedures, but rather seeks a consultant who, in turn, obtains specific tests. The situation is different for most of the patient studies described in this book because we have selected procedures that a surgeon is more likely to request directly. Such procedures may be new or well established. This book aims to acquaint the surgeon with some new procedures and to summarize the current status of other tests that might be required during the management of a surgical patient.

Diagnostic Patient Studies in Surgery is limited because less emphasis is placed on technique and interpretation than on short explanatory descriptions of the studies, their strengths and weaknesses, and the main indications for their use. Our primary aim in preparing the book was not to teach the surgeon how to perform or to interpret patient studies, but rather to teach an understanding of how the tests are best used during the diagnostic process. The emphasis is on the surgeon as decision maker regarding which tests to order, the timing of these tests, and the meaning of test results.

This book is further limited by not providing specific approaches or algorithms for performing diagnostic workups of individual problems. The book describes many types of patient studies that the surgeon may consider, but it does not initiate the problem-solving search. The surgeon must have already started the diagnostic process and must have some idea of which studies should be performed. Questions about the possible use of a particular study should prompt the reader to refer to a section or chapter dealing with that study. This book need not be read sequentially because each chapter is independent, except the chapter on general principles of radiation, which is background reading for other topics in radiographic imaging. For those wishing further information, each chapter contains references to the literature or suggestions for general reading in the subject. For common patient studies, however, this book should provide adequate background information. I hope that this book will promote a more informed and cost-effective use of patient studies in surgical practice.

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# Contents

# Part I

## IMAGING

# 1

# Radiologic Physics, Technique, and Radiobiology

Robert H. Choplin ■ Wells Martin, III

Although detailed knowledge of the physics and technique of radiology is unnecessary for clinical practice, an overview of these processes may be helpful in understanding some of the limitations of x-ray equipment and the reasons for the appearance of x-ray films. It may also be useful as background information for discussing potential technical problems with a radiologist or technologist. For readers with greater interest in this subject, several excellent texts are available.[1–3]

A developed radiograph is the product of a complex process that includes generation of an x-ray beam, passage of that beam through an object with which it interacts to create spatial differences in intensity, and the capture of those spatial inequalities on a receptor. It is possible to alter each of these processes, with differences in the resulting image. Although radiologists attempt to alter the processes to enhance an area of interest, the final product always reflects a compromise between enhancement and suppression of desired and undesired variables. When viewing a radiograph, it is sometimes possible to tell which variables have been altered, but often it is not.

## GENERATION OF AN X-RAY BEAM

X rays are electromagnetic radiations with properties of both waves and particles. They travel at the speed of light, have wavelengths of 0.1 to 1 angstrom (for diagnostic x-ray studies) and energy levels of 10 to 300 kiloelectron volts (keV). X rays are produced by bombardment of a target by a stream of electrons in a vacuum tube (Fig. 1–1). When the electrons hit the target, they may interact with the nuclei of target atoms to produce *bremstrahlung* (general radiation), which emerges as a beam with a peak and a spectrum of lesser-energy x rays (Fig. 1–2). Electrons may also interact with a target-atom electron to produce characteristic radiation, which has a single energy level. Charac-

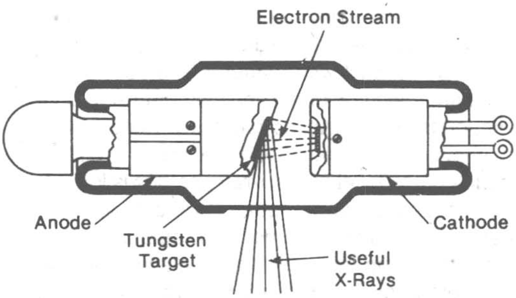


**FIG. 1–1.** Cross-sectional view of an x-ray tube. A stream of electrons is accelerated across a vacuum tube in such a way that they collide with a target, which is usually made of tungsten. Interaction between these electrons and the tungsten atoms produces x-rays. Because the tube is shielded, x-rays may only leave through a small window.

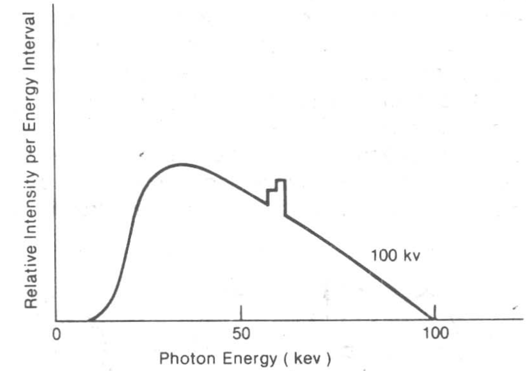


**FIG. 1–2.** Photon energies in an x-ray beam produced by *bremstrahlung*. The beam is composed of x-ray photons of energies ranging from about 10 to 100 keV, with the majority of photons occurring at lower energy levels. The step up at 62 keV results from the characteristic radiation of tungsten.

teristic adiation contributes 0 to 30% of the total energy of an x-ray beam, depending on how it is produced. Both the peak energy and the total amount of x rays in the beam may be controlled by an operator. X-ray equipment is usually constructed to suit desired needs and ranges from simple machines useful for imaging the chest and the extremities to more complex and powerful units suitable for angiography.

## INTERACTION OF X RAYS WITH MATTER

Such interaction occurs at the atomic level, as well as with the object under radiographic study.

### Interactions at the Atomic Level

As an x-ray beam traverses an object, interactions take place at the level of the atom. Although an x-ray photon may interact with matter in five basic ways, only the photoelectric effect and Compton scattering are important in diagnostic radiology. Photoelectric reactions are more likely to take place when the average energy level of the x-ray photons is low and when the tissues under study are composed of higher-atomic-number atoms, such as bones.

A photoelectric reaction takes place when an x-ray photon collides with a tightly bound electron from an atom's *inner* shell and ejects it from its orbit. When this reaction happens, the photon is completely absorbed, and spatial differences in beam intensity (shadows) are created as other x-ray photons completely traverse the object. The photoelectric effect therefore plays a major role in creating the contrast differences between tissues and allows their visualization. Unfortunately, films exposed using low-photon-energy beams result in a high radiation dose to the patient. Because of this high absorbed radiation dose, one attempts to obtain films at low enough photon energy levels to provide some photoelectric effect and therefore crisp images, but at high enough energy levels to maintain minimum radiation exposure.

Compton scattering is the other important interaction between x-ray photons and atoms. When a high-energy x-ray photon strikes a free electron in the *outer* shell of an atom, it ejects the electron from its shell and is itself deflected in a new direction. The distribution of scattered photons varies with the energy of the incident beam in such a way that photons are scattered in an increasingly forward direction as the average energy of the beam increases (Fig. 1–3). Because scattered radiation is deflected randomly, it adds to overall film blackening and decreases the difference in intensity between black and white regions of a film. This decrease in contrast may degrade the imaged because scattered radiation may account for 50 to 90% of the photons emerging from a patient. As with the photoelectric effect, a compromise must be made in selecting the energy level used in taking a radiograph. Decreasing beam energy lessens Compton scatter, but increases the radiation dose to the patient. Increasing beam energy lessens the radiation dose, but increases the amount of scatter and therefore degrades the image.

### Interaction with the Object to be Radiographed

An x-ray beam is characterized by a quality variable, which is the average energy of the photons, and by a quantity variable, which is the number of photons. Beam intensity is the product of these two variables. Attenuation is the reduction in intensity of the x-ray beam by either absorption or deflection of photons as it traverses an object. Attenuation across an absorber occurs in an exponential fashion, so the intensity of a beam emerging from a patient may be as little as 1% of the intensity at entrance. Attenuation is influenced by the energy of the incident beam, the density of the absorber, the atomic number of the absorber, and the electrons per gram of tissue. The first two factors are of primary importance in diagnostic radiology. Most radiographs must be taken with a beam energy of 60 to 120 keV, an energy level at which Compon reactions predominate and at which differential attenuation almost entirely depends on tissue density.

### Scatter Reduction

The x-ray beam exiting from a patient consists of both primary and scattered radiation and has as-

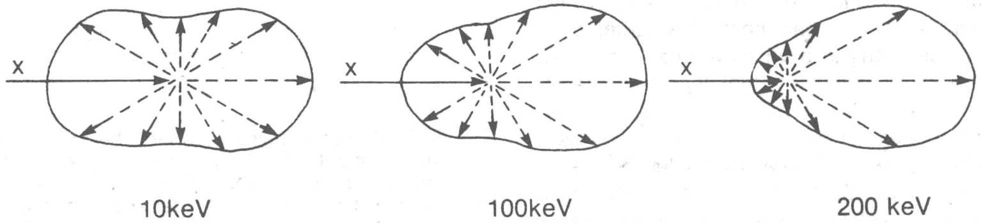


**FIG. 1–3.** The distribution patterns from Compton scattering occurring with beams of three different energy levels. As the average energy of the beam increases, the deflected (scattered) photon is more likely to continue in a forward direction.

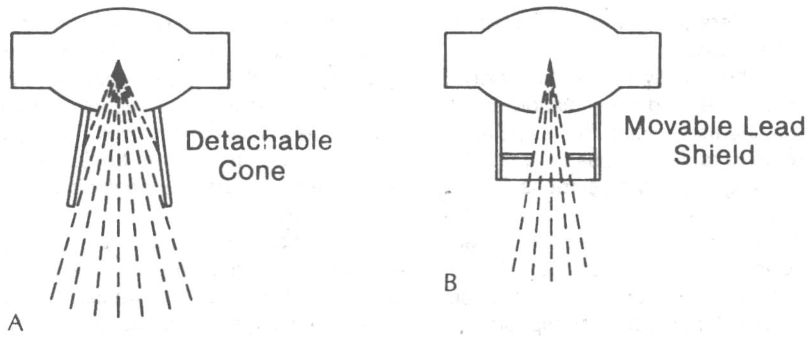


**FIG. 1–4.** Radiation beam restrictors. X-ray beams are restricted to a size appropriate to examine a body part by using detachable cones *(A)* of various sizes or a collimator. *B,* The collimator has movable lead shields that can be adjusted to limit the x-ray field.

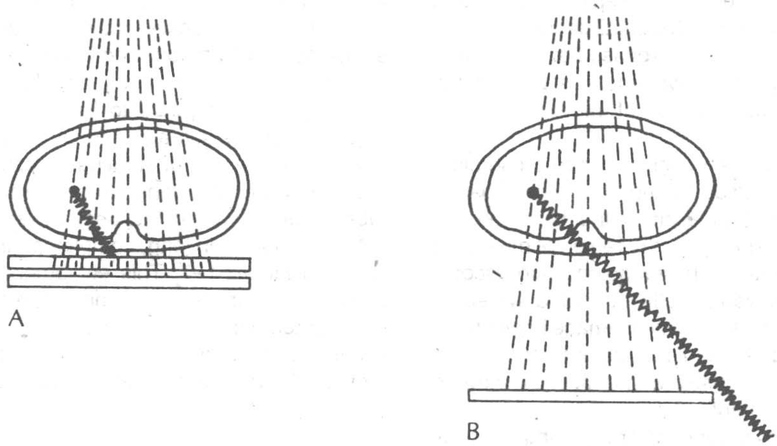


**FIG. 1–5.** Reduction of scattered radiation; two methods. *A,* A grid consisting of lead foil strips and aluminum has been placed between the patient and the film. Because the scattered radiation (zig-zag line) is not parallel to the lead strips, it cannot reach the film to degrade the image. *B,* An air gap of about 20 cm has been placed between the patient and the film. Because of this gap, a scattered photon (zig-zag line) may not hit the film.

sumed spatial differences in intensity because of interactions with various anatomic structures. The amount of scattered radiation increases not only with increasing beam energy, but also with the size of the x-ray field and the part examined. For example, an x-ray beam in an abdominal study has more scatter radiation than an x-ray beam in the radiographic study of a finger. The amount of scattered radiation may be minimized by decreasing field size or part thickness and by the use of grids or an air gap when the beam has left the patient. Field size is decreased by using cones or a collimator to restrict the beam as it comes from the x-ray tube (Fig. 1–4). Scattered radiation in the beam exiting from a patient may be reduced by use of either a grid or an air gap (Fig. 1–5). A grid is constructed of parallel strips of lead foil interposed between strips of radiolucent material, usually aluminum or an organic compound. A grid allows passage of primary radiation, but only minimal amounts of scattered radiation pass through because they are not parallel to the lead foil. An air gap between the patient and the receptor decreases scattered radiation because the majority of the scattered photons do not hit the film. Use of either an air gap or a grid requires a slight increase in radiation dose to the patient.

## IMAGE RECEPTORS

To study the information carried by the x-ray beam, the beam must be captured on an appropriate receptor. This capture may be accomplished by exposure of film, by a film-screen system, by a xeroradiographic system, or by a fluoroscopic screen. Information capture with processing before display, as in computed tomography or some digital imaging system, is beyond the scope of this chapter and is discussed in the chapters devoted to computed tomography (CT) and angiography.

Although film may be directly exposed by x rays, this method is insensitive, and the radiation doses are too high for routine use, except for radiographs of extremities. To keep radiation doses low, almost all films are taken using intensifying screens. These film-screen systems are plastic screens in which an inorganic salt, called a phosphor, has been imbedded. When exposed to x rays, the phosphor emits a large amount of light per x-ray photon, and this light exposes the film. A number of phosphors are available, each of which is usually matched to a particular film; the result is a film-screen combination with a defined speed (sensitivity to x rays) and resolving power. In general, as the speed of a system increases, its ability to resolve detail decreases. One must therefore make a compromise between radiation dose and film quality. Systems must be selected according to the requirements of the anatomic part to be imaged.

A fluoroscopic screen uses either zinc cadmium sulfide or cesium iodide as the phosphor because these compounds emit light in the blue-to-green area of the visible spectrum, the region of maximum sensitivity of the retina. The image on a fluoroscopic screen may be viewed directly, through a system of mirrors, or by a television system. Image intensifiers, devices that magnify the light output from the fluoroscopic screen, are used with almost all modern fluoroscopic equipment.

Xeroradiography is a means of capturing the x-ray image by use of an electrostatically charged selenium plate. The plate is partially discharged when exposed to x rays, and a powder of charged particles is used to develop the electrostatic image, which is then transferred to paper. Because the radiation dose required for exposure of a xeroradiographic plate is higher than that required for film-screen systems, the technique is unsuitable for general radiography. Xeroradiography has an advantage over film in imaging soft tissue detail, however. This advantage has made xeroradiography popular for mammography. When the technique was first used for this purpose, xeroradiographic mammograms could be performed at a radiation dose lower than that required for film mammograms. Since that time, modifications in both film-screen systems and mammographic x-ray units have made it possible to produce high-quality film mammograms at a lower radiation dose than needed for xeroradiography. Both forms of breast imaging are in widespread use and are considered acceptable.

## BODY-SECTION RADIOGRAPHY

Body-section imaging has used conventional tomography for many years. The development of CT scanning, gray-scale ultrasonography, and magnetic resonance imaging have made body section imaging one of the most rapidly evolving areas in medical diagnosis. Each technique is discussed in a separate chapter of this book. The principle underlying all these methods is to view a section of the body unencumbered by confusing overlapping anatomic structures.

Conventional tomography is body-section radiography that uses movements of the radiographic tube and x-ray film to blur unwanted information while keeping the region of interest in focus.[4] The simplest form of tomography is a linear movement of both the radiographic tube and the film, but in opposite directions with respect to the patient (Fig. 1–6). The focal plane is at the level of the axis of rotation of the beam. Theoretically, only a single plane is in sharp focus, and defocusing is progressive as one moves above or below that plane. In practice, however, a section appears to have "thickness;" the objects in that region are in focus, and objects outside that plane are out of focus. Because the effectiveness of blurring depends on the total length of tube travel, equipment has been developed to move the tube and film in long, complex motions, as illustrated in Figure 1–7. This equipment is more expensive than simple linear units. One disadvantage of linear tomography, however, is its inability to blur linear structures that are parallel to the line of tube motion. This phenomenon happens because the

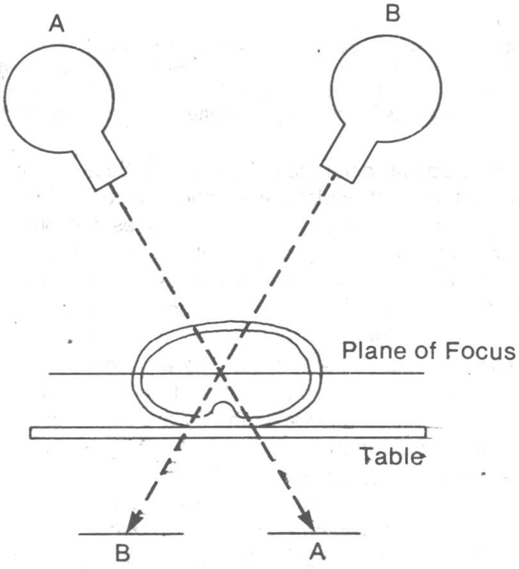


**FIG. 1–6.** Tomography. The radiograph is performed while the x-ray tube and film move from A to B, resulting in a plane of focus. To obtain images at other levels, the patient is moved up or down with respect to the plane of focus.

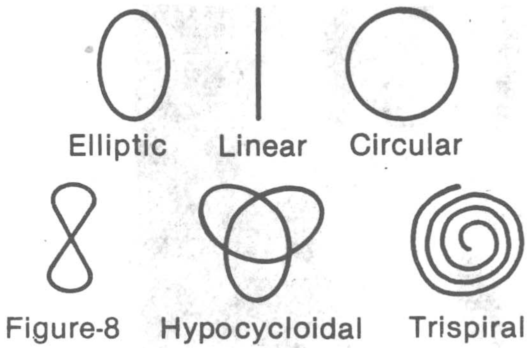


**FIG. 1–7.** Pathways of movement for tomography. The tube and film are moved in opposite directions along one of these pathways. The complex pathways have more effective blurring, but they are expensive. Each pathway results in its own artifacts.

projected image of the linear structure moves so little. As such, linear tomography may not be beneficial in evaluating some structures, such as bones, which are linear and cannot be oriented perpendicular to tube travel to avoid this artifact (Fig. 1–8).

## PERCEPTION OF THE RADIOGRAPHIC IMAGE

Perception of the radiographic image is a complex process involving acquisition of visual information, psychophysiologic processing of the information into a recognizable pattern, and assignment of an appropriate meaning to that pattern.[5] Although much of this process takes place unconsciously and is poorly understood, several factors can be used to optimize one's ability to make a diagnosis.

Perception of any light signal depends on the state of foveal adaptation, which becomes less sensitive as the ambient lighting becomes brighter. Therefore, extraneous lighting should be excluded as much as possible, to lower the threshold for signal detection. In addition, perception depends on the difference between the signal and the background. Elimination of possible sources of reflected light is therefore important in maximizing the signal-to-noise ratio.

The visual system is much more sensitive to contrast than to brightness. Although contrast is often thought of as the difference in illumination between two points, it may also be considered as the rate of change of illumination with respect to distance across the retina. The greater the rate of change, the greater the contrast and the more apparent an "edge" becomes. The lower the rate of change, the more difficult it is to detect an abnormality. Some radiologic diagnosis depends on detection of abnormal opacity, but to a lesser extent than on margin detection. The posteroanterior and lateral images and CT scan of a patient with a ganglioneuroma clearly demonstrate this principle; one sees the reason that this lesion is obvious on the posteroanterior film and invisible on the lateral film (Fig. 1–9). Finally, one's ability to detect subtle margins changes with viewing distance. It has been suggested that films should always be viewed not only from a normal distance of about 30 inches, but from an increased viewing distance or through minifying lenses, both of which have the effect of sharpening contrast differences.

## RADIATION PROTECTION

Protection from radiation involves measurement and restriction of doses, as well as an understanding both of the effects of radiation and of permissible limits.

### Measurement of Radiation

Radiation measurements may be expressed in terms of exposure, absorbed dose, or biologic effectiveness.[1] The original unit of exposure, the roentgen, is that amount of radiation that ionizes air under standard conditions releasing electrons equal to a charge of $2.58 \times 10^{-4}$ coulombs/kg air. The roentgen is limited in that it applies only to x or gamma rays and cannot be accurately measured at beam energy levels higher than 3 million electron volts (3 MeV), a level above which most modern radiotherapy equipment operates. The biologic consequences of radiation are related more closely to the portion of the x-ray beam that is absorbed by the patient than to the exposure itself. Although the absorbed dose is proportional to exposure, the relationship is complex, and the number of units of absorbed dose varies with the energy of the beam and the composition of the absorber. The unit of absorbed dose, the rad, is equal to an energy transfer of 100 ergs/g irradiated material from any form of ionizing radiation. The rem, a unit of dose equivalent, measures biologic effectiveness and is required for a comparison of the effects of different types of ionizing radiation. For x and gamma rays in the diagnostic energy range, all these units of measure are close enough to be considered equal. Dosages from x-ray or nuclear medicine examinations of patients are preferably expressed in rad or mrad (1/1000 rad). The International System of Units (SI) has suggested changing the name of the unit of absorbed dose from rad to Gray and the unit of biologic effectiveness from rem to Sievert. A Gray equals 100 rad, and a Sievert equals 100 rem. The method of calculation of these quantities is unchanged.[6]

### Effects of Ionizing Radiation

Ionizing radiation used in diagnostic imaging includes x rays and gamma rays. Gamma rays are qualitatively similar to x rays, but they are a product