International Journal of Information Science and Intelligent System, 4(2): 37-58, 2015

A Comparative Study of Medical Imaging Techniques

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Received: 25 January 2015; Accepted: 12 March 2015

Abstract

Medical Imaging Techniques (MITs) are non-invasive methods for looking inside the body without opening up the body surgically. It used to assist diagnosis or treatment of different medical conditions. There are many medical imaging techniques; every technique has different risks and benefits. This paper presents a review of these techniques; concepts, advantages, disadvantages, and applications. The concerning techniques 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. The concepts, benefits, risks and applications of these techniques will present with details. A comparison between these techniques from point of view, image quality (spatial resolution and contrast), safety (effect of ionizing radiation, and heating effect of radiation on the body), and system availability (real time information and cost) will present.

Keywords: Medical imaging; X-ray; CT; MRI; Ultrasonography; Elastography; Scintigraphy.
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1. Introduction

MITs consider one of the most common medical tests with the laboratory tests (blood and specimen tests). Medical imaging has been undergoing a revolution in the past decade with the

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fast development, more accurate, and less invasive devices [1]. 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.

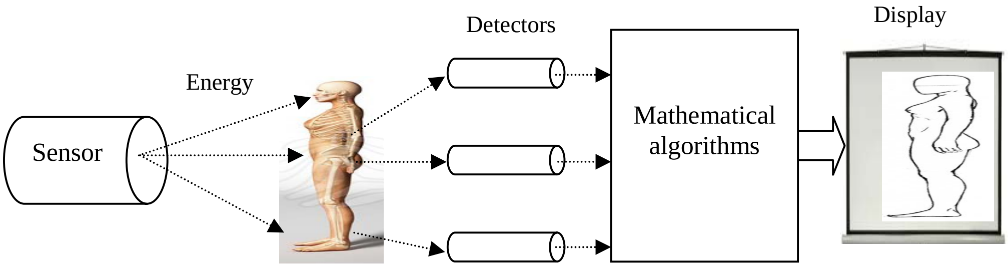


Figure 1. Concept of a medical imaging system

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 [2].

Radiography started with the discovery of X-ray by Röntgen in 1895. Its medical use was discovered when Rontgen saw a picture of his wife's hand on a photographic plate formed due to X-ray. CT as an imaging technique was described by Cormack in 1963. In 1972, Hounsfield presented the first clinical CT scanner [3]. Since then, the clinical X-ray CT has revolutionized medical imaging and may be described as the greatest advancement in radiology since the discovery of X-ray. Research on MRI started in the early 1970s and the first MRI prototypes were tested in 1980. The first used for Sonography as a diagnostic tool has been presented in 1942 for localizing brain tumors, and its used as real-time imaging in 1965. Now the medical Sonography is used in the many different applications. Elastography developed in 1991 for detecting non-uniform areas in tissue [4]. Recently, different types of Elastography (ultrasound elasticity imaging, magnetic resonance elasticity imaging, optical elasticity imaging or tactile imaging) have been applied to study tissues in a variety of different conditions.

The idea of using light as a medical diagnostic technique has been revisited in the past few years as a result of theoretical and experimental advances in optical spectroscopy and imaging of the human breast. Nuclear medicine started in 1936 when John Lawrence made the first application in patients of an artificial Radionuclide when he used phosphorus-32 to treat leukemia.

The widespread clinical use of nuclear medicine began in the early 1950s, as knowledge expanded about Radionuclide, detection of radioactivity, and using certain Radionuclide to trace biochemical processes. In the 1980s, Radiopharmaceuticals were designed for use in diagnosis of heart disease. The development of SPECT, around the same time, led to three-dimensional reconstruction of the heart and establishment of the field of nuclear cardiology. More recent developments in nuclear medicine include the invention of the first PET scanner. Nowadays, fully integrated systems such as PET/CT and MRI/PET scanners are used. Clinical thermography started as a diagnostic tool for different medical conditions since the 1960s. The rapidly developing of this technology is used to detect and locate thermal abnormalities characterized by an increase or decrease found at the skin surface. The Terahertz (THz) imaging started for biomedical use in 1995 [5], and since then imaging modality has emerged. THz is still developing and more research is still needed.

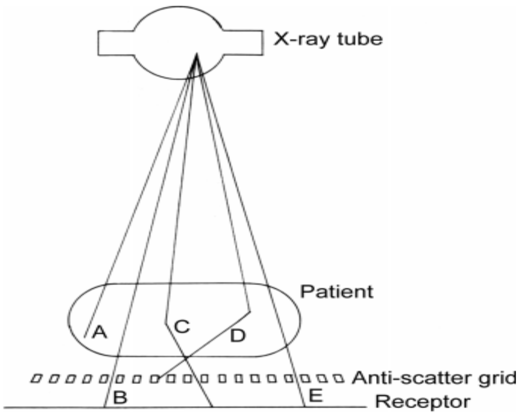
This paper presents a comparative study between the different medical imaging techniques, the concepts, benefits, risks and applications of these techniques will present with details. A comparison between these techniques from point of view, image quality (spatial resolution and contrast), safety (allergy, ionizing effect of radiation, and heating effect of radiation on the body), and system availability (real time information, scanning time, complexity and cost) will present. The paper is organized as follows; Section 2 presents the X-ray radiography imaging technique. Section 3 presents the X CT imaging technique. Section 4 presents the MRI technique. Section 5 presents the Ultrasonography imaging technique. Section 6 presents the Elastography imaging technique. Section 7 presents the optical imaging technique. Section 8 presents the Radionuclide imaging technique. Section 9 presents the thermography imaging technique. Section 10 presents the Terahertz imaging technique. Section 11 presents a comparison between MITs. Finally, section 12 gives the concluding remarks.

2. X-Ray Radiography

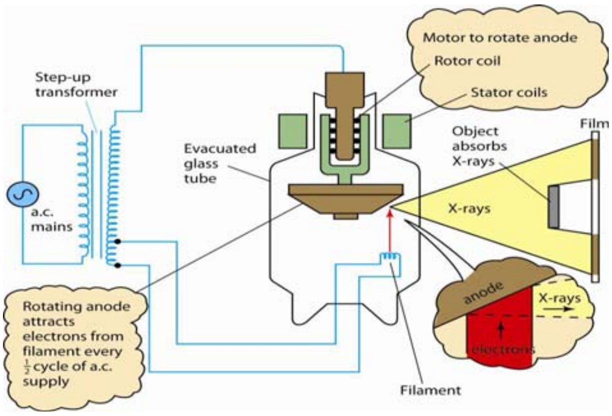
Radiography is a diagnostic technique that used the ionizing electromagnet radiation, such as X-ray to view objects. X-ray is a high energy electromagnetic radiation that can penetrate solids and ionize gas; it has a wavelength between 0.01 and 10 manometers. For medical imaging [6 - 9], X-ray passes 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 as shown in figure 2-a. The construction of the X-ray tube that used for medical imaging is shown in figure 2-b. 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. Figure 3 shows some examples of X-ray images.

2.1 X-Ray Radiography Benefits

- 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.



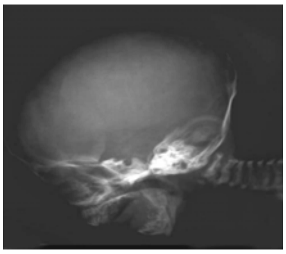
(a) X-ray imaging concept

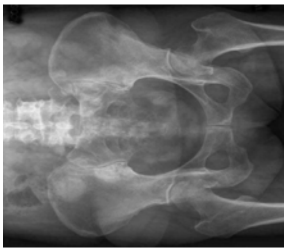


(b) Rotating X-ray tube

Figure 2. X-ray radiographic medical imaging


Shoulder


Head


Pelvis

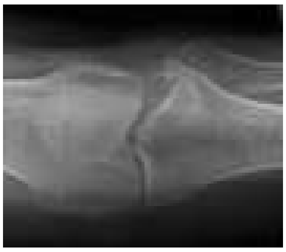

Knee

Figure 3. Examples of X-ray images

2.2 X-Ray Radiography Risks

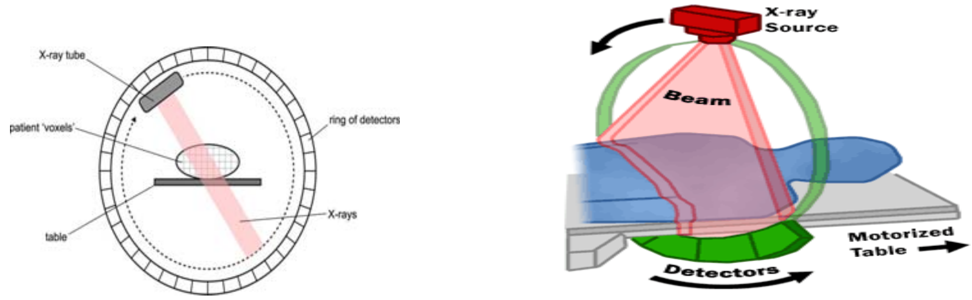
- Exposure to ionizing radiation, this increase the possibility of developing cancer later in life.
- Tissue effects such as cataracts, skin reddening, and hair loss, which occur at relatively high levels of radiation exposure.

2.3. X-Ray Radiography Medical Applications

- 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.

3. X-Ray Computed Tomography

Computed Tomography (CT) [10, 12] 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 as shown in figure (4). 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 [13], 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.



(a) CT scanner (b) CT fan beam

Figure 4. X-ray CT imaging

2D CT 3D CT 4D CT

Figure 5. Example of CT scan

3.1 CT Benefits

- Non invasive, quick, and painless.
- Good spatial resolution.
- Global view of veins.
- Distinguished by small differences in physical density.
- Avoids invasive insertion of an arterial catheter and guidewire.

3.2 CT Risks

- Exposure to ionizing radiation, this increase the possibility of developing cancer later in life.
- No real time information.
- Cannot detect intra-luminal abnormalities.
- Cannot be performed without contrast (allergy, toxicity).
- Less contrast resolution where soft tissue contrast is low.

3.3 CT Medical Applications

- Examining many parts of human body such as; brain, sinus, facial bones, dental, spines, cervical, hands, wrist, elbow, shoulder, hip, knee, ankle foot, renal tract.
- Diagnosing disease, trauma and abnormality.
- Planning and guiding the interventional or therapeutic procedures.
- Monitoring the effectiveness of therapy (cancer treatment).

4. Magnetic Resonance Imaging (MRI)

MRI is a diagnostic technology that uses magnetic and radio frequency fields to image the body tissues and monitor body chemistry [14-16]. 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. The MR scanner consists of three main components; a main magnet, a magnetic field gradient system, and a Radio Frequency (RF) system as shown in figure 6-a. The main magnet is a permanent magnet generates a magnetic field. The magnetic field gradient system normally consists of three orthogonal gradient coils, essential for signal localization. The RF system consists of a transmitter coil that is capable of generating a rotating magnetic field, for exciting a spin system, and a receiver coil that converts a precessing magnetization into an electrical signals as shown in figure 6-b. The signals are measured by the MR scanner and digital computer reconstructs these signals into images. Examples of MRI images are shown in figures 7- a, b. Recently, a new procedure that uses MRI to measure the tiny metabolic changes that take place in an active part of the brain called functional magnetic resonance imaging (fMRI) is designed [17-24]. Example of fMRI image is shown in figure 7-c.

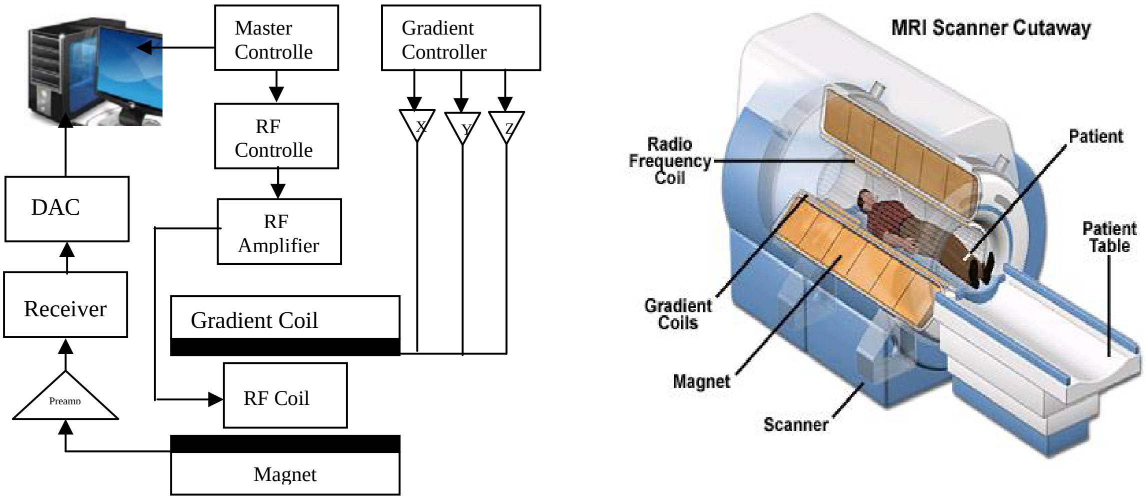
4.1 MRI Benefits

- Noninvasive and painless.
- Without ionizing radiation.
- High spatial resolution.
- Operator independent.
- Easy to blind and ability to measure flow and velocity with advanced technique.
- Can be performed without contrast (pregnancy allergy).
- Good soft tissue contrast.

4.2 MRI Risks

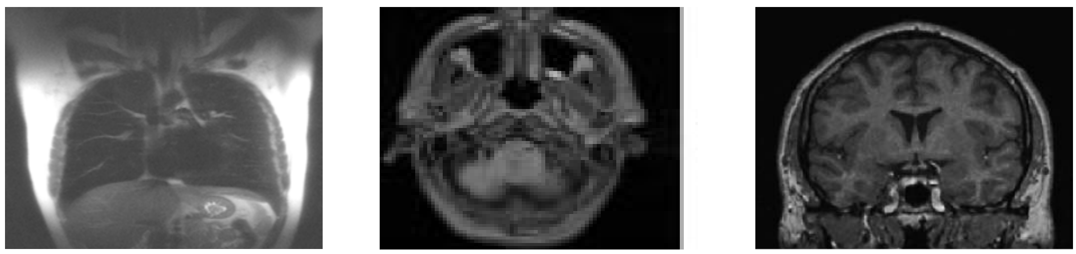
- Relatively low sensitivity.
- Long scan and post processing time.

- Mass quantity of the probe may be needed.
- No real time information.
- Cannot detect intra-luminal abnormalities.
- Can make some people feel claustrophobic.
- Sedation may be required for young children who can't remain still.
- Relatively expensive.



(a) MR scanner drawing (b) MRI machine

Figure 6. MRI system



(a) MRI (b) MRI (brain) (c) fMRI (brain)

Figure 7. Example of MRI images

4.3 MRI Medical Applications

- 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.

5. Ultrasonography

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 [25-28]. 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. Figure 8 shows three types of ultrasound machines and figure 9 shows some examples of ultrasound images.

Figure 8. Ultrasound machines

Figure 9. Examples of ultrasound images

5.1 Ultrasonography Benefits

- Noninvasive and painless.
- Without using ionizing radiation.
- High resolution.
- Real time information.
- Sensitive to detect flow changes, intra and extra luminal abnormalities.
- Ability to measure velocity.
- Possible control of respiratory phases.

5.2 *Ultrasonography* Risks

- No standardized guidelines.
- Operator dependent.
- Time consuming.
- Blinding procedures are challenging.
- Cannot perform global view of the veins.
- Influenced by hydration status.

5.3 Ultrasonography Medical Applications

- Checking the development of the fetus during pregnancy.
- Imaging most structures of the head and neck, including the thyroid and parathyroid glands, lymph nodes, and salivary glands.
- Imaging the solid organs of the abdomen such as; the pancreas, aorta, inferior vena cava, liver, gall bladder, bile ducts, kidneys, and spleen.
- Guiding the injecting of needles when placing local anesthetic solutions near nerves.
- Echocardiography used for diagnosing the heart and function of heart ventricles and valves.

6. Elastography

Elastography is a non-invasive medical imaging technique that detects the biological tissues based on their stiffness (elasticity) compared to normal tissue [29, 30]. Elastography imaging may be ultrasound elasticity imaging, magnetic resonance elasticity imaging, optical elasticity imaging or tactile imaging. Ultrasound Elastography was the first technology to perform Elastography and is widely studied in clinical diagnostic applications to image the biomechanical properties of soft tissues [31-34]. MR Elastography measures the mechanical properties of soft tissues by introducing shear waves and imaging their propagation using MRI [35-39]. MR Elastography works using the gradient waveform in the pulse sequence to sensitize the MRI scan to shear waves in the tissue. The shear waves are generated by the electromechanical transducer on the surface of the skin. The mechanical excitation and the motion sensitizing gradient are at the same frequency. Optical Elastography is performed using of optical coherence tomography to perform Elastography [40-43]. To make optical coherence elastography on human subjects feasible, an annular piezoelectric loading transducer is designed, through it a simultaneous image can be obtained [44]. Tactile imaging [45, 46] is a medical imaging modality that translates the sense of touch into a digital image. The tactile image is a function of the pressure on the soft tissue surface under applied deformation. Tactile imaging closely mimics manual palpation, since the probe of the device with a pressure sensor array mounted on its face acts similar to human fingers during the examination, slightly deforming soft tissue by a probe and detecting resulting changes in the pressure pattern.

6.1. Elastography Benefits

- Noninvasive and non-ionizing radiation
- Results are obtained immediately.
- High precision 2D time shift based strain estimation techniques.
- High frame rate to obtain a detailed map of the transmural strain in normal.

6.2. Elastography Risks

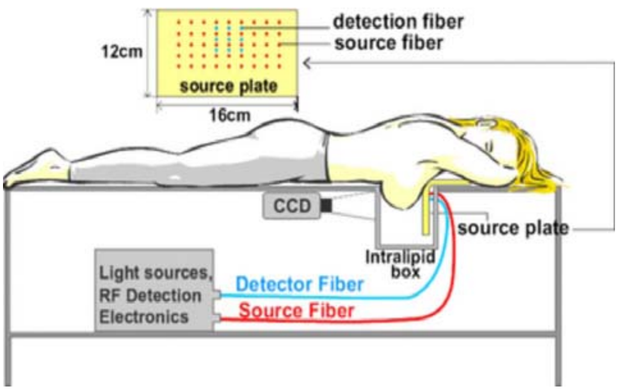
- By increasing the applied pressure, the Elastography is influenced by both Elastography images as well as elasticity score this may lead to wrong diagnosis.
- Suffering from medical conditions that cause stiffness in tissues affected by abnormal growths.
- Low resolution.

6.3 Elastography Medical Applications

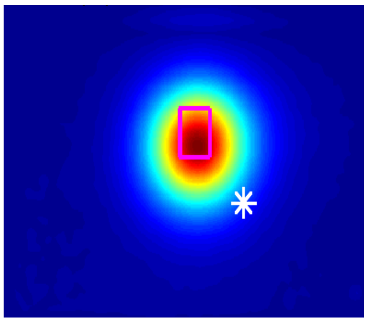
- Detecting and evaluating liver disease, particularly cirrhosis.
- Investigations of the soft tissues.
- Measuring the mechanical response of the cardiac muscle at the various phases of the cardiac cycle.
- MR Elastography used for examining changes in material properties of muscle associated with aging.
- MR Elastography used for diagnosing breast cancer.
- Ultrasound Elastography used for determining the muscle material properties.
- Ultrasound Elastography used for determining the stiffness of the plantar fascia.
- Tactile imaging used for imaging of the prostate, breast, vagina and pelvic floor support structures, and myofascial trigger points in muscles.

7. Optical Imaging

Optical imaging is a noninvasive technology that uses the light to show the cellular and molecular function in the living body. Optical imaging considered as a powerful tool for probing in deep tissues, where light propagates in a diffuse manner [47, 48]. The information is ultimately derived from tissue composition and biomolecular processes. Contrast is derived either from the use of exogenous agents that provide signal or from endogenous molecules with optical signatures. The light propagates in a diffuse manner. The interaction of light with different tissue components enables the visualization of tissue abnormalities or pathologic processes [49]. Optical imaging system that used commercially for breast cancer examination system is shown in figure 10-a, and an example of the captured image is shown in figure 10-b.



(a) Breast tumor imaging



(b) Capture image

Figure 10. Optical imaging system [50]

7.1. Optical Imaging Benefits

- Noninvasive.
- Non-ionizing radiation.
- The tumor characteristics can be imaged while the patient is lying in a prone position, and there is reasonably good coverage of most of the breast.
- Longitudinal measurements can be made over a period of time.
- Potential to differentiate between soft tissues, due to their different absorption or scatter.
- Specific absorption by natural chromophores allows functional information to be obtained.

7.2 Optical Imaging Risks

- Low spatial resolution due to the diffusive nature of light propagation in breast tissue.
- Sensitive to water blood concentration, blood oxygenation and lipid concentration in breast tissue.

7.3. Optical Imaging Medical Applications

- Probing hemodynamics [51].
- Detecting tumors [52].
- Providing functional imaging of the brain [53].
- Scanning the breast cancer.
- Scanning the bone health.
- Scanning the teeth, gums and jaws.

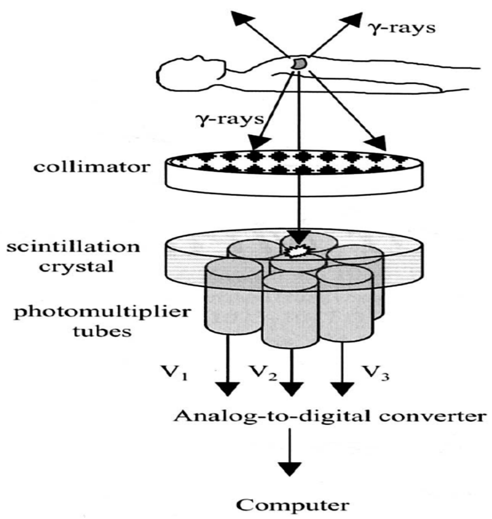
8. Radionuclide Imaging

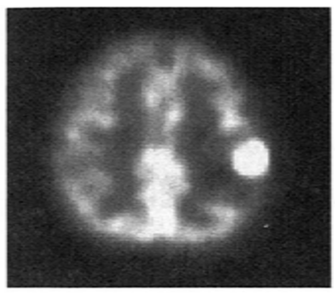
Radionuclide imaging or nuclear medicine is a diagnostic technology that uses small amounts of radioactive material to produce images of internal body. Small amounts of low level radioactive isotopes are given as an injection or by mouth. These isotopes are attracted to specific organs, bones or tissues, which absorb the radioactive material. Once an organ or tissue has absorbed the radioactive material, it produces emissions, which can be detected by special radiation detectors. The scanner works with a computer to convert the emissions into an image. Radionuclide imaging includes three techniques; planner Scintigraphy [54-57], SPECT [57-62] and PET [62-64], a comparison between these techniques is shown in table 1.

Planner Scintigraphy uses a certain organs to accumulate either for a short time or permanently, some radioactive substances after they have been administered to a patient by mouth or by injection. Radioisotope such as Tc^{99m} used within 2 hours and no later than 6 hours after preparation. The recommended dose of Tc^{99m} is 20 to 25 millicurie [65]. Hydration of the patient before imaging is useful; it is suggested that the patient drink 4 to 6 glasses of water between the injection of the isotope and imaging. The time of imaging depends on age; in patients younger than 20 years, imaging is done 2 hours after injection, and in older patients, a 3 to 4 hour delay is recommended to provide better image quality. The pattern of their distribution allows some diagnostically useful conclusions to be drawn as to the size of the organ and its normal or abnormal position within the body. Figure 11-a show the basis of planner scintigraphy, and an example of the captured image is shown in figure 11-b.

Table 1. Comparison between radionuclide imaging techniques

	Planar Scintigraphy	SPECT	PET
Source	Radioisotope generates gammay decay, which generates one photon in a random direction at a time.	Radioisotope generates gammay decay.	Radioisotope generates positron decay.
Methodology	Similar to X-ray, but uses emitted gamma rays from the patient, the photons captured in one direction only,	Similar to X-ray CT, the photons captured in multiple directions,	Capture projections on multiple directions. Positron decay produces two photons in two opposite directions at a time.
Detector	Anger scintillation camera	Rotating anger camera to obtain projection data from multiple angles.	Special coincidence detection circuitry to detect two photons in opposite directions simultaneously.

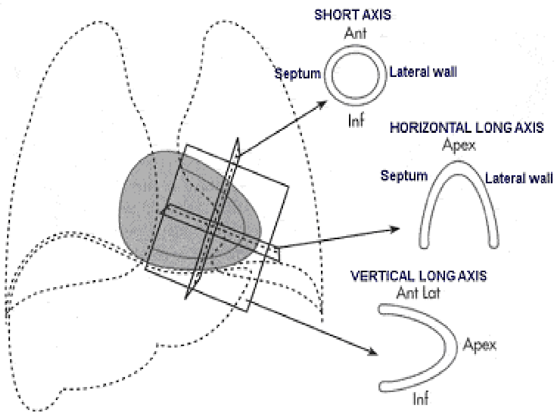


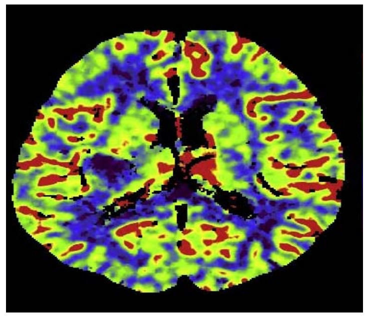


(a) Basic principles (b) Captured image

Figure 11. Planner scintigraphy

Single Photon Emission Computed Tomography (SPECT) is an imaging technique that relies on drugs that are labelled with atoms that emit at least one gamma ray when they decay. Since gamma rays are normally emitted equally in every direction, it is necessary to use a collimator in front of the detector that allows only the gamma rays emitted in the direction of the detector to be registered. In this way, the collimator defines the direction of the radiation when it is detected. By moving the detector completely around the patient, a 360º image is obtained. Mathematical methods are used to trace the emitted gamma rays back in the direction that they were emitted in order to produce the image. Figure 12-a show the basis of SPECT, and an example of the captured image is shown in figure 12-b.

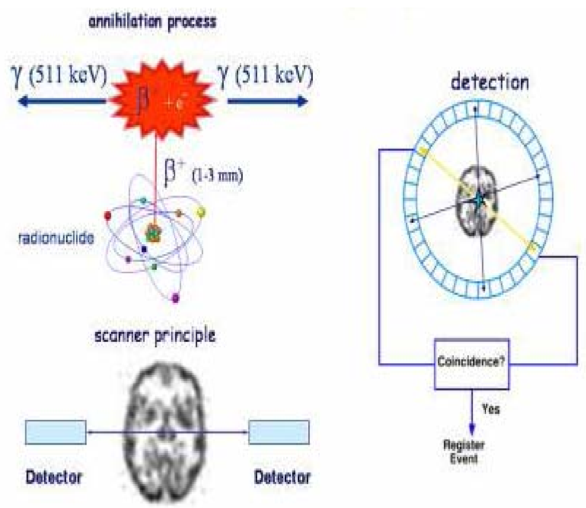


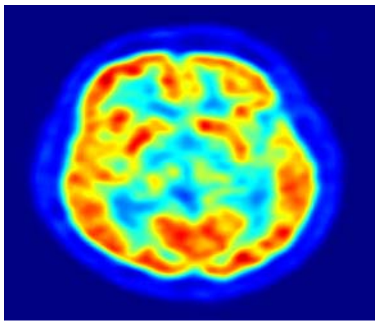


(a) Basic principles (b) SPECT brain image

Figure 12. SPECT

PET is a very similar technique to SPECT in that they both provide information about the metabolism of a disease. Isotopes used in PET imaging are decayed by positron emission. The emitted positron travels only a minimal distance before it undergoes an annihilation reaction with the production of two photons that travel in opposite directions to one another. Localization of the annihilation event is achieved by placing two detectors on opposite sides of the patient. When the photons are detected at the same time, the position of the emitted positron can be traced back with a straight as shown in figure 13-a. An example of capture image using PET is shown in figure 13-b.





(a) Physical principles (b) PET brain image

Figure 13. PET

Recently, image fusion has been used for combining PET images with CT images or with MRI images to produce special views for capturing the information from the two different exams to be correlated and interpreted on one image. This gives more precise information and accurate diagnoses. Commercially there are three combinations; SPECT/CT [56, 66-68], PET/CT [69-71] and PET/MRI [72-74].

8.1. Radionuclide Imaging Benefits

- Provides functional information that is often highly accurate and specific.
- Provides a global view of the system of interest.
- Good tissue specific contrast.
- Can check how far a cancer has spread and how well the treatment is working.

8.2. Radionuclide Imaging Risks

- Use ionizing radiation and makes the patient radioactive for a variable period of time.
- Relatively low spatial resolution.
- High cost (equipment and isotope production).
- Extra care required in handling radioactive materials.
- May cause some people to feel claustrophobic, which may mean sedation is required.

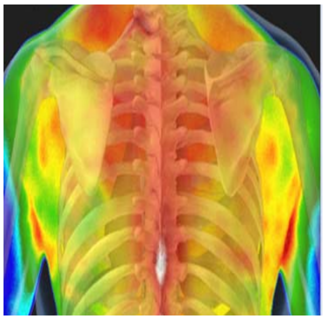
8.3 Radionuclide Imaging Medical Applications

- Diagnosing the cancers (breast, cervical, colorectal, esophageal, head and neck, lung, lymphoma, melanoma, pancreatic, thyroid and others).
- Evaluating the potential effectiveness of therapy.
- Diagnosing the cardiovascular disease.
- Diagnosing the Alzheimer's disease, Parkinson's disease, dementia, epilepsy and other neurological diseases.

9. Infrared Thermography

Thermography is a diagnostic technology that uses infrared to maps the physiological processes of the body. It is based on the measurement of the skin's surface temperature, where the temperature is dependent on the blood circulation in the outer millimeters of the skin. Infrared medical thermography is sensitive to detect slight, dynamic temperature changes (0,05°C) on the surface of the skin [75]. Clinical thermography [76, 77] is the recording of temperature to form an image (thermogram) of the temperature distribution on the surface of the body. An infrared thermography imaging system that used commercially is shown in figure 14-a. Figure 14-b show an example of an infrared image.

(a) Infrared thermography



(b) Infrared image imaging system

Figure 14. Infrared thermography imaging

9.1 Thermography Imaging Benefits

- Noninvasive.
- Non-ionizing radiation.
- Low cost.
- Uniquely suited to observing dynamic physiological changes in the body.
- Able to identify connections and causes of pain and disease at a very early stage.
- Low processing time, a single image may contain several thousands of temperature points, recorded in a fraction of a second.

9.2 Thermography Imaging Risks

- Limited as a primary (stand-alone) breast cancer diagnostic [78, 79].
- By increasing temperature breast cancer cells produce nitric oxide, this oxide interferes with the nervous system control of breast tissue blood vessel flow by causing regional vasodilation in the early stages of cancerous cell growth, and enhancing new blood vessel formation in later stages [80].
- Poor spatial resolution
- Poor calibration systems.

9.3 Thermography Medical Applications

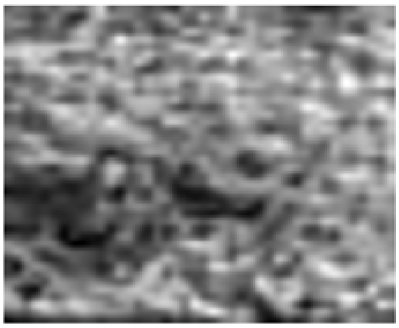
- Determining the areas of the body that have inflammation.
- Breast imaging thermography offers women information that no other procedure can provide, but breast thermography is not a replacement for or alternative to mammography or any other form of breast imaging.

10. Terahertz Imaging

Terahertz (THz) radiation is defined as the submillimeter (1 mm - 0.1 mm) electromagnetic spectrum with frequencies between 300 GHz and 3 THz, and is a relatively new and expanding area that promises unique imaging capability. Due to the high absorption of THz electromagnetic radiation in the water, reflective THz imaging has distinct advantages over earlier transmission-based systems. A commercial THz medical probe that used in particular is shown in figure 15-a. In THz imaging, the probe beam interacts with the sample, and the detection signal is obtained by combining the probe laser with the THz radiation. The image of the subject can be built up due to the selective absorption of the THz radiation. The detector receives the signals and by scanning the sample an image can be formed [81, 82]. Figure 15-b show an example of rough surface scattering from porcine skin.

10.1. Terahertz Imaging Benefits

- Safe and nonionising radiation.
- Uniquely sensitive to the vibration modes of water.
- THz radiation can penetrate many materials due to the long wavelength of the THz photons.



(a) THz medical probe (b) THz image

Figure 15. THz imaging

10.2. Terahertz Imaging Risks

- THz detectors were characterized by poor signal-to-noise ratio and slow processing.
- The emitters produce only incoherent and low-brightness THz radiation [81].
- THz sources require cryogenic operating temperatures [83].
- Low contrast between healthy and pathological tissues.
- Poor source performance [84].

10.3. Terahertz Imaging Medical Applications

- Detecting the cancers (skin, breast and colon) [85].
- Imaging the tooth crown.
- Used in medical imaging experiments on different in-vitro and some in-vivo biological tissues and has shown promising results in differentiating certain features in those tissues [86].
- Detecting certain polar molecules due to these molecules' fingerprint in the Terahertz range of frequencies tissues [86].

11. Comparisons Between Medical Imaging Techniques

The medical applications can be compared in terms of 3 concepts; the first concept is the image quality that can be represented by the spatial resolution and better contrast. The spatial resolution refers to the spatial extent of small objects within the image. Noise refers to the precision with which the signal is received. The contrast refers to the difference in brightness or darkness in the image between an area of interest and its surrounding background. The second concept is the system available that can be represented by the system cost and the availability of real time information. The third concept is the safety that can be represented by the effect of ionizing radiation on the patient, and the effect of heating on the body. The comparison between the different MITs is summarized in table 2.

Table 2. A Comparison between the different MITs

Imaging Technique	Image quality		System availability		Safety	
	Spatial resolution	Good contrast	Cost	Real time information	Ionising radiation effect	Heating effect
Radiography	1 mm	Soft tissues and fluid	Medium	No	Yes	Low
CT	0.5 mm	Hard and soft tissue	High	No	Yes	Low
MRI	0.5 mm	Hard and soft tissue	High	No	No	Medium
Ultrasonography	1 mm	Soft tissues	Low	Yes	No	Negligible
Elastography	200 µm	Soft tissues	Medium	Yes	No	Low
Optical	100 nm	Soft tissues	Low	No	No	Medium
Radionuclide	3 mm	Soft tissues	High	No	Yes	Medium
Thermography	15 µm	Soft tissues	Low	No	No	High
Terahertz	40 µm	Soft tissues	High	No	No	High

12. Conclusions

The paper presented a comparative study between the different medical imaging techniques, the concepts, benefits, risks and applications of these techniques has been presented with details. The concerning techniques are; X-ray radiography, X-ray CT, MRI, ultrasonography, elastography, optical imaging, radionuclide imaging includes (Scintigraphy, PET and SPECT, thermography, and terahertz imaging. A comparison between these techniques from point of view, image quality (spatial resolution and contrast), safety (effect of ionizing radiation, and heating effect of radiation on the body), and system availability (real time information, and cost) has been presented. The discussions show, nothing of these techniques can be individual reliable in all medical applications.

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