CHAPTER 3. PRINCIPLES AND METHODS OF RADIOLOGY

3.1. The general principles of visualisation of medical images

Nowadays 60 - 80 % of all initial diagnoses are made by means of radiology methods of research.

Most widely electromagnetic radiation is used for visualisation of anatomical structures which are opaque and inaccessible for direct supervision. Now electromagnetic radiation is known with length of a wave from ten billionth of a millimetre to hundreds of kilometres.

The wide area of electromagnetic radiation (0,001-10 nanometers) belongs to X-rays.

At present in medicine about 90 % of all visualised images are received by means of X-rays. The electromagnetic ionising radiation created by radioactive substances is called gamma radiation. Radioisotope diagnostics which is based on visualisation of the images formed in gamma-rays of radionuclides is widely applied in functional researches, diagnostics of some diseases.

Resonant effects observed in substance (nuclear magnetic resonance) have a lot of benefits.

Acoustic imaging is widely used in medicine. It is a range of methods and techniques of optical imaging of the ultrasonic field appearing after interaction of elastic acoustic waves and the object. Ultrasound is identical to radio region in wave periods from 1 mm to 10 km.

Investigated object changes the physical fields or waves and the doctor observes these changes on imaging systems.

The penetrating reflection or radiation emitted by the investigated object is modulated in one or several parametres by properties of the investigated object and it contains certain information about it. Spatial distribution of radiation field of the object is converted by the visualizer into similar spatial distribution of luminous flux, brightness or colour of which varies from element to element of the image depending on the object modulated field parameters.

In beam images the morphological information is mostly presented. For example, the x-ray picture of thorax in most cases gives the information about an anatomic structure of human organs. However some images contain the information on a physiological status of human organs. So, if the patient inhales air containing radionuclide ^{133}Xe, variations of radionuclide distribution in lungs will give the information on spatial characteristics of an air stream in lungs. The distribution mentioned can be visualised by means of gamma radiation emitted by ^{133}Xe.

There are analogue and digital images in radiology.

Analogue images contain the information of continuous nature, for example, conventional radiographs.

Digital images are received by computers. They have cellular structure (matrix). All digital technologies and techniques at the initial stage are analogue. Degree of radiopacity on x-ray film, light intensity on the fluorescent screen, electric current in detectors of x-ray computed tomographic scanner, of radiodiagnostic device, ultrasonic device, receiver coil of MR-imager are all analogue reciprocal information. The analogue information mentioned above converts into digital by means of special devices (analogue-to-digital converters). The digital image appears on the display. It can be transformed into the analogue image by digital-to-analogue converters.

3.2. X-rays methods of research

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, which could penetrate into objects and cause fluorescence "X-strahlung" (x-rays) because initially he did not understand its nature. This name did not change in his native land and in the West countries. It was not long before a new medical speciality, radiology, emerged.

The main properties of x-rays:

1. X-rays, proceeding from focus of x-ray tube, propagate in straight lines.
2. They do not deviate in electromagnetic field.
3. Propagation speed is equal to the speed of light.
4. X-rays are invisible, but, being absorbed by some substances, they make them glow. This glow is called fluorescence, it is the basis of fluoroscopy.
5. X-rays have photochemical effect. This property of x-rays is the basis of radiography.
6. X-ray radiation has ionising effect, and enables the air to conduct an electric current. Neither visible, nor thermal, nor radio waves can cause this phenomenon. Based on this property x-ray radiation, as well as radiation of radioactive substances, is called as an ionising radiation.
7. Another important property of x-rays is their penetration ability, i.e. ability to pass through bodies and objects. Penetration ability of x-rays depends on:

– quality of beams. The shorter x-rays are, the deeper these beams penetrate and, vice versa, the longer x-ray wave is, the more shallow they penetrate;

– volume of an investigated body: the thicker the object is, the more difficult is for x-rays to move through it;

– chemical composition and structure of an investigated body. The more atoms of elements with high atomic weight and atomic number (in the periodic table) in the substance exposed to x-rays, the more it absorbs x-ray radiation and, vice versa, the less nuclear weight is, the more transparent substance to these rays is. The explanation for this phenomenon is that in electromagnetic radiation with very small wave length, which x-rays are, high energy is concentrated.

8. X-rays have active biological effect. DNA and cells membranes are critical structures.

9. X-rays complies with the inverse square law, i.e. intensity of x-rays is inversely proportional to squared distance.

Gamma rays have the same properties, but these types of radiation differ in a way of their formation: x-ray radiation is obtained on high-voltage electric installations, while gamma radiation is obtained as a result of nuclear decay.

Methods of x-ray examination are divided into basic, special and particular methods.

The basic radiological methods. The basic methods of radiological research are: radiography, fluoroscopy, x-ray computed tomography (CT).

Radiography and fluoroscopy are carried out by x-ray machines (fig.3.1).

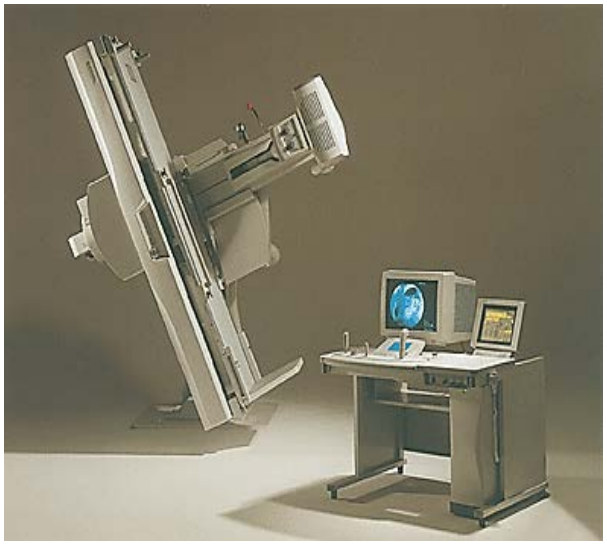

Fig. 3.1. Modern x-ray machine.

The basic elements of x-ray machines are: high-voltage pover sourse, an x-ray tube, device for x-ray radiation formation, operating console and radiation detector. The x-ray machine receive an alternating current from a city network. The high-voltage pover sourse raises voltage up to 40-150 кV and reduces pulsation; in some devices current is almost direct. Quality of x-ray radiation as well as its penetrating power depends on voltage. As the voltage increases, radiation energy increases too. Thus wave length decreases and penetrating power of radiation received increases.

The x-ray tube (vacuum tube) is an electronic device transforming electric energy into x-ray energy. Cathode and the anode are important elements of the tube.

When applying low voltage current to the cathode filament heats up and starts to emit free electrons, forming an electronic cloud around the filament. Electrons emitted by the cathode accelerate in electric field between cathode and anode, fly from cathode to anode and, and hitting against anode surface, slow down producing x-ray quanta. To reduce the influence of radiation on radiographs quality diaphragm is used.

The operating console is the control unit, which works to manage the currents, voltage and timer. The current control has a display that allows adjustment of the tube current to vary radiation intensity. The voltage control also has a display, allowing adjustments in the anode to change the energy of radiation. The timer control determines the duration of the exposure; once the time stops, no more radiation is being produced.

Receivers of x-ray radiation are: x-ray film, fluorescent screen, digital radiography systems, and dosimetric detectors (in CT).

Imaging is a result of x-rays attenuation by the material through which they penetrate (fig. 3.2).

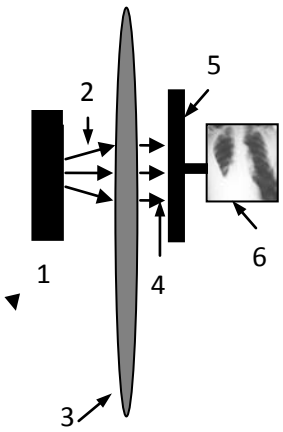

Fig. 3.2. The scheme of imaging in x-ray methods. 1 – x-rays tube; 2 – x-rays; 3 − object; 4 – x-rays modulated after interaction with the object; 5 − detector; 6 − image

The denser the structure is, the greater the attenuation is, and as a result there is less blackening of the film as fewer x-rays strike the film. Less dense structures attenuate the beam to a lesser degree and this results in a greater blackening of the film as more x-rays strike it. Radiografic density is a term that refers to the degree of blackness of film. Structures that produce more blackening on film are referred to fs being radiolucent; those that produce less blackening are called radiopaque or radiodense (fig. 3.3).

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. Structures that

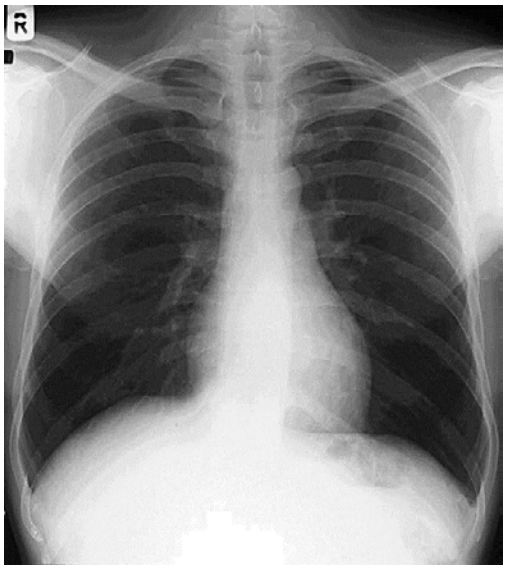

Fig. 3.3.Chest radiograph. Frontal view

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.

The most common type of recording media 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. Light or ionizing radiation produces chemical changes within the emulsion, resulting in the deposition of metallic silver, which is black. The amount of blackening in a film is dependent entirely upon the amount of radiation reaching the film and, therefore, on the amount attenuated from the beam by the subject.

Digital radiography involves detecting radiation pattern, processing, and image recording and viewing an image, retaining information. With digital radiography analog information is converted to digital form by an analog-to-digital converters, the reverse is happening with the digital-to-analog converters. To display the digital image matrix (numeric row and column) is transformed into a matrix of visible picture elements – pixels. Pixel – reproducible imaging system the minimum element of the picture. Each pixel in accordance with the digital value of the matrix is assigned a shade of gray scale. The number of possible shades of gray scale ranging between black and white is often determined based on the binary, for example, 10

bits = 210 or 1024 shades.

Now technically implemented and having already received four clinical applications of digital radiography:

- digital radiography screen electro-optical converter (electron optical image intensifier) (EOC);
- digital X-ray fluorescent;
- scanning digital radiography;
- digital selenium radiography.

Digital radiography system with the EOC consists of EOC screen, television tract and analog-to-digital converter. As an image detector is used EOC screen. The TV camera converts the optical image on the screen image converter in an analog video signal, which is then by an analog-to-digital converter is formed by a set of digital data and transmitted to the storage device. Then, the computer translates the data into a visible image on the screen. Image is studied on the monitor and can be printed on film.

In the digital X-ray fluorescent storage plate after exposure X-rays are scanned by special laser device, and arising during the laser scanning beam is transformed into a digital signal that reproduces the image on the monitor screen, which can be printed. Fluorescent plate inserted in cassettes reusable (from 10000 to 35000 times) with any X-ray apparatus.

In digital X-ray scanning through all sections of the object is passed sequentially moving a narrow X-ray beam, which is then detected by the detectors, and after digitization in the analog-digital converter is transmitted to a computer screen with a possible subsequent printing.

Digital selenium radiography as a receiver uses the X-ray detector is coated with selenium. Selenium is formed in the layer after exposure to form a latent image portions with different electrical charges read by the scanning electrodes and is converted to digital form. Next, the image can be viewed on the screen or printed on film.

The advantages of digital radiography:

- reducing the radiation dose to patients and medical staff;
- cost of operation (during shooting immediately receive an image, eliminating the need for x-ray film and other consumables);
- high performance (about 120 images per hour);
- digital image processing improves picture quality, and thereby increases the diagnostic information content of digital radiography;
- cheap digital archiving;
- quick search for x-ray image in computer memory;

- reproduction of the image without losing its quality;

- the possibility of include in networking of the various equipment radiology department;

- the possibility of integration into the local network facilities;

- the possibility of organizing remote consultation.

Fluoroscopy − raying organs and systems with the use of x-rays. Fluoroscopy is anatomical and functional method that allows the study of normal and pathological processes of organs and systems, as well as shading tissues on fluorescent screen. The research is performed in real-time, i.e., production and obtaining its image coincide in time. This method give a positive x-ray image:

-allows to use different positions for research of patients, which in some cases it is important to diagnose;

- the possibility of studying the functional state of organs: lungs, at different phases of the breath, pulsation of the heart with the great vessels, the motor function of the gastro-intestinal tract;

- palpation under visual control;

- the ability to perform manipulation (biopsies, catheterization, etc.) under control of x-ray images.

Disadvantages:

-relatively high radiation dose to the patient and personnel;

-relatively long duration of research

-restriction in the detection of small shadows and fine structures of tissues; indications for fluoroscopy is limited.

Currently used for fluoroscopy an x-ray image intensifier (XRII), is an imaging component which converts x-rays into a visible image.

The term image intensifier refers to a specific component an X-ray image system, which allows low intensity x-rays to be converted to a visible light output. The device contains a low absorbency/scatter input window, typically aluminum, input fluorescent screen, photocathode, electron optics, output fluorescent screen and output window. These parts are all mounted in a high vacuum environment within glass or more recently, metal/ceramic. It allows the viewer to more easily see the structure of the object being imaged than past fluorescent screens.

X-rays, bearing the image of the inspected object fall on the input phosphor screen, where their energy is converted into light energy radiation input phosphor screen. Next, the photons emitted by the phosphor screen, hit the photocathode, which converts the light beam into a stream of electrons. Under the influence of a constant electric field of high voltage (up to 25 kV), and as a result of the focus electrode and anode, a special form of energy of the electrons increases several

thousand times and they are sent to the output phosphor screen (fig. 3.4). Brightness of the display output is amplified to 7000 times, compared with the input screen. Images from the output phosphor screen with the picture tube is transmitted to the display. The use of XRII allows to detect the detail of 0,5 mm, i.e. 5 times better than conventional fluoroscopic examination.

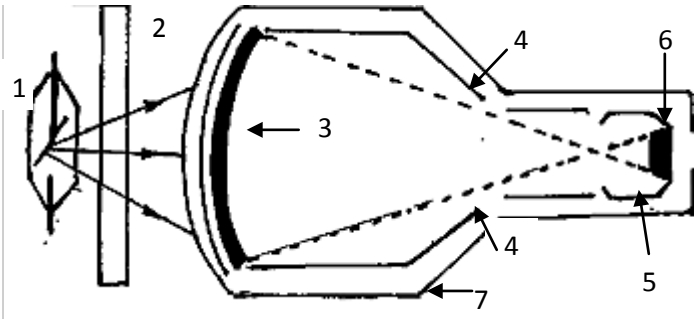

Fig. 3.4. Scheme of imaging intensifer: 1 − x-ray tube; 2 − object; 3 − detector screen; 4 − focusing electrodes; 5 − anode; 6 − viewing screen; 7 – housing. Dotted line indicate electron flow

X-ray computed tomography (CT). Creation of x-ray computed tomography became the major event in radiology. For the development and clinical testing of computed tomography Cormack (USA) and Hounsfield (England) shared the 1979 Nobel Prize.

CT enables to study position, form, sizes and structure of different organs, and also their interrelation relations with other organs and tissues. The advancements in diagnostics of different diseases reached by CT challenged fast technical development of devices and significant increasing of their types.

CT registration is based on X-ray recording performed by sensitive dosimetric detectors and X-ray imaging of organs and tissues by computers. The principle of the method is that after beams move through patient's body they get to the detectors in which electric impulses arise. After amplification they are transmitted in the computer where they are reconstructed according to a special algorithm and create an image of the investigated object (fig. 3.5, 3.6).

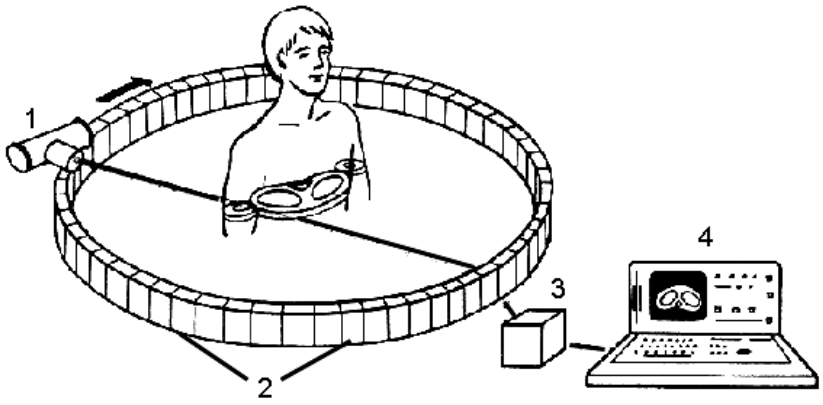

Fig. 3.5. Scheme X-ray computed tomography. 1 – x-ray tube, 2 – detectors, 3 – computer, 4 – imaging system [32]

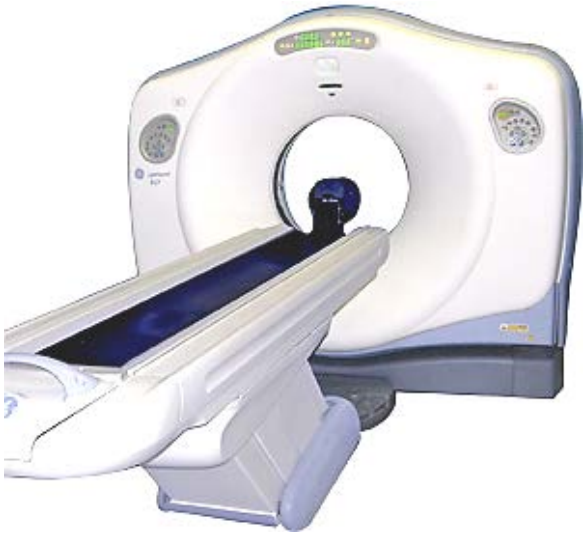

Fig. 3.6. A typical computed tomography scanner

Computed tomography (CT) is a planar, transaxial imaging method providing excellent contrast resolution (fig. 3.7, 3.8).

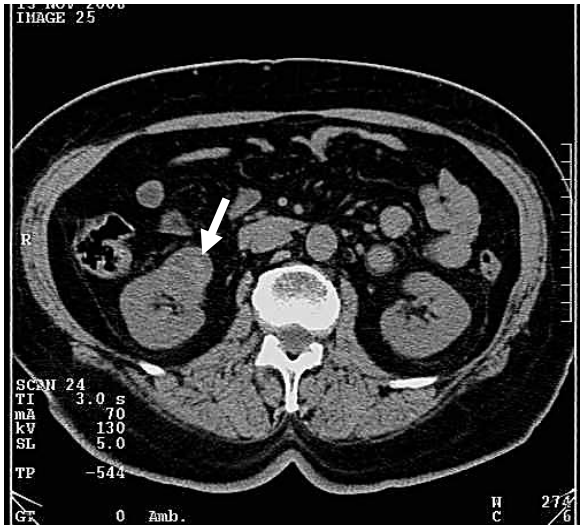

Fig. 3.7. CT-imaging. Computer tomogram of an abdomen cavity at level L2 vertebrae. The right kidney is enlarged, its contours rough (arrow). Renal cell carcinoma

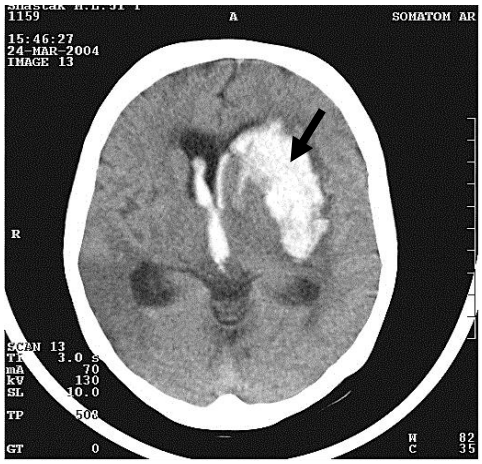

Fig. 3.8. The x-ray computer tomogram of a brain. A hemorrhage in left hemisphere and ventricles of a brain, forming hyperdensity zones (arrow)

Computed tomography (CT scanning) can define alterations in soft tissue and bone that are undetectable with conventional radiography because of its cross-sectional display, excellent contrast resolution, and ability to measure specific attenuation values. CT images are produced in computers that enable reformation of transaxial data in the coronal or sagittal plane and three-dimensional analysis of image data. In step-by-step and spiral CT-scanners one or two types of detectors are used. Multislice CTs are supplied with 4, 8, 16, 32 and even 128 rows of detectors. In multislice devices time of scanning is considerably less and spatial resolution in axial direction is better. They enable to obtain information with the help of high resolution techniques. Quality of multiplanar and volume reconstruction improves considerably (fig. 3.9).

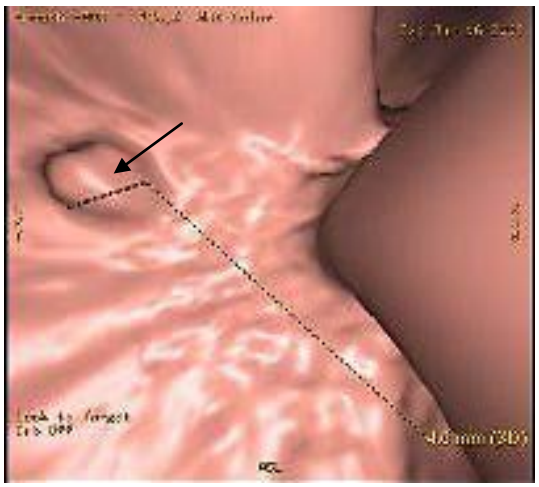

Fig. 3.9. Helical CT of a large bowel (virtual colonoscopy). Diverticulum of a large bowel in the size of 4,6 mm (arrow)

Attenuation number is a number used to denote the attenuation coefficient obtained in a CT reconstruction. At present it is accepted the representation that uses a scale in which air is assigned a value of 1000 and water has a value of 0. Depending on its density, bone has values between 1000 and 3 000. The values are measured in Hounsfield units (HU).

The minimum size of a tumour or other pathological centre defined by means of CT, differs from 0,5 to 1 cm provided that HU the tissue affected differs from that healthy one in 10 - 15 units.

Disadvantage of CT is the increase of irradiation dose in patients. Nowadays 40 % from the collective dose received by patients at radiology researches falls on CT whereas this research makes up only 4 % from the number of all important radiological researches.

Both in CT, and at other x-ray researches there is a necessity of application for increase in resolution of a technique of "contrast enhancement”.

Methods of radiological research are called special if it is used contrast agents.

Organs and human body tissues become distinguishable if they absorb x-rays in various degree. In physiological conditions such differentiation is possible only in the presence of natural contrast which is caused by a difference in density (a chemical compound of these bodies), size, position. The bone structure against soft tissues, heart and large vessels against an air pulmonary tissue well comes to light, however chambers of heart in the conditions of natural contrast cannot be allocated separately, as well as organs of an abdomen, for example.

Necessity of studying by x-rays of organs and the systems having identical density, has led to creation of a technique of contrast enhancement. The essence of this technique is in introduction of contrast agents into an investigated organ, i.e. the substances having density, differing from density of organ and his environment (fig. 3.10).

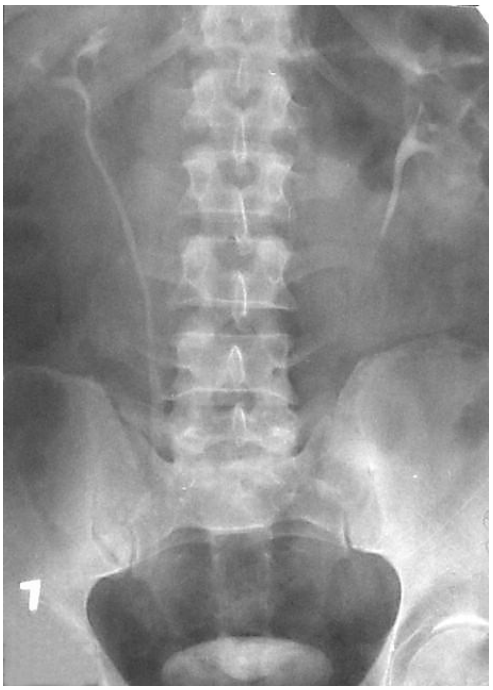

Fig. 3.10. Contrast enhancement of urinary ways: intravenous urography

Contrast agents for x-ray researches (CA) can be subdivided into substances with high nuclear weight (positive contrast agents) and low (negative contrast agents). Contrast substances should be harmless.

The contrast substances intensively absorbing x-rays (positive contrast agents):

1. Suspensions of salts of heavy metals – the barium sulfate applied to research gastrointenstinal tract (GT) (it is not absorbed and is removed through natural ways).

2. Water solutions of organic compounds of iodine which are injected into a vascular channel, get to all organs with a blood current; besides vascular channel contrast enchancement they enable contrast studies of other systems, e.g. of urinary tract, bile duct etc.
3. Oil solutions of organic compounds of iodine, e.g. iodolipol, etc. which are injected into fistulas and lymphatic vessels.

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 from any severe long-lasting effects after this shift, patients who are dehydrated or in a precarious state of cardiac and fluid balance are at special risk, particularly for renal failure. Secondary effects from the changes in viscosity and tonicity of the blood include platelet aggregation, changes in blood pressure, change in cardiac output, and changes in pulse rate. As the serum osmolality rises, there may be changes in blood coagulation, with a resultant bleeding tendency.

Rapid injection, high-volume injection, and high tonicity and viscosity of the agent are associated with more severe reactions. Occasionally a vagal reaction occurs where there is vasodilation and systemic hypotension. Bradycardia is encountered rather more than tachycardia.

In kidneys, 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 effects of the ionic contrast agents led to the development of a new class of water-soluble media. These agents are of two types. The first one includes nonionic monomers (variants of triiodobenzene) in which the sodium or meglumine cation has been replaced by a side chain that will not dissociate 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 in comparison with the older ionic agents, and now are 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.

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 GT 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 GT. However, there is one important contraindication for water-soluble contrast media: suspected communication between GT and the tracheobronchial tree (tracheo-esophageal fistula).

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."

Contrast examination. 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).

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 have been largely superseded by others radiological technologies.

A 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 can produce a severe and often fatal chemical pneumonia.

Diseases affecting 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 intervertebral 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. Myelography is often combined with CT. The development of magnetic resonance imaging, however, has decreased the number of myelograms performed today, as compared with a decade ago.

All radiological offices where intravascular contrast enhancement researches are performed, should have the tools, devices and medicines necessary for rendering of urgent medical aid.

Premidication with the use of antihistamines and glucocorticoids is expedient as a preventive measure before radiographic contrast study; also a test is carried out for prediction of patient’s hypersensitivity to contrast agents. The most appropriate tests are: determination of histamine release from basophils of peripheral blood when mixing it with contrast agents; determination of total complement activity in serum of the patients, who were prescribed radiographic contrast study; selection of patients for premidication by determining the levels of serum immunoglobulins.

Less frequent complications are "water" intoxication after irrigoscopy in children with megacolon and vascular air (or fat) embolism.

The symptoms of "water" intoxication, when considerable quantity of water is quickly soaked up through bowel walls in a blood channel which unbalances electrolytes and plasma proteins, are tachycardia, cyanosis, vomiting, respiratory impairment with cardiac arrest; the patient can die. Thus, first aid includes intravenous injection of blood or plasma. Prevention of complications in children is irrigoscopy with barium suspension in an isotonic solution of salt, instead of a water suspension.

Symptoms of vascular embolism include difficulty in breathing, dyspnea, cyanosis, bradycardia and blood pressure drop, spasms, respiratory arrest. Thus it is necessary immediately to stop injecting the contrast agent, to lay the patient in Trendelenburg position, to start artificial respiration and external cardiac massage, to inject 0,5 ml of 0,1 % adrenaline solution intravenously. It is also important to call the intensive care brigade for possible intubation of trachea, mechanical ventilation and further medical steps.

Linear tomography is designed to eliminate summational character of X-ray image. In tomographs the X-ray tube and film (fig. 3.11) move in opposite directions.

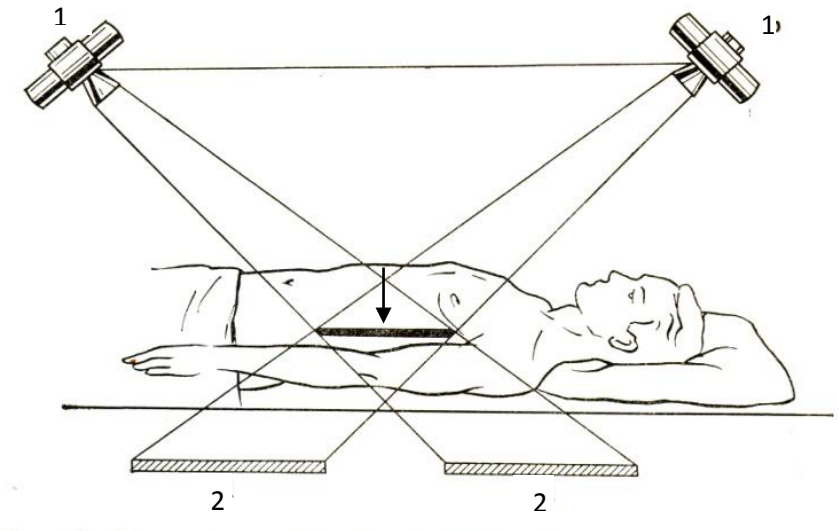

Fig. 3.11. Principles of linear (conventional) tomography. The x-ray tube (1) and the film (2) move in opposite directions. The focal plane remains in sharp focus (arrow), whereas the other images are blurred [33]

During the motion of tube and film in opposite directions, pivot of tube movement is formed. It is a layer which remains as if fixed, and on the tomogram derails of this layer are displayed in the form of sharp-outlined shade; tissues above and below the pivot appear to be blurred and are not detectedon the image of this layer (fig. 3.12).

Interventional radiology or invasive radiology is the subspecialty of diag-

nostic radiology in which diagnostic examinations are performed by percutaneous

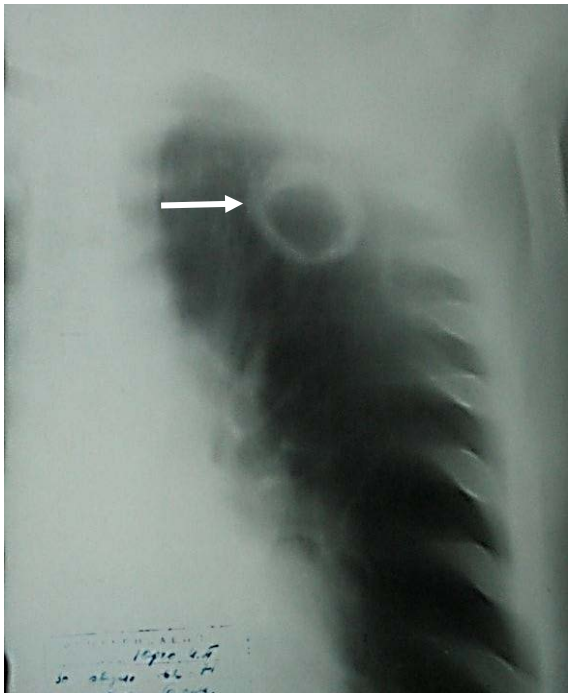

Fig. 3.12. The conventional tomogram of chest. Frontal view. Notice forward and back departments of ribs are not visible.
Ring shaped shadow in upper lobe of left lung with equal thick walls without of liquid (arrow)

puncture. It is also known as interventional or surgical radiology. This subspecialty is the most labor intensive in diagnostic radiology and includes biopsy procedures, percutaneous puncture, decompression and drainage procedures, ballon dilations (angioplastic procedures), extraction techniques, vascular chemotherapy, vascular embolism.

Ultimately, subject of x-ray researches is the shadow image. Features of the x-ray shadow image include:

1. The image consisting of many dark and light areas; according to areas of unequal attenuation of x-ray in different parts of the object.
2. The sizes of x-ray image are always increased (except CT) if compared with object of study and the bigger distance between the object and a film is and the lesser focal length is (distance between a film and focus of X-ray tube), the bigger the image is (fig. 3.13).
3. When the object and the film are not in parallel planes, then the image becomes distorted (fig. 3.14).
4. The image has summational character (except tomography) (fig. 3.15). Hence, x-ray pictures should be made not less, than in two mutually perpendicular projections.
5. Negative image at radiography and CT.

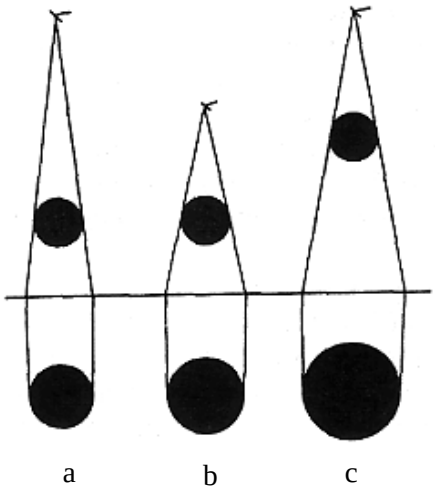

Fig. 3.13. Dependence of the sizes of the x-ray image (a, b, c) on distance between an X-ray tube, object and the receiver of the X-ray image (screen, film) [63].

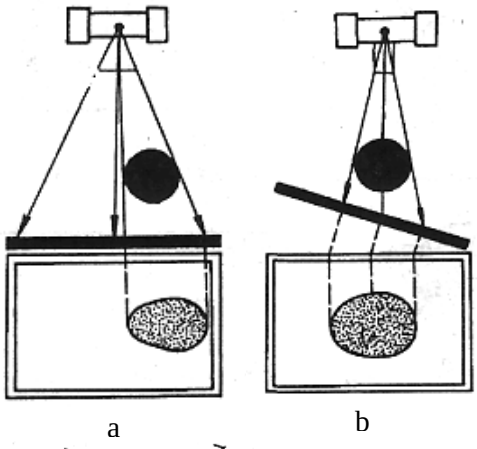

Fig. 3.14. Change of the object form depending on direction of X-rays (a) and position of the X-ray receiver (b) [63]

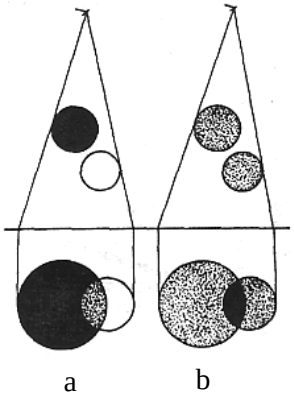

Fig. 3.15. Summational character of the X-ray image at radiography and fluoroscopy. Subtraction (a) and superposition (b) of shadows of X-ray image [63]

3.3. Nuclear medicine

Nuclear medicine traditionally has two divisions, nuclear imaging (radiology) and laboratory analysis. The diagnostic radiologist is the person concerned with the imaging aspect.

The principles of nuclear imaging depend on the selective uptake of certain compounds by different organs of the body. These compounds may 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 (^{99m}Tc) 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 staying 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 on either a static or dynamic basis. Static studies include the thyroid, skeleton, and renal scans. Dynamic studies include e.g. perfusion-diffusion studies of the lung, renal and liver scans. The gamma camera represents the basic nuclear medical device allowing to visualise radionuclide distribution in organs. Static scintigraphy (fig. 3.16) investigates distribution and accumulation of radiopharmaceuticals (RP) in object of study. Dynamic scintigraphy (fig. 3.17) investigates distribution of RP and time characteristics of accumulation and excretion of radiopharmaceuticals in object of study.

In SPECT (single photon emission computed tomography), applied in nuclear medicine, photons are registered by one or several rotating gamma cameras around the patient for data acquisition systems to creation of the images. A computer is then used to apply a tomographic reconstruction algorithm to the multiple projections, yielding a 3-D dataset. This dataset may then be manipulated to show thin slices along any chosen axis of the body. SPECT allows to receive volume representation about distribution radiopharmaceutical in organ or research area. The basic advantage SPECT is possibility to perform slices of distribution radiopharmaceutical in studied organs.

Parts with higher accumulation of radiopharmaceuticals on scintigrams are called hyperfixation ("hot"), and parts with the lower accumulation – hypofixation ("cold").

Equipment for detecting of the isotopes uptake and for recording their images includes the gamma camera and the tomographic scanner. Any nuclear medicine

research is carried out by radio-electronic devices specially intended for these purposes.

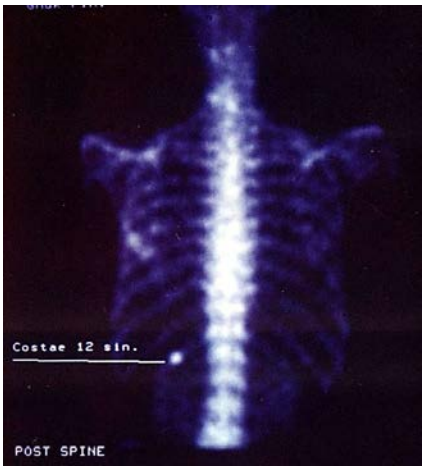

Fig. 3.16. Radionuclide bone imaging (static scintigraphy), with ^{99m}Tc-methylene diphosphonate. Hyperfixing in left 12 rib. Sign of metastasis of a malignant tumour in the 12 rib on the left

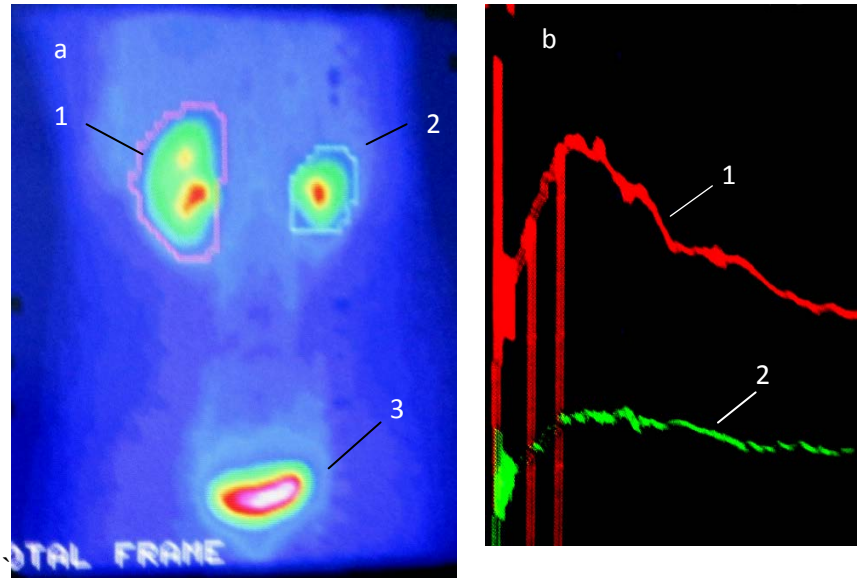

Fig. 3.17. Dynamic nephroscintigraphy (research of glomerular filtration with ^{99m}Tc-DTPA (the pharmacological moiety is a pentavalent chelating agent): a) distribution of radiopharmaceutical in kidneys due glomerular filtration. 1- left kidney, 2- right kidney, 3 – urinary bladder. Note sharp decrease size of right kidney; b) histogram: curves reflecting level of a filtration in the left kidney (1) and in the right kidney (2). Hypoplastic kidney on the right with its hypofunction.

In the majority of devices for nuclear medicine gamma cameras are used which include scintillation counter. Every such scintillation counter apparatus has three basic elements: detector, photoelectronic multiplier and collimator. Collimator is a device that narrows a beam of gamma-photons. In detector (scintillator) at full or partial absorption of energy of gamma-photons falling on it there are light flashes (scintillation) of very low intensity. Detector is usually a large crystal of sodium

iodide containing thallium iodide as activator. To register such flashes, the special device − the photoelectronic multiplier is necessary. In the photomultiplier light energy of flashes turns into a stream of electrons which amplifies like avalanche (fig. 3.18).

The output signal from the photomultipliers is currents, which are proportional to the energy of the gamma ray. The positional information is recorded using an analogue output onto film or a digital image is stored in a computer coupled to the camera.

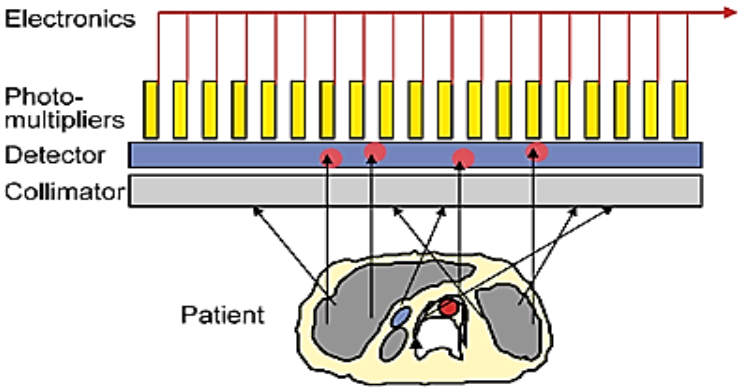

Fig. 3.18. Registration scheme photon radiation in nuclear medicine. Photons are selected by a collimator and produce light flashes which are detected by the photomultipliers [101]. See text

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).
5. Cell sequestration (e.g., spleen scan).

Conventional nuclear scans utilize isotopes that produce gamma radiation.

Positron emission tomography (PET) scanning uses cyclotron-produced isotopes of extremely short half-life that emit positrons. PET is a nuclear medicine imaging technique that produces a three-dimensional image or picture of functional processes in the body. As the radioisotope undergoes positron emission decay (also known as positive beta decay), it emits a positron, an antiparticle of the electron with opposite charge. The emitted positron travels in tissue for a short distance (typically less than 1 mm), but dependent on the isotope, during which time it loses kinetic energy, until it decelerates to a point where it can interact with an electron. The encounter annihilates both electron and positron, producing a pair of annihilation (gamma) photons moving in approximately opposite directions (fig. 3.19).

The system detects pairs of gamma rays emitted indirectly by a positron-emitting radionuclide (tracer), which is introduced into the body on a biologically

active molecule. Three-dimensional images of tracer concentration within the body are then constructed by computer analysis (fig. 3.20).

In modern scanners, three dimensional imaging is often accomplished with the CT scan performed on the patient during the same session, in the same machine.

Radioactive tracer isotope is injected into the living subject (usually into blood circulation). The tracer is chemically incorporated into a biologically active molecule.

There is a waiting period while the active molecule becomes concentrated in tissues of interest; then the subject is placed in the imaging scanner. The molecule most commonly used for this purpose is fluorodeoxyglucose (FDG). During the scan a record in tissues concentration of FDG is made as the tracer decays.

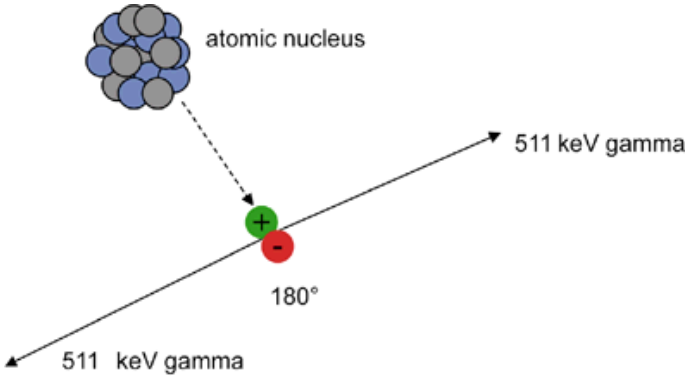

Fig.3.19. Annihilation reaction: an electron and a positron meet, annihilate and form two gamma rays [101]

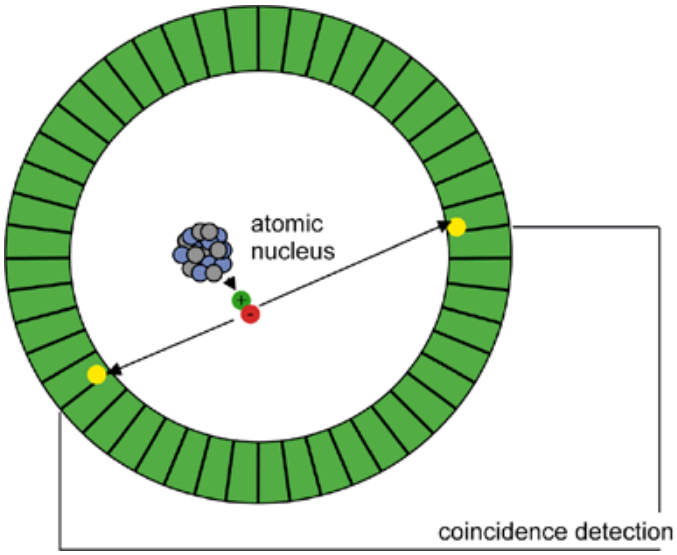

Fig. 3.20. PET imaging: PET principle showing annihilation reaction between positron and electron, production of two gamma rays and detection in coincidence detection system [101]

Positron emission tomography scanning is used to evaluate physiologic function of organs such as brain or tumors on a dynamic basis. Areas of hyperfixation of radiopharmaceutical show the high level of metabolic activity (fig.3.21).

If the biologically active molecule chosen for PET is FDG, an analogue of glucose, the concentrations of tracer imaged then give tissue metabolic activity, in

terms of regional glucose uptake. Although use of this tracer results in the most common type of PET scan, other tracer molecules are used in PET to image the tissue concentration of many other types of molecules of interest.

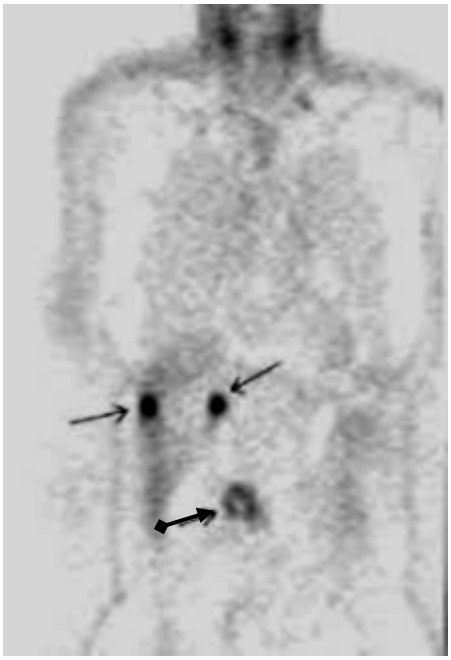

Fig. 3.21. PET imaging. Coronal FDG-PET (fluorodeoxyglucose) slice at level of the pancreas head. The pancreas head tumour (arrow with rhombus) and two metastasises in the liver (arrows) [28]

3.4. Diagnostic ultrasound

Obtaining of ultrasonic images of internal organs (structures) of biological objects is based on application of sound field formed in elastic environments (liquid, solid). To investigate biological objects longitudinal acoustic waves of ultrasonic range of frequencies (1-15 MHz) are used. An important advantage of ultrasound is the absence of ionizing radiation and the relatively lower cost of the equipment (fig. 3.22).

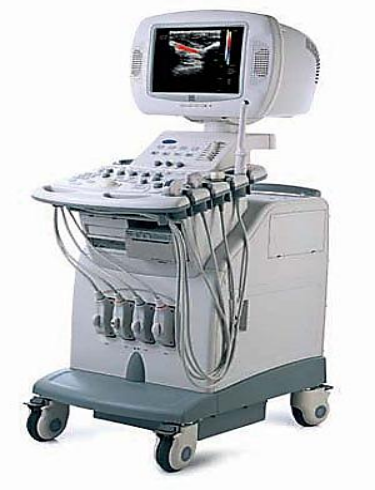

Fig. 3.22. A typical ultrasound machine.

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.

As they distribute, directions of environmental particles fluctuations and wave motion coincide. 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 waves are greatly reflected by air-soft tissue and bone-soft tissue interfaces, thus limiting its use in the chest and musculoskeletal system.

Distribution and ultrasound reflexion are two main principles on which operation of all diagnostic ultrasonic equipment is based.

The basis for generation and registration of ultrasonic oscillations is the direct and inverse piezoelectric effect. For obtaining ultrasonic oscillations the inverse piezoelectric effect is used. Its essence lies in the fact that crystal starts to contract and stretch during the formation of electric charges on the crystal face. Oscillations occur, and their frequency depends on frequency of change of potential sign on crystal faces. One of the main advantages of piezoelectric converters is that the source of ultrasound can serve as its receiver at as well. In this case direct piezoelectric effect takes place, when opposite electric potentials are formed on the faces of piezocrystal during its deformation by perceived ultrasound. These opposite electric potentials can be registered. To obtain ultrasonic oscillations, the crystal zirconium titanate is used more commonly.Three display modes are commonly used (fig. 3.23). In amplitude mode (A-mode), information is displayed on a television screen 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.

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 television screen. The cardiac structures form patterns in the M-mode relating to their motion.

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 television screen (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 (fig. 3.24 and 3.25). 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.

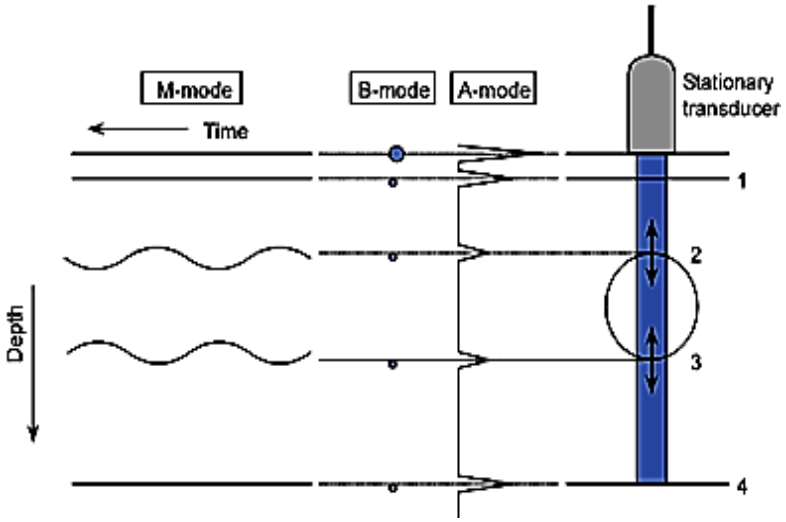

Fig. 3.23. Schematic A-mode, B-mode and M-mode presentation [101]

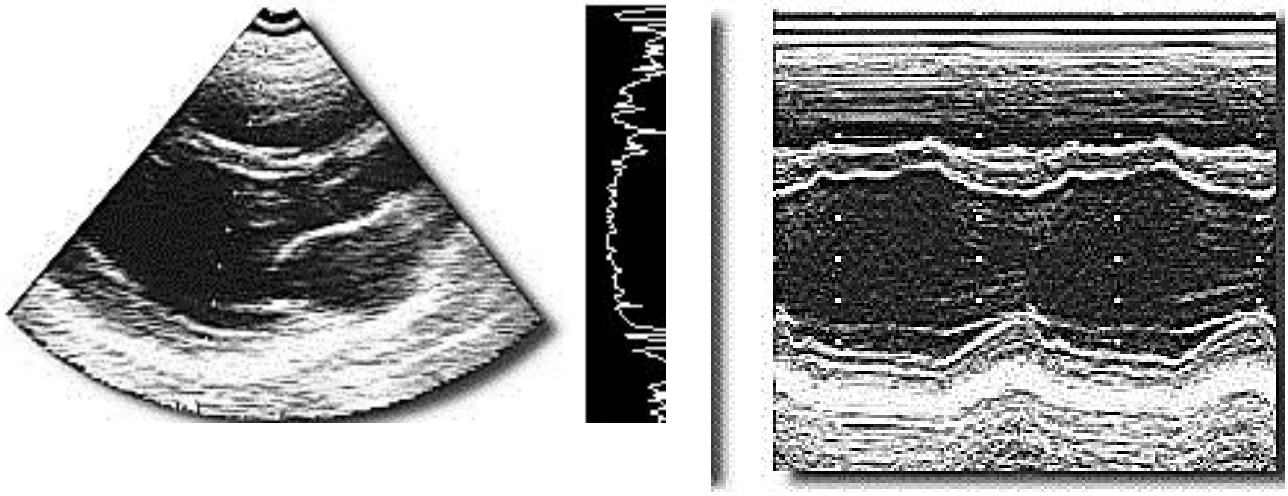

Fig. 3.24. The scheme of one- and two-dimensional modes illustrated by research contractile function of basal portion of the left ventricle. From the left to the right: two-dimensional ultrasonic B-scanning (the arrow shows the direction of ultrasound beam for one-dimensional researches); A-mode in the form of the echogenicity vertical graph of intracardiac structures; M-mode enables to estimate character of movement of cardiac walls in time (throughout all cardiac cycle)

Three-dimensional (3D) mode implies synthesising of a three-dimensional image obtained by electronic or mechanical scanning in two and more planes (fig. 3.26).

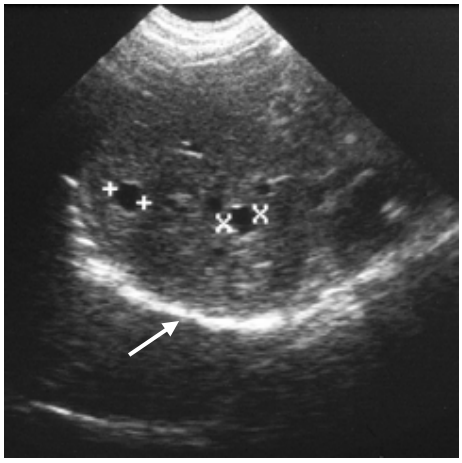

Fig. 3.25. B-mode examination of the liver. Two small anechoic structures with perceptible wall and dorsal acoustic enhancement represent simple hepatic cysts (are designated by daggers). Diaphragm view as arcuate hyperechoic structure (arrow). Hepatic cysts [101]

Fig. 3.26. Three-dimensional image of a fetus

Doppler mode. The velocity of blood flow towards or away from an ultrasound probe can be derived from the reflected ultrasound wave using the well known Doppler principle. The effect has found widespread use in fetal monitoring, cardiology and vascular studies. Duplex scanners combine both pulse echo ultrasound and Doppler shift facilities.

Continuous wave Doppler uses two transducer crystals mounted by side, one transmitting and the other receiving ultrasound waves. The method is the best for measuring high velocity flow and for recording peak velocities.

Pulsed-Wave Doppler uses a single transducer to emit short bursts of ultrasound which are received back by the same transducer and recorder in the interval between emission pulses (fig. 3.27). This method permits precise focusing on small sample volumes but is less accurate than Continuous Wave Doppler for peak and high velocity flow.

Colour flow imaging uses pulsed-wave ultrasound but allows assessment across the whole field of two-dimensional image. The results can be coded in colour permitting immediate visual recognition of flow towards the transducer or away from it.

The power mode allows to register structures with low velosity but without differentiation of their speed, direction and laminarity of a stream.

When interpreting sonograms echoic indicator is important. Dense structures (e.g. stones) fully reflect ultrasonic waves, therefore they are hyperechogenic. The liquid is homogeneous and it passes freely through ultrasonic waves, therefore it is hypoechogenic. Thus, white sites on sonograms are hyperechogenic, dark sites are hypoechogenic, what is connected with echoic intensity of ultrasound (fig. 3.28).

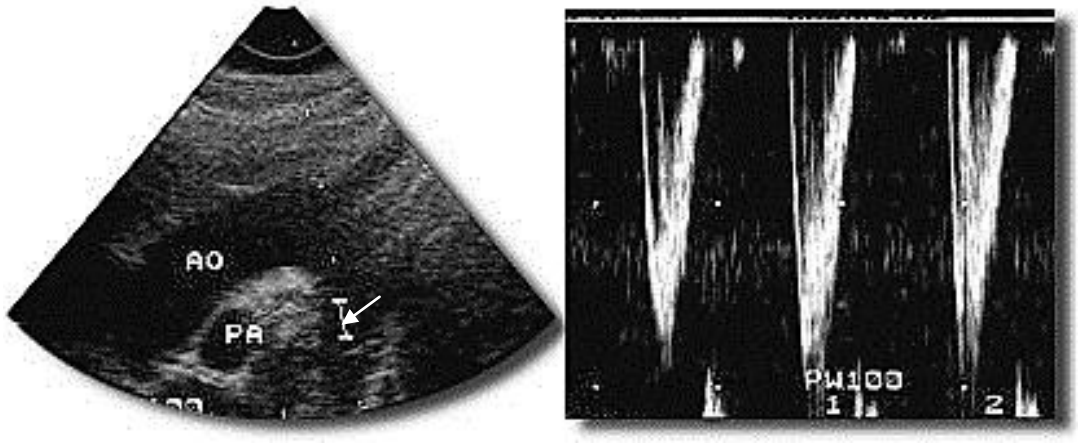

Fig. 3.27. At the left - the two-dimensional image of heart with a label of control volume (arrow), established at level of descending department of an aorta (AO). PA it is a pulmonary artery.
On the right – the schedule a blood-groove through aorta, displaying a direction (from the transducer), speed (amplitude size) and flow disturbances

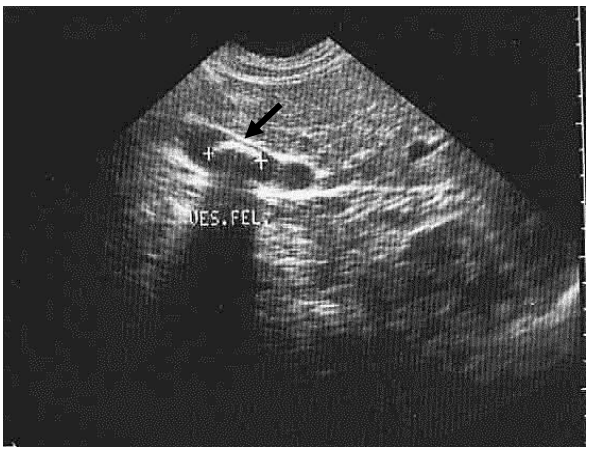

Fig. 3.28. Sonogram of gallbladder. The stone on the sonogram looks as hyperechogenic formation (arrow) with an ultrasonic shade behind it (ultrasonic track).
Cholelitiasis

The normal liver serves as a test organ with average echogenicity.

Ultrasonic methods enabled to solve issues of diagnostics of numerous diseases of cardiovascular, digestive, urinogenital systems more precisely. By means of these methods valuable data in obstetrics and gynecology, oncology, neurology and neurosurgery, ophthalmology can be obtained.

Negative effects of ultrasound. One of the main advantages of ultrasound is keeping tissues safe with powers of ultrasound energy used in diagnostics; thus, there are no contraindications for its application. This is important especially for children and pregnant women. However ultrasound should not be considered as an absolutely safe method. Ultrasound influence does not cause ionisation in tissues, but under certain conditions can damage them. Cells with fast fission are the most sensitive to thermal action of ultrasound. Therefore there are certain restrictions for Doppler research for women during I and III trimesters of pregnancy (this method of ultrasound researches has more energy impact on tissues). It is recommended to abstain also from US of a fetus without medical indications.

3.5. Magnetic resonance imaging

Magnetic resonance imaging (MRI) has the major value in modern radiology. MRI gives the valuable diagnostic information on the physical and chemical parametres, allowing to judge the nature and a morphological structure of investigated organs and tissues. Besides the image can be received in anyplane. The basic components of the MR-tomograph are the power magnet, a radio transmitter, the reception radio-frequency coil and the computer. To obtain information from certain areas or slices gradient magnetic field used in MRI system (fig. 3.29).

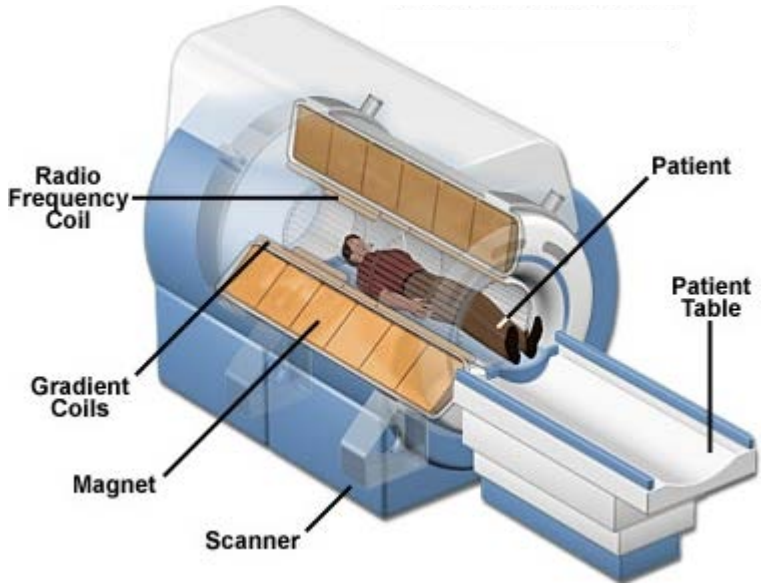

Fig. 3.29. MRI scanner cutaway [47]

The majority of magnets have a magnetic field which is parallel to a long axis of a person's body. Force of a magnetic field is measured in tesla (T). For clinical MRI fields with force 0,02-3 T are used. When the patient is put in the strong magnetic field, all small proton body magnets (a hydrogen nucleus) turn towards an external field (like the compass arrow which is guided by a magnetic field of the

Earth). Besides, magnetic axes of each proton start to rotate round a direction of an external magnetic field. When passing through a patient's body of the radio-waves with the frequency equal to the protons rotation frequency (Larmor frequency), a magnetic field of radio-waves forces the magnetic moments of all protons to rotate clockwise. This phenomenon is called magnetic resonance. Resonance is understood as synchronous vibrations. To change orientation of a magnetic vector of protons, magnetic fields of protons and radio-waves should resonate, i.e. they should have identical frequency. In tissues of the patient the total magnetic moment is created when tissues are magnetized, and their magnetism is oriented precisely parallel to an external magnetic field. The MRI 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 (fig. 3.30).

T1 and T2 measurements reflect quantitative alterations in MR signal strength due to interactions of the nuclei being studied and their surrounding chemical and physical characteristic. 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.

At present magnetic resonance is used mainly 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.

Agents to enchance MRI. 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.

Disadvantages of MRI:

1. Poor calcification imaging.
2. Long time of imaging; artifacts from respiratory and other movements limit the application of MRI in diagnostics of chest and abdominal diseases.

Negative effects of MRI. MRI systems do not use ionizing radiation and have no radiation harm. For the overwhelming majority of patients the method is not dangerous.

MRI is contraindicated for:

1. Patients with pacemakers or with intraorbital, intracranial, intraspinal and other ferromagnetic foreign bodies (absolute contra-indication).
2. Intensive care patients because of influence of magnetic fields of the MRI on life-support systems.
3. Claustrophobic patients (about 1%), though they can be sedated.
4. Women during their first trimester of pregnancy.

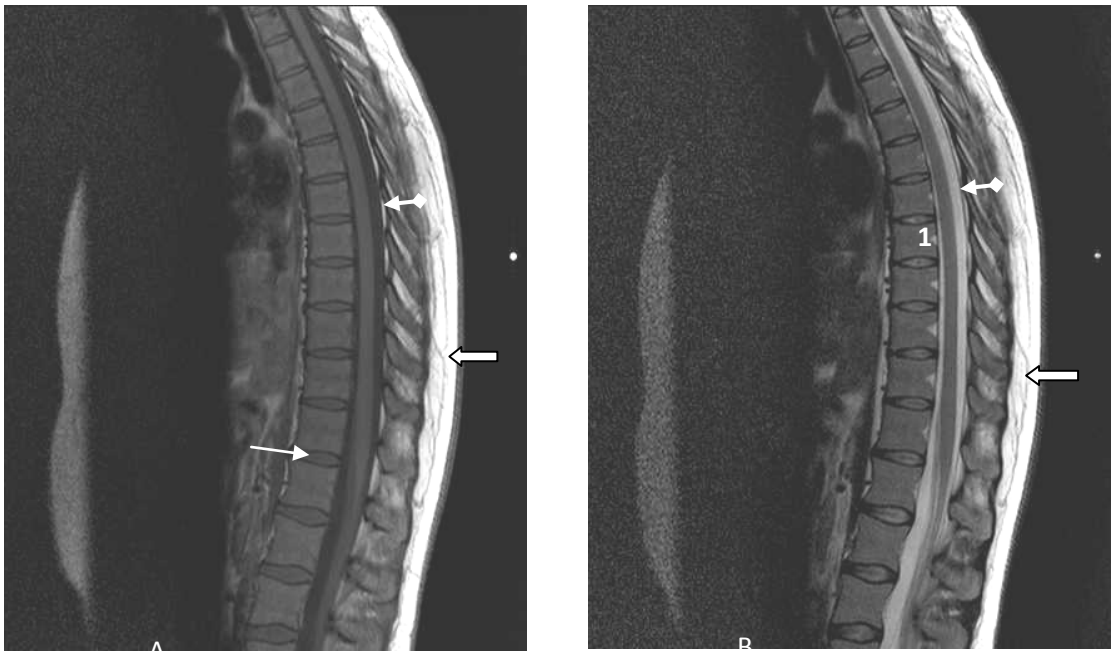

Fig 3.30. MRI. T1-WI (A) and T2-WI (B) of the thoracic spine in the sagittal projection. Visible vertebral bodies correct form (1), intervertebral discs without changes (arrows). In the lumen of the dural sac – the spinal cord as a dark band of uniform width. Note that the cerebrospinal fluid is white on T2 WI and dark on T1 WI (arrows with rhombus). Fat is white on T1-WI and T2-WI (curly arrows). Norm