Principles and methods of radiology

Historical perspectives

Wilhelm Conrad Roentgen, a Dutch physicist, discovered a form of radiation that now bears his name, the roentgen ray, in 1895. He called this new form of unknown radiation, which was invisible, could penetrate objects, and caused fluorescence, "X-strahlung" (x-rays) because initially he lid not understand its nature. Roentgen was doing experiments with cathode ray tubes, and studying their behavior in a completely darkened room. He noticed that when the tube was operating, there was a faint glow on the table of his laboratory. He discovered the glow was caused by a fluorescent plate that he had inadvertently left on the bench. When he reached for the plate, he was shocked to see the image of the bones of his hand cast onto the plate. His meticulous work investigating his discovery provided the world with an understanding of this new form of radiation. For his monumental work he was awarded the Nobel Prize in physics in 1901.

The first recorded diagnostic use of x-rays was in 1896. In the 1-st decade of the discovery of the roentgen ray, the physical effects of x-rays on patients were also observed. It was not long before a new medical specialty, radiology, was born.

The last quarter of a century has brought changes and developments in diagnostic radiology that far surpassed those made the nearly 75 previous years. These newer developments have revolutionized medical diagnosis, making areas of the body previously inaccessible to nonsurgical examination clearly visible. Furthermore, the ability to accurately image all areas of the body made it possible for interventional and biopsy procedures to be performed using newer methods of diagnostic imaging for guidance. Previously, these procedures would have required surgical exploration.

The realm of diagnostic radiology encompasses a variety of modalities of imaging that may be used individually or, more commonly, in combination to provide the clinician with enough information to aid in making a diagnosis. Diagnostic imaging includes plain film radiography, contrast-enhanced radiography, computerized tomography, magnetic resonance imaging, and diagnostic ultrasound. The first three of these imaging forms utilize x-rays. Nuclear radiology involves the detection of emissions from radioactive isotopes in various parts of the body; magnetic resonance and ultrasound do not have any associated ionizing radiation. A brief introduction to each type of examination is necessary at this point for the reader to understand how these modalities are used in clinical problem solving.

Radiography

X-rays, or roentgen rays, are a form of electromagnetic radiation or energy of extremely short wavelength. X-rays in the diagnostic range are in the spectrum of short wavelengths (0,001-10 nm). The shorter the wavelength of an electromagnetic radiation form, the greater its energy and, as a rule, the greater the ability to penetrate various materials. X-rays are described in terms of particles or packets of energy called quanta or photons. Photons travel at the speed of light. The amount of energy carried by each photon depends on the wavelength of the radiation. This is measured in electron volts. An electron volt is the amount of energy an electron gains as it is accelerated through a potential of 1 volt. An atom is ionized when it has lost an electron. Any photon that has about 15 or more electron volts of energy is capable of producing ionization in atoms and molecules (ionizing radiation). X-rays, gamma rays, and certain types of ultraviolet radiation are all typical ionizing radiation forms.

Production of X– rays

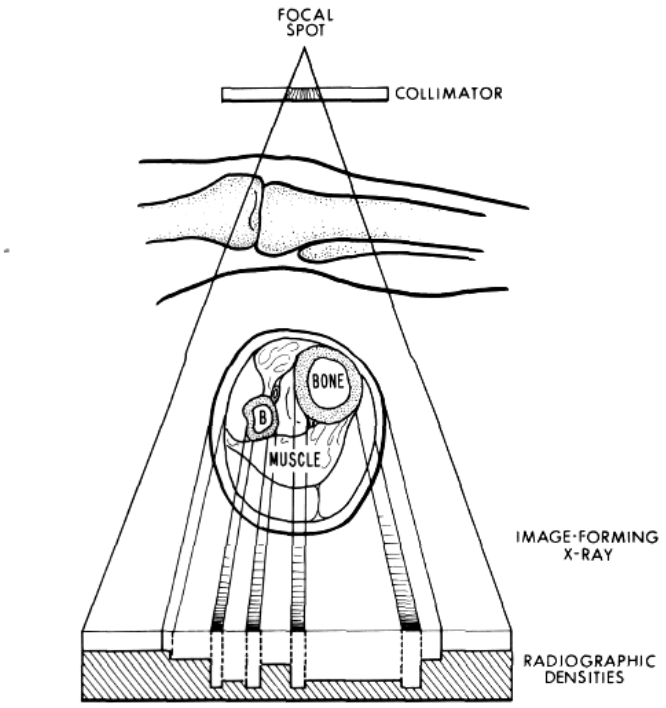
X-rays used in diagnostic radiology require a vacuum and the presence of a high potential difference between a cathode and an anode. In the basic x-ray tube, electrons are boiled off the cathode (filament) by heating it to a very high temperature. To move these electrons toward the anode at an energy sufficient to produce x-rays, a high potential, up to

125,000 volts (125 kV), is used. When the accelerated electrons strike the tungsten anode, x-rays are produced.

Production of Images

Image production by x-rays results from attenuation of those x-rays by the material through which they pass. Attenuation is the process by which x-rays are removed from a beam through absorption and scatter. In general, the greater the density of the material, i.e., the number of grams per cubic centimeter, the greater its ability to absorb or scatter x-rays. Absorption is also influenced by the atomic number of the structure. The denser the structure, the greater the attenuation, which results in less blackening of the film (fewer x-rays strike the film). Less-dense structures attenuate the beam to a lesser degree and result in more blackening of the film (more x-rays strike the film) (Fig. 1).

It is important to differentiate between two types of "density" that you will hear mentioned when discussing radiographs with radiologists or other colleagues—physical density and radiographic density. Physical density is the type of density just described. Radiographic density is a term that refers to the degree of blackness of a film. Radiographic contrast is the difference in radiographic densities on a film. The radiographic density of a substance is related to its physical density. The effect on film or other recording media occurs "paradoxically"; structures of high physical density produce less radiodensity and vice versa. Structures that produce more blackening on film are referred to as being radiolucent; those that produce less blackening are called radiopaque or radiodense. There are four types of radiographic densities; these are, in increasing order of physical density, gas (air), fat, water, and bone (metal). Radiographically these appear as



black, gray-black, gray, and white, respectively.

Figure 1

Differential absorption of x-rays depends on the composition of various tissues. Denser tissue absorbs more x-rays; less dense tissue transmits more x-rays. The resultant radiographic image is essentially a "shadowgram."

Recording Media

The type of recording medium with which you are most familiar is x-ray film. X-ray film consists of a plastic sheet coated with a thin emulsion that contains silver bromide and a small amount of silver iodide. This emulsion is sensitive to light and radiation. A protective coating covers the emulsion. When the film is exposed to light or to ionizing radiation and then developed, chemical changes take place within the emulsion, resulting in the deposition of metallic silver, which is black. The amount of blackening on the film depends entirely on the amount of radiation reaching the film and, therefore, on the amount attenuated or removed from the beam by the subject.

Other recording media include the fluoroscopic screen/image intensification system, photoelectric detector crystals, xenon detector systems, and computer-linked detectors that measure actual attenuation. These last detectors are linked to magnetic tape or disks in the computer.

A fluoroscopic screen is a screen coated with a substance (phosphor) that gives off visible light (or "fluoresces") when it is irradiated. The brightness of the light is proportional to the intensity of the x-ray beam striking the plate and depends on the amount of radiation removed from the beam by the object irradiated. In its most common use today, the fluorescent screen is combined with an electronic device that converts the visible light into an electron stream that amplifies the image (makes it brighter) by converting the electron pattern back into visible light. This system allows the radiologist to see the image clearly without necessitating dark adaptation of the eyes, as is necessary in "conventional" (non-image-enhanced) fluoroscopy. This technology has been adapted for military use for nighttime security and warfare.

The detection of photons emitted by radioisotopes is accomplished with sodium iodide crystals. These crystals respond, when irradiated, by emitting light whose brightness is related to the energy of the photons striking them. Photodetectors convert the light into an electronic signal, which is then amplified and converted into a variety of display images.

Computed tomography (CT) scanners and digital radiography units utilize electronic sensors that actually measure the attenuation coefficient of tissue through which the x-ray beam has passed and converts this mathematical value into a digitalized shade of gray. The data are fed into a computer that plots the location of each of those measurements to produce the computer image. This is recorded on magnetic tape or disks and is displayed on a TV monitor or made into a hard copy (film) by the multiform at camera.

Image Quality

There are physical and geometric factors that affect the radiographic image. These include thickness of the part being irradiated, motion, scatter, magnification, and distortion.

The thickness of the part will determine how much of the beam is removed or attenuated. This was explained earlier. Thus, an obese patient requires more x-rays for adequate penetration than does a thin patient; bone requires more x-rays for penetration than does the surrounding muscle.

Motion of a part being radiographed results in a blurred nondiagnostic image. Motion may be overcome by shortening the exposure time. One way of decreasing the time of exposure is to enhance the effectiveness of the recording medium. This may be done by using intensifying screens. An intensifying screen is a device coated with a fluorescent material that gives off visible light when struck by x-rays. This light exposes the film. Cassettes (film holders) containing screens are used for about 99% of diagnostic x-ray work. This has the advantage of reducing the exposure time during which motion could occur. Improvements in screen technology have allowed us to obtain detailed examinations without increasing radiation dosage. This has been particularly advantageous for mammography.

Scatter is produced by deflection of some of the primary radiation beam; this can produce fog on the film and is undesirable. To eliminate as much scatter as possible, a grid that has alternating angled slats of very thin radiolucent material combined with thin lead strips is used (Fig. 1.4). This results in the removal of much of the scatter. To prevent the lead strips from casting their own shadows as they absorb radiation, the whole grid is moved very quickly during the exposure, eliminating these lines. This system is known as the Bucky-Potter system, after the two men who invented it.

The radiographic image is a two-dimensional representation of a three-dimensional structure. Consequently, some structures will be farther from the film than others. Geometrically, x-rays behave similar to light. Hence, magnification of objects will occur when they are some distance from the film. The farther an object is from the film, the greater the magnification; the closer the object is to the film, the less the magnification (Fig. 1.1). This has considerable importance in evaluating structures such as the heart on chest radiographs. On the standard chest radiograph, the x-ray beam enters through the back of the patient and exits from the front (posterior to anterior [PA]). Since the heart is located anteriorly, there will be relatively little magnification. However, on an anterior to posterior (AP) radiograph of the chest, the beam enters from the patient's front and exits through the back. Hence, there is somewhat greater magnification of the heart because of its distance from the film. The best rule to follow to reduce the undesirable effect of magnification is to have the part of greatest interest closest to the film. This will give the truest image of the region of interest. Distortion occurs when the object being radiographed is not perfectly perpendicular to the beam. The radiographic image of an object depends on the sum of the shadow produced by that object when x-rayed. Changes in the relationship of that object to the x-ray beam may distort its radiographic image. For diagnostic clarity, therefore, it is best to have the part of major interest as close and as perpendicular to the film as possible.

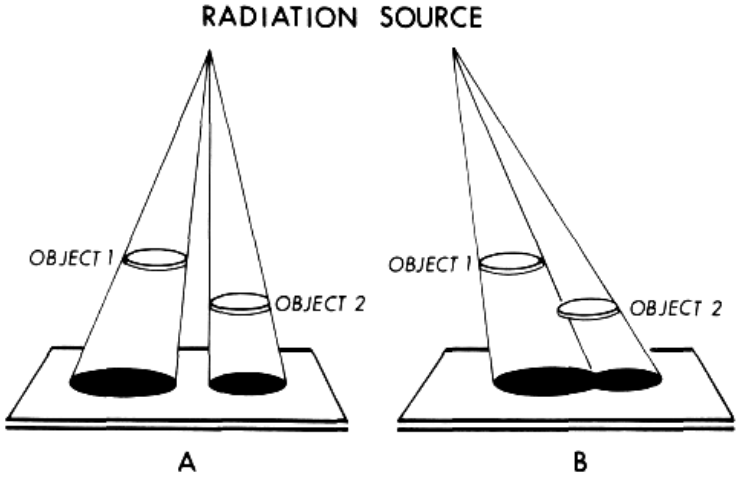


Figure 1.1.

Distortion. The shape of an object on a radiograph depends on the angle at which the radiographic beams strikes it.

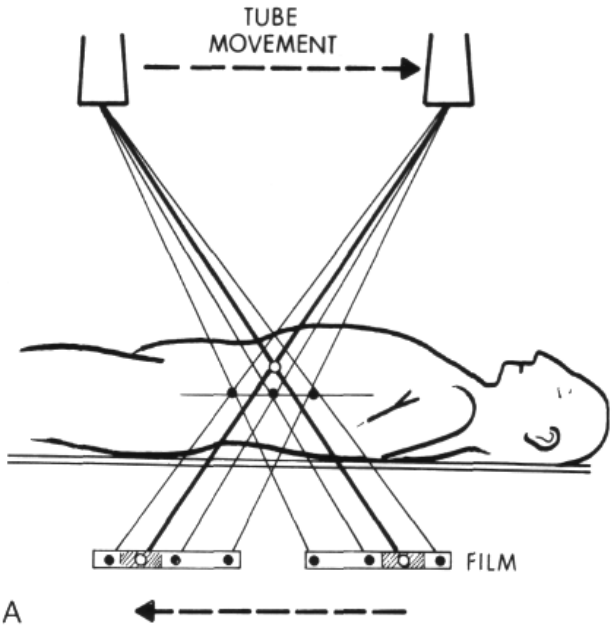
A, two objects of similar size cast distinct images when the x-ray beam is nearly perpendicular. The difference in size is the result of magnification.

B, angling the x-ray beam while the objects remain in the same relationship to one another results in an overlapping image that is not a true representation of the actual objects.

Plain film radiography is the bread and butter of the diagnostic radiologist. The term "plain film" means that no contrast material is used to enhance various body structures. In performing plain film examinations, the natural contrast between the basic four radiographic densities—air, soft tissue (water), fat, and bone—is relied on to define abnormalities. Examples of plain film studies with which you are familiar include chest radiographs, plain films of the abdomen, and skeletal films.

Plain film radiography has its special modifications: fluoroscopy and tomography. Fluoroscopy is a useful modality for visualizing the diaphragm, heart motion, valve calcification within the heart, and localization of chest masses.

Conventional tomography is a mode of imaging in which the x-ray tube and the film move in concert to produce a blurred image. The objects in the focal plane, or fulcrum, however, remain in sharp focus (Fig. 1.2). Tomography blurs out unwanted structures while keeping the object of interest in clearer focus. It is most useful in evaluating the lungs , kidneys, and bony structures. Tomography will improve contrast, but it will not create contrast where there is none to begin with.



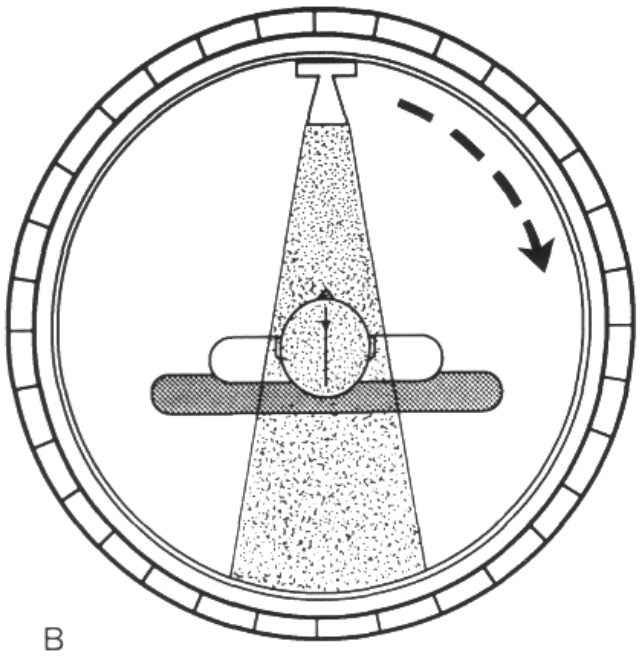


Figure 1.2.

Principles of tomography. **A**, conventional tomography. The x-ray tube and the film move in opposite directions. The focal point (open circle) remains in sharp focus, whereas the other images are blurred. **B**, computerized tomography. In the modern CT scanner, the x-ray tube rotates within the gantry. Instead of film, detectors measure the amount of radiation removed from the x-ray beam

Contrast examination

Plain film radiography is adequate for situations where natural radiographic contrast exists between body structures such as the heart and lungs or the bones and adjacent soft tissues. To examine structures that do not have inherent contrast differences from the surrounding tissues, it is necessary to use one of a variety of contrast agents. The vast majority of contrast studies are of the gastrointestinal tract, urinary tract, and blood vessels.

The most common contrast material used for gastrointestinal examinations is a preparation of barium sulfate mixed with other agents to produce a uniform suspension. These products are available as premixed powders or liquids. They may be administered alone or in combination with air, water, or an effervescent mixture that produces carbon dioxide. These gas-enhanced studies are referred to as "air contrast" studies. Administration of these preparations is either by mouth (antegrade) or by rectum (retrograde).

In addition to barium preparations, water-soluble agents are available for studying the gastrointestinal tract whenever there is a possibility of leakage of the contrast material beyond the bowel wall. Although barium is a chemically inert substance, it produces a severe desmoplastic reaction in tissues. Water-soluble agents, on the other hand, do not produce this type of reaction and are absorbed from the rupture site to be excreted through the kidneys. The water-soluble agents, however, are not without hazard, since they can cause a severe chemical pneumonia if aspirated. Water-soluble agents also cost more and hence are not used on a routine basis.

Gallbladder studies are performed by oral-administration drugs that are removed from the bloodstream, conjugated by the liver, excreted in the bile, and transported to the gallbladder, where concentration takes place. This results in visualization of this structure.

Urography is the radiographic study of the urinary tract. The contrast agents used for this study are primarily the ionic water-soluble salts of diatrizoic or iothalamic acids or the nonionic agents (iopamidol, iohexol). The common term for this study is the intravenous urogram (IVU). An older and less appropriate term is intravenous pyelogram (IVP). The physiology of these agents will be discussed in the next chapter.

Angiography is the study of the vascular system. Water-soluble agents similar to those used for urography are injected either intraarterially or intravenously, and a rapid sequence exposure is made to follow the course of the contrast material through the blood vessels.

The lymphatic system may be studied by injecting an iodinated form of poppy seed oil into the lymph vessels on the dorsum of the foot or the hand. The resultant study shows the flow of lymph from the limb to the regional lymph nodes and then to the deep lymphatic system. These studies are infrequently used today to stage patients with malignancies. They haw been largely superseded by computerized tomography.

A sinogram (fistulogram) involves the injection of contrast material through an abnormal sinus tract into the body. Water-soluble agents are commonly used for these studies. In evaluating an empyema cavity in the chest where there is a danger that a bronchopleural fistula may be present, an oil-soluble material such as Dionosil is used because water-soluble contrast material entering the bronchial tree could produce a severe and often fatal chemical pneumonia.

Sialography is the study of the salivary glands to evaluate patients with suspected salivary tumors or ductal obstructions. As with lymphangiography, an oily contrast material (iodinated poppy seed oil) is injected into the duct, which has been cannulated.

Diseases encroaching on the spinal canal may be studied by myelography. The main indication is evidence of cord or nerve root compression. The most common lesion is a herniated nucleus pulposus from a himbar disc. Myelography is performed by inserting a needle between the spinous processes of a lumbar vertebra and entering the subarachnoid space. It may also be performed by puncture of the cisterna magna when there is a complete block within the vertebral canal and it is necessary to inject contrast medium above the lesion. Cerebrospinal fluid may be removed for study at this time. Nonionic, iodinated, water-soluble compounds are injected under fluoroscopic monitoring in varying amounts, and the patient is positioned for the study. Note the compression of the thecal sac by the herniated material. Myelography is often combined with computerized tomography. The development of magnetic resonance imaging, however, has decreased the number of myelograms performed today, as compared with a decade ago.

Computerized tomography

Under ordinary circumstances, the fleshy organs of the body such as the heart, kidneys, liver, spleen, and pancreas are considered to be of uniform radiographic density, like water, which produces a gray appearance on conventional radiographs. However, these tissues vary somewhat in their chemical properties and it is possible, using computer-enhancing techniques, to measure these differences, magnify them, and display them in varying shades of gray or in color; this is the basis of computerized tomography.

In CT, an x-ray beam and a detector system moves through an arc of 360°, irradiating the subject with a highly collimated (restricted) beam. This allows the detector system to measure the intensity of radiation passing through the subject. The data from these measurements are analyzed by a computer system where various shades of gray (CT numbers) are assigned to different structures based on their absorption or attenuation coefficients. The computer

reconstructs a picture based on geometric plots of where these measurements were taken. This system of diagnosis was developed in the early 1970s.

The information obtained with CT systems is displayed on a television screen (CRT) and recorded on magnetic tape on disc. Once the information has been recorded, it is possible to alter the visual intensities of the various densities on the reading console. The data from the television screen may be recorded further on x-ray film using a device known as a multiformat camera.

To enhance the appearance of certain viscera or vascular neoplasms, contrast material is injected intravenously. The contrast agent used is identical to that used in urography or arteriography.

Cranial scanning is performed for the evaluation of patients with a variety of neurologic findings. This study is particularly useful in defining and localizing brain tumors (primary or metastatic) and in evaluating patients with neurologic emergencies such as intracerebral hemorrhage or subdural hematoma.

Scanning the rest of the body is particularly useful in evaluating visceral neoplasms. Other uses include studies of patients with abdominal trauma, investigation of patients with suspected pancreatic disease, mediastinal studies for defining the extent of tumors, evaluation of patients with Hodgkin's disease/lymphoma for staging purposes, diagnosis of intraabdominal abscess, and scanning the musculo-skeletal system for a variety of bone and soft tissue disorders.

Nuclear imaging

Nuclear medicine traditionally has two divisions, nuclear imaging (radiology) and laboratory analysis. The diagnostic radiologist is concerned with the imaging aspect. The use of isotopes for laboratory purposes and for evaluation of physiologic functions will not be discussed. However, the reader should be aware that the laboratory aspect of nuclear medicine is an area equally as important as the imaging aspect.

The principles of nuclear imaging depend on the selective uptake of certain compounds by different organs of the body. These compounds mav be labeled with a radioactive substance of sufficient energy level to allow detection outside the body. The ideal isotope is one that may be administered in low doses, is nontoxic, has a short half-life, is readily incorporated into "physiologic" compounds, and is relatively inexpensive. At the present time, technetium-99m fulfills most of these requirements.

The half-life of an element is the time necessary for its degradation to one-half of its original activity. There are actually three types of half-lives: physical, biologic, and effective. The physical half-life is that time period in which the element would "decay" on its own. This occurs naturally whether the element is sitting on the laboratory shelf or has been administered to a patient. Biologic half-life concerns the normal physiologic removal of the substance to which the isotope has been attached. For example, the sodium pertechnetate commonly injected for nuclear scanning is excreted in the urine and into the gastrointestinal tract. Although the physical half-life of technetium-99m is approximately 6 hours, the biologic half-life is less. The effective half-life is a mathematical derivation based on a formula combining biologic and physical half-lives. It measures the actual time the isotope remains effective within the body.

Nuclear imaging is performed either on a static or on a dynamic basis. Static studies include the thyroid, liver, and renal scans. Dynamic studies include rapid sequence flow to the skeleton and perfusion-diffusion studies of the lung. Equipment for detecting the uptake of isotopes and for recording their images includes the gamma camera and the tomographic scanner.

There are basically five mechanisms of isotope concentration within the body:

1. Blood pool or compartmental localization (e.g., cardiac scan);
2. Physiologic incorporation (e.g., thyroid scan, bone scan);

3. Capillary blockage (e.g., lung scan);
4. Phagocytosis (e.g., liver scan);
3. 5. Cell sequestration (e.g., spleen scan)

Conventional nuclear scans utilize isotopes that produce gamma or x-radiation. Positron emission tomography (PET) scanning uses cyclotron-produced isotopes of extremely short half-life that emit positrons. Positron emission tomography scanning is used to evaluate physiologic function of organs such as the brain on a dynamic basis. Areas of increased brain activity will show selective uptake of the injected isotope.

Magnetic resonance imaging

Magnetic resonance (MR) imaging is a noninvasive technique that does not use ionizing radiation. In the parameters used for medical imaging it is without significant health hazard. Magnetic resonance imaging is based on the principles described by Bloch and Purcell in an experimental procedure they designed to evaluate the chemical characteristics of matter on a molecular level. For their work, Bloch and Purcell were awarded the Nobel prize for physics in 1962. Damadian began investigating the possibilities of using MR for imaging in 1971. The development of computer imaging algorithms for CT accelerated the development of MR for medical diagnosis.

Magnetic resonance uses radiofrequency radiation in the presence of a high magnetic field to produce high-quality images of the body in any plane. The nucleus of any atom with an odd number of nucleons (protons and neutrons) behaves like a weak magnet in that they align themselves with a strong magnetic field. If a specific radiofrequency signal is employed to perturb the nucleus under study, its relationship to the external magnetic field is altered and it will generate a radio signal of its own having the same frequency as the signal that initially disrupted it (Fig. 1.3). This signal can then be amplified and recorded and this forms the basis for MR. Although many nuclei may be used for MR, the most common is hydrogen because of its abundance in tissue and its sensitivity to the phenomenon of magnetic resonance.

Magnetic resonance has the ability to display structures in a transverse or axial fashion, similar to CT. However, MR has the additional advantage of being able to produce images in virtually any plane. The common display parameters used are sagittal and coronal planes. Furthermore, MR has the advantage of being able to highlight the pathologic changes in different tissues through contrast manipulation. This is accomplished by altering the pattern of radiofrequency pulses in a study. The MR image reflects the strength or intensity of the MR radiofrequency signal received from the sample. Signal intensity depends on several factors such as hydrogen density and two magnetic relaxation times (Tl and T2). The greater the hydrogen density, the more intense (bright) the MR signal will be. Tissues that contain very little hydrogen such as cortical bone, flowing blood, and air-filled lung, generate little or no MR signal and appear black on the images produced. Tissues high in hydrogen, such as fat, have high-signal intensity and appear white.

A detailed explanation of Tl and T2 is beyond the scope of this text. However, in simple terms, these two measurements reflect quantitative alterations in MR signal strength due to interactions of the nuclei being studied and their surrounding chemical and physical milieu. Tl is the rate at which nuclei align themselves with the external magnetic field after radiofrequency stimulation. T2 is the rate at which the radiofrequency signal emitted by the nuclei decreases after radiofrequency perturbation.

Magnetic resonance is presently used primarily for studying intracranial and intraspinal pathology, and for evaluating abnormalities of the musculoskeletal system and the heart. Less commonly, it is used to evaluate abdominal visceral problems

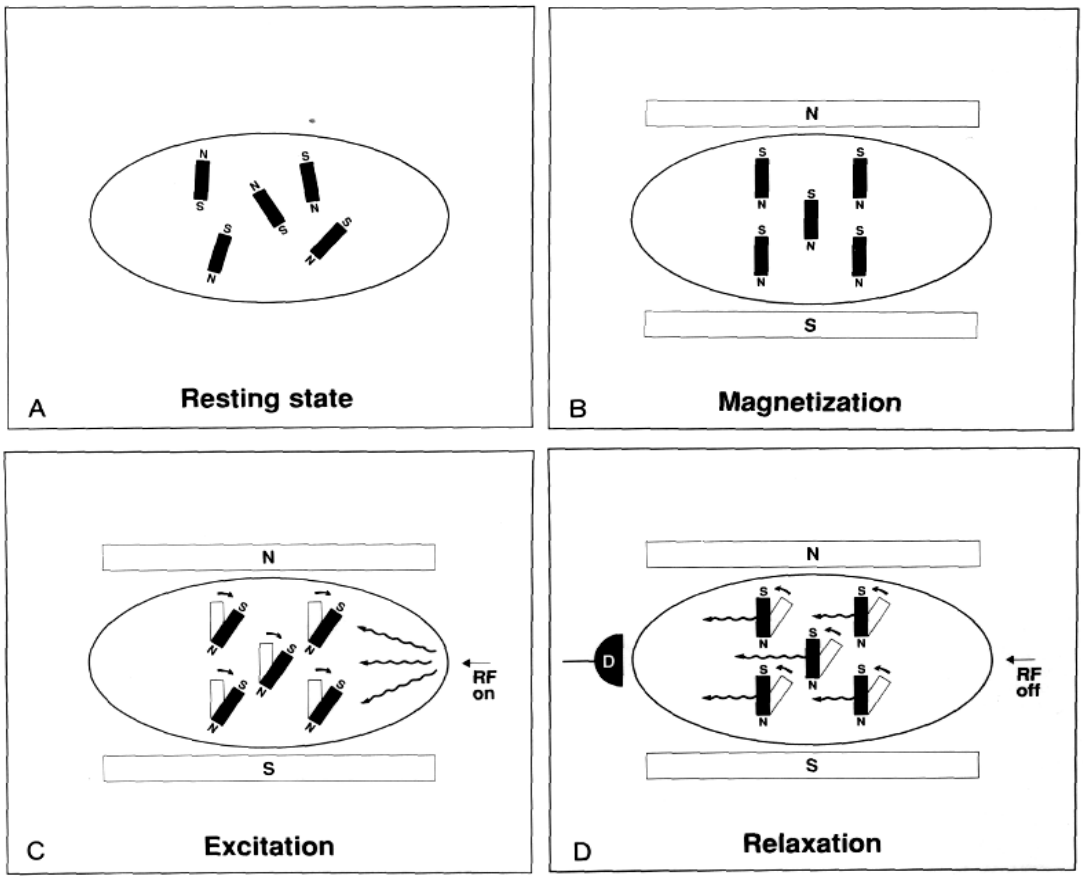


Figure 1.3.

Principles of MR1. A, in the resting state, the molecules in the body behave like small bar magnets and are arranged in a random fashion. B, following the magnetization, the molecules align themselves along the plane of magnetization. C, excitation. A pulsed radiofrequency (RF) beam deflects the molecules as they absorb the energy from that beam. D, relaxation. When the radiofrequency beam is switched off, molecules return to their preexcitation position giving off the energy they absorbed. This may be measured with a detector (D).

Diagnostic ultrasound

Diagnostic ultrasound is a noninvasive imaging technique utilizing sonic energy in the frequency range of 1 to 10 MHz (1,000,000 to 10,000,000 cps). This is well above the normal human ear response of 20-20,000 Hz. Ultrasound is a nonionizing form of energy. Echoes or reflections of the ultrasound beam from interfaces between tissues with different acoustic properties yield information on the size, shape, and internal structure of organs and masses. However, ultrasound is greatly reflected by air-soft tissue and bone-soft tissue interfaces, limiting its use in the chest and musculoskeletal system.

Both pulsed and continuous wave ultrasound are used. Pulsed ultrasound is used principally for static cross-sectional images in the abdomen or pelvis. The transducer transmits ultrasound waves for approximately 1 usec and then acts as a receiver for the returning echoes for approximately 1 msec. More commonly, real-time ultrasound techniques are used to perform

dynamic imaging (moving picture) of moving objects such as the fetus in utero or the pulsating aorta. This technique also permits rapid and efficient screening of a body region. The continuous wave or Doppler method is used primarily to record the dynamics in periodically changing regions such as the fetal heart or blood vessels.

Three display modes are commonly used. In amplitude mode (A-mode), information is displayed on a CRT as vertical spikes. The height or amplitude of a spike is related to the size of the echo; the distance from the initial or transducer spike is related to the depth of the reflecting interface from the transducer. Amplitude mode is now used very infrequently for echoencephalography to detect any shift of midline brain structures.

In brightness mode (B-mode), information is displayed as dots, the brightness of which corresponds to the strength of the corresponding echo. The location of the dot is proportional to the distance of the reflecting interfaces from the transducer. Since this constitutes only a single line on the CRT (corresponding to the line of sight of the transducer), one can build up a cross-sectional image or B-scan by a composite of many such lines obtained during a scan. The images can then be displayed over a wide range of gray scale or shading (Figs. 1.32 and 1.33). In particular, the difference in acoustic properties of various tissues is seen as a difference in the gray scale display of these tissues. Brightness mode and real-time ultrasound techniques are used extensively to evaluate the abdominal viscera, the fetus, and the heart.

Motion mode (M-mode) is used in echocardiography to study the dynamic changes of the cardiac structures. Essentially the base line is moved at a constant rate on the CRT screen. The cardiac structures form patterns in the M-mode relating to their motion.

An important advantage of ultrasound is the absence of ionizing radiation and the relatively lower cost of the equipment. However, a great deal of technical skill is required to perform a study.

Because ultrasound is unable to cross a tissue-gas or tissue-bone boundary, it is not useful for evaluating the lung or the skeleton. Furthermore, bony and gas-containing structures can obscure other tissues lying deeper to them.

The radiologist as a consultant

The complexity of today's diagnostic imaging studies make it imperative that the radiologist be more than an interpreter of x-rays. As the practice of radiology has become more organ-system oriented in larger hospitals, radiologists have gravitated to subspecialty areas through extra training following residency. Thus, large radiology groups have members who are specialists in neuroimaging, angiography and invasive procedures, body imaging, musculoskeletal imaging, pulmonary imaging, trauma, gastrointestinal imaging, uroradiology. pediatric radiology, and nuclear imaging. As such, these radiologists work closely with specific groups of clinicians to solve their special diagnostic problems. These clinicians consult with their radiologic colleagues on a daily basis either for interpretation of studies or to determine the best method of working up a particular diagnostic problem. The radiologic subspecialists are often on call to perform studies after normal working hours. They make themselves available to consult on request with the clinician. They often participate in multidisciplinary conferences such as the Surgery-Radiology-Pathology conference, and lecture the clinicians on topics of mutual interest.

You should learn to make use of this most valuable resource, the radiologist. Keep in mind, however, that he/she can best help you when informed of clinical or laboratory data on a patient. This means that requests for diagnostic studies should contain pertinent clinical information. The radiologist may thus be able to tailor an examination to the exact needs of the patient as well as you, the clinician. This will result in time saved in both the studies obtained as well as the hospital stay. A secondary benefit will be cost containment—a topic of current importance. Many studies provide similar information. There is little benefit in ordering expensive studies

that will duplicate the diagnostic information. Remember, your prime consideration is for the welfare of your patient. Consultation with the radiologist is as important for helping that patient as consulting with any other specialist.

Radiographic Contrast Agents

We are able to recognize various structures within the body either because of their inherent radiographic density (such as bone distinguished from muscle) or because they contain one of the basic natural materials (e.g., air). However, since most of the internal viscera are of the radio-graphic density of water or close to it, it is necessary to introduce into these structures a material that will outline walls, define anatomy, and demonstrate any pathologic conditions. The first chapter briefly mentioned these agents and some of the studies for which they are used. This chapter will deal with their physiology and pharmacology, define indications and contraindications for their use, and discuss the treatment of reactions to them.

Barium preparations

Barium sulfate (USP), in one of its many forms, provides the mainstay far radiographic examinations of the gastrointestinal (GI) tract. Barium is of high atomic weight, which results in considerable absorption of the x-ray beam, thus providing excellent radiographic contrast. In the usual preparation, finely pulverized barium mixed with dispersing agents is suspended in water. When administered orally or rectally, it provides adequate coating of the GI tract.

Although barium itself is chemically inert, when it is extravasated outside the GI tract, a severe desmoplastic reaction may develop. This is most likely to occur when there is a perforation of the GI tract. In the past, barium mixed with fecal material was deemed to be a rapidly lethal mixture when introduced into the peritoneal cavity. However, studies have shown that the combination of barium and feces is no more lethal than the introduction of feces alone into the peritoneum. However, because of the tendency to produce severe granulomas and adhesions, barium should not be used whenever a suspected perforation exists. In these situations a water-soluble contrast material should be used.

Barium preparations are safe as long as the entire GI tract is patent. Oral barium may be used if an obstruction is present proximal to the ileocecal valve, since the contents of the small intestine remain fluid up to that point. If the obstruction is distal to the ileocecal valve, the patient is best examined with a retrograde study (barium enema) because once the bowel contents enter the cecum, water is rapidly absorbed. If barium is allowed to remain within the colon for a long time behind an obstruction, it may inspissate and compound the patient's problem.

WATER-SOLUBLE CONTRAST MEDIA

Water-soluble contrast agents are used predominantly for urography, angiography, and contrast enhancement of computed tomography (CT) studies. The most common agents used are the sodium or meglumine salts of diatrizoic or iothalmic acid in concentrations of 60 to 90%.

The common chemical structure of all water-soluble contrast media is triiodobenzoic acid. These agents are referred to as ionic media because of their property in solution to dissociate into the sodium or meglumine cation and their iodine-containing anion.

These agents are very hypertonic (three times that of serum), resulting in a fluid shift from the intra- or extracellular to the intravascular space or lumen of the GI tract (depending on the route of administration). Although normal individuals may not suffer any severe long-lasting effects from this shift, patients who are dehydrated or in a precarious state of car-diac and fluid balance are at special risk, particularly for renal failure. Sec-ondary effects from the changes in viscosity and tonicity of the blooc include platelet aggregation, changes in blood pressure, change in cardiac output, and changes in pulse rate. As the serum osmolality rises, thene may be changes in blood coagulation, with a resultant bleeding tendency.

The extent and severity of these changes will depend on the volume of the agent injected, the speed of injection, and the tonicity and viscosity of the agent. Rapid injection, high-volume

injection, and high tonicity and viscosity of the agent are associated with more severe reactions. Fortu-nately, the majority of these agents are used for urography, where a slower injection rate prevents many of these effects. Occasionally a vagal reaction occurs in which there is vasodilation and systemic hypotension. Bradycardia is encountered rather than tachycardia.

Cardiac changes include bradycardia, a fall in systemic blood pres-sure, flattening of the T waves, and decreased cardiac output. This occurs especially if the contrast agent is injected directly into the heart. In the kid neys, especially in a dehydrated patient, glomerular and tubular damage may result in temporary impairment of renal function and oliguria.

The goal of reducing the normal physiologic and abnormal adverse ef-fects of the ionic contrast agents led to the development of a new class of water-soluble media. These agents are of two varieties. The first are rionionic monomers—variants of triiodobenzene—in which the sodium or meglumine cation has been replaced by a side chain that will not dissoci-ate from the iodine-containing portion of the molecule. This results in a pronounced lower osmolality than the ionic agents.

The second class of low-osmolality agents is an ionic dimer formed by linking two triiodobenzoic acid molecules, one of which contains a sodium or meglumine cation. However, doubling the iodine content in the anionic portion reduces the overall osmolality.

These new lower osmolality contrast media are associated with a lower overall incidence of side effects and mortality than the older ionic agents, and are now used in greater frequency than their ionic counterparts. The main reason for their less than universal adoption is the higher cost (approximately 10 times greater) of the low-osmolality agents. Hopefully, this should change in the future.

The low osmolality contrast media are also used for myelography. In the dilutions used, they provide excellent contrast without excessive density. Thus, they may be used for CT myelography. These agents may produce headache in up to 30% of patients and transient psychologic disturbances due to intracranial flow of contrast in less than 5% This last complication is reduced by keeping the patient's head elevated after the myelogram.

In addition to their use in angiography, urography, myelography, and arthrography, these same agents may be injected into sinus tracts or used in diluted form to examine the GI tract when there is a suspected perforation. They do not cause any of the undesirable side effects that barium is known to produce when outside the GI tract. However, there is one important contraindication for water-soluble contrast media: suspected communication between GI tract and the tracheobronchial tree (tracheo-esophageal fistula). As mentioned in Chapter 1, water-soluble materials are extremely irritating to the tracheobronchial mucosa and produce a severe chemical pneumonia that may result in death. A barium or oil-soluble preparation should be used when airway communication is suspected.

Excretion of these agents is by pure glomerular filtration within the kidney. The material is removed intact by the glomeruli. In patients with chronic renal failure, however, the material may be secreted into the bile or small bowel by a process known as "vicarious excretion."

AGENTS USED TO VISUALIZE THE BILIARY TREE

The agents used for cholecystography are iopanoic acid (Telepaque), iocetamic acid (Cholebrine), sodium tyropanoate (Biloqaque). and calcium or sodium ipodate (Oragrafin). These agents are ingested orally, absorbed in the duodenum, conjugated as a glucuronide salt in the liver, and excreted in the bile. The material is then stored and concentrated within the gallbladder. In their native form, these agents are not water-soluble, allowing for their absorption from the GI tract. In the conjugated form, they are water-soluble and are not reabsorbed on passage through the bowel.

AGENTS USED TO ENHANCE MAGNETIC RESONANCE (MR) IMAGING

Despite the wide variety of pulse sequences available for MR imaging difficulties still exist for differentiation between neoplasm and chronic cerebral infarction, tumor and perifocal cerebral edema, or recurrent herniated intervertebral disc and surgical scar. For these reasons, a number of paramagnetic contrast agents have been developed for intravenous use during MR imaging. To date, gadolinium-diethylenetriaminepentaacetic acid (Gd-DTPA) is most commonly used. Gadolinium was chosen because of its strong effect on the relaxation time in the scanning sequence. Chelation with DTPA has reduced the inherent toxicity of the free Gd ion. In diagnostic doses, Gd-DTPA increases the signal in vascular structures, similar to the effect of conventional water-soluble contrast media.

OIL-SOLUBLE AGENTS

Oil-soluble agents such as propyliodone (Dionosil) are used for bronchography. The material is inert within the tracheobronchial tree and provides adequate coating and definition of the structures. It may be used for esophagography in suspected esophago-airway fistulas. Ethiodized oil (Ethiodol) is an oily agent used for lymphangiography. It also may be used for sialography (study of the salivary ducts) or hysterosalpingography (study of uterine cavity and fallopian tubes).

ADVERSE REACTIONS TO CONTRAST MATERIAL AND THEIR MANAGEMENT

The incidence of adverse reaction to iodinated contrast material is variable and unpredictable. The Subcommittee on Treatment of Adverse Reactions of the Committee on Contrast Media from the International Society of Radiology reviewed the data from 150,000 case reports. They found that the overall incidence of adverse reactions was 5%. Serious reactions were reported to vary between 1:1000 and 1:2000, with fatalities occurring from 1:13,000 to 1:40,000. Although many adverse reactions occur in patients with no previous allergic history, the study revealed that a patient with a history of allergy has a risk of reaction that is twice that of the general population. If the patient has a history of a previous reaction to contrast media, the chances of another reaction are three times greater than that of the general population. Pretesting with a small injection of the contrast medium was found to have little or no value in identifying patients who would later react. Similarly, pretreatment with antihistamines and steroids in patients with known allergies to contrast material were shown to be ineffective.

Two recent studies from Japan and Australia on 337,647 patients reevaluated the incidence of adverse reactions (including death) from ionic and low osmolar contrast media. The studies revealed that the overall incidence of adverse reactions from ionic contrast material was 12.7% and from nonionic (low osmolar) contrast it was 3.1%. Severe reactions occurred in 0.22% and 0.04% of each group respectively. There was one death in each group, but no causal relationship to the contrast medium was found. The conclusions of the studies were that nonionic (low osmolar) contrast media significantly reduced the incidence of severe and potential life-threatening reactions and their general use to increase the overall safety for contrast media examinations was recommended.

Types of Adverse Reactions to Contrast Media

There are three basic types of adverse reactions to contrast media: mild, intermediate, and severe. Mild or minor reactions (nausea, vomiting, sneezing, flushing, diaphoresis, feeling

of warmth, and occasional headache) resolve without therapy. Intermediate reactions are those that require therapy for the patient's symptoms, but are not life-threatening. These include urticaria, angioneurotic edema, and wheezing. Severe reactions include cardiovascular collapse, which may be associated with pulmonary edema, laryngeal edema, and apnea. There may be central nervous system depression. Death may result if proper treatment is not instituted immediately.

Table 2.1 lists signs and symptoms of reactions to contrast agents in order of increasing severity.

Treatment of Adverse Reactions to Contrast Material

Before instituting treatment, the severity of the reaction and the body systems involved should be carefully evaluated. The patient's vital signs should be monitored. Once a determination has been made regarding the organ system involved and the nature and severity of the reaction, proper treatment may be instituted. After successful treatment of a reaction of any kind, the type of reaction, severity, and mode of treatment should be entered in the patient's permanent medical record. In addition, a notation should be made on the patient's x-ray folder that he/she has had an allergic reaction, and the type of reaction should be stated. Furthermore, the patient's referring physician should be notified immediately whenever a reaction occurs.

Mild reactions require careful observation of the patient and reassurance by the radiologist that the symptoms are not serious and will resolve quickly. Most of these symptoms will pass within a few minutes. Anxiety is believed to play a key role in the development of minor reactions.

The intermediate reactions are treated by intravenous administration of 25 to 50 mg of diphenhydramine (Benadryl). This may be augmented by 0.3 to 0.5 ml of a 1:1000 solution of epinephrine subcutaneously. Cimetidine (Tagamet) is a histamine antagonist and may be used as a bolus injection of 300 mg instead of Benadryl or epinephrine. In the majority of the cases, the patient will respond favorably within several minutes; hives begin to fade, wheezing subsides, and the patient appears less apprehensive. The use of steroids for intermediate types of reaction is controversial. Some authorities believe that a 100 mg bolus of prednisolone is useful in treating the more severe type of intermediate reaction.

Table 2.1. Signs and Symptoms of Reactions to Contrast Material

Type	Cardiovascular	Respiratory	Cutaneous	Cl	Nervous	Urinary
Mild	Pallor Diaphoresis Tachycardia	Sneezing Coughing Rhinorrhea	Erythema Feeling of warmth	Nausea Vomiting Metallic taste	Anxiety Headache Dizziness	
Intermediate	Bradycardia Palpitations Hypotension	Wheezing Acute asthma attack	Urticaria Pruritis	Abdominal Cramps Diarrhea	Agitation Vertigo Slurred speech	Oliguna
Severe	Acute pulmonary edema Shock	Laryngospasm Cyanosis Laryngeal	Angioneurotic edema	Paralytic ileus	Disorientation Stupor Coma	Acute renal failure

Congestive heart failure Cardiac arrest	edema Apnea	Convulsions

Severe reactions require immediate recognition and evaluation of the patient's cardiopulmonary status. Cardiopulmonary resuscitation (CPR) equipment should be readily available in any area where contrast media are used. Furthermore, the radiologist and the technical staff should be well trained in the techniques of CPR. In general, the radiologist is the first physician called to the scene when a reaction occurs. Proper treatment of a severe reaction follows the "ABCD system":

A. Airway open
B. Breathing restored
C. Circulation maintained
D. Drug and definitive therapy

Once the initial CPR has begun, a code/crash team should be summoned. The principles and practice of CPR are a subject with which the reader should be familiar and will not be covered further in this book. The reader should never inject contrast agents unless familiar with CPR and the management of reactions.

A vagal type of reaction has been recognized as a distinct complication of the use of contrast material. This reaction may be recognized by the presence of hypotension and bradycardia rather than tachycardia, the latter occurring in the anaphylactoid reactions. Treatment of patients with vagal reactions is by the use of 0.5 to 1.0 mg of atropine intravenously.

Adjunctive procedures that should be performed before the patient has a reaction and that may aid in the later treatment of a reaction include recording the patient's pulse and blood pressure and noting the cardiac rhythm. In addition, the use of a scalp vein-type needle-tubing combination that is taped in place to the forearm will ensure a ready channel of access to the patient's bloodstream in the event of an emergency.

Figure 2.1 is a flow chart of steps to follow in managing a patient who has had a reaction to contrast material.

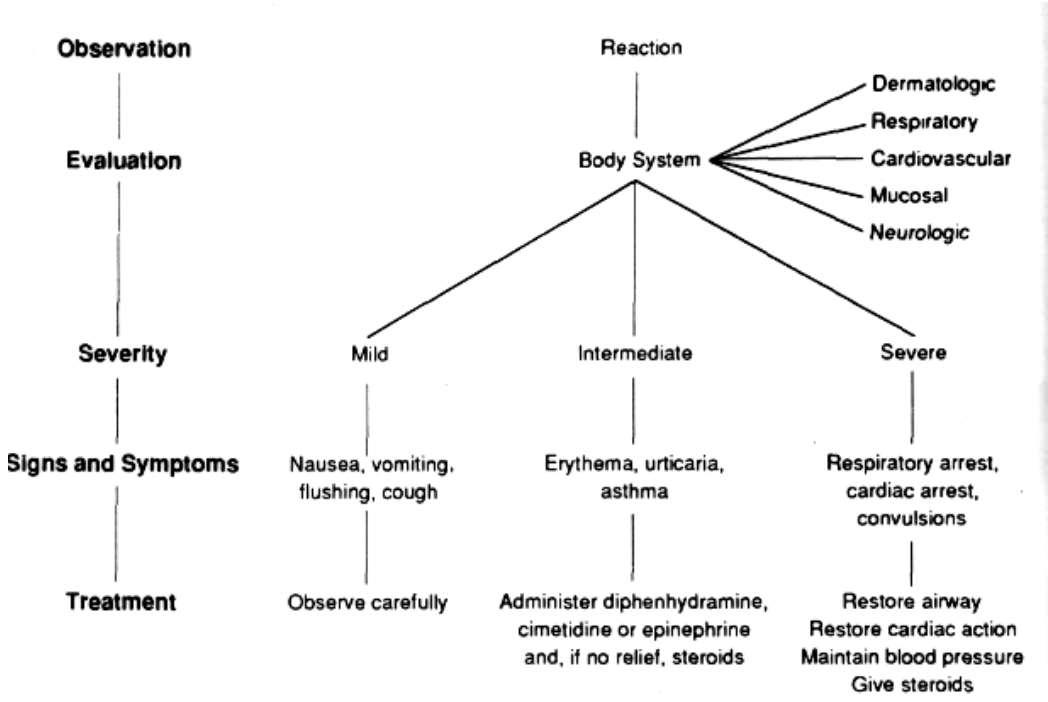


Figure 2.1.
Flow chart for management of reactions to radiographic contrast material