Physical Principles and Recent Advances of Medical Imaging Systems

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Citation

Abstract
In this paper, a variety of medical imaging systems including Ultrasonography, MRI, Bone Densitometry, Optical Coherence Tomography, Arthrography, etc. are reviewed and their advantages and disadvantages are also described. In addition to these methods, new techniques in medical imaging such as Shear Wave Elastography and Ultrashort Echo Time are also being reviewed. One of the most important of these methods is radiology imaging. Radiology is one of a variety of methods for imaging various parts of the body. Basically, the first assessment of the patient is radiology. Radiology is a non-invasive and rapid method for diagnosis. The basis of this method is the ionizer radiation rays. Radiology medicine is divided into two parts: diagnostic and therapeutic. Radiology medicine based on the energy used is divided into two types: radiology and nuclear medicine. The basis for the function of radiology is X-rays and the basis for the performance of nuclear medicine is radioactive material. Radiology is more dangerous than nuclear medicine, and is not suitable for pregnant women and children. But radiology is more accurate and faster than other methods. In addition to its advantages, this method also includes dangers for the human body. Wilhelm Röntgen was the first scientist to discover X-rays and record the first radiology image. This paper describes the components of a radiology device, including a X-ray tube, a collimator, a detector, and so on.

1. Introduction
Radiology is derived from the word Radius, which means radiation. Ionized rays in radiology, for diagnosis and treatment [1]. Diagnostic radiology includes Radiography, Computed Tomography, Mammography and Fluoroscopy, and so on. Therapeutic radiology is also used for radiation therapy for the treatment of various types of cancer which includes radiotherapy devices. Electromagnetic spectrum used for radiology include X-rays, gamma rays, visible light and radio waves. X-rays can be created by throwing an electron toward an atom [2]. X-rays are divided into two types, Braking radiation and Characteristic radiation. In Braking radiation, the electron crosses near the core, and then its speed and energy are changed and converted to the X-photon. In Characteristic radiation when an electron is thrown towards the core, it hits one of the electrons and removes it from the orbit. This free space in the orbit causes energy difference and the release of the X-ray photon [3]. These two types of radiation are shown in Figure 1.
2. Method

In the following, the X-ray generating device, the radiology device, Nuclear Medicine method and Other recent Imaging Methods are described. Also, the advantages and disadvantages of these methods are also described.

2.1. X-Ray Generating Device

X-ray generating device are different according to their function. In general, all of them include: X-ray tube (Figure 2), high-voltage generator and control panel.

One of the important parts of this device is the X-ray tube, which is an electronic vacuum tube equipped with a cathode electrode and anode electrode which the cathode is the negative pole of the tube and the anode is the positive pole of the tube. The anode is in two forms, fixed and rotating [6]. The fixed type is the Target of Tungsten type which is for imaging that does not require high power. In the rotating anode, the Target is a rotating disk of Tungsten type which is rotated by an electromagnetic induction motor. The reason for using Tungsten is because it is thermic conductor and has a high melting point. In an X-ray tube, the cathode infuses and the electrons are thrown toward the anode, and the electrons hit the target and X-rays are produced. A high-voltage generator is designed to produce a potential difference between the two sides X-ray tube. This part includes: high-voltage transformer, filament transformer and rectifier. The control panel is also for controlling the device, which creates functions for the operator [7].

2.2. Radiology Device

Types of radiological devices include: X-ray tube, collimator, high-voltage generator, detector, resonator, control circuit, user's panel and processor device. The collimator is a beam size regulator that has lights and mirrors. Detector of this device is a radiology film that has a base and emulsion. These films are an old method for detection, and today in most countries these images are digitally stored in databases. Film cassettes have a plate called Grid that is used to remove irregular beams. The processor is an automatic device for creating radiology film. Radiological devices are available in both portable and fixed form. The traditional radiology has limitations which these limitations include: time-consuming, high-noise images, low-quality images, and inability to display at the same time in different locations [8].

Today, with the advancement of technology and the development of computer systems, two technologies, Computer Radiology (CR) and Digital Radiology (DR) are used to detect radiological images. In the CR method, the X-rays hit a plate of phosphorus, and then read by the scanner and converted to digital data for computer with the ADC converter. In the DR method, X-rays hit flat panel detectors, converted to digital data by an ADC converter, and sent to the computer for storage. The advantages of these two technologies, compared to traditional methods, are that they can be processed before and after recording the results also have high resolution and high quality images. This information can be transmitted to other locations by Tele Radiology system at the same time [9].

One of the most important uses of radiology is the examination of internal organs of the abdomen and the digestive tract, diagnosis of bone fractures, imaging of the lungs, teeth, jaw and face, as well as the imaging and diagnosis of kidney stones. And also radiology in therapy to remove tumors and cancer cells [10].

2.2.1. Diagnostic Radiology

Diagnostic radiology for the Diagnosis is a variety of disorders in the human body, including Radiography, Computed Tomography, Mammography and Fluoroscopy, and so on. In radiography, X-rays are exposed to electrical conditions, and can be diagnosed with various parts of the body's disease. In simple radiography, external materials are not required for imaging, but in some cases, the need for contrast agents is required to detect some tissues. Consequently, the contrast agents enter the body and then the imaging is done. In the tomography technique, the X-ray tube and the detector around the tissue are rotated, then the imaging is done. Computed Tomography or CT scan, transmits radiation to the patient's body and is received by the detectors and convert to the signal and then sent to the computer. These data are processed by the computer and displayed. In this method, images are obtained based on the difference in linear absorption coefficient of the body organ. Computed Tomography is based on the scan movement, to different types [11]. Mammography is a method for detecting abnormal breast changes. In this method, the patient is placed
on the front of the device and the imaging is done. Through this method, can detect tumors or cancer cells in the breast [12]. Fluoroscopy method is the simplest method of radiology. In this method, the patient is placed behind the fluoroscope and in a short time imaging is done. The disadvantages of this method are the excessive transmission of radiation to the patient. This method is used for respiratory movements of the lung, aperture movements and heart movements [13].

2.2.2. Therapeutic Radiology

The ionizing rays, by changing the instruction of the atoms of the human body, causes biological effects in the body. These rays can also cause cancer and can also treat cancer. These rays destroy cancerous cells and tumors. These rays are irradiated relative to the cancerous cell type and the patient's body physics and measured the amount of radiation and sent it to the patient according to the required amount [14].

2.2.3. Advantages of Radiology

The first method for diagnosing diseases is the use of radiology imaging. This method has a high speed and is very efficient. This method is very useful in detecting, and the images that it offers have high contrast and high resolution. This method is very effective in detecting artery stenosis and stenting. This method is less costly and easier than other methods [15].

2.2.4. Disadvantages of Radiology

X-rays produced in this way and radiating to the patient's body have dangers. These beams are a factor in changing atoms in the body that cause cancer also cause disorder cell function. Therefore, this method should not be used too much. This radiation is very harmful to pregnant women and causes a genetic mutation in newborns. Therefore, pregnant women should not use this method as far as possible [16].

2.3. Nuclear Medicine

As previously mentioned, Radiology medicine based on the energy used is divided into two types: radiology and nuclear medicine. Imaging is done in nuclear medicine based on nuclear properties and radioactive materials which the radioactive radiation used is gamma rays. In nuclear medicine, visual information is obtained from the metabolic function of the body. Radiopharmaceuticals used for this method include isotopes or drugs that are marked with an isotope. These drugs are injected into the body by intravaginal injection, subcutaneous injection, oral and respiration [17]. Instruments used in nuclear medicine include: Geiger-Muller Counter, Photomultiplier-Tube (PMT), Absorption Probes, Scintillator Detector, Collimator, and Dosage Meter. Each of the nuclear medicine devices has a gamma camera, scanner and electronic circuit X and Y [18]. Two devices used in nuclear medicine, MRI and CT scan devices. The methods used for imaging in nuclear medicine include: (PET) Positron Emission Tomography (SPECT), PET-CT, SPECT-CT, SPECT-CT-PET (Figure 3) and PET-MR.

In the PET method, imaging is based on the detection of gamma photons created by the destruction of positrons and electrons. Its function is for neurological diseases and oncology. Due to the number of crystals and electronic components, it is more expensive than other methods, and the number of centers with this method is very few because they should be alongside an accelerator for isotopes [21]. The SPECT method is like a PET method, but in the SPECT method, other radioisotopes are used, and the half-life of these radioisotopes is higher [22]. The SPECT images show less detail than the PET method. The SPECT method is less costly than the PET method, the number of these centers is high [23]. In the PET-CT combination method, first the CT scanner is located and then the PET scanner is located. In this way, 2-dimensional and 3-dimensional images are displayed. This method is used for neurological diseases, cancer, heart attacks and epilepsy [24]. In the SPECT-CT method, first the SPECT scanner is located and then the CT scanner is located. In this method, the applied information from the SPECT and the anatomical information from CT are obtained, and then this information is combined together. In this combination method, CT data is used to modify the SPECT data [25]. The PET-MR method, the PET scanner, is located inside the MRI device, and the imaging is done simultaneously. The pet's device uses PMT. Because PMT is sensitive to the magnetic field, in this combination method with MRI, other detectors are used instead of PMT. These alternative detectors include: Avalanche photodiode and silicon photomultiplier. The function of nuclear medical devices includes bone scan, heart scan, thyroid scan, lung perfusion scan, lung ventilation scan, and brain perfusion scan [26].

2.4. Other Recent of Imaging Methods

Ultrasonography is one of the most common methods of imaging. In this method ultrasonic waves are sent by the probe to the patient's body, and then these waves hit the target tissue and are reflected and received by the receiver and an image is displayed on the monitor. This method is most useful for examining the condition of the fetus, uterus, and ovaries. This method is safe and does not pose a risk to the fetus [27].

Bone densitometry is another method of imaging. In this
method, the severity of the bones of the body is measured. This type of imaging is for people who are exposed to osteoporosis [28]. Several methods are available, but the most commonly used method is Dual Energy X-ray Absorptiometry (DEXA). In this method, two x-ray tubes are used for radiation to the bone. The higher the bone density, the greater the amount of radiation absorbed. The beam received by the detector is transferred to the computer, where processing and calculation are performed. The reason is the use of two sources for more accurate measurement. In this method, two types of environmental scanners and central scanners are used [29].

Magnetic Resonance Imaging (MRI) is another imaging method. In this way, instead of X-rays, radio waves and magnetic waves are used, and therefore they do not pose a risk to the human body. The patient is placed in a magnetic field and then the radio waves are emitted to the patient's body. Then the reflected waves of the patient's body are analyzed by the computer. Compared with the CT scan method, this method is purely for imaging soft tissues such as tendons, veins, nerves and cartilage in the body. But the CT scan is more commonly used to examine bone problems. In some cases, the drug is injected into the patient before doing the imaging. In this method, the patient must remove all the metal devices because they are absorbed by the magnetic field. Therefore, people who have implants or pacemakers cannot use this method [30].

Venography is one of the complementary methods of radiology that the contrast agents are injected into the arteries or veins [31]. Then x-rays are radiating to the body. With this method, blood clots in the main vessels can be detected [32].

Myelography is also one of the complementary methods of radiology. In this method, the contrast agent is injected into the patient's spinal cord, and X-rays are irradiated. This method is used to detect the pressure of the disk on the spinal cord and the neural roots [33].

In Arthrography, a contrast agent is injected with the air into the joints and x-rays are radiating to the body. This method is used to detect cruciate ligament and meniscus damage and rupture of the rotator cuff shoulder [34].

Shear Wave Elastography (SWE) is one of the newest methods in medical imaging. Due to the fact that the elasticity of the healthy and unhealthy tissues is different, it is possible to detect unhealthy tissues on this basis. This type of method is based on tissue consistency [35]. In this method, the liver chronic masses are examined without the need for sampling and non-invasive. This method can detect the severity of tissue damage in hepatitis and liver fibrosis. This method can also be used to evaluate malignant tumors in the thyroid, breast, and prostate [36]. Diagnosis of fatty liver with SWE method is shown in figure 4.

![Figure 4. Diagnosis of fatty liver with Shear Wave Elastography method [37].](image-url)
THz imaging is based on terahertz waves. This method has two fundamental types: Transmission Based and Reflection Based. This method is used to diagnose skin cancer, breast cancer and corneal moisture measurement. The Optical Coherence Tomography method is a cross-sectional methodology that is the basis of its optical interferometry. This method creates 3-dimensional images [38].

Another method is Ultrashort Echo Time (UTE). This method is one of a variety of MRI methods. The echo time is the time between the frequency radio pulse and the peak sent in the coil. This is a method for recording lung parenchymal. Using this method, it can display complete lung anatomy and detect pulmonary disorders. This method is without ionizing radiation, so there is no danger and is therefore more appropriate than CT scan [39]. This method creates 2-dimensional and 3-dimensional images [40, 41]. The image taken from the lungs, at different echo times, is shown in Figure 5.

3. Result

Initially, a radiology device, including a X-ray tube, a collimator, a detector, a high-voltage generator, resonator, etc., was described. The X-ray generator is responsible for producing x-rays using two anode and cathode electrodes. The collimator also adjusts the size and radius of the beam and radiology films are detectors of this device. Radiological device in diagnostic and therapeutic fields. Radiology is harmful for the human body because of the use of X-rays, but more accurate and faster than other methods. In nuclear medicine, imaging is performed based on nuclear properties and radioactive material. Also, Instruments used in nuclear medicine include: Geiger-Muller Counter, Photomultiplier-Tube (PMT), Absorption Probes, Scintillator Detector, Collimator, and Dosage Meter. Imaging based on nuclear medicine involves various methods that each of them has different advantages and disadvantages.

4. Discussion

Radiology method is based on X-rays and a nuclear medicine method based on radioactive material. Radiology is very dangerous for pregnant women due to the use of ionizing radiation and causes a genetic mutation in the fetus. The methods used for imaging in nuclear medicine include: (PET) Positron Emission Tomography, Single Photon Emission Computed Tomography (SPECT), PET-CT, SPECT-CT, SPECT-CT-PET and PET-MR. An Ultrasonography method is based on ultrasound that enters the body by the probe. Bone densitometry is used to measure the degree of bone hardness that is based on X-rays. The MRI imaging method is based on magnetic field resonances that do not have the harm caused by ionizing radiation. In the Shear Wave Elastography method, based on the elasticity of the tissue, it can detect unhealthy tissue that is most commonly used for liver disease. Ultrashort Echo Time is an MRI imaging technique used to record parenchymal lung.
5. Conclusion

In this paper, types of imaging methods have been investigated. One of the most important of these methods is radiology imaging that is faster and more accurate than other methods. But this method has some disadvantages due to the use of X-rays. This method is very dangerous for pregnant women and children. In nuclear medicine, nuclear properties and radioactive materials are used. Radioactive material is also harmful to the body, but its intensity is less than that of X-rays. Methods that are based on the Magnetic field intensification spend more time than the radiological method but do not have the dangers of ionizing radiation. In this method, all metal objects and objects that are sensitive to the magnetic field should be away from the patient at the time of imaging. These imaging methods are diagnostic and therapeutic. These imaging methods are invasive and non-invasive. Some imaging techniques require contrast agents to display the tissue properly. All the methods described have advantages and disadvantages each of which, according to their function, are used in various diseases.

References


[42] https://www.itnonline.com/content/toshiba-introduces-ultrashort-echo-time-sequence-pulmonary-mr-imaging