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Research Article

AN OVERVIEW TO MEDICAL IMAGING TECHNIQUES AND NON-INVASIVE MRI MEDICAL SYSTEM – AS A SCIENTIFIC DIAGNOSTIC TOOL

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ABSTRACT

Medical imaging is an essential diagnostic tool in medical field and one of the main key issues in health care. Medical imaging is done through invasive, minimally invasive and non-invasive techniques. Medical imaging through non-invasive technique is widely used to view the internal organs of human body. Among the various non-invasive medical imaging modalities, ultrasound medical imaging and magnetic resonance imaging modalities are used for imaging the internal organs as these imaging modalities are safe, risk free, no harmful radiation exposures and do not cause any damage to tissues of the human body. Biomedical image processing has been an interdisciplinary research field which interests many experts and researchers from various fields. The principal objective of this review article is to discuss on the advantages of using magnetic resonance imaging over ultrasound imaging modality, provide an introduction to basic principles and instrumentation of magnetic resonance imaging medical system, generation of magnetic resonance signals and how to process and analyze a significant volume of images for getting high quality anatomical information for diagnosing abnormalities of internal organs within human body thereby to promote interests for further study and research in medical imaging and medical image processing.

INTRODUCTION

Medical Imaging Techniques

The direct way to look the internal organs of a human body is to cut it open i.e., through surgery known as invasive technique (surgical procedure). A refinement of this surgical procedure might be to use an endoscope known as minimally invasive technique i.e., a light tube is threaded through the body which conveys an image of the internal organ to a display device (endoscopic procedure). Both these surgical and endoscopic procedures use invasive techniques which offer direct optical viewing of the internal organs of human body. But these invasive techniques involve cutting or operating and inserting a physical device through the body to view the internal organs and thus have the potential to cause damage or trauma to the human body cells or tissues. Another way to look the internal organs of human body cells or tissues without causing any damage can be achieved by adapting non-invasive techniques. Thus by using these non-invasive techniques in medical imaging is considered as the best way to view and diagnose the internal organs abnormalities of human body easily if present.

METHODS AND MATERIALS

Non-Invasive Medical Imaging Modalities

Medical imaging through non-invasive techniques allow us to view the internal organs that are not visible to our naked eye without any need to cut the body or put a physical device to view the internal organs of the human body. There are various non-invasive medical imaging modalities such as projection radiography, x-ray computed tomography, nuclear medicine imaging, ultrasound imaging and magnetic resonance imaging. Non-invasive medical imaging modalities such as ultrasound imaging (USI) [1, 2] and magnetic resonance imaging (MRI) [3, 4] are safe, risk free and does not involve any harmful ionizing radiation exposure on tissues and does not cause any damage or trauma to the human body. Some non-invasive medical imaging modalities such as projection radiography, X-ray computed tomography (X-Ray CT) [5] and nuclear medicine imaging (NMI) [8] has some risk as they are associated with harmful ionizing radiation exposure on tissues and has the potential to cause damage or trauma to the human body.

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Non-invasive Medical Imaging Principles

The various non-invasive medical imaging modalities allows us to get the images of internal organs inside the human body in different ways i.e., the signal obtained or measured is different in each case and can reveal anatomical information that the other imaging modalities cannot. Medical imaging through non-invasive technique allows us to acquire the images by using certain physical parameters of the body tissues such as reflectivity in ultrasound imaging (USI), and hydrogen proton density in magnetic resonance imaging (MRI). These physical parameters within the body are called as signals. These signals are the input signals given to a medical imaging system. In medical imaging, the 'object' or 'signal' arising from the patient are intrinsically different and depends on the physical processes governing a given medical imaging modality. Thus a given patient represents an ensemble of different objects or signals. While considering a given medical image, it is important to start with the physics that underlies in the creation of signals from the patient for a particular imaging modality. The first output of any medical imaging system is based on the physical measurements, which might be returning echoes in an ultrasound system, radio frequency waves in an MRI system or x-ray intensities in a CT [7] system. The final output in this medical imaging system is created through image reconstruction i.e., the process of creating an image from the measurements of input signals. The overall quality of a medical image is determined by how well the image portrays the true spatial distribution of the physical parameter(s) of interest within the human body. In the study of image quality some of the important factors such as resolution, noise, contrast, geometric distortion, artifacts and accuracy are to be considered. Thus we can say that the clinical utility of a medical image for diagnosing abnormalities involves both the image's quality and the medical information contained in the physical parameters themselves. Thus these medical imaging systems depend on the physics of each imaging modality.

Ultrasound Imaging Modality

Ultrasound imaging (USI) modality is a non-invasive imaging technique used for diagnosing tissue abnormalities. USI utilizes sound waves for getting the physical parameters of area of tissues of human body. The ideal frequency window for ultrasound in medical imaging is (1-20) MHz where 1Hz=1 cycle/sec.USI fires high frequency sound into the body and receives the echoes returning from the structures within the body area of interest and often called as reflection imaging because it relies on acoustic reflections to create images. The different physical parameters or signals arising from the patient by the process of reflection of ultrasonic waves within the human body are detected and transformed into medical images. USI uses electrical to acoustical transducers to generate repetitive bursts of high frequency sound. These pulses travel into the soft tissues of the human body and reflect back to the transducer. The time of return of these pulses gives information about the location (depth) of a reflector and the intensity of these pulses gives information about the strength of a reflector. By rapidly moving or scanning the transducer or its acoustical beam, real time images of cross-sections of soft tissues are generated. Image resolution is not adequate for wavelength longer than a couple of millimeters and attenuation is too high for very short wavelengths.

Ultrasound Imaging Medical System-Advantages

Ultrasound imaging systems are small and compact. Two transducers are connected with the connecting cables and only one transducer is used at any given time. Transducers with different frequencies and geometries are usually available to serve the examination requirements. USI systems are comparatively inexpensive, portable and completely non-invasive imaging at low intensities used and no ionizing radiation exposure. These USI systems are widespread, common in usage and are designed primarily to image the anatomy of internal organs of human body in real time.

Ultrasound Imaging Medical System-Artifacts and Limitations

In USI medical system, spurious echoes pretend as real echoes which are called as artificial echoes. These artificial echoes appear on the screen as factual echoes and can be misinterpreted as true echoes leading to erroneous diagnosis. The electrical interference from nearby equipments such as ECG monitors, cordless phones etc causes artificial noise. Incorrect distance markers can give false measurement and improper focusing results in fuzzy images and can cause difficulty in interpretation [10]. The respiratory movement of the patient causes breathing artifacts during the scan results in a fuzzy image. Improper selection of transducer and time gain compensation (TGC) settings will result in missing of lesions and loss of information. Too much transducer pressure during scan results in flat distortion of the image and leads to erroneous measurements [9, 10]. Bright echoes occur linearly throughout the section when TCG is improperly set and can also result in creation of atrifactual space occupying lesions in the internal organ studied. i.e., creation of liver abscess when there is none actually. Due to acoustic impedence mismatch ultrasound cannot penetrate through gas and bones i.e., at the soft tissue-bone and soft tissue-gas interface [9, 10]. So imaging could not been done by USI at these interfacing regions.

Magnetic Resonance Imaging Modality

Magnetic Resonance Imaging utilizes the electromagnetic energy. Electromagnetic energy or Electromagnetic waves consist of electric waves and magnetic waves travelling together at right angles. Wavelength and frequency are inversely related. Energy and frequency are directly related. The electromagnetic spectrum spans the frequency range from DC to cosmic rays and only a small portion of this spectrum is used in medical imaging. MRI requires a combination of high strength magnetic field and radio waves to image properties of proton nucleus of hydrogen atom. The physical signal in MRI arises from the precession motion of nuclei of the hydrogen atom i.e., protons. Hydrogen is the most abundant element present in all living organisms. Proton MRI plays well as a very good investigation method in medicine and biology by giving morphological information. MRI also gives additional diagnostic insights through relaxation parameters which are not possible by other imaging modalities. The three principal MRI parameters are spin density (SD), Spin-lattice or longitudinal relaxation time (T_1) and Spin-spin or transverse relaxation time (T_2). MRI modality exploits the property of nuclear magnetic resonance (NMR) phenomenon [6]. When subject area of interest to be investigated is placed on a large external magnetic field, collection of protons can be set into motion which is termed as spin systems. By applying radio frequency (RF) currents through wire coils surrounding the patient causes magnetization of protons of hydrogen atoms in the body tissues. These protons align and precess about the large external magnetic field. RF pulse at resonance frequency is transmitted into the patient under controlled and prescribed condition. Due to resonance condition the individual proton responds by emitting a RF signal called NMR signal. These protons emit NMR signals during their return from higher nuclear energy state to ground state. These NMR signals by the protons are picked up by RF coils and processed by computers using transforming techniques to produce an image of the area of investigation or interest of the internal organs.

Magnetic Resonance Imaging Medical System – Advantages

MRI has the following advantages over USI and other medical imaging modalities. MRI modality has superior contrast resolution [11]. Multiplanar imaging can be obtained directly i.e., slices in saggital, coronal, and oblique directions. No exposure of harmful ionizing radiations like X-rays, gamma rays, positrons etc. on tissues of human body. MRI can penetrate through the soft tissue-bone and soft tissue-gas interfaces to obtain accurate images. Thus it is the job of biomedical engineers and scientists to develop medical imaging systems to produce images that are as accurate as possible and useful in examining the internal organs area of interest of the human body. Hence we can say MRI non-invasive technique is safe, no harmful ionizing radiation exposure and is absolutely a risk free medical imaging diagnostic tool used for diagnosing abnormalities of internal organs without causing any damage to human body tissues.

Basic Principles of MRI System

MRI is a noninvasive tomographic imaging technique that produces images of physical and chemical characteristics of an internal organ from externally measured nuclear magnetic resonance (NMR) signals which is based on NMR phenomenon. MRI is safe, risk free and a reliable imaging diagnostic tool used by radiologists and physicians for detecting and diagnosing [12, 13] abnormalities. As the human body consists largely of H_2O, we hence usually prefer ^1H (proton) imaging [12]. The imaging process involves only the use of non-ionizing radiation and hence does not have the associated potential harmful effects. The NMR signals which are generated come directly from the subject area of investigation itself and these NMR signals are used for image formation. Then these acquired NMR signals are processed by digital signal processor to form a three dimensional computed tomography MR images.

Basic Instrumentation of MRI System

The instrumentation setup of basic MRI system is shown in fig.1. The three main hardware components of MR scanner are namely the main magnet, a magnetic field gradient system and a radio-frequency (RF) system as shown in fig. 1.

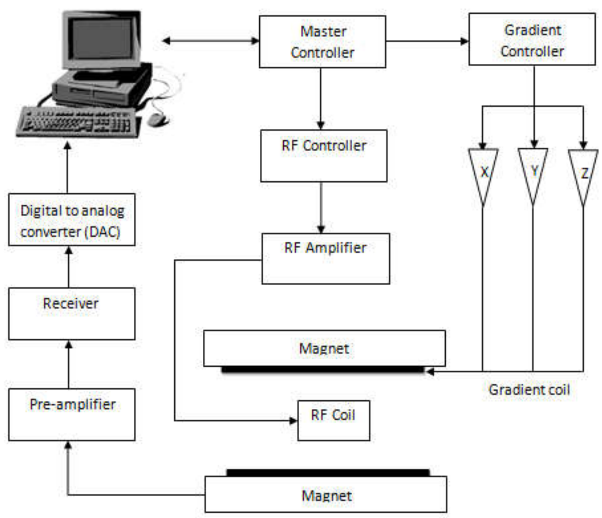

Fig 1 Basic MRI System Instrumentation setup

The main magnet is a permanent magnet and generates a strong uniform static field, B_0 for polarization of nuclear spins in the subject area of investigation. Most imaging systems operate at fixed field strength expressed in units of Tesla (1 Tesla (T) = 10^4 Gauss (G)). The magnetic field gradient system consists of three orthogonal gradient coils namely G_x, G_y and G_z essential for signal localization. The gradient field strength is usually less than 1 G/cm. The RF system consists of a transmitter coil capable of generating a rotating magnetic field, B_1 used for exciting a spin system and a receiver coil converts a precessing magnetization into an electrical signal. On imaging human internal organs, the strength of B_1 used is typically a small fraction of a Gauss.

Nuclear Magnetic Resonance Phenomenon

Especially from the signal processing point of view, MRI system is complex and the imaging principles of MRI system are rather straightforward. The imaging process of MR signals involves forward and inverse Fourier transforms. The MR imaging process does not have the potential harmful effects as it does not involve the use of ionizing radiation. MR signals acquired for image formation come directly from the subject area of interest itself. To understand how MR signals are generated requires the understanding of quantum mechanics in the classical vector model. Atoms with an odd number of protons and/or an odd number of neutrons posses a nuclear spin angular momentum and therefore exhibit the MR phenomenon. Qualitatively these nucleons can be visualized as spinning charged spheres that give rise to a small magnetic moment is referred to as spins as shown in fig. 2.

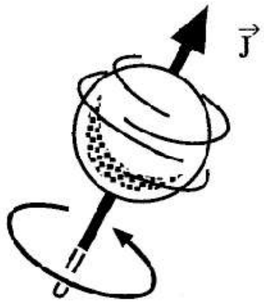

Fig 2 Nuclei with a nonzero spin are regarded as microscopic magnets.

In biological specimens, hydrogen (^{1}H) with a single proton is the most abundant and sensitive and usually used for the anatomical study of most internal organs of human body.

Larmor Frequency

In the absence of an external magnetic field, the spins are oriented randomly due to thermal random motion and the net macroscopic magnetic moment is zero as given in fig. 3 (a). To activate macroscopic magnetism from a subject, it is necessary to line up the spin vector. This is accomplished by exposing the subject to a strong external magnetic field B_0. The magnetic moment vectors tend to align in the direction of B_0 (referred to as the z direction) to create a net magnetic moment M as shown in fig. 3 (b) [12, 13]. Also the spins exhibit resonance at a well-defined frequency, called the Larmor frequency, ω. The Larmor frequency, ω is defined as

$$\omega = \gamma B_0 \quad \text{or} \quad f = \frac{\gamma}{2\pi} B_0$$

where γ, denotes the gyromagnetic ratio which is a known constant for each type of atom. For ^{1}H, $\gamma/2\pi$ = 42.58MHz/Tesla.

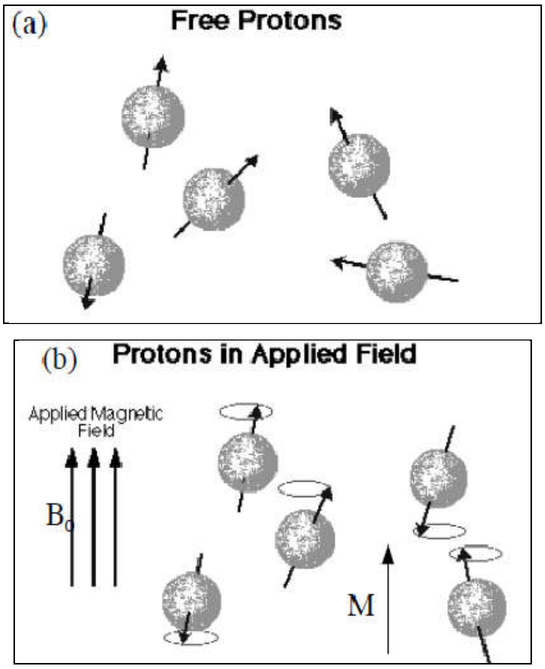

Fig 3 Nuclear magnetic moment vectors (a) pointing in random directions and (b) aligned in the direction of an external magnetic field.

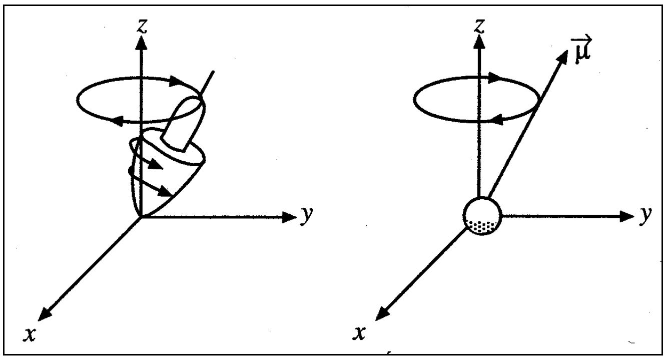

Fig 4 Precession of a nuclear spin about an external magnetic field is similar to the wobbling of a spinning top in a gravitational field.

MR Signals Formation

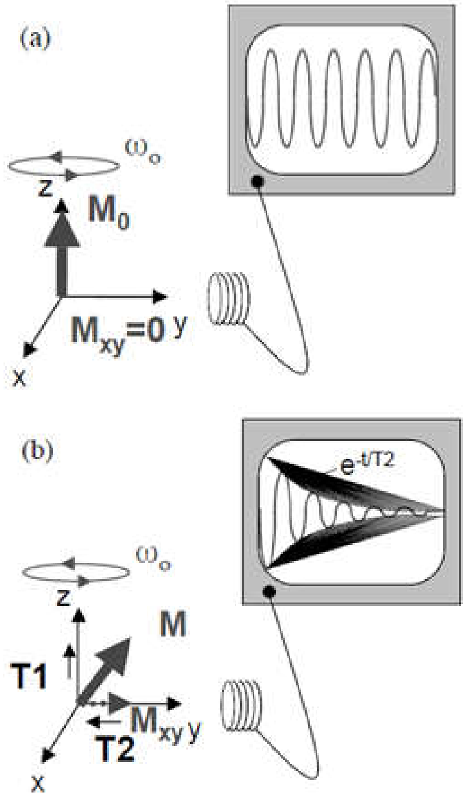

Fig 5 (a) Precessing nuclei induce a voltage in a receiver coil placed parallel to the x-y plane. Frequency of induced voltage is the same as the precessional frequency ω_0. (b) Detected signal is modulated by the fundamental relaxation process, T_1 and T_2 decays. Both processes decrease M_{xy} as $M \rightarrow M_0$.

As an analogy, precession of a nuclear spin about an external magnetic field is similar to a spinning top does in a gravitational field as shown in fig. 4. At equilibrium, the transverse component of M_0 (i.e., the projection of M_0 in the x-y plane, namely, M_{xy}) is zero as given in fig. 5. To obtain a MR signal, a RF field B_1 applies an external force on the transverse plane to excite these spins out of equilibrium and tip M_0 away from the z-axis (the direction of B_0), creating a measurable (nonzero) transverse component M_{xy} as given in fig. 5b. When turning the excitation off, relaxation back to its equilibrium also occurs with the length of the magnetization vector [14, 15] not remaining constant over time.

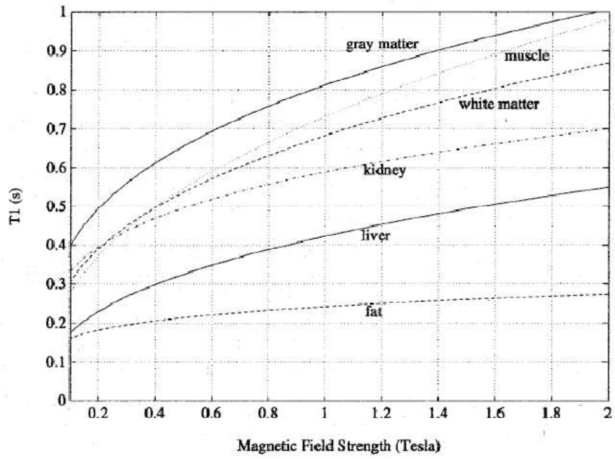

Fig 6 Approximate T_1 values as a function of B_0.

The time constant characterizing the return of the magnetization vector along the z-axis (longitudinal axis) is called T_1, while the time constant characterizing the decay of the transverse component is called T_2. In humans, T_1 values of most tissues range from about 100-1500 ms as shown in fig. 6 and T_1 values increase as B_0 increases. T_2 values range from about 20-300ms as given in Table 1 and it is largely independent of field strength [12].

Table 1 T_2 values of some normal tissue types.

Normal Tissue Types	T_2 (ms)
Gray matter	100
White matter	92
Muscle	47
Fat	85
Kidney	58
Liver	43

MR Images as a Scientific Diagnostic Tool

MR images are extremely rich in anatomic information content. The image pixel value can be considered as a function of a host of parameters, including the relaxation time constants T_1 and T_2, and the proton density (that has distinct values for different tissues). Therefore, by changing the effect of these parameters, MR images obtained from the same anatomical position can look drastically different [16]. These images can be further processed to produce new maps regarding water diffusion and blood flow etc [17]. Hence, the flexibility in data acquisition and the rich contrast mechanisms of MRI endow the technique with superior scientific diagnostic values [17].

DISCUSSION AND CONCLUSION

Medical imaging relies on non-invasive techniques to image body structures and to analyze functions of internal organs of human body. Due to acoustic impedence mismatch ultrasound cannot penetrate through gas and bones i.e., at the soft tissue-bone and soft tissue-gas interface. So imaging at these interfacing regions is possible by using MR imaging modality than US imaging modality. The advantages of using non-invasive MRI for imaging internal organs than USI as an imaging modality in medical diagnostics were discussed briefly. The physical signal of interest is defined by the imaging modality and specific imaging physical parameters. So the clinicians, radiologists and technical operators are trained to look for specific patterns defined by the particular imaging modality and specific imaging physical parameters in acquiring medical images for subject area of investigation. These specific patterns depend on both the patient and the imaging modality. NMR signals provide rich anatomic information of the subject area of interest. These NMR signals are processed by digital signal processor to get three dimensional computed tomography MR images based on MR phenomenon. The MR image pixel is considered as the function of a host of physical parameters. The differences in the expected signal help the examiner to differentiate the healthy and diseased condition of tissues. As we have discussed that noninvasive MRI medical imaging modality is safe, reliable and risk free using only non ionizing radiations for imaging the internal organs, we conclude that non-invasive MR imaging modality could be used as a scientific diagnostic tool by radiologists and physicians for diagnosing abnormalities of internal organs to differentiate the cancer cells from the normal cells of the examined subject area of interest within the human body.

References

1. PNT Wells, “Ultrasound imaging”, IOP Publishing Ltd., *Physics in Medicine and Biology*, vol. 51, no. 13, 2006.
2. Aldrich, John E. PhD, FCCPM, “Basic physics of ultrasound imaging”, *Critical Care Medicine*: vol. 35, no. 5, pp. S131-S137, 2007.
3. Z-P Liang, PC Lauterbur, “Principles of Magnetic Resonance Imaging: a signal processing erspective”, IEEE press series in biomedical engineering, 1999.
4. N Bloembergen, EM Purcell and RV Pound, “Relaxation effects in nuclear magnetic resonance absorption”, *Phys. Rev*., vol. 73, pp. 679-712, 1948.
5. Singh S , Kalra MK, Gilman MD, Hsieh J, Pien HH, Digumarthy SR, and Shepard JA, “Adaptive statistical iterative reconstruction technique for radiation dose reduction in chest CT: a pilot study”, *Radiology,* vol. 259, no. 2, pp. 565-573, 2011.
6. Santhi Maniam and Janio Szklaruk, “Magnetic resonance imaging: Review of imaging techniques and overview of liver imaging”, *World J Radiol.* vol. 2, no. 8, pp. 309–322, 2010.
7. Jensen K, Andersen HK , Tingberg A , Reisse C , Fosse E, and Martinsen AC, “Improved Liver Lesion Conspicuity With Iterative Reconstruction in Computed Tomography Imaging”, *Curr Probl Diagn Radiol*., vol. 45,no. 5, pp. 291-296, 2016.
8. Pat Zanzonico, “Principles of Nuclear Medicine Imaging: Planar, SPECT, PET, Multi- modality, and Autoradiography Systems”, *Radiation Research*, vol. 177, no. 4, pp. 349-364. 2012.
9. Wei Lu , Oleg A. Sapozhnikov , Michael R. Bailey , Peter J. Kaczkowski , Lawrence A.Crum, “Evidence for Trapped Surface Bubbles as the Cause for the Twinkling Artifact in Ultrasound Imaging”, *Ultrasound in Medicine & Biology,* vol. 39, no. 6, pp. 1026-1038, 2013.
10. Gimber L.H., Taljanovic M.S., “ultrasound imaging artifacts”, Pitfalls in Musculoskeletal Radiology, Springer Cham, pp. 33-44, 2017.
11. Mahoney MC, Newell MS., “Screening MR imaging versus screening ultrasound: pros and cons”, *Magn Reson Imaging Clin N Am*., vol. 21, no. 3, pp. 495-508, 2013.
12. N Bloembergen, EM Purcell, and RV Pound, “Relaxation effects in nuclear magnetic resonance absorption,” *Phys. Rev*. vol. 73, pp. 679-712, 1948.
13. DG Nishimura, Principles of Magnetic Resonance Imaging, 1996.
14. D Canet, Nuclear Magnetic Resonance: Concepts and Methods, John Wiley & Sons, New York, 1996.
15. RH Hashemi and WG Bradley Jr., MRI: The Basics, Williams & Williams, Baltimore, MD, 1997.
16. M NessAiver, All You Really Need to Know about MRI Physics, Simply Physics, Narcissus Ave, Baltimore, MD, 1997.
17. WJ Schempp, Magnetic Resonance Imaging: Mathematical Foundations and Applications, John Wiley and Sons, New York, 1998.