

Chapter

Radiation and radiology – the basics

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Ionizing radiation

Ionization may be simply defined as any process by which an atom or molecule gains an electric charge. Any radiation which is capable of causing this effect is known as ionizing radiation. Non-ionizing radiations include such things as light and microwaves. Ionizing radiations emitted from radioactive atoms or produced by devices such as X-ray tubes include:

- Alpha particles
- Beta particles
- Gamma rays
- X-rays

Alpha particles

Alpha particles are identical with helium nuclei, having two protons and two neutrons. Alpha particles are usually emitted by heavy radioactive atoms such as uranium and radium. Being large and relatively slow, they quickly dissipate their energy by colliding with the atoms of the material through which they travel causing ionization to take place. Alpha particles thus have very little power of penetration and are stopped completely by a thin sheet of paper, the outer layer of human skin, or a few centimeters of air. Alpha emitters are most damaging when incorporated into the body, and are not normally used unless securely sealed.

Beta particles

Beta particles are high-speed electrons emitted from the nuclei of radioactive atoms. Having low mass, and emitted with a speed close to that of light, beta

particles have greater penetrating ability than alpha particles of the same energy, but still will be stopped by a few millimeters of aluminum, a centimeter or so of human tissue or a few meters of air, dependent on their energy. Beta emitters are most hazardous when ingested, but can cause skin and eye damage. Beta emitters are frequently used therapeutically.

Gamma rays

Gamma rays are a form of electromagnetic radiation (as is visible light). They may be extremely penetrating and can pass through several hundreds of meters of air or many centimeters of dense materials such as iron or lead. Gamma emitters are hazardous internally and externally, although less damaging than the particle sources alpha and beta particles.

X-rays

X-rays are physically identical to gamma rays although of lower energy. They differ in their means of production, which is usually by means of electrons striking a dense material such as occurs in diagnostic or therapeutic X-ray tubes.

Radiation hazards and protection

X-rays (ionizing radiation) can produce harmful effects, which can be divided into two types:

- Those that inhibit cell growth and lead to cell death and
- Those that modify cell DNA (chromosomes) increasing the probability of cancer and the incidence of fetal damage and genetic defects.

These hazardous effects occur as a result of direct damage to cells caused by ionization. Ionization results in the production of free radicals – atoms which have a single unpaired electron in the outer electron orbit. Free radical interactions are the primary mechanism of radiation damage to organic molecules such as DNA.

There are no data available to determine whether there may be a threshold below which no effects occur, therefore there is no proven totally “safe” dose.

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Effects of radiation

Stochastic effects

Stochastic effects are effects that occur on a random basis with the effect being independent of the size of dose. The effect typically has no threshold and is based on probabilities, with the chances of seeing the effect increasing with dose. Cancer, leukemia, and genetic mutations are stochastic effects.

Non-stochastic effects

Non-stochastic effects are related directly to the dose received. They typically have a threshold below which the effect will not occur and the effect is more severe with a higher dose. Skin burns and other skin changes, cataracts and decreased fertility are examples of non-stochastic effects.

The nature and degree of cell damage vary according to: the radiation dose, the dose rate, irradiated volume, and type of radiation.

The aim of radiotherapy is to cause cell death and inhibition of cell growth. It causes these effects by breaking one or both of the DNA strands within the cell, which will die when attempting to divide. DNA rupture results from damage caused by free radicals produced from the water that makes up 80% of the cell, or directly from the radiation. Radiotherapy operates at much higher energies (up to 10 000 000 volts) than diagnostic radiology (e.g. 100 000 volts).

Diagnostic radiology is not so much concerned about cell death and inhibition of growth as with the possibility of creating a free radical, and producing cancer or other chromosomal disease.

Man-made radiation contributes approximately 15% to the total population dose, of which 97% is from diagnostic radiology. The other 85% comes from natural background sources.

Background radiation

Everyone receives a dose of radiation from naturally occurring radiation sources in the environment and from cosmic rays. This amounts to approximately 2 mSv/year. The sources include cosmic radiation from the sky, inhaled air, and diet.

Radiation doses from common diagnostic investigations

Doses from diagnostic X-ray procedures vary widely according to the type of examination, patient thickness and the choice of technique. The average or typical radiation doses for a variety of examinations are shown in Table 1.1.

Table 1.1. Typical radiation doses for a range of examinations and the approximate time taken to receive the same dose from natural background radiation

Radiological examination	Effective dose (mSv)	Equivalent time at natural background levels (2 mSv/year)
Abdomen AP	0.41	10 weeks
Chest PA	0.013	3 days
Thoracic spine		
-AP	0.20	5 weeks
-Lateral	0.10	2.5 weeks
Coronary angiogram	3.1	1.5 years
Barium meal	2.6	1.3 years
CT (chest)	10.7	5.4 years
CT (abdomen)	17.5	9 years
CT (Liver)	13.4	6.7 years
^{99m} Tc lung scan	2.7	1.3 years

Radiation dose units

Gray (Gy)

The Gray is a unit used to measure a quantity called absorbed dose. This relates to the amount of energy actually absorbed in some material, and is used for any type of radiation and any material. One Gray is equal to one joule of energy deposited in one kg of a material. The unit Gray can be used for any radiation, but it does not describe the biological effects of the different radiations. Absorbed dose is often expressed in terms of hundredths of a Gray, or centi-Grays.

Sievert (Sv)

The Sievert is a unit used to derive a quantity called equivalent dose. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of millionths of a Sievert, or micro-Sievert. To determine equivalent dose (Sv), you multiply absorbed dose (Gy) by a quality factor (Q) that is unique to the incident radiation. Equivalent dose takes into account the type of radiation, rate at which it is received and other factors. Effective dose takes into account the biological effects of the radiation on the tissue. It is the sum of the equivalent doses in all tissues and organs of the body weighted for tissue effects of radiation.

Protection in radiological practice

The risks of cancer due to radiological imaging are extremely low and population studies have not confirmed any increase in genetic defects in exposed populations. Nonetheless, it is important to keep radiation doses as low as reasonably possible so as to minimize risks.

Certain tissues are more sensitive to damage from X-rays, especially thyroid, breast, the lens of the eye, and rapidly dividing cells (gonads, bone marrow, lymph glands, and the developing fetus). Particular care is taken to protect these regions. The protective measures are primarily the responsibility of the radiology department; however, there are ways in which referring clinicians can contribute.

- Order only the minimum number of tests that use ionizing radiation
 - Request the use of mobile equipment as little as possible
 - Ask about possible pregnancy
- Explanation of radiation risks to patients should include:
- Risks versus potential benefits
 - Comparison with natural background radiation

Protection of patients

Aims and principles of radiation protection are:

- To prevent harmful effects by keeping all justifiable exposure as low as reasonably achievable (ALARA principle).
- To prevent non-stochastic effects and to limit the chance of stochastic effects to an acceptable level.
- No practice is accepted unless its introduction results in a benefit that outweighs its detriment. Specifically:
 - Each film should be justified
 - Focus beam accurately to area of interest and shield relevant sensitive areas
 - Minimize use of mobile equipment
 - Use ultrasound or MRI where appropriate and possible
 - Ensure good equipment is used and is regularly tested
 - Ensure only trained personnel operate equipment.
 - Take care with women of reproductive age

Protection of staff

- Only necessary staff should be present in a radiology procedure room. If viewing monitors

are in use outside the screening room, staff may observe the procedure at a safe distance. If not, staff need to wear the appropriate protective clothing including lead aprons and thyroid shields.

- At no time should staff be directly irradiated by the primary X-ray beam. Where necessary, lead gloves should be worn if hands are at risk of irradiation (e.g. in reducing a fracture under fluoroscopic guidance in theater).
- All X-ray rooms should be fully lead lined.
- If a mobile image intensifier or X-ray machine is in use, all staff and students should stand well behind the portable unit so as not to be in the direct radiation or scatter field. The further away from the X-ray source, the less risk of exposure (several meters is adequate). The inverse square rule states that dose is inversely proportional to the distance (squared) away from the source.
- Rotate places of work, so that the same staff are not constantly working in areas that lead them to have higher levels of radiation exposure (e.g. angiography).
- Personnel radiation dose monitoring.

Radiation and the pregnant patient

Avoiding radiation exposure in pregnancy

A number of particular precautions should be taken when irradiation of women of reproductive age is contemplated. The aim is to minimize or avoid any exposure of the unborn fetus given that fetal tissues are thought to be more radiosensitive than those of mature adults.

Radiation exposure of the lower abdomen and pelvis of women of reproductive capacity should be kept to a minimum. During pregnancy, radiation exposure to these regions should only occur if the procedure cannot be postponed because of the urgent nature of the investigation.

It is prudent to consider as pregnant any woman of reproductive capacity whose menstrual period is overdue or clearly missed at the time of presenting for radiological examinations. The primary responsibility for identification of patients at risk rests with the referring doctor, but prior to any procedure involving ionizing radiation, all women of reproductive age should be asked about the possibility of being pregnant. If pregnancy is confirmed, consideration must be given to the possibility of delaying the procedure at

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least until such time as the fetal sensitivity is reduced (post-24 weeks).

When radiography of areas remote from the fetus is needed, such as head, chest, or extremities, these can be undertaken with negligible exposure to the fetus at any time during pregnancy provided proper X-ray beam collimation is used. The use of protective drapes may be helpful also.

The following guidelines and precautions are useful in minimizing irradiation of the embryo or fetus, even though inadvertent exposure in utero from a diagnostic radiological examination is unlikely to result in an absorbed dose in excess of 20 mGy which is well below the probable threshold for the induction of malformations or mental retardation.

Points to remember

- Indicate on request form whether patient is pregnant or potentially pregnant.
- Avoid ionizing radiation procedures not essential for optimal medical care. This is good practice in any event. Substitute a non-radiological procedure (ultrasound, MRI, laboratory test) if possible.
- If a patient is pregnant or a procedure must be performed before pregnancy can be ruled out, consider the relative importance of the examination and risks to the mother and child.
- If pregnancy is confirmed and the procedure must be performed, the minimum amount of exposure that provides diagnostic information is used.

Procedure when patient is found to be pregnant after an X-ray

Occasionally, a patient will not be aware of a pregnancy at the time of an X-ray examination, and may become very concerned when the pregnancy becomes known.

In such cases, estimation of the radiation dose to the fetus should be obtained. A radiation safety officer should be consulted for advice in these circumstances. The patient can then be better advised as to the risks involved in the procedure. In many cases there is very little risk as the irradiation will have occurred in the first 3 weeks following conception. In a few cases, however, the fetus will be older and the dose involved may be considerable. It is, however, extremely rare for the dose to be large enough to warrant advising the patient to consider termination.

Fetal irradiation – current knowledge

There is some evidence to suggest that the fetus is more susceptible to the harmful effects of ionizing radiation than is the mature human being (Table 1.2). Certainly, any effect of irradiation in utero will be dependent on stage of development. In the first few days following fertilization the most likely effect is death with little or no chance of malformation. Subsequently, during the period of early organogenesis, malformation, and growth retardation may be expected.

The International Community for Radiological Protection (ICRP) have suggested that these effects are deterministic with an estimated threshold in humans of at least 100 mSv. From 8 weeks to 25 weeks following fertilization, the most likely effect will be an increased incidence of mental retardation although growth retardation at relatively high doses (>200 mSv) may occur.

However, human abnormalities, explicitly identified as due to radiation, are impossible to isolate given that the spontaneous incidence of all such effects is about 6%. In comparison, it is estimated that an effective dose of 10 mSv delivered over the whole

Table 1.2. Types of effects following irradiation in utero compared where appropriate with the normal incidence (modified from International Commission on Radiation Protection)

Time after conception	Effect	Normal incidence
First 3 weeks	None in live-born. Failure to implant may result in an undetectable death. Almost certainly a threshold of approximately 100 mSv	30% to 50% of impregnations may result in spontaneous abortion
3rd to 8th week	Potential for malformations of organs with a probable threshold of 100 mSv	4–6%
8th to 15th week	Potential for severe mental retardation – no observed effect below 100 mSv	0.5–1%
16th to 25th week	Reduced potential for severe mental retardation	
4th week until term	Possibility of growth retardation	
4th week until term	Cancer in childhood or adult life. Risk is likely to be two to three times higher than for the general population	0.1% for childhood cancer and 0.04% for childhood leukemia*

*The percentages reflect death rates, not incident rates, which are about 70% higher.

pregnancy would add a probability of an adverse health effect in the live born of less than 0.2%.

There is some evidence of increased levels of childhood leukemia and cancer following in utero irradiation at any stage of development after the third week. There is some evidence to suggest that the major part of the risk is associated with irradiation during the latter part of the first trimester.

Since the doses from diagnostic radiological procedures (typically a few mSv) and from occupational exposures (typically a few mSv per year) are small, it should be clear that the risks to the unborn child from diagnostic and occupational levels of radiation exposure are very small. Nevertheless, the deliberate irradiation of pregnant and potentially pregnant female patients naturally requires some caution. The general rule is to ask the patient if she is, or could be, pregnant.

Guidelines for administration of radionuclides to pregnant patients

Nuclear medicine studies in a pregnant woman, because they have the potential to irradiate the whole body, are best avoided entirely but they are not absolutely contraindicated. When a patient is pregnant, indications for the study should be discussed with the nuclear medicine specialist and the fact that the patient is pregnant should be clearly marked on the request form. A smaller than normal dose of radioisotope may be administered.

It is worth noting that the fetal irradiation does not arise just from uptake of radionuclide by the mother. Depending on the degree of organogenesis that has occurred, radionuclides may be concentrated in specific fetal organs resulting in substantial radiation burden to the fetus. A most obvious case of this is thyroid scanning with ^{131}I or $^{99\text{m}}\text{Tc}$ -pertechnetate but even bone agents will be taken up in the fetal skeleton if organogenesis is complete. As a rule, a pregnant woman should not be treated with a radioactive substance unless the therapy is required to treat a life-threatening condition. In that event the fetal dose should be estimated and consideration given to terminating the pregnancy.

The radiology department

The many types of radiology departments range in size from small private centers, which may specialize in imaging specific organs (e.g. mammography breast screening clinics) to large departments in major

hospitals. These may have multiple subsections and subspecialists who engage in a wide spectrum of clinical imaging, interventional procedures, and research projects. Radiology departments are also called Medical Imaging departments or similar names. There are several features which most departments have in common:

- Imaging rooms and the equipment for each imaging modality
- Darkroom or processor where films are developed or processed (unless entirely digital)
- Filing room where films are recorded, stored, and retrieved; or more commonly now, servers and archives for digital images
- Reporting rooms where films or digital images are interpreted by radiologists
- Patient care facilities where patients in need of close attention can be monitored

In large hospital centers the radiology department is not usually confined to a single area within the hospital, but involves other departments of the hospital. These include:

- The emergency department – where X-rays, US, and often CT are performed
- The wards and ICU (intensive care unit) – where portable X-rays and US are performed on patients too sick to be moved
- The operating rooms where portable fluoroscopy units are used in surgical procedures

Radiology staff

The professional staff within a department include the following groups.

Radiologists and trainee radiologists

Radiologists are the specialists trained to interpret images and to perform radiological procedures. As the hospital size and range of services increase, radiologists tend to become experts in one or more subspecialty areas. The responsibility for interpreting examinations rests with the radiologist.

Radiology tends to attract doctors who like the challenge involved in reaching a diagnosis. It is an attractive area for those seeking to be involved in many disciplines in medicine.

Radiology is no longer a “hands-off” specialty of medicine, dedicated to the interpretation of films. It has entered the treatment realm with interventional procedures offering an alternative or supplementary treatment option to surgery, in many instances

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reducing complications and length of hospital stay. The rapid enlargement of the radiologist's field has seen the specialty change tremendously in the last few decades. Procedures involving direct patient contact make up a large part of a radiologists work. The training program for radiology is about 5 years in most Western countries usually after at least 2 clinical resident years.

Radiographers (medical imaging technologists)

These are the staff who perform the acquisition of the images or assist the radiologist in image acquisition for the procedural studies. They are trained in radiation, MRI and ultrasound physics and image processing, as well as in anatomy and pathology. They work with radiologists to ensure quality control.

Many departments also have trainee radiographers who rotate through the various specialty areas.

Radiation physicist

Physicists are concerned with patient and staff radiation safety issues and related quality control within the department, and more broadly within a hospital.

Radiology nursing staff

These are specially trained nurses working within the department. They are responsible for monitoring patients in need of close attention and for assisting with diagnostic and interventional procedures. They also ensure that emergency carts, appropriate medications, and patient monitoring devices are available for patient care.

A department in a hospital performing 100 000 radiological examinations per year would typically have approximately 15 radiologists, 15 trainee radiologists, 50 radiographers, 10 trainee radiographers, 15 nursing staff, 5 assistants for patient transport, 20 administration and clerical staff, 5 audiotypists (unless voice recognition software is used), 2 or 3 IT staff to support information systems and PACS (see below), and a physicist.

Picture archive and communication systems (PACS)

Traditionally imaging departments have produced the record of the examination on film as a hard copy X-ray. As a result of the introduction of digital imaging, images can now be acquired, archived and transferred electronically. This has allowed more efficient and reliable access to images from multiple locations. Images can be manipulated in many ways on dedicated workstations, which is how radiologists

report them, and also can be viewed remotely on routine computer monitors and even hand-held devices usually using, for example, web browser technology. Radiology departments now tend to make use of this in systems known as Picture Archive and Communication Systems (PACS).

Requesting radiology tests

When requesting radiology studies there are a range of issues to consider.

Communication with the radiologist

- Relevant clinical information needs to be made available to the radiologist before imaging tests are performed so that the examination can best answer the specific clinical problem.
- The selection of imaging test, the way in which it is performed and its interpretation can all be critically affected by clinical information provided.
- When requesting complex imaging, it can be very useful to speak directly with a radiologist to discuss imaging planning.

Guidelines to help determine the usefulness of an imaging test or procedure

Imaging examinations should not be requested without considering the impact of the result on patient management.

The referring clinician should make clear the clinical question that needs to be answered.

To help prevent unnecessary or inappropriate requests some basic questions should be considered:

- Is the test suitable for the patient?
 - In particular, does the examination image the area of interest and will it yield the needed diagnostic information?
- Is the patient suitable for the test?
 - Is the patient able to co-operate to lie still or breath-hold for a CT or MRI scan?
 - Does the patient have a pacemaker, for example, that would make them unsuitable for MRI?
 - Is the patient pregnant?
 - Is the patient allergic to radiographic intravascular contrast agents?
 - Can the patient tolerate the examination?
 - Does the patient have renal impairment, which may preclude the use of intravascular contrast agents?

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- Is the patient a diabetic taking metformin, which may preclude the use of intravascular contrast agents?
- Can the same information be obtained by other methods that are cheaper, more available or safer?
- Has the patient previously had the examination?
 If an examination does need to be repeated then the previous images are invaluable to the radiologist to assess any change.
- Will the examination interfere with other planned examinations?
 For example, a barium study of the gastrointestinal tract can degrade a CT image so that interpretation is impossible.
- Is the patient properly prepared for the examination?
 This not only includes physical preparation (e.g. fasting prior to an abdominal US) but also mental preparation, that is, what to expect with the examination or procedure.

Consent

Consent should be obtained for any radiological procedure which carries a material risk.

The legal responsibility for informed consent of a patient lies with the person performing the procedure, namely the radiologist. However, the referring clinician may also be legally accountable if the indication for the procedure is questionable or the procedure is particularly hazardous for that patient.

Furthermore, the process of the referring clinician obtaining consent helps ensure good communication with the patient so that they are informed well ahead of the procedure being performed and know what to expect. So the provision of informed consent is the domain of both the clinician and the radiologist. Radiology departments and practices need to attempt to provide information in suitable format about common examinations and procedures both to referring clinicians and to patients.

Follow-up arrangements

It is most important for the referring doctor to actively check the results of any tests ordered to avoid a missed diagnosis.

Risk versus benefit

The potential benefit of the examination must always outweigh the risk in order to justify a test.

This depends in part on the pre-test probability of the provisional diagnosis and how important it is to confirm this diagnosis. For example, where the provisional diagnosis is lung cancer, one would want to be almost 100% certain of the diagnosis before embarking on hazardous treatment. However, where the provisional diagnosis is sinusitis, one might start antibiotic treatment when one is only 75% certain of the diagnosis and not request paranasal sinus X-rays to confirm the hypothesis. Ordering tests should not be about reaching a diagnosis at any cost, but rather be aimed at gaining information which has a reasonable likelihood of affecting patient care.

Chapter

2

Imaging modalities and contrast agents

Contents

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Plain films

Plain films are what are generally meant when referring patients for “X-rays.” Plain radiography requires less sophisticated equipment compared to other methods of imaging. The physics of X-ray production is beyond the scope of this text. A basic description of plain film production is outlined below.

Equipment

Plain film production requires an X-ray tube, filters, grids, a film in a light-tight film holder, or a digital recording medium, and controls for determining radiographic exposures (Fig. 2.1).

High energy X-rays are produced in an X-ray tube and travel toward the patient. A filter is placed between the patient and the tube to remove unwanted low energy X-rays that do not contribute to the final image but would add to the radiation dose the patient receives.

Then the X-rays pass through the patient, exiting as a pattern of X-ray intensities (subject image) dependent on the type of tissue traversed. The X-rays then pass through a grid, which filters out scattered radiation, producing a clearer image.

The pattern of X-ray intensities (which represents the image of the body part) is then recorded by a number of means

- Traditional film cassette where they stimulate chemicals in the film screen to fluoresce. It is this fluorescence that exposes the film rather than the X-rays themselves. This results in traditional hard copy films.
- Digital recording – this may then be converted to film or retained purely as a digital “soft copy” to be viewed on a monitor.

Differentiation of tissues

The absorption of the X-ray beam is directly proportional to the physical thickness and density of the tissue it traverses, and more importantly, to the atomic number of the elements in the beam. Thus the following densities, in increasing order of absorption can be identified on plain films:

- Air
- Fat
- Soft tissues (including body fluids)
- Calcifications
- Teeth
- Metal (e.g. surgical plates and screws)

Costs and utility

Plain film imaging is cheaper than more sophisticated radiological modalities, but nonetheless accounts for a huge proportion of diagnostic imaging expenditure, simply by virtue of the enormous number of examinations performed.

Doctors should not request a radiographic examination unless it will have an effect on patient management. It is important to avoid an unnecessary radiation dose to the patient, and minimise unnecessary costs. Clinicians bear the responsibility for knowing when plain films are indicated, as most are performed without radiologist input prior to the performance of the test.

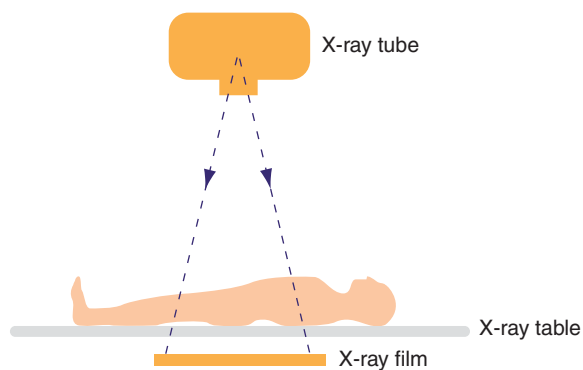


Fig. 2.1. Plain X-ray schematic.

Plain film projections

A number of projections or views are commonly used.

If the beam passes through the patient's ventral (anterior) surface first, and then through the dorsal (posterior) surface to reach the film, it is called an anteroposterior (AP) projection.

Conversely, if the beam passes from dorsal to ventral through the body, then a posteroanterior (PA) view is obtained.

Lateral and oblique films are named according to which part of the body is closest to the film. For instance, a left lateral projection indicates that the left side of the body is closest to the film. When the right anterior part of the body is placed adjacent to the film it is called a right anterior oblique (RAO) view.

A lateral decubitus film (chest or abdomen) is obtained with the patient lying on their side and the film is placed vertically, with the X-ray beam being horizontal. Left side down is referred to as left lateral decubitus.

Tomography

Tomography allows imaging of a selected section or "layer" of a patient. Only structures within the focal plane are clearly visualized, and those outside it are blurred. This sometimes assists in clarifying uncertainties on plain films.

It is performed by moving the X-ray tube and the film cassette about an adjustable fulcrum during exposure. The fulcrum point defines the focal plane where structures are kept "in focus."

Tomography is commonly used for renal evaluation as part of an intravenous pyelogram.

Computed tomography has almost totally replaced conventional tomography.

Fluoroscopy

Fluoroscopy uses low intensity X-ray beams to continuously visualize the area of interest in "real time."

The fluoroscopy system consists of an X-ray tube and on the opposite side of the patient a means of X-ray detection to generate an image; increasingly this is done by digital flat panel detectors. The image is viewed "live" on a computer or television monitor. Recordings of each study can be made using a range of storage media. The system and/or the patient can be moved to examine any body part of interest.

Indications

Fluoroscopy is routinely used to monitor contrast studies and angiograms. It is also used in innumerable other procedures requiring continuous visualization including endoscopy, bronchoscopy, orthopedic surgery, myelography, diaphragmatic motion studies, arthrography, and urethrography.

Radiation risks

The radiation dose from modern fluoroscopic equipment is relatively low, but the amount of fluoroscopy time is monitored for each patient, as the dose is related to total fluoroscopy time so has the potential to be unacceptably high.

Portable fluoroscopy

Portable C-arm units are often used in operating rooms, e.g. to assess orthopedic alignment or for intraoperative cholangiography. Imaging on these units is usually of adequate quality, but in general, standard fluoroscopic units in radiology departments offer superior image quality and optimal radiation protection.

Computed tomography (CT)

Image production

The basis of CT image generation is that a narrow beam of X-rays is transmitted through the patient and received by radiation detectors that transmit the data in digital form into a computer. The X-ray tube rotates around the body as it generates the X-ray beam and the amount of X-ray transmission through the body is recorded at numerous points by the detector ring that lies on the outside of the ring that is the path of motion of the X-ray tube. The measurement of transmitted X-ray energy at many points in the

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rotation is then translated by the computer into a “map” of X-ray absorption of the tissue slice. The patient lies on a special table that can be moved in steps for each X-ray tube rotation or can be moved continuously as the X-ray tube also rotates continuously, so-called spiral or helical CT.

Terms

- Increased attenuation or hyperdensity = whiter (more X-rays are absorbed)
- Decreased attenuation or hypodensity = darker (fewer X-rays are absorbed)

CT image display

- The computer mathematically reconstructs a digitized image of the “slice” of the body part being studied.
- The slices are made up of small volumes (“voxels”), which are precisely placed in space and have an attenuation value ascribed to them in Hounsfield Units (HU) based on how much X-ray energy each voxel absorbs.
- Tissue attenuation or density is therefore measured in Hounsfield Units (HU), named after the inventor of CT. A scale of arbitrary numbers is used to display this information, from -1000 HU (air) to $+1000$ HU (cortical bone) with zero HU, the center, representing the attenuation value of water.
- These density values are displayed as shades of gray (gray-scale) with dense structures (e.g. bone) shown as white, and least dense shown as black (air). The voxels are displayed in two dimensions as an array of pixels with their gray-scale depending on the HU of the voxel as well as on “windowing” (see below). These pixel values are directly related to the attenuation coefficients of the tissue at corresponding locations within the slice.
- Approximate density measurements are shown in Table 2.1.

Image display: windowing

By changing the settings of the gray-scale display (the window “width” and window “level”), one can change the appearance of the image, in order to demonstrate specific anatomy or pathology. There are a number of standardized windows including those optimized for looking at bones, brain, lungs, and soft tissues (Figs. 2.2, 2.3).

Table 2.1. Approximate CT density measurements in Hounsfield Units (HU)

Air	-1000 HU
Fat	-100 HU
Water	0 HU
Body fluids	< 25 HU
Soft tissues	$25-90$ HU
Calcification	> 100 HU
Bone	1000 HU

CT scanners now have the ability to generate multiple slices with each rotation and combined with spiral scanning now have the ability to rapidly collect data from a volume of tissue which, with software functions, allows displays in a variety of planes (multiplanar reformatting), and three-dimensional displays (Fig. 2.4), used, for example, in CT angiography, CT cholangiography, and CT colonography.

Intravascular contrast

Intravenous (IV) water-soluble iodinated contrast media is often administered as the scanning is started to allow:

- Identification of vascular structures
- Detection of avascular tissue
- Delineation of the extent of abnormal tissue/tumor.

Studies where contrast has been administered are usually labeled as such, with the annotation “C” or “C+” on the image.

The scans can be timed to coincide with maximum arterial or venous opacification as well as more delayed scans, for example, to assess the urinary tract.

Gastrointestinal contrast

For abdominal and pelvic studies, gastrointestinal contrast is usually given to delineate normal bowel from possible masses, as well as to help identify bowel pathology.

Oral contrast is usually given up to an hour before the examination.

Rectal contrast (via a rectal tube) is sometimes administered in pelvic examinations, to better delineate rectum from surrounding structures.

Computed tomography angiography (CTA)

Computed tomography angiography (CTA) may be used to show vascular anatomy. CT slices are made after the rapid i.v. injection of a large bolus of contrast.

Dynamic scans can be performed for assessment of, for example, aortic dissection, arterial stenoses and