Chapter one

Introduction

Radiologic Technologists, Diagnostic Radiographers, Medical Radiation Technologists are Healthcare Professionals who specialize in the imaging of human anatomy for the diagnosis and treatment of pathology. Radiographers are infrequently, and almost always erroneously, known as *X-Ray Technicians.* Radiographers work in both public and private healthcare and can be physically located in any setting where appropriate diagnostic equipment is located, most frequently in hospitals. Their practice varies country to country and can even vary between hospitals in the same country.

During the 1970 a team led by John Mallard built the first full body MRI scanner at the University of Aberdeen. On 28 August 1980 they used this machine to obtain the first clinically useful image of a patient's internal tissues using Magnetic Resonance Imaging (MRI), which identified a primary tumour in the patient's chest, an abnormal liver, and secondary cancer in his bones. In 1975, the University of California, San Francisco Radiology Department founded the Radiologic Imaging Laboratory (RIL). In 1981 RIL researchers, including Leon Kaufman and Lawrence Crooks, published Nuclear Magnetic

Resonance Imaging in Medicine.

1.1: Problem of search

Exposure to ionizing radiation causes damage to living tissue, and can result in mutation, radiation sickness, cancer, and death.

1.2: Aim of search

This search aimed to study and providing method enabled from obtaining to images precise for tissues brain by using the magnetic resonance imaging (MRI**).**

1.3: Methodology of search

In his search orphan collection information about nuclear magnetic resonance imaging from reference collage sciences library and internet network to obtaining basic concepts and recognizers method of obtaining magnetic resonance image.

1.4: Contents of project

Here we are going to discuss the effect of the electromagnetic radiation on the human body using MRI. Chapter two introduced the physical concept of electromagnetic radiations, where chapter three comes across the phenomena of Resonance. Chapter four introduced the physics of magnetic resonance imaging , MRI system and advantages and disadvantages of MRI finally, chapter five talk about the medical uses of MRI,precisely brain imaging .

Chapter Two

Fields and Radiation

2.1: Magnetic Field

Magnetic fields are produced by electric currents and the intrinsic magnetic moments of elementary particles associated with a fundamental quantum property, their spin. In special relativity, electric and magnetic fields are two interrelated aspects of a single object, called the electromagnetic tensor; the split of this tensor into electric and magnetic fields depends on the relative velocity of the observer and charge, It can be defined in terms of force on moving charge in the Lorentz force law. The interaction of magnetic field with charge leads to many practical applications. Magnetic field sources are essentially dipolar in nature, having a north and south magnetic pole. The SI unit for magnetic field is the Tesla. The magnetic field is represented by magnetic field lines, which Show the direction of the field at different [1].

2.1.1: Magnetic field lines

Compasses reveal the direction of the local magnetic field. As seen here, the magnetic field points towards a magnet's South Pole and away from its north pole, mapping the magnetic field of an object is simple in principle. First, measure the strength and direction of the magnetic field at a large number of locations. Then, mark each location with an arrow (called a vector) pointing in the direction of the local magnetic field with its magnitude proportional an alternative method to map the magnetic field is to 'connect' the arrows to form magnetic field lines. The direction of the magnetic field at any point is parallel to the direction of nearby field lines, and the local density of field lines can be made proportional to its strength, The direction of magnetic field lines represented by the alignment of iron filings sprinkled on paper placed above a bar magnet .Various phenomena have the effect of "displaying" magnetic field lines as though the field lines were physical phenomena. Magnetic forces can be understood by imagining that the field lines exert a tension, (like a rubber band) along their length, and a pressure perpendicular to their length on neighboring field lines. 'Unlike' poles of magnets attract because they are linked by many field lines; 'like' poles repel because their field lines do not meet, but run parallel, pushing on each other. The rigorous form of this concept is the electromagnetic stress energy tensor [2].

2.1.2: Force on a charged particle

Often the magnetic field is defined by the force it exerts on a moving charged particle. It is known from experiments in electrostatics that a particle of charge q in an electric field E experiences a force:

$$\mathbf{F} = q\mathbf{E} \qquad 2.1$$

However, in other situations, such as when a charged particle moves in the vicinity of a current-carrying wire, the force also depends on the velocity of that particle. Fortunately, the velocity dependent portion can be separated out such that the force on the particle satisfies the Lorentz force law [3].

2.1.3: Lorentz Force Law

Both the electric field and magnetic field can be defined from the Lorentz force law:

The electric force is straightforward, being in the direction of the electric field, the force is given by [3]:

$$\mathbf{F} = q\,(\mathbf{E} + \mathbf{v} \times \mathbf{B}) \qquad 2.2$$

A charged particle moving in a B-field experiences a sideways force that is proportional to the strength of the magnetic field, the component of the velocity that is perpendicular to the magnetic field and the charge of the particle. This force is known as the Lorentz force, and is given by

$$\mathbf{F} = q\,\mathbf{v} \times \mathbf{B} \qquad 2.3$$

The Lorentz force is always perpendicular to both the velocity of the particle and the magnetic field that created it. When a charged particle moves in a static magnetic field, it traces a helical path in which the helix axis is parallel to the magnetic field, and in which the speed of the particle remains constant. Because the magnetic force is always perpendicular to the motion, the magnetic field can do no work on an isolated charge. It can only do work indirectly, via the electric field generated by a changing magnetic field. It is often claimed that the magnetic force can do work to a non-elementary magnetic dipole, or to charged particles whose motion is constrained by other forces, but this is incorrect because the work in those cases is performed by the electric forces of the charges deflected by the magnetic field [3].

2.1.4: Energy stored in magnetic fields

Energy is needed to generate a magnetic field both to work against the electric field that a changing magnetic field creates and to change the magnetization of any material within the magnetic field. For non-dispersive materials this same energy is released when the magnetic field is destroyed so that this energy can be modeled as being stored in the magnetic field [4].

2.1.5: Maxwell's equations

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0} \qquad 2.4$$

$$\nabla \cdot \mathbf{B} = 0 \qquad 2.5$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \qquad 2.6$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} \qquad 2.7$$

These equations are not any more general than the original equations (if the 'bound' charges and currents in the material are known). They also must be supplemented by the relationship between B and H as well as that between E and D. On the other hand, for simple relationships between these quantities this form of Maxwell's equations can circumvent the need to calculate the bound charges and currents [4].

2.2: Electric field

The electric field at a given point is defined as the (Victoria) force that would be exerted on a stationary test particle of unit charge by electromagnetic forces (i.e. the Lorentz force). A particle of charge would be subject to a force, Electric field lines emanating from a point positive electric charge suspended over an infinite sheet of conducting material [5].

2.2.1: Energy in the electric field

If the magnetic field **B** is nonzero, the total energy per unit volume stored by the electromagnetic field .The total energy E stored in the electric field in a given volume V *from equation* [6]*:*

$$E=Vd \qquad 2.8$$

2.3: Electromagnetic field

An electromagnetic field (EMF) is a physical field produced by electrically charged objects. It affects the behavior of charged objects in the vicinity of the field. The electromagnetic field extends indefinitely throughout space and describes the electromagnetic interaction. It is one of the four fundamental forces of nature the others are gravitation, weak interaction and strong interaction. The field can be viewed as the combination of an electric field and a magnetic field. The electric field is produced by stationary charges, and the magnetic field by moving charges (currents); these two are often described as the sources of the field. The way in which charges and currents interact with the electromagnetic field is described by Maxwell's equations (1.1.5) and the Lorentz force law(1.1.3), the behavior of the electromagnetic field can be divided into four different parts of a loop: The electric and magnetic fields are generated by electric charges, interact with each other, produce forces on electric charges, the electric charges move in space-charged particles generate electric and magnetic fields, The fields interact with each other changing electric field acts like a current, generating 'vortex' of magnetic field [5].

2.4: Structure of Electromagnetic field

The electromagnetic field may be viewed in two distinct ways: a continuous structure or a discrete structure [7].

2.4.1: Continuous structure

Classically, electric and magnetic fields are thought of as being produced by smooth motions of charged objects. For instance, the metal atoms in a radio transmitter appear to transfer energy continuously. This view is useful to a certain extent radiation of low frequency, but problems are found at high frequencies [7].

2.4.2: Discrete structure

The electromagnetic field may be thought of in a more 'coarse' way. Experiments reveal that in some circumstances electromagnetic energy transfer is better described as being carried in the form of packets called quanta (in this case, photons) with a fixed frequency. Planck's relation links the energy *E* of a photon to its frequency ν through the equation [7].

$$E = h\nu \qquad 2.9$$

Where *h* is Planck's constant, and ν is the frequency of the photon. Although modern quantum optics tells us that there also is a semi-classical explanation of the photoelectric effect the emission of electrons from metallic surfaces subjected to electromagnetic radiation the photon was historically (although not strictly necessarily) used to explain certain observations. It is found that increasing the intensity of the incident radiation so long as one remains in the linear regime increases only the number of electrons ejected, and has almost no effect on the energy distribution of their ejection. Only the frequency of the radiation is relevant to the energy of the ejected electrons, This quantum picture of the electromagnetic field has proved very successful, giving rise to quantum electrodynamics, a quantum field theory describing the interaction of electromagnetic radiation with charged matter. It also gives rise to quantum optics, which is different from quantum electrodynamics in that the matter itself is modeled using quantum mechanics rather than quantum field theory [7].

2.5: Applications of Electromagnetic field

When an EM field is not varying in time, it may be seen as a purely electrical field or a purely magnetic field, or a mixture of both. However the general case of a static EM field with both electric and magnetic components present is the case that appears to most observers. Observers, who see only an electric or magnetic field component of a static EM field, have the other (electric or magnetic) component suppressed, due to the special case of the immobile state of the charges that produce the EM field in that case. In such cases the other component becomes manifest in other observer frames. A consequence of this, is that any case that seems to consist of a "pure" static electric or magnetic field, can be converted to an EM field, with both E and M components present, by simply moving the observer into a frame of reference which is moving with regard to the frame in which only the “pure” electric or magnetic field appears. That is, a pure static electric field will show the familiar magnetic field associated with a current, in any frame of reference where the charge moves. Likewise, any new motion of a charge in a region that seemed previously to contain only a magnetic field, will show that that the space now contains an electric field as well, which will be found to produces an additional Lorentz force upon the moving charge, Thus, electrostatics, as well as magnetism and magneto statics, are now seen as studies of the static EM field when a particular frame has been selected to suppress the other type of field, and since an EM field with both electric and magnetic will appear in any other frame, these "simpler" effects are merely the observer's. The "applications" of all such non-time varying static fields are discussed in the main articles linked in this section [8].

2.6: Electromagnetic radiation

Electromagnetic radiation (EM radiation or EMR) is the radiant energy released by certain electromagnetic processes. Visible light is one type of electromagnetic radiation; other familiar forms are invisible to the human eye, such as radio waves, infrared light and X-rays. Classically, electromagnetic radiation consists of electromagnetic waves, which are synchronized oscillation of electric and magnetic fields that propagate at the speed of light through a vacuum [9].

The oscillations of the two fields are perpendicular to each other and perpendicular to the direction of energy and wave propagation, forming a transfer wave. Electromagnetic waves can be characterized by either the frequency or wavelength of their oscillations to form the electromagnetic spectrum, which includes, in order of increasing frequency and decreasing wavelength: radio waves, micro waves, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays. Electromagnetic waves are produced whenever charged particles are accelerated, and these waves can subsequently interact with any charged particles. EM waves carry energy, momentum and angular momentum away from their source particle and can impart those quantities to matter with which they interact. Quanta of EM waves are called photons, which are mass less, but they are still affected by gravity. Electromagnetic radiation is associated with those EM waves that are free to propagate themselves ("radiate") without the continuing influence of the moving charges that produced them, because they have achieved sufficient distance from those charges. Thus, EMR is sometimes referred to as the far field. In this language, the *near field* refers to EM fields near the charges and current that directly produced them, specifically, electromagnetic induction and electrostatic phenomena. In the quantum theory of electromagnetism; EMR consists of photons, the elementary particles responsible for all electromagnetic interactions. Quantum effects provide additional sources of EMR, such as the transition of electrons to lower energy levels in an atom and black-body radiation. The energy of an individual photon is quantized and is greater for photons of higher frequency. This relationship is given by Planck's equation

(2.9).The effects of EMR upon biological systems depend both upon the radiation's power and its frequency. For EMR of visible frequencies or lower (i.e., radio, microwave, infrared), the damage done to cells and other materials is determined mainly by power and caused primarily by heating effects from the combined energy transfer of many photons. By contrast, for ultraviolet and higher frequencies (i.e., X-rays and gamma rays), chemical materials and living cells can be further damaged beyond that done by simple heating, since individual photons of such high frequency have enough energy to cause direct molecular damage [9].

2.6.1: Ionizing radiation

Ionizing radiation is radiation that carries enough energy to free electrons from atoms or molecules, thereby ionizing them. It is made up of energetic subatomic particles, ions or atoms moving at high speeds (usually greater than 1% of the speed of light), and electromagnetic waves on the high-energy end of the spectrum. Gamma, X-rays, and the higher ultraviolet part of the electromagnetic spectrum are ionizing, whereas the lower ultraviolet part of the electromagnetic spectrum, and also the lower part of the spectrum below UV, including visible light including nearly all types of laser light, infrared, microwaves, and radio waves are all considered non-ionizing .The boundary between ionizing and non-ionizing electromagnetic radiation that occurs in the ultraviolet is not sharply defined, since different molecules and atoms ionize at different energies. Conventional definition places the boundary at photon energy between 10 eV and 33 eV in the ultraviolet. Typical ionizing subatomic particles from radioactivity include alpha particles, beta particles and neutrons. Almost all products of radioactive decay are ionizing because the energy of radioactive decay is typically far higher than that required to ionize. Other subatomic ionizing particles which occur naturally are muons, mesons, positrons, neutrons and other particles that constitute the secondary cosmic rays that are produced after primary cosmic rays interact with Earth's atmosphere. Cosmic rays may also produce radioisotopes on Earth, which in turn decay and produce non-ionizing radiation .Ionizing radiation is applied constructively in a wide variety of fields such as medicine, research, manufacturing, construction, and many other areas, but presents a health hazard if proper measures against undesired exposures aren’t followed. Exposure to ionizing radiation causes damage to living tissue, and can result in mutation, radiation sickness, cancer, and death [9].

2.6.2: Non-ionizing radiation

Non-ionizing radiation refers to any type of electromagnetic radiation that does not carry enough energy per quantum (photon energy) to ionize atoms or molecules that is, to completely remove an electron from an atom or molecule.

Instead of producing charged ions when passing through matter, the electromagnetic radiation has sufficient energy only for excitation, the movement of an electron to a higher energy state. *Ionizing radiation* which has a higher frequency and shorter wavelength than non-ionizing radiation has many uses but can be a health hazard; exposure to it can cause burns, radiation sickness, cancer and genetic damage. Using ionizing radiation requires elaborate radiological protection measures which in general are not required with nonionizing radiation. The region at which radiation becomes considered as "ionizing" is not well defined, since different molecules and atoms ionize at different energies. The usual definitions have suggested that radiation with particle or photon energies less than 10 electron volts (eV) be considered non-ionizing. Another suggested threshold is 33 electron volts, which is the energy needed to ionize water molecules. The light from the Sun that reaches the earth is largely composed of non-ionizing radiation, since the ionizing far-ultraviolet rays have been filtered out by the gases in the atmosphere, particularly oxygen. Different biological effects are observed for different types of non-ionizing radiation. A difficulty is that there is no controversy that the upper frequencies of non-ionizing radiation near these energies (much of the spectrum of UV light and some visible light) is capable of non-thermal biological damage, similar to ionizing radiation. Health debate therefore centers on the non-thermal effects of radiation of much lower frequencies (microwave, millimeter and radio wave radiation). The International Agency for Research on Cancer recently stated that there could be some risk from non-ionizing radiation to humans. But a subsequent study reported that the basis of the IARC evaluation was not consistent with observed incidence trends. This and other reports suggest that there is virtually no way that results on which the IARC based its conclusions are correct **[9].**

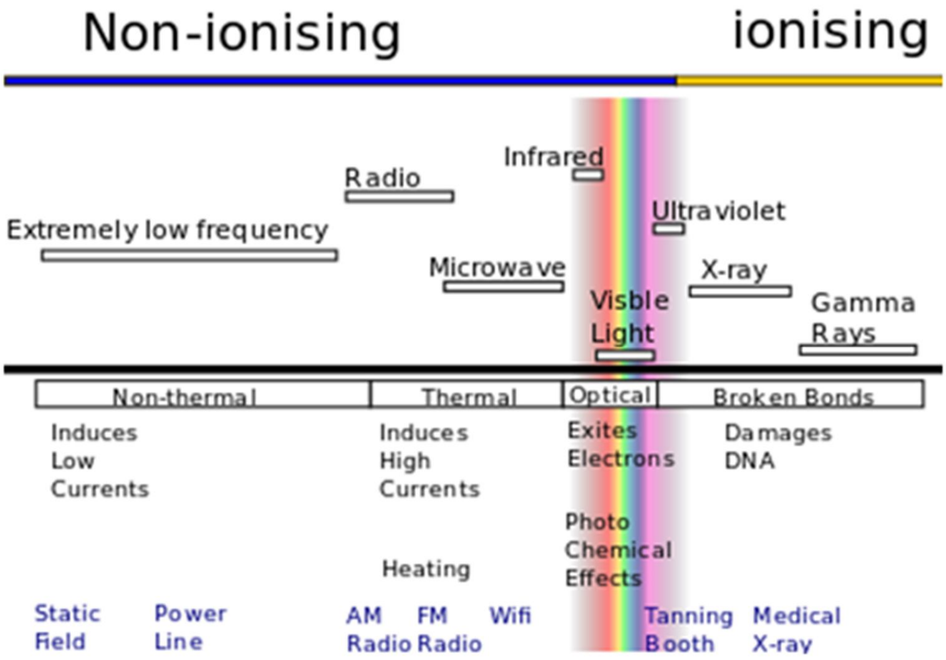

Figure 2.1: ionizing and non-ionizing radiation

Chapter three

3.1: Resonance

In physics, resonance describes when a vibrating system or external force drives another system to oscillate with greater amplitude at a specific preferential frequency Increase of amplitude as damping decreases and frequency approaches resonant frequency of a driven damped simple harmonic oscillator, Frequencies at which the response amplitude is a relative maximum are known as the system's resonant frequencies, or resonance frequencies. At resonant frequencies, small periodic driving forces have the ability to produce large amplitude oscillations. This is because the system stores vibration energy Resonance occurs when a system is able to store and easily transfer energy between two or more different storage modes. However, there are some losses from cycle to cycle, called damping. When damping is small, the resonant frequency is approximately equal to the natural frequency of the system, which is a frequency of unforced vibrations. Some systems have multiple, distinct, resonant frequencies. Resonance phenomena occur with all types of vibrations or waves: there is mechanical resonance, acoustic resonance, electromagnetic resonance, nuclear magnetic resonance (NMR), electron spin resonance (ESR) and resonance of quantum wave function. Resonant systems can be used to generate vibrations of a specific frequency (e.g., musical instruments), or pick out specific frequencies from a complex vibration containing many frequencies (e.g., filters).The term resonance (from Latin resonant, 'echo', from resonate, 'resound') originates from the field of acoustics, particularly observed in musical instruments, e.g., when strings started to vibrate and to produce sound without direct excitation by the player .The phenomenon whereby an oscillating system, such as a swing, will oscillate more strongly when it is exposed to a periodic force that is applied with the same frequency as that of the oscillating system ,A radio is tuned by adjusting the frequency of the receiver so that it matches that of the incoming radio waves [10].

3.2: Types of resonance

3.2.1: Mechanical resonance

Mechanical resonators are used in electronic circuits to generate signals of a precise frequency. The high dimensional stability and low temperature coefficient of quartz helps keeps resonant frequency constant. In addition, the quartz's piezoelectric property converts the mechanical vibrations into an oscillating voltage, which is picked up by the attached electrodes. These crystal oscillators are used in quartz clocks and watches, to create the clock signal that runs computers, and to stabilize the output signal from radio transmitters. Mechanical resonators can also be used to induce a standing wave in other. In this case the standing wave is imposed on the beam [11].

This type of system can be used as a sensor to track changes in frequency or phase of the resonance of the fiber. One application is as a measurement device for dimensional metrology [12].

3.2.2. Acoustic resonance

Acoustic resonance is a branch of mechanical resonance that is concerned with the mechanical vibrations across the frequency range of human hearing, in other words sound. For humans, hearing is normally limited to frequencies between about 20 Hz and 20,000 Hz (20 kHz).Acoustic resonance is an important consideration for instrument builders, as most acoustic instruments use resonators, such as the strings and body of a violin, the length of tube in a flute, and the shape of, and tension on, a drum membrane [13].

3.2.3. Optical resonance

An optical cavity, also called an optical resonator, is an arrangement of mirrors that forms a standing wave cavity resonator for light waves, Optical cavities are a major component of lasers, surrounding the gain medium and providing feedback of the laser light. They are also used in optical parameters oscillators and some interferometers. Light confined in the cavity reflects multiple times producing standing waves for certain resonant frequencies. The standing wave patterns produced are called "modes". Longitudinal modes differ only in frequency while transverse modes differ for different frequencies and have different intensity patterns across the cross-section of the beam. Ring resonators and whispering galleries are examples of optical resonators that do not form standing waves, Different resonator types are distinguished by the focal lengths of the two mirrors and the distance between them; flat mirrors are not often used because of the difficulty of aligning them precisely. The geometry resonator type must be chosen so the beam remains stable, i.e., the beam size does not continue to grow with each reflection. Resonator types are also designed to meet other criteria such as minimum beam waist or having no focal point and therefore intense light at that point inside the cavity .Optical cavities are designed to have a very large factor. A beam reflects a large number of times with little attenuation therefore the frequency line of the beam is small compared to the frequency of the laser [14].

3.2.4: Electrical resonance

An electrical circuit composed of discrete components can act as a resonator when both an inductor and capacitor are included. Oscillations are limited by the inclusion of resistance, either via a specific resistor component, or due to resistance of the inductor windings. Such resonant circuits are also called RLC circuits after the circuit symbols for the components. A distributed-parameter resonator has capacitance, inductance, and resistance that cannot be isolated into separate lumped capacitors, inductors, or resistors, Electrical resonance occurs in an electric circuit at a particular *resonant frequency* when the impedance of the circuit is at a minimum in a series circuit or at maximum in a parallel circuit or when the transfer function is at a maximum [15].

3.2.5. Cavity resonators

A cavity resonator is a hollow closed conductor such as a metal box or a cavity within a metal block, containing electromagnetic waves -radio waves- reflecting back and forth between the cavity's walls. When a source of radio waves at one of the cavity's resonant frequencies is applied, the oppositely-moving waves form standing waves, and the cavity stores electromagnetic energy, Since the cavity's lowest resonant frequency, the fundamental frequency, is that at which the width of the cavity is equal to a half-wavelength ($\lambda/2$), cavity resonators are only used at microwaves frequencies and above, where wavelengths are short enough that the Cavity is conveniently small in size , due to the low resistance of their conductive walls, it is have very high Q factors; that is their bandwidth, the range of frequencies around the resonant frequency at which they will resonate, is very narrow. Thus they can act as narrow band pass filters. Their resonant frequency can be tuned by moving one of the walls of the cavity in or out, changing its size ,Cavity resonator, usually used in reference to electromagnetic resonators, is one in which waves exist in a hollow space inside the device. Acoustic cavity resonators, in which sound is produced by air vibrating in a cavity with one opening, are known as Helmholtz resonators [15].

3.2.6. Orbital resonance

In celestial mechanics an orbital resonance occurs when two orbiting bodies exert a regular, periodic gravitational influence on each other, usually due to their orbital periods being related by a ratio of two small integers. Orbital resonances greatly enhance the mutual gravitational influence of the bodies. In most cases, this results in an *unstable* interaction, in which the bodies exchange momentum and shift orbits until the resonance no longer exists. Under some circumstances, a resonant system can be stable and self-correcting, so that the bodies remain in resonance [15].

3.2.7: Nuclear magnetic resonance

Nuclear magnetic resonance (NMR) is the name given to a physical resonance phenomenon involving the observation of specific quantum mechanical magnetic properties of an atomic nucleus in the presence of an applied, external magnetic field. Many scientific techniques exploit NMR phenomena to study molecular physics, crystals, and non-crystalline materials through NMR spectroscopy. NMR is also routinely used in advanced medical imaging techniques, such as in magnetic resonance imaging (MRI). All nuclei containing odd numbers of nucleons have an intrinsic magnetic moment and angular momentum. A key feature of NMR is that the resonant frequency of a particular substance is directly proportional to the strength of the applied magnetic field. It is this feature that is exploited in imaging techniques; if a sample is placed in a non-uniform magnetic field then the resonant frequencies of the sample's nuclei depend on where in the field they are located. Therefore, the particle can be located quite precisely by its resonant frequency, otherwise known as *Electron Spin Resonance* (ESR) is a spectroscopic technique similar to NMR, but uses unpaired electrons instead. Materials for which this can be applied are much more limited since the material needs to both have an unpaired spin and be paramagnetic [15].

3.3: Resonators

A resonator is a device or system that exhibits resonance or resonant behavior, that is, it naturally oscillates at some frequencies, called its resonant frequencies, with greater amplitude than at others. The oscillations in a resonator can be either electromagnetic or mechanical (including acoustic). Resonators are used to either generate waves of specific frequencies or to select specific frequencies from a signal. Musical instruments use acoustic resonators that produce sound waves of specific tones**,** A physical system can have as many resonant frequencies as it has degrees of freedom; each degree of freedom can vibrate as a harmonic oscillator. Systems with one degree of freedom, such as a mass on a spring, pendulums, balance wheels ،and LC tuned have one resonant frequency. Systems with two degrees of freedom, such as coupled pendulums and resonant transformers can have two resonant frequencies. As the number of coupled harmonic oscillators grows, the time it takes to transfer energy from one to the next becomes significant. The vibrations in them begin to travel through the coupled harmonic oscillators in waves, from one oscillator to the next, extended objects that can experience resonance due to vibrations inside them are called resonators, such as organ pipes, vibrating strings, quartz crystals, microwave and laser cavities. Since these can be viewed as being made of millions of coupled moving parts such as atoms, they can have millions of resonant frequencies. The vibrations inside them travel as waves, at an approximately constant velocity, bouncing back and forth between the sides of the resonator. If the distance between the sides is, the length of a round tripis. To cause resonance, the phase of a sinusoidal wave after a roundtrip must be equal to the initial phase, so the waves reinforce the oscillation. So the condition for resonance in a resonator is that the round trip distance, be equal to an integer number of wavelengths of the wave, So the resonant frequencies of resonators, called normal modes, are equally spaced multiples of a lowest frequency called the fundamental frequency. The multiples are often called overtones. There may be several such series of resonant frequencies, corresponding to different modes of oscillation [15].

3.4: Applications of Resonance in Medicine

3.4.1: Magnetic Resonance Imaging

Figure 3.1: Magnetic Resonance Imaging (MRI).

The application of nuclear magnetic resonance best known to the general public is magnetic resonance imaging for medical diagnosis and magnetic resonance microscopy in research settings however, it is also widely used in chemical studies, notably in NMR spectroscopy such as proton NMR carbon-13NMR, deuterium NMR and phosphorus-31 NMR. Biochemical information can also be obtained from living tissue (e.g. human brain tumors) with the technique known as in vivo magnetic resonance spectroscopy or chemical shift NMR Microscopy .These studies are possible because nuclei are surrounded by orbiting electrons, which are charged particles that generate small, local magnetic fields that add to or subtract from the external magnetic field, and so will partially shield the nuclei. The amount of shielding depends on the exact local environment. In addition, two hydrogen nuclei can interact via a process known as spin-spin coupling, if they are on the same molecule, which will split the lines of the spectra in a recognizable way .As one of the two major spectroscopic techniques used in metabolomics, NMR is used to generate metabolic fingerprints from biological fluids to obtain information about disease states or toxic insults [15].

Chapter four

Physics of magnetic resonance imaging

4.1: Medical MRI scanner

Magnetic resonance imaging (MRI) or nuclear magnetic resonance imaging (NMRI), or magnetic resonance tomography (MRT) is a medical imaging technique used in radiology to image the anatomy and the physiological processes of the body in both health and disease. MRI scanners use strong magnetic fields, radio waves, and a field gradient to form images of the body. MRI is based upon the science of Nuclear Magnetic Resonance (NMR). Certain atomic nuclei can absorb and emit radio frequency energy when placed in an external magnetic field. In clinical and research MRI, hydrogen atoms are most-often used to generate a detectable radio-frequency signal that is received by antennas in close proximity to the anatomy being examined. Hydrogen atoms exist naturally in people and other biological organisms in abundance, particularly in water and fat. For this reason, most MRI scans essentially map the location of water and fat in the body. Pulses of radio waves are used to excite the nuclear spin energy transition, and magnetic field gradients localize the signal in space. By varying the parameters of the pulse sequence, different contrasts can be generated between tissues based on the relaxation properties of the hydrogen atoms therein. Since its early development in the 1970s and 1980s, MRI has proven to be a highly versatile imaging modality. While MRI is most prominently used in diagnostic medicine and biomedical research, it can also be used to form images of non-living objects. MRI scans are capable of producing a variety of chemical and physical data, in addition to detailed spatial images.MRI is widely used in hospitals and clinics for medical diagnosis, staging of disease and follow-up without exposing the body to ionizing radiation [16].

To perform a study, the person is positioned within an MRI scanner which forms a strong magnetic field around the area to be imaged. In most medical applications, protons (hydrogen atoms) in tissues containing water molecules are used to create a signal that is processed to form an image of the body. First, energy from an oscillating magnetic field is temporarily applied to the patient at the appropriate resonance frequency. The excited hydrogen atoms emit a radio frequency signal which is measured by a receiving coil. The radio signal can be made to encode position information by varying the main magnetic field using gradient coils. As these coils are rapidly switched on and off they create the characteristic repetitive noise of an MRI scan. The contrast between different tissues is determined by the rate at which excited atoms return to the equilibrium state. Exogenous contrast agents may be given intravenously, orally or intra-particularly, Lower field strengths can be achieved with permanent magnets, which are often used in "open" MRI scanners for claustrophobic patients [17].

4.2: Magnetic Resonance Imaging System

The MRI system consists of several major components, as shown in Figure 4-1. At this time we will introduce the components and indicate how they work together to create the MR image.

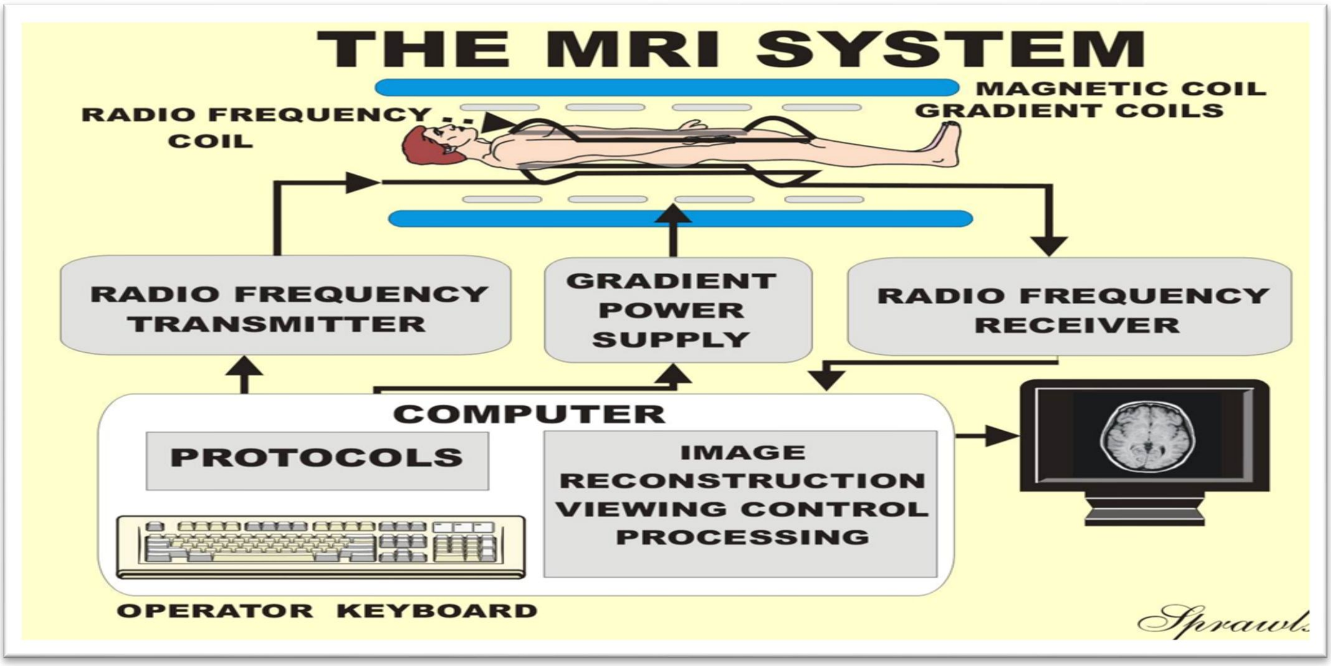

Figure 4.1: the major components of the Magnetic Resonance Imaging System.

The heart of the MRI system is a large magnet that produces a very strong magnetic field. The patient's body is placed in the magnetic field during the imaging procedure. The magnetic field produces two distinct effects that work together to create the image [18].

4.2.1: Tissue Magnetization

When the patient is placed in the magnetic field, the tissue becomes temporarily magnetized because of the alignment of the protons, as described previously. This is a very low-level effect that disappears when the patient is removed from the magnetic field. The ability of MRI to distinguish between different types of tissue is based on the fact that different tissues, both normal and pathologic, will become magnetized to different levels or will change their levels of magnetization at different rates [18].

4.2.2: Tissue Resonance

The magnetic field also causes the tissue to "tune in" or resonate at a very specific radio frequency. That is why the procedure is known as *magnetic resonance imaging*. It is actually certain nuclei, typically protons, within the tissue that resonate. Therefore, the more comprehensive name for the phenomenon that is the basis of both imaging and spectroscopy is *nuclear magnetic resonance* (NMR). In the presence of the strong magnetic field the tissue resonates in the RF range. This causes the tissue to function as a tuned radio receiver and transmitter during the imaging process. The production of an MR image involves two-way radio communication between the tissue in the patient's body and the equipment [18].

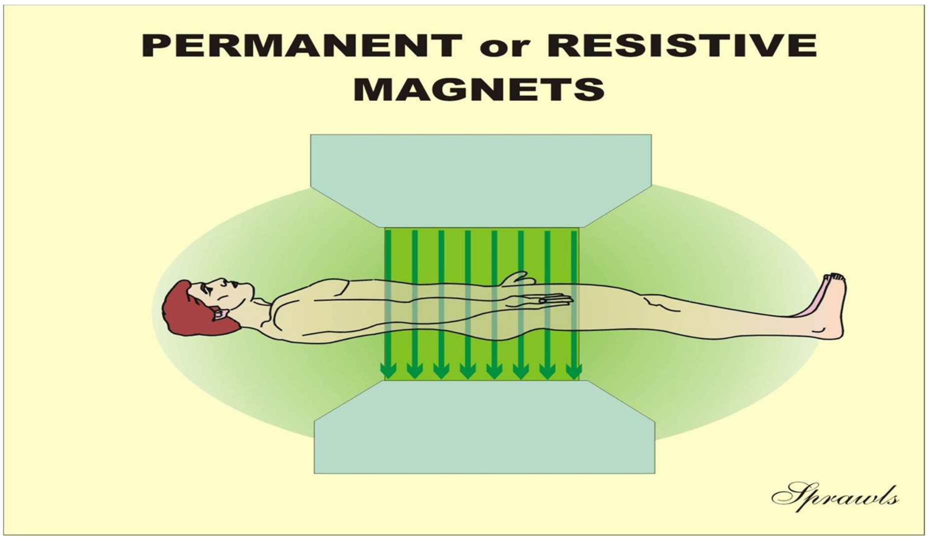

Figure 4.2: The magnetic field produced by superconducting magnets.

Figure 4-2 shows the general characteristics of a typical magnetic field. At any point within a magnetic field, the two primary characteristics are *field direction* and *field strength*.

4.2.3: Field Direction

It will be easier to visualize a magnetic field if it is represented by a series of parallel lines, as shown in Figure 3.2. The arrow on each line indicates the direction of the field. The north-south designation is generally not applied to magnetic fields used for imaging. Most of the electromagnets used for imaging produce a magnetic field that runs through the bore of the magnet and parallel to the major patient axis. As the magnetic field leaves the bore, it spreads out and encircles the magnet, creating an external fringe field. The external field can be a source of interference with other devices and is usually contained by some form of shielding [18].

4.2.4: Field Strength

Each point within a magnetic field has a particular intensity, or strength. Field strength is expressed either in the units of tesla (T) or gauss (G), Magnetic field strengths in the range of 0.15 T to 1.5 T are used for imaging. The significance of field strength is considered as we explore the characteristics of MR images [18].

4.2.5: Homogeneity

MRI requires a magnetic field that is very uniform, or homogeneous with respect to strength. Field homogeneity is affected by magnet design, adjustments, and environmental conditions. Imaging generally requires a homogeneity (field uniformity) on the order of a few parts per million within the imaging area. High homogeneity is obtained by the process of shimming, as described later [18].

.4.2.6: Superconducting

Most MRI systems use superconducting magnets. The primary advantage is that a superconducting magnet is capable of producing a much stronger and stable magnetic field than the other two types (resistive and permanent) considered below. A superconducting magnetic is an electromagnet that operates in a superconducting state. A superconductor is an electrical conductor (wire) that has no resistance to the flow of an electrical current. This means that very small superconducting wires can carry very large currents without overheating, which is typical of more conventional conductors like copper. It is the combined ability to construct a magnet with many loops or turns of small wire and then use large currents that makes the strong magnetic fields possible. There are two requirements for superconductivity. The conductor or wire must be fabricated from a special alloy and then cooled to a very low temperature. The typical magnet consists of small niobium-titanium (Nb-Ti) wires imbedded in copper. The copper has electrical resistance and actually functions as an insulator around the Nb-Ti superconductors. During normal operation the electrical current flows through the superconductor without dissipating any energy or producing heat. If the temperature of the conductor should ever rise above the critical superconducting temperature, the current begins to produce heat and the current is rapidly reduced. This results in the collapse of the magnetic field. This is an undesirable event known as a *quench*. Superconducting magnets are cooled with liquid helium. A disadvantage of this magnet technology is that the coolant must be replenished periodically. A characteristic of most superconducting magnets is that they are in the form of cylindrical or solenoid coils with the strong field in the internal bore. A potential problem is that the relatively small diameter and the long bore produce claustrophobia in some patients. Superconducting magnetic design is evolving to more open patient environments to reduce this concern [18].

4.2.7: Resistive

A resistive type magnet is made from a conventional electrical conductor such as copper. The name “resistive” refers to the inherent electrical resistance that is present in all materials except for superconductors. When a current is passed through a resistive conductor to produce a magnetic field, heat is also produced. This limits this type of magnet to relatively low field strengths [18].

4.2.8: Permanent

It is possible to do MRI with a non-electrical permanent magnet. An obvious advantage is that a permanent magnet does not require either electrical power or coolants for operation. However, this type of magnet is also limited to relatively low field strengths. Both resistive and permanent magnets are usually designed to produce vertical magnetic fields that run between the two magnetic poles [18].

4.2.9: Gradients

When the MRI system is in a resting state and not actually producing an image, the magnetic field is quite uniform or homogeneous over the region of the patient's body. However, during the imaging process the field must be distorted with gradients. A gradient is just a change in field strength from one point to another in the patient's body. The gradients are produced by a set of gradient coils, which are contained within the magnet assembly. During an imaging procedure the gradients are turned on and off many times. This action produces the sound or noise that comes from the magnet. The effect of a gradient is illustrated in Figure 3-3. When a magnet is in a "resting state," it produces a magnetic field that is uniform or homogenous over most of the patient's body. In this condition there are no gradients in the field. However, when a gradient coil is turned on by applying an electric current, a gradient or variation in field strength is produced in the magnetic field.

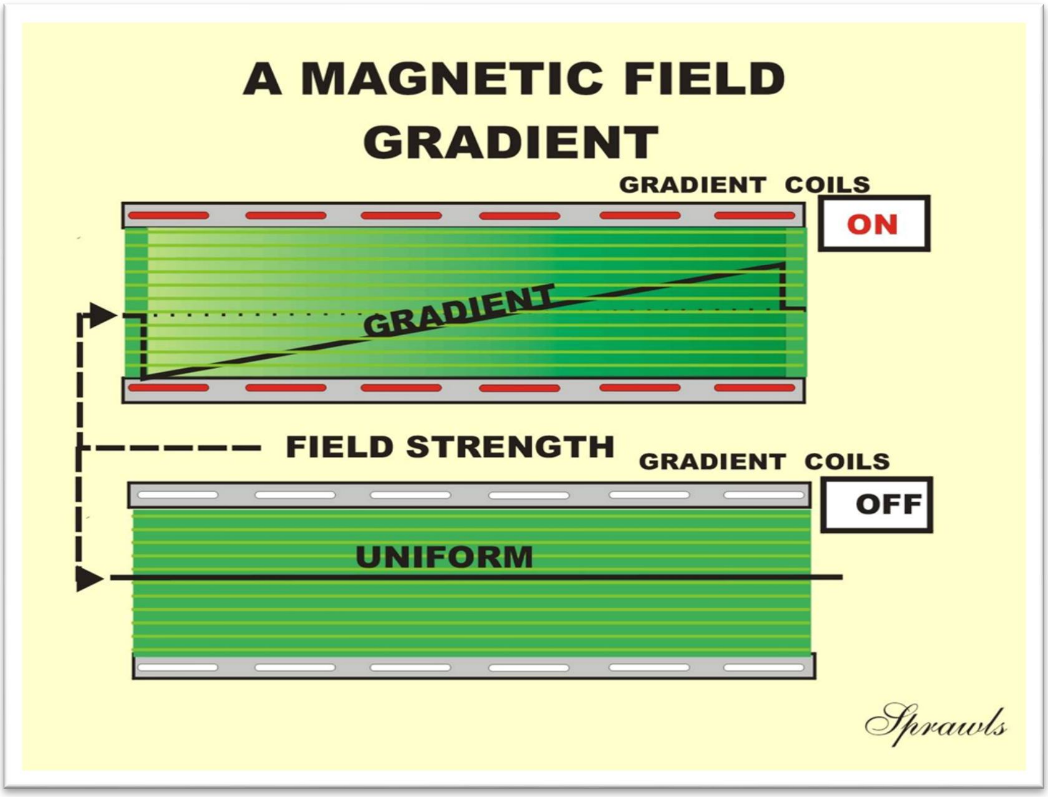

Figure 4.3: A magnetic field gradient produced by a current in the gradient cell.

4.2.10: Gradient Orientation

The typical imaging magnet contains three separate sets of gradient coils. These are oriented so that gradients can be produced in the three orthogonal directions (often designated as the x, y, and z directions). Also, two or more of the gradient coils can be used together to produce a gradient in any desired direction [18].

4.2.11: Gradient Strength

The strength of a gradient is expressed in terms of the change in field strength per unit of distance. The typical units are milli tesla per meter (mT/m). The maximum gradient strength that can be produced is a design characteristic of a specific imaging system. High gradient strengths of 20 mT/m or more are required for the optimum performance of some imaging methods [18].

4.2.12: Rise time and Slew-Rate

For certain functions it is necessary for the gradient to be capable of changing rapidly. The *rise time* is the time required for a gradient to reach its maximum strength. The *slew-rate* is the rate at which the gradient changes with time [18].

4.2.13 Eddy Currents

Eddy currents are electrical currents that are induced or generated in metal structures or conducting materials that are within a changing magnetic field. Since gradients are strong, rapidly changing magnetic fields, they are capable of producing undesirable eddy currents in some of the metal components of the magnet assembly. This is undesirable because the eddy currents create their own magnetic fields that interfere with the imaging process. Gradients are designed to minimize eddy currents either with special gradient shielding or electrical circuits that control the gradient currents in a way that compensates for the eddy-current effects [18].

4.2.14: **Shimming**

One of the requirements for good imaging is a homogeneous magnet field. This is a field in which there is uniform field strength over the image area. Shimming is the process of adjusting the magnetic field to make it more uniform. In homogeneities are usually produced by magnetically susceptible materials located in the magnetic field. The presence of these materials produces distortions in the magnetic field that are in the form of in homogeneities. This can occur in both the internal and external areas of the field. Each time a different patient is placed in the magnetic field, some in homogeneities are produced. There are many things in the external field, such as building structures and equipment that can produce in homogeneities. The problem is that when the external field is distorted, these distortions are also transferred to the internal field where they interfere with the imaging process. In homogeneities produce a variety of problems that will be discussed later. It is not possible to eliminate all of the sources of in homogeneities. Therefore, shimming must be used to reduce the in homogeneities. This is done in several ways. When a magnet is manufactured and installed, some shimming might be done by placing metal shims in appropriate locations. Magnets also contain a set of shim coils. Shimming is produced by adjusting the electrical currents in these coils. General shimming is done by the engineers when a magnet is installed or serviced. Additional shimming is done for individual patients. This is often done automatically by the system [18].

4.2.15: Magnetic Field Shielding

The external magnetic field surrounding the magnet is the possible source of two types of problems. One problem is that the field is subject to distortions by metal objects (building structures, vehicles, etc.) as described previously. These distortions produce in homogeneities in the internal field. The second problem is that the field can interfere with many types of electronic equipment such as imaging equipment and computers. It is a common practice to reduce the size of the external field by installing shielding as shown in Figure 4-4. The principle of magnetic field shielding is to provide a more attractive return path for the external field as it passes from one end of the magnetic field to the other. This is possible because air is not a good magnetic field conductor and can be replaced by more conductive materials, such as iron. There are two types of shielding: *passive* and *active*.

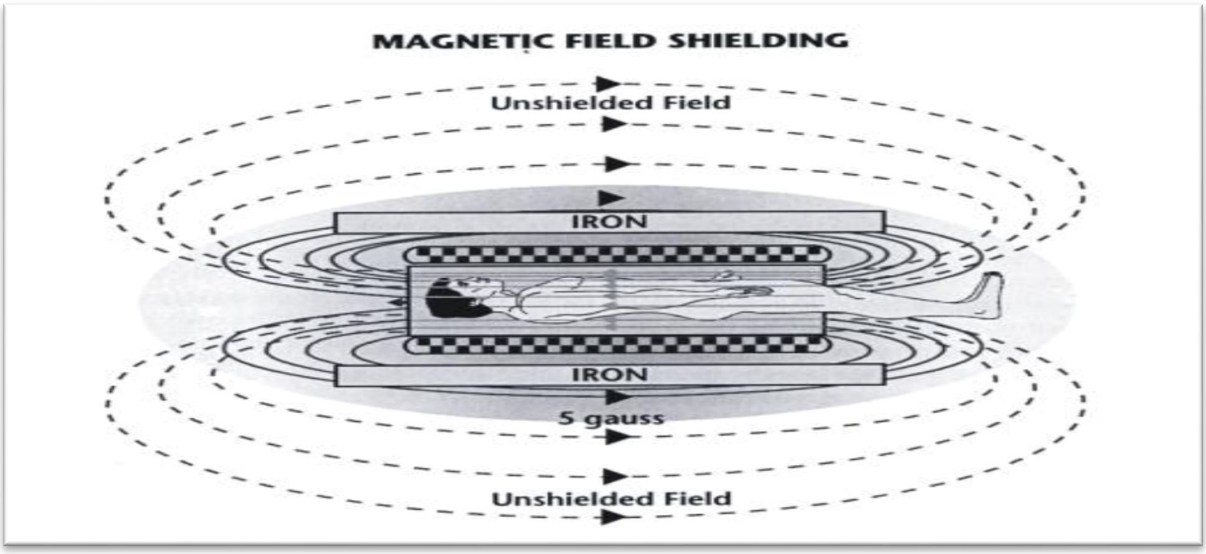

Figure 4.4: The principle of magnetic field shielding

4.2.16: Passive Shielding

Passive shielding is produced by surrounding the magnet with a structure consisting of relatively large pieces of ferromagnetic materials such as iron. The principle is that the ferromagnetic materials are a more attractive path for the magnetic field than the air. Rather than expanding out from the magnet, the magnetic field is concentrated through the shielding material located near the magnet as shown in Figure 3.4. This reduces the size of the field [18].

4.2.17: Active Shielding

Active shielding is produced by additional coils built into the magnet assembly. They are designed and oriented so that the electrical currents in the coils produce magnetic fields that oppose and reduce the external magnetic field [18].

4.2.18: the Radio Frequency System

The radio frequency (RF) system provides the communications link with the patient’s body for the purpose of producing an image. All medical imaging modalities use some form of radiation (e.g., x-ray, gamma-ray, etc.) or energy (e.g., ultrasound) to transfer the image from the patient’s body. The MRI process uses RF signals to transmit the image from the patient’s body. The RF energy used is a form of non-ionizing radiation. The RF pulses that are applied to the patient’s body are absorbed by the tissue and converted to heat. A small amount of the energy is emitted by the body as signals used to produce an image. Actually, the image itself is not formed within and transmitted from the body. The RF signals provide information (data) from which the image is reconstructed by the computer. However, the resulting image is a display of RF signal intensities produced by the different tissues [18].

4.2.19: RF Coils

The RF coils are located within the magnet assembly and relatively close to the patient’s body. These coils function as the antennae for both transmitting signals to and receiving signals from the tissue. There are different coil designs for different anatomical regions (shown in Figure 4-5), The three basic types are body, head, and surface coils. In some applications the same coil is used for both transmitting and receiving; at other times, separate transmitting and receiving coils are used [18].

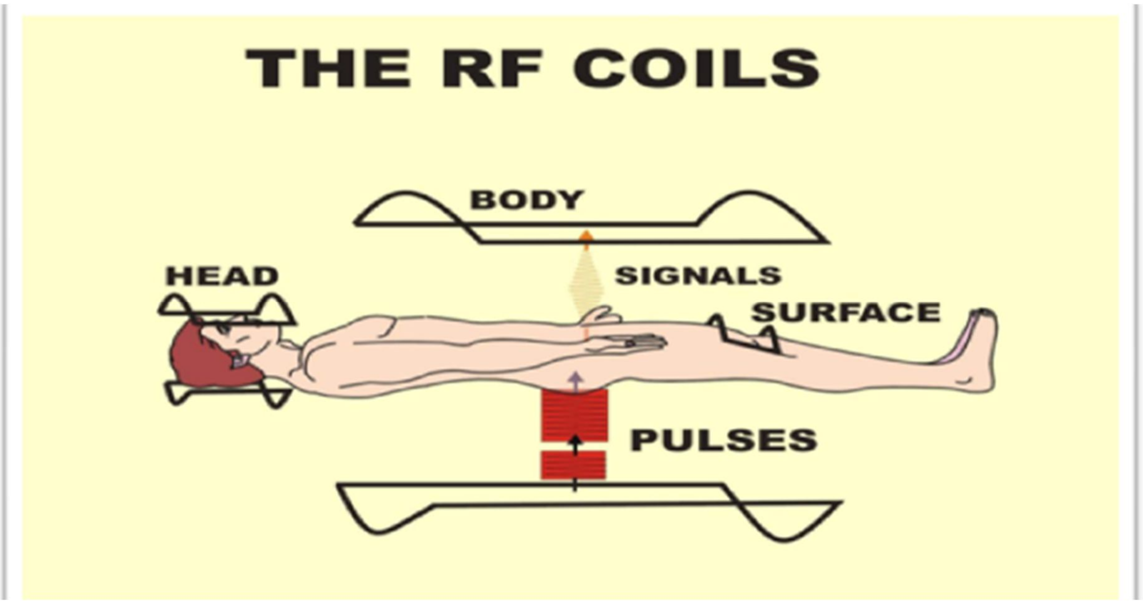

Figure 4.5: The three types of RF coils (body, head, and surface) that are the antennae for transmitting pulses and receiving signals from the patient's body.

Surface coils are used to receive signals from a relatively small anatomical region to produce better image quality than is possible with the body and head coils. Surface coils can be in the form of single coils or an array of several coils, each with its own receiver circuit operated in a *phased array* configuration. This configuration produces the high image quality obtained from small coils but with the added advantage of covering a larger anatomical region and faster imaging [18].

4.2.20: Transmitter

The RF transmitter generates the RF energy, which is applied to the coils and then transmitted to the patient’s body. The energy is generated as a series of discrete RF pulses. The transmitter actually consists of several components, such as RF modulators and power amplifiers, but for our purposes here we will consider it as a unit that produces pulses of RF energy. The transmitters must be capable of producing relatively high power outputs on the order of several thousand watts. The actual RF power required is determined by the strength of the magnetic field. It is actually proportional to the square of the field strength. Therefore, a 1.5 T system might require about nine times more RF power applied to the patient than a 0.5 T system. One important component of the transmitter is a power monitoring circuit [18].

4.2.21: Receiver

A short time after a sequence of RF pulses is transmitted to the patient’s body, the resonating tissue will respond by returning an RF signal. These signals are picked up by the coils and processed by the receiver. The signals are converted into a digital form and transferred to the computer where they are temporarily stored [18].

4.2.22: RF Polarization

The RF system can operate either in a linear or a circularly polarized mode. In the circularly polarized mode, Quadrature coils consist of two coils with a 90° separation. This produces both improved excitation efficiency by producing the same effect with half of the RF energy (heating) to the patient, and a better signal-to-noise ratio for the received signals [18].

4.2.23: RF Shielding

RF energy that might be in the environment could be picked up by the receiver and interfere with the production of high quality images. There are many sources of stray RF energy, such as fluorescent lights, electric motors, medical equipment, and radio communications devices. The area, or room, in which the patient’s body is located, must be shielded against this interference. An area can be shielded against external RF signals by surrounding it with an electrically conducted enclosure. Sheet metal and copper screen wire are quite effective for this purpose. The principle of RF shielding is that RF signals cannot enter an electrically conductive enclosure. The thickness of the shielding is not a factor even thin foil is a good shield. The important thing is that the room must be completely enclosed by the shielding material without any holes. The doors into imaging rooms are part of the shielding and should be closed during image acquisition [18].

4.3: MRI Advantages and Disadvantages

4.3.1: Advantages

MRI is particularly useful for the scanning and detection of abnormalities in soft tissue structures in the body like the cartilage tissues and soft organs like the brain or the heart, There is no involvement of any kind of radiations in the MRI, so it is safe for the people who can be vulnerable to the effects of radiations such as pregnant women or babies , MRI scan can provide information about the blood circulation throughout the body and blood vessels and also enabling the detection of problems related to the blood circulation [19].

4.3.2: Disadvantages

MRI scan is done in an enclosed space, so the people who are claustrophobic, i.e. fearful of being in a closely enclosed surface, are facing problems with MRI to be done, MRI scans involve really loud noises while processing because they involve a really high amount of electric current supply ,MRI scanners are usually expensive [19].

Chapter five

5.1: Medical uses

MRI has a wide range of applications in medical diagnosis and over 25,000 scanners are estimated to be in use worldwide [19]. MRI affects diagnosis and treatment in many specialties although the effect on improved health outcomes is uncertain. Since MRI does not use any ionizing radiation, its use is generally favored in preference to CT when either modality could yield the same information, MRI is not preferred as it can be more expensive, time-consuming, and claustrophobia-exacerbating [20].

5.1: Magnetic Resonance Imaging (MRI) – Head

Magnetic resonance imaging (MRI) of the head uses a powerful magnetic field, radio waves and a computer to produce detailed pictures of the brain and other cranial structures that are clearer and more detailed than other imaging methods. This exam may require an injection of a contrast material called gadolinium, which is less likely to cause an allergic reaction than iodinated contrast material, tell your doctor about any health problems, recent surgeries or allergies and whether there’s a possibility you are pregnant. The magnetic field is not harmful, but it may cause some medical devices to malfunction. Most orthopedic implants pose no risk, but you should always tell the technologist if you have any devices or metal in your body. Guidelines about eating and drinking before your exam vary between facilities. Unless you are told otherwise, take your regular medications as usual. Leave jewelry at home and wear loose, comfortable clothing. You may be asked to wear a gown. If you have claustrophobia or anxiety, you may want to ask your doctor for a mild sedative prior to the exam [21].

MRI uses a powerful magnetic field, radio frequency pulses and a computer to produce detailed pictures of organs, soft tissues, bone and virtually all other internal body structures. Detailed MR images allow physicians to evaluate various parts of the body and determine the presence of certain diseases. The images can then be examined on a computer monitor, transmitted electronically, printed or copied to a CD, Currently; MRI is the most sensitive imaging test of the head (particularly the brain) in routine clinical practice [22].

5.1.2: Brain Imaging

Autism Spectrum Disorders (ASDs) are a constellation of psychological conditions that share common behavioral effects. It is clear that the direct cause of the affected behaviors is changes in how the brain of a person with ASD is put together and how it functions. Researchers have been using brain imaging studies to look for changes in the brains of people with ASD since the early 1960s. However, the past 15 years have been marked by the development of new brain imaging techniques and by an ever-growing interest in using these techniques to study autism. In the past 50 years, approximately 1,500 research papers have been published about studies of the brains of people with autism. The same number of papers will probably be published in the next 6 years, here, we look at exactly what brain imaging studies are, what they can tell us, and what prospects they have of helping those diagnosed with ASD (and even those who have not yet been diagnosed with ASD). We also look at another brain-based disorder that has benefited from more brain imaging studies [23].

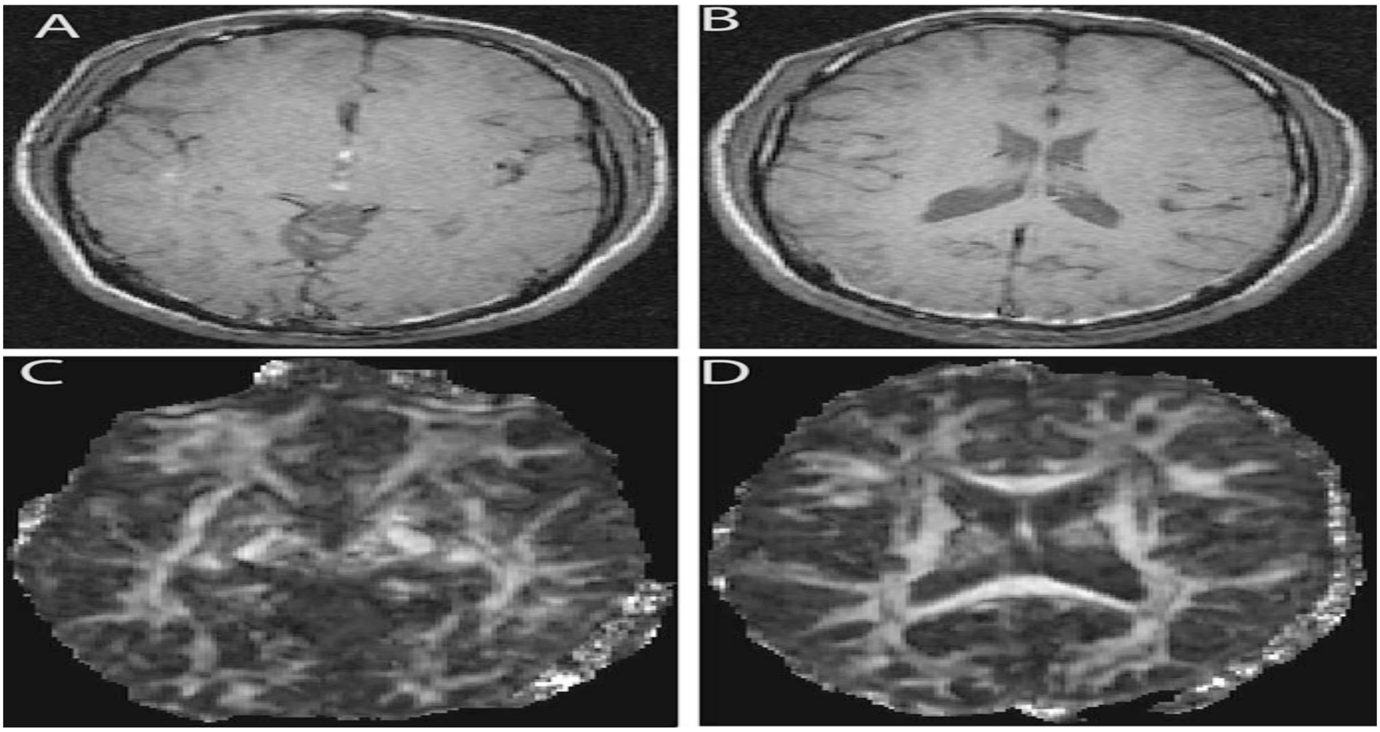

Figure 5.1: Structural image and its FA maps. (A and B) are MRI structural images. (C and D) are the Corresponding FA maps.

5 .1.3: Measuring brain

Researchers measure four different components in human brain studies:

The volumes and positions of the different brain areas, the interconnections between different brain areas, the activity of a particular brain area and the chemical composition of a brain area [23].

5.1.4: Measuring volumes and positions of different brain areas

If you were asked to find differences in the brain of a person diagnosed with ASD, probably your first approach would be to look at brains and see whether there are any differences between an individual with ASD and a neurotypical person. Although this can be done after a person dies, it is more common to do this while the person is still alive. The workhorse for this approach has been a technique called magnetic resonance imaging (MRI) [24].

5.1.5: Measuring interconnections between different brain areas

In the early 1990s, some researchers found a way to slightly modify the MRI technique to measure connections between areas [2].This modified technique is called diffusion tensor imaging (DTI). The number of studies using this technique is growing rapidly, and we are now at the beginning of an era of connectivity studies in the human brain [24].

5.1.6: Measuring the activity of a particular brain area

Neurons use a lot of energy and oxygen when they are busy processing information. The brain appears to be compartmentalized in some way so that different areas process different types of information. So, at least in theory, if you can measure where energy is being used while a person is performing a certain task, then you can deduce what each brain area does. And for people with ASD, perhaps you could find areas that are not being used when they should be [24].

5.1.7: Measuring the chemical composition of a brain area

Neurons function by communicating with other neurons. One of the ways that a neuron can "talk" to another neuron is by transferring a specific chemical, or neurotransmitter. When researchers looked at different brain areas, they found that each area had a specific set of neurotransmitters that was different from those of other brain areas. The set of neurotransmitters found in a brain area affects the types of messages it can send to the rest of the brain [25].

5.2: Conclusion

Magnetic Resonance Imaging is one of the most efficient and inventions in history, it can make many things that were not possible earlier, to be possible. Some of these things are the way that MRI examines the body. MRI does not radiate any unhealthy waves to the body that can be mutating the human gene.

Despite the astonishing advantages of MRI, the fact that it is not for everyone to afford makes MRI an unreachable for developing world countries. The principles of physics behind this amazing machine sparked an interest in me and I am hoping for more people to be influenced by the connection of these concepts to our daily lives. The only major concern over the technology is its expense. For the best quality of imaging, unfortunately it is not possible to exchange any of the parts with affordable pieces. Extensions to the technology of MRI can be the elimination of certain iron/metal body implants by the magnets in the MRI. MRI does not let any patient to go in it with any body piercings/implants that contain any metal. This project has helped me to develop many areas of my understanding of modern science and improved my appreciation towards the advantages science provides us today**.**

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