Application of Medical Radiation Physics in Imaging

Arghavan keshavarzi baramchi
Masters student of physics solid state, Department of Physics Islamic Azad University Science and Research Branch. Tehran. IRAN.

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Abstract
Medical physics is the application of physics to the "prevention, diagnosis and control of illness, disease and disability. Medical imaging refers to the technique and processes implemented to make images of the parts or function of human body for clinical purposes including to diagnose diseases or medical science such as the study of normal anatomy and physiology. The X-rays, Magnetic resonance, molecular imaging, optical imaging Ultrasound and radioactivity are some of well known, rapidly growing and frequently used medical diagnostic tools. Radiography is a diagnostic technique that used the ionizing electromagnet radiation, such as X-ray to view objects. Computed Tomography (CT) is a diagnostic technology that combines X-ray equipment with a computer and a cathode ray tube display to produce images of cross sections of the human body. Ultrasonography is a diagnostic technology that uses high frequency broadband sound waves in the megahertz range. MRI is a diagnostic technology that uses magnetic and radio frequency fields to image the body tissues and monitor body chemistry. Radionuclide imaging is a diagnostic technology that uses small amounts of radioactive material to produce images of internal body. The process of finding appropriate medical imaging technique is a matter of decision making and identifying the problem, different alternatives, cost, availability, suitability, physical effects and mental effects should be considered.

Keywords: Medical physics, Radiation, Medical imaging, Magnetic resonance, Ultrasound.

1.INTRODUCTION

Medical physics has historically been defined in various ways. The most general definition is that medical physics is "the scientific discipline which is concerned with the application of the concepts and methods of physics in medicine" [1]. However, a more precise definition of the role is that medical physics is the application of physics to the "prevention, diagnosis and control of illness, disease and disability" [2]. Diagnostic procedures involving ionizing radiation use relatively low energy x rays in the 100 kV range (diagnostic radiology) or γ rays (nuclear medicine also known as molecular imaging); therapeutic procedures involving ionizing radiation most commonly use high energy megavoltage x rays and γ rays or megavoltage electrons (radiotherapy also known as radiation therapy, radiation oncology, and therapeutic radiology). Other applications of physics in diagnosis of disease include the use of nuclear magnetic resonance in anatomic, functional, and spectroscopic magnetic resonance imaging (MRI); ultrasound (US) in imaging; bioelectrical investigations of the brain (electroencephalography) and heart (electrocardiography); biomagnetic investigations of the brain (magnetoencephalography); and infrared radiation in thermography. Physicists are also involved in the use of heat for cancer therapy (hyperthermia), in applications of lasers for surgery, and in medical informatics.

Medical imaging refers to the technique and processes implemented to make images of the parts or function of human body for clinical purposes including to diagnose diseases or medical science such as the study of normal anatomy and physiology. Medical Imaging Techniques consider one of the most common medical tests with the laboratory tests (blood and specimen tests). MITs can be considered as tools for learning more about the neurobiology and human behaviors. The basic concept of a medical imaging system is shown in figure 1, it consists of a sensor or source of energy that can penetrate the human body, the energy pass through the body, they are absorbed or attenuated at differing levels, according to the density and atomic number of the different tissues, creating signals. These signals are detected by special detectors compatible with the energy source, then mathematically manipulated to create an image. The obtained images are through the energy from the human tissue, leading to a classification based on the energy applied to the body [3].

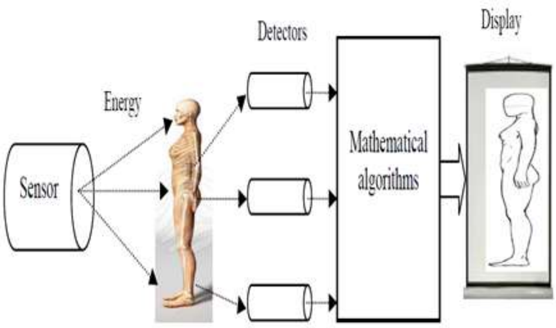


Figure 1. Concept of a medical imaging system

According to the energy sources, there are many different techniques can be being used to get a look inside the patient. These techniques are based on a signal travelling right through a patient. These signals interact with the tissues of the patient. By detecting the signal coming out of the body an image of the inside of the patient can be made. The interesting techniques in this paper are; X-ray radiography, X-ray Computed Tomography (CT), Magnetic Resonance Imaging (MRI), ultrasonography, elastography, optical imaging, radionuclide imaging includes (Scintigraphy, Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT)), thermography, and terahertz imaging. Up to 2010, 5 billion medical imaging studies had been conducted worldwide [4].

Medical imaging has transformed the healthcare science. Innovations in medical imaging have created faster and more precise imaging that are less invasive. This caused to wide use of imaging for more conditions and for more patients. Former, imaging was thought as a diagnostic tool for diseases, but now it is also used to treat, manage, and predict illnesses. It has become a need for almost all major medical conditions and diseases. Medical imaging is one of the standards of new medical care for diseases such as: cancer, cardiovascular disease, trauma, and neurological conditions, and many others. It has been used by a wide range of medical specialists, from oncologists to internists[5].

In last few decades, the rapid progress in Medical imaging techniques has completely revolutionized medical diagnostic system. The modern imaging system is not only limited to image production, but also focused on image processing, image transmission, image recording and automated diagnosis [6]. In order to give best treatment doctor needs to examine patient's body from inside. Medical imaging system reveals internal organs hidden by skin and creates visual representation of internal body for diagnosis purpose. Earlier the interpretation of medical images was done by physicians manually i.e. doctor had only 5 senses to examine problem but in these days computer aided diagnosis system acts as an intermediate between doctor and patient ,the machine examine patients body and doctor examines the report generated by machine which gives fast, accurate , reliable and consistent results. The study of medical imaging system is interrelated to biological imaging whereas study of sub area of medical science such as neurology, cardiology, orthopedics and areas like radiology, thermograph are prerequisite for study of medical imaging [7]. The X-rays, Magnetic resonance, molecular imaging, optical imaging Ultrasound and radioactivity are some of well known, rapidly growing and frequently used medical diagnostic tools.

2.MATETIAL AND METHOD

This article reviews an outline of medical radiation physics in imaging. Key issues were identified through review of literature on radiation physics in medicine and through review of literature on the medical imaging. It starts with a brief history of Use of Ionizing Radiation in Medicine, continues with brief description of improvements of medical imaging and some medical imaging techniques, and concludes how medical imaging help physicians to make better diagnosis, manage and treat patients with less harm

Results:

Brief History of Use of Ionizing Radiation in Medicine:

The study and use of ionizing radiation started with three important discoveries: x rays by Wilhelm R¨ontgen in 1895, natural radioactivity by Henri Becquerel in 1896, and radium by Pierre and Marie Curie in 1898. Since then, ionizing radiation has played an important role in atomic and nuclear physics where it ushered in the era of quantum mechanics, provided the impetus for development of radiology and radiotherapy as medical specialties and medical physics as a specialty of physics. In addition, ionizing radiation also proved useful in many other diverse areas of human endeavor, such as in industry, power generation, waste management, and security services. The potential benefit of x ray use in medicine for imaging and treatment of cancer was recognized within a few weeks of R¨ontgen's discovery of x rays. Two new medical specialties: radiology and radiotherapy evolved rapidly, both relying heavily on physicists for routine use of radiation as well as for development of new techniques and equipment. Initially, most technological advances in medical use of ionizing radiation were related to: (1) improvements in efficient x-ray beam delivery; (2) development of analog imaging techniques; (3) optimization of image quality with concurrent minimization of delivered dose; and (4) an increase in beam energies for radiotherapy.

During the past two decades, on the other hand, most developments in radiation medicine were related to integration of computers in imaging, development of digital diagnostic imaging techniques, and incorporation of computers into therapeutic dose delivery with high-energy linear accelerators. Radiation dosimetry and treatment planning have also undergone tremendous advances in recent years: from development of new absolute and relative dosimetry techniques to improved theoretical understanding of basic radiation interactions with human tissues, and to the introduction of Monte Carlo techniques in the determination of dose distributions resulting from penetration of ionizing radiation into tissue.

History and improvements of medical imaging:

During the 19th century, machines were more implemented for diagnosis or therapeutics in medicine [8]. The use of electricity resulted in the invention of the x-ray. Electromagnetic radiation in a wavelength range commonly known as X-rays was first discovered by a German professor of physics, Wilhelm Roentgen. Because of the unknown nature of his discovery, he called them X-rays. They are also still known as Roentgen-rays, particularly in Germen-speaking countries. Before the Roentgen discovery, many people had observed the effects of X-ray beams, but he was the first one to study them systematically. He discovered a radiation that could penetrate solid objects of low density, could be viewed on a fluorescent screen and stored on photographic film. Physicians gained the ability to view the inside of the body, by using X-rays [9].

Stemming from Roentgen discovery in 1985, medical imaging has undergone remarkable improvements. It was after the Second World War that the interaction of computerization and imaging technologies took place. Before that time, the main focus was on the processing of X-ray technology. After the War, multiple generations of innovations and new discoveries; some amazing, some augmenting, in X-ray, computed tomography (CT), magnetic resonance imaging (MRI), nuclear imaging, and ultrasound (US), made medical imaging to have a renewal role in modern medicine [5] Using medical imaging increased rapidly. Imaging has become more accurate, smaller, faster and less invasive due to the progresses in electronics, miniaturization, visualization, and computing power, as well as advances in imaging acquisition, resolution, transmission, and manipulation [10].

Remarkable revolutions in the medical imaging industry are taking place; making a move from expensive, large, stationary, and complex systems to smaller, easier to use, and more accessible devices. Technological advances in medical imaging led to use the devices in small hospitals, physicians' offices, and on wheels outside medical settings, not just be limited to the large hospitals and institutions. Newer imaging technologies focus on combining ease-of-use with higher levels of accuracy, allowing information to be accessed efficiently, while providing higher throughput. These new solutions are cost effective and can be used in a variety of clinical applications [11].

Transformations in design and materials of imaging led to more mobile and portable devices. Ultrasound created images by using only sound waves; MRI did so using magnetic fields. Progresses in imaging technologies also allowed physicians to watch in real-time as they snaked catheters through arteries to the heart, brain, or kidneys. CT scanning and mammography introduced new detail that enabled new diagnostic power and clinical capabilities. The development of digital imaging brought a new generation of efficiency and speed as it offered new options for data access and transmission and vast new volumes of information (fig 2) [5].

Over the 20th century, medical imaging development was driven by technological innovation and engineering improvements in physical equipment. A new imaging modality driven by development of the biological knowledge base represents a fundamental change. Understanding such an important change is of utmost importance to medical physicists working in imaging research. The measure of success and the economic growth of medical imaging reside firmly in the ability to implement new procedures with higher diagnostic specificity and sensitivity [12].

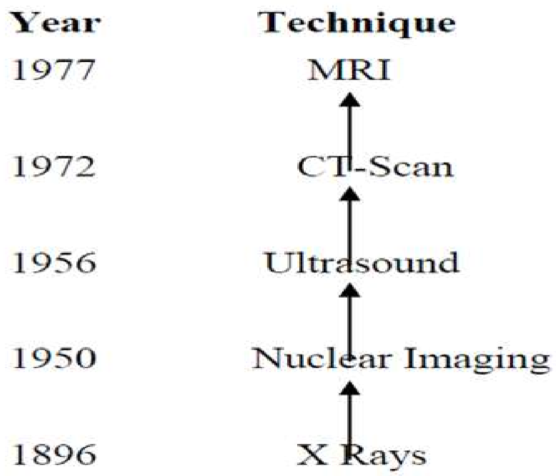


Figure 2. Evaluation of Medical Imaging Techniques [13,14].

Typed of radiation used:

The medical imaging techniques use some kind of radiations in order to diagnose internal body organs. The intensity of these radiations depends upon part of body is being examined. These radiations are of different energy level, different frequency and may belong to different level of electromagnetic spectrum. The electromagnetic spectrum has 2 major divisions which are given in figure 3.

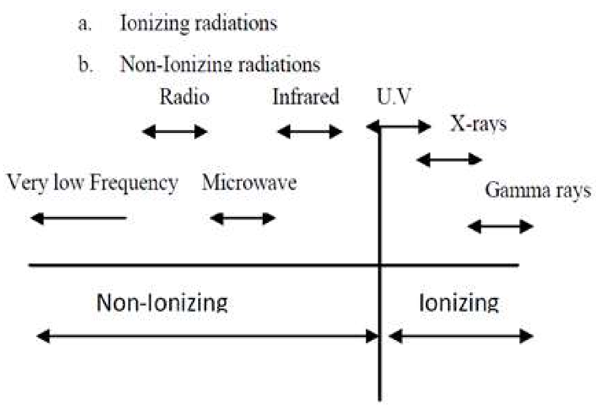


Figure 3. Ionizing and Non Ionizing radiations [15].

Ionizing radiations have sufficient energy to break some chemical bond and remove tightly bound atom from an electron and creates an ions whereas Non-Ionizing radiation can only move atom in a molecule and make them to vibrate. The alpha, beta, gamma rays and radiations produce during Radioactive decay are Ionizing radiations. On the other hand Microwave, Infrared and Ultrasound rays are Non-Ionizing radiations. Non-Ionizing radiations of low intensity can only heat up tissues and its long term effects are not known whereas Ionizing radiations have many severe stochastic and Non-stochastic health effects. Cancer is the primary health effect that can be caused due to Ionizing radiations exposure. These radiations can permanently damage our cells. It can also cause change in our DNA. As all medical imaging techniques uses some kind of radiations. So in this paper health effects of various medical imaging techniques will also be compared [15].

3.MEDICAL IMAGING TECHBIQUES

1. X Rays Radiography

Radiography is a diagnostic technique that used the ionizing electromagnet radiation, such as X-ray to view objects. History of medical imaging system began in nineteenth century with the X-Rays, discovered by German physicist Wilhelm roentgen [16]. X-ray is a high energy electromagnetic radiation that can penetrate solids and ionize gas; it has a wavelength between 0.01 and 10 manometers. For medical imaging [17] X-ray passes through the body, they are absorbed or attenuated at differing levels, according to the density and atomic number of the different tissues, creating a profile. The X-ray profile is registered on a detector creating an image. Electrons are emitted by the filament wire when it is heated by an electric current. A rotating metal anode attracted the electrons providing an alternating current in the filament wire. The area of the anode from which X-ray are emitted is referred to as the focal spot. The used photon energies range from 17- 150 KeV, the choice for a particular application or tissue probed being a trade-off between acceptable radiation dose and achievable image contrast [18]. The X-ray image of roentgen's wife hand is given in figure 4.

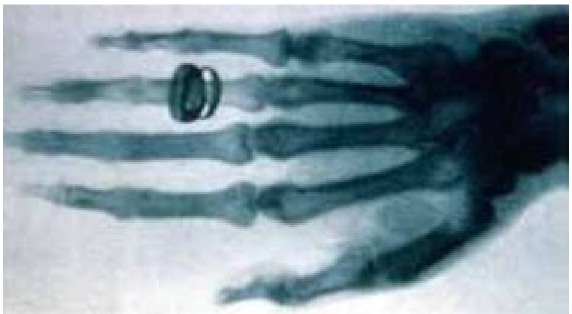


Figure 4. X-Ray Image of Roentgen's wife Hand [15].

X-Ray radiography benefits include:noninvasive, quick, and painless, support medical and surgical treatment planning, guide medical personnel as they insert catheters or stents inside the body to treat tumors,or remove blood clots. X-Ray radiography risks include exposure to ionizing radiation, this increase the possibility of developing cancer later in life, tissue effects such as cataracts, skin reddening, and hair loss, which occur at relatively high levels of radiation exposure.

X-Ray radiography medical applications are listed below:

• X-ray radiography is used in many types of examinations such as; chiropractic, dental.

• Fluoroscopy radiographs used for showing the movement of organs, such as the stomach, intestine, and colon, in the body, also can be used for studding the blood vessels of the heart and the brain.

• Projectional radiographs used for determining the type and extent of a fracture, also used for detecting pathological changes in the lungs, and used for visualizing the structure of the stomach and intestines.

• Mammography used for diagnosing and screening of the breast tissue.

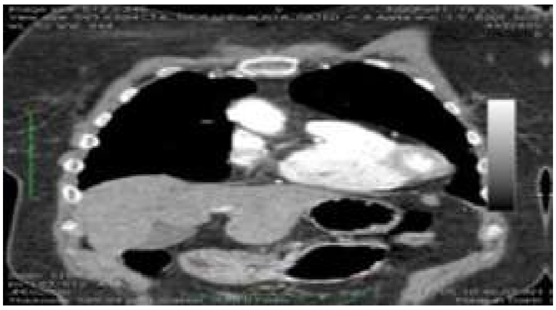
• Bone Densitometry used for measures bone mineral content and density.

• Arthrography used for seeing inside the joint.

• Hysterosalpingogram used for examining of the uterus and Fallopian tubes [19]

2. X-Ray Computed Tomography:

Computerized Tomography (CT-Scan) is also an X-ray based technique developed by godfrey Hounsfield. Computed Tomography (CT) [20,21] is a diagnostic technology that combines X-ray equipment with a computer and a cathode ray tube display to produce images of cross sections of the human body. The Radiographic film is replaced by a detector which measures the X-ray profile. Inside the CT scanner, there is a rotating frame that has an X-ray tube mounted on one side and the detector mounted on the opposite side. A beam of X-ray is generated as a rotating frame spins the X-ray tube and detector around the patient. Each time the X-ray tube and detector make one complete rotation, an image or slice is acquired. As the X-ray tube and detector make this rotation, the detector takes numerous profiles of the attenuated X-ray beam. Each profile is reconstructed by the computer into a 2D image of the slice that was scanned. 3D CT can be obtained using spiral CT [22], spiral CT acquires a volume of data with the patient anatomy all in one position. This volume data set can then be computer reconstructed to provide three dimensional (3D) images of complex structures. The resulting 3D CT images help in visualization of the tumor masses in three dimensions. Recently, four dimensional (4D) CT has been introduced to overcome problems imposed by respiratory movements. 4D CT generates both spatial and temporal information on organ mobility. Some examples of CT scans are shown in figure 5 [23].



2D CT

3D CT

4D CT

Figure 5. Example of CT scan

3. Ultrasound Imaging:

Ultrasonography is a diagnostic technology that uses high frequency broadband sound waves in the megahertz range that are reflected by tissue to varying degrees to produce medical images [24]. In addition, ultrasound images have the advantage of being portable, versatile, and not requiring ionizing Radiations. Moreover the diagnosis procedure in ultrasound is of low cost and in order to diagnose an illness, person need not to go through dangerous invasive procedures. The ultrasound transducer is placed against the skin of the patient near the region of interest. The transducer produces a stream of high frequency sound waves that penetrate into the body and reflect from the organs inside. The transducer detects sound waves as they echo back from the internal structures of the organs. Different tissues reflect these sound waves differently resulting a signature that can be measured and transformed into an image. These waves are received by the ultrasound machine and turned into live pictures. The real time moving image obtained can be used to guide drainage and biopsy procedures. Doppler capabilities of the recent scanners allow the blood flow in arteries and veins to be assessed [25].

The Study related to ultrasound was started in 1794 by lazaro spallanzani but In 1942 Karl Dussik introduced ultrasound in the field of diagnostic. Ultrasound waves travels freely through fluid and soft tissues however it reflected back when it collides with some solid surface. These reflected sound waves are displayed as an image on moniter. It is a part of routine check up in case of pregnancy, where it is used to check fetus in womb. The Ultrasound image of fetus is given in figure 6. The advancement of ultrasound imaging is Doppler ultrasonography. Doppler ultrasound records sound waves reflected from moving objects. If body or organ is moving then echo comes back at different frequency which is Doppler effect. Ultrasound imaging is used to check position of fetus in womb whereas Doppler Ultrasound can also check heartbeat of fetus. When long term side effects of X-Rays were not known , it was common practice to use X-Rays for diagnosis in pregnancy but later study on 700,000 children born between 1947 and 1964 in 37 major hospitals revealed that cancer mortality of children whose mother received X-Rays during pregnancy is 40% higher than the children whose mother had not gone for the X-Rays diagnosis [26] (fig 6). Unlike X-Rays ultrasound are non-ionizing radiation so it doesnot have same risks as that of X-Rays. Sometime when ultrasound enters in body that can heats the tissues slightly. But even then major risks and long term effects are not known . when we compare Ultrasound imaging with other diagnostic techniques like X-Rays, MRI, Nuclear Imaging it turns out to be most cost effective than other techniques [27].

Figure 6. Ultrasound Image of Unborn baby

4. Magnetic Resonance Imaging:

MRI is a diagnostic technology that uses magnetic and radio frequency fields to image the body tissues and monitor body chemistry [28,29]. It was developed by Raymond damadian. But discovery was not accidental actually it was gradual enhancement of some inventions, which was started by joseph fourier , his mathematical model was first used for magnetic resonance signal analysis by Richard Ernst, then Raymond damadian in 1974 published a technique ' field focusing NMR' (nuclear magnetic resonance) which contained an image of scanned volume element through a mouse [30] (fig7).

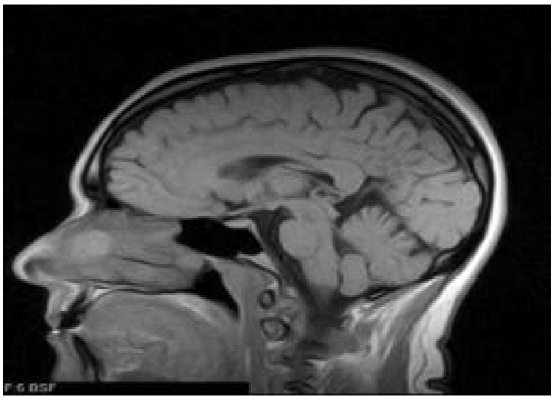


Figure 7. MRI Scan of Human brain

In MRI very strong radio waves which are 20000 times stronger than earth's magnetic field are sent through the human body. The MRI used for visualizing morphological alterations rests on its ability to detect changes in proton density and magnetic spin relaxation times, which are characteristic of the environment presented by the diseased tissue [31-36]. These radio waves compel hydrogen atom in the body to vibrate, and radiation which these hydrogen atoms emit are detected outside the body and forms an image with the help of computer. The MRI of human brain is given in figure 5. It ignores bones as they contains very small water content it mainly focuses on soft tissues. It does not uses Ionizing radiations so this technique is relatively safer than other techniques which uses Ionizing radiations like X-Rays. But in this case slight movement can ruin the image even breathing can caus artifacts or image distortions. Contrast medium is required in this case which can have many adverse effects. The Contrast medium is generally injected into a vein of a hand or arm that contrast medium may cause allergic reactions. MRI can be used to evaluate heart, liver, blood vessels, kidney, bladder etc [34]. The visualization of abnormal tissues is better in case of MRI.

MRI medical applications are listed below:

- Examining the abnormalities of the brain and spinal cord
- Examining the tumors, cysts, and other abnormalities in various parts of the body.
- Examining the injuries or abnormalities of the joints.
- Examining the diseases of the liver and other abdominal organs.
- Knowing causes of pelvic pain in women.
- Finding the unhealthy tissue in the body
- Planning the surgery.
- Providing a global view of collateral veins.
- Providing a global view of intra and extra cranial [19].

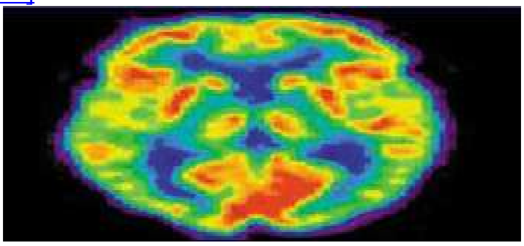


Figure 8. PET Scan of Human brain

identify internally. In next step different alternatives are generated and for evaluating them different aspects of medical imaging techniques must be known. The following aspects are evaluated before making any decision.

1 .Cost : The cost of medical imaging technique is the first aspect to be studied. It needs to be verified that for this given problem how much money should be spend.

2. Availability: The availability of tool must ensure and also ensure that is there any social restriction on this tool.

3 .Suitability: The main aspects which we should check that which imaging technique will give best result for a problem which we want to diagnose.

4. Physical effects: The negative effects of different alternatives must be considered while making final selection

5 .Mental effects: The negative effects of different medical imaging techniques on mental health must be known while making final selection.

While evaluating different alternatives information about strong and weak points of each technique is arranged in structured way. There will be a weight for a each criteria and imaging technique with maximum weight will be selected. The benefit of given decision making procedure is that you can defend your choice of appropriate imaging technique and will also get good results [15].

	X-ray	CT Scan	MRI	Ultra Sound	Nuclear Imaging
Types of Radiation	Ionizing	Ionizing	Non ionizing	Non ionizing	Ionizing
Radiation used	X-rays	X-rays	Electromagnetic Radio waves	High frequency Sound waves	Radioactive isotopes
Image type	Transmissive	Transmissive	Emissive	Reflective	Emissive
Unit to measure	Msv Millisievert	Msv Millisievert	Tesla (for magnetic field)	Hertz	Becquerel(unit of radioactivity)
Typically Used to check	Bone Injuries Infections Arthiritis	Bones injuries Cancer detection Lungs exam	Tumor of chest Angiography Uterine abnormalities	Health of Fetus Breast cancer Swelling	Coronary artery disease Infection Cancer
Technical problems	Quantum Noise or Random noise	Quantum Noise or Random noise	Rician Noise	Speckle Noise	Random Noise
Side effect	Increases a risk of cancer by 0.08%	Increases a risk of cancer	Contrast medium may cause kidney problem	Excessive dose may burn tissues, but relatively less side effects	Injection site reaction in some peoples.
Cost	Very low	High	Very high	Low	Very high
Contrast agent	No	No	Yes	No	Yes

Table 1. Comparison of different medical imaging [15].

Selection of imaging technique:

The process of finding appropriate medical imaging technique is a matter of decision making. The first step of decision making is identifying the problem. In this case medical problem of a patient is considered and for that particular problem which organs are needs to

The Comparison of various medical imaging techniques on the basis of different parameters like radiation type, cost, health effects, technical problems is given below in Table 1.

4-Conclusion

Medical physics is the application of physics to the "prevention, diagnosis and control of illness, disease and disability. Medical imaging refers to the technique and processes implemented to make images of the parts or function of human body for clinical purposes including to diagnose diseases or medical science such as the study of normal anatomy and physiology. The study of medical imaging system is interrelated to biological imaging whereas study of sub area of medical science such as neurology, cardiology, orthopedics and areas like radiology, thermograph are prerequisite for study of medical imaging. The X-rays, Magnetic resonance, molecular imaging, optical imaging Ultrasound and radioactivity are some of well known, rapidly growing and frequently used medical diagnostic tools. Radiography is a diagnostic technique that used the ionizing electromagnet radiation, such as X-ray to view objects. Computed Tomography (CT) is a diagnostic technology that combines X-ray equipment with a computer and a cathode ray tube display to produce images of cross sections of the human body. Ultrasonography is a diagnostic technology that uses high frequency broadband sound waves in the megahertz range that are reflected by tissue to varying degrees to produce medical images. MRI is a diagnostic technology that uses magnetic and radio frequency fields to image the body tissues and monitor body chemistry. Radionuclide imaging or nuclear medicine is a diagnostic technology that uses small amounts of radioactive material to produce images of internal body. The process of finding appropriate medical imaging technique is a matter of decision making and identifying the problem, different alternatives, cost, availability, suitability, physical effects and mental effects should be considered.

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CONFLICT OF INTEREST
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