Anatomical and Functional Imaging Modalities: A Brief Review

Ayush Dogra[1], Bhawna Goyal[1], Sunil Agrawal[1,] B.S.Sohi[2]
[1]*UIET, PANJAB UNIVERSITY CHANDIGARH*
[2]*CHANDIGARH UNIVERSITY, CHANDIGARH*

Abstract**—**The precise and accurate diagnose of an ailment is foundation of an effective medical aid. For this the medical fraternity relies heavily upon the various radiographic scans which help in the diagnosis, staging and treatment of a particular disease. These imaging modalities depict the anatomical, functional as well as molecular level information about body organs. In this paper we have presented the basic principle, advancement and applications of some of the major imaging modalities. These multi-sensor images depicting complimentary information are fused together to generate a composite image with higher amount of information.

Keywords—*radiogarphy, radiation, angiogarphy, magnetic resonance, modalities, imaging*

I. INTRODUCTION

Medical Imaging is an extensively studied subject in literature. The various abnormalities which are reflected by the images of different organs of the body are localized with the help of such imaging modalities. There is an abundance of research work published in journals and magazines since 2000 [1]. This can largely be attributed to the fact that there is an increased usage of medical diagnostic devices by the medical community, sustained by advancement in low computing and imaging techniques [2]. The medical technologies like image registration [3,4], image denoising [5,6], image enhancement [7,8,9] and image fusion [10-14] serves an extremely user-friendly platform to the medical practitioners, strengthening their improved and precise diagnosis. The applicability of imaging is not just limited to being an important research topic, rather has reached advanced hospitals across the globe.

The general information about structuring of an atom, basic elementary nuclear physics, the generation of X-rays and the nature of electromagnetic radiation is essential to the comprehension of the physics of medical imaging. Radiation may be characterized as particulate or electromagnetic, with electromagnetic waves including visible light, ultraviolet, visible light, X rays and gamma rays and particulate radiation includes electrons, positrons, protons and neutrons. There is a huge variety of medical imaging modalities which serve as fundamental inputs to several imaging technologies. The major kinds of imaging modalities are CT (Computed Tomography), MRI (Magnetic Resonance Imaging), PET (Positron Emission Tomography), X-Ray, Ultrasound, SPECT (Single Photon Emission Tomography) and DSA (Digital Subtraction Angiography). These imaging modalities finds applications in assessment of various organs of the body like brain, bone, teeth, soft tissues, blood vessels, breast and stomach etc [1, 2, 10, 15].

These medical imaging modalities are often corrupted with various types of noises such as MRI is corrupted with Gaussian and Rican noise and PET and SPECT are corrupted with speckle noise [16].

These multi-sensor imaging modalities possess information which is complimentary. These images serve as the primary inputs to the field of medical image fusion. To enhance the image fusion quality, these images need to be denoised and enhanced prior to image fusion

In this paper we are presenting a brief insight into basic definition, history, usage and applications of some of the major types of imaging modalities.

II. X-RAY

Any electromagnetic wave can be distinguished by its amplitude, frequency, wavelength and its velocity. On the electromagnetic spectrum, the wavelength of X-ray ranges in nm (nanometres 10^{-9}) and frequency in the range of 10^{16} -10^{19} Hz (Hertz). X-rays have wavelengths shorter than the visible light. In some parts across the world X-ray is also known as Rontgen radiation after the name of its discoverer, German scientist Wilhelm Rontgen. It was identified as an unknown radiation, hence the name X-ray is famous since its discovery in 1985. The underlying property that makes X-Ray very popular in medical imaging is that it can identify bone structures. By exposing the patient to the X-ray radiation, 2-dimensional projection radiographs can be produced. The regions where X-rays are blocked by the object in the body are projected as shadows (white areas) on the radiographic plains and the black regions are those areas where the X-Rays are not stopped by the object [17, 18].

The primary body organs capable of blocking the X-Rays and projecting them, which further can be read for ailments using X-ray radiography include bones and soft tissues. One can predict the basic pathology of the skeletal system using X-rays but it harder to depict the type of the tissue (hard or soft) as there are low on density. For instance, chest X-rays are used to identify ailments like pneumonia and lung cancer. Abdominal X-rays can be used to detect the bowel movements along with trapped and free air in the intestines. Dental radiographs are very useful in finding cavities in the teeth. Besides these and several other applications X-rays are also used in management and treatment of skin cancers, lung cancer, breast and prostate cancer. However the X-ray radiography should be handled very carefully as it can cause adverse effects, if a patient is exposed to the higher doses of the same. Fig.1 shows examples of plain radiographs.

Fig 1 Female Chest X-ray; Knee X-ray; Neck X-ray (L-R) [19]

III. CT

The conventional tomography (X-Ray imaging) was unable to represent the subtle changes with less than 5 percent of contrast variation. The conventional tomography could not project the structures below and above the tomographic objects due to very slight difference in their contrast values. To a significant extent these problems were resolved by Computed Tomography (CT) by enabling the visualization of anatomy of various sections of body. Although spatial resolution of objects about a millimetre was better represented with X-ray, the subject contrast was clearly visible with CT [20].

A CT scan produces a combination of many X-rays taken from different angles which are processed by a computer. These X-ray taken from various angles acquires a series of radiographs (virtual slices) of various cross sections of the organ/object under study allocating the user with an inside view of the object without actually cutting them. The results of these 2-D axial CT slices are further accumulated to form a 3D representation of the object under study. The CT scans are primarily used in overall estimation of colon health with help of CT colonography and vascular condition/ blood flow (CT angiography). CT pulmonary angiogram is used to diagnose pulmonary embolism. The images of the pulmonary arteries are obtained with iodine based contrast agent and CT. The ability of CT scans to construct area of interest in many planes enables the depiction of the complex fractures, ligament injuries and dislocations. CT scans are also employed in diagnosis and staging of cancer and abdominal diseases. CT scans also enables a very effective visualization of the coronary arteries because of producing multiple slices at high resolution as well as at high speed [20]. Fig 2 shows the CT scan of pulmonary arteries demonstrating a saddle embolus and Fig 3 shows the CT scan of brain.

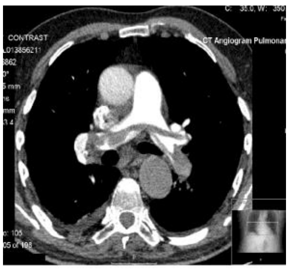

Fig.2 Computed Tomography for pulmonary arteries [21]

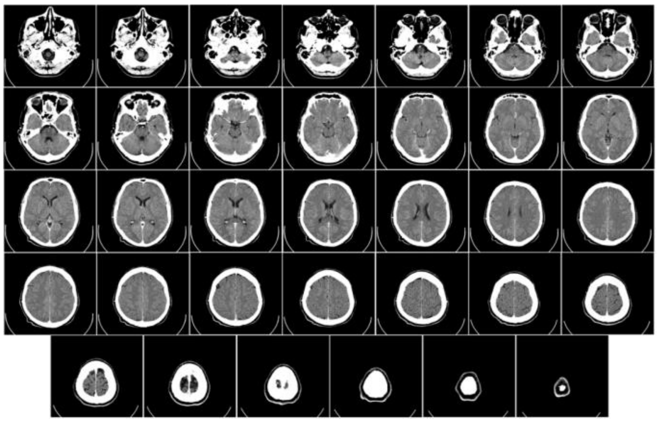

Fig.3 Computed Tomography of brain from skull to back taken with a contrast medium [22]

IV. EMISSION COMPUTED TOMOGRAPHY [ECT]

Unlike various other imaging modalities which focus on anatomical studies, emission computed tomography deals with physiology of the organs as well as functions and mapping associated with those organs. ECT can be understood as computed tomography which uses radioactive substances. ECT is the documentation of track of a radioactive substance inside the object under study. The two types of emission computed tomography are

- PET (Positron Emission Tomography)
- SPECT (Single Positron Emission Computed Tomography).

A. PET

PET is a nuclear medicine functional imaging technology which helps in the observation of different metabolism related processes in the body. A PET system records 2D radiographs detecting the gamma rays released by a positron emitted by radioactive nuclide like ^{11}C, ^{13}N, ^{15}O and ^{18}F. Then the computer analysis generates the 3D images of the tracer concentration. PET finds extensive application in clinical oncology i.e. detection of tumours and metastasis and diagnosis of various diffuse brain ailments which causes dementias. Also, it is an important research tool used for the mapping of normal human brain and heart function [23].
Besides these PET finds its applications in the diagnosis of Atherosclerosis and various infectious diseases. Fig 4 shows the image of a brain positron emission tomography.

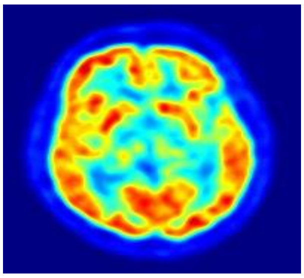

Fig.4 Brain Positron Emission Tomography [24]

B. SPECT

Single positron emission tomography is very similar to the conventional nuclear substance imaging technique however in SPECT; the photonic radiations emitted by the radioactive tracer are recorded as time independent events. It provides more true information than PET which can be reformatted or manipulated as per need. SPECT is the basic functional imaging modality which provides information about the functional changes in the region of interest which precedes any anatomical change or abnormality in the body.

Though other imaging modalities like CT and MR provide higher spatial resolution, PET and SPECT are extremely sensitive to the changes in contrast, even at the order picomolar concentrations. In SPECT the soluble radioactive is injected into the blood stream, whose properties bind itself to the tissue to create a radioligand. This bonding of the ligand and the radioactive medicine carries them to area of the interest and hence the concentration spread of the ligand is viewed by gamma ray sensitive cameras.

Since SPECT provides accurate localization in 3D space it is actively employed in the study of the blood stream blow in organs and tissues, brain imaging, cancer detection and treatment, liver ailment diagnosis and biopsy. Fig 5 shows brain imaging with a SPECT scan [25].

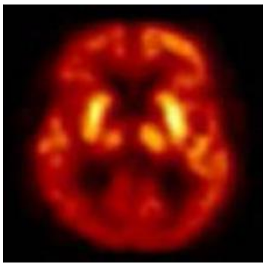

Fig 5 Brain SPECT scans [17]

V. DSA (DIGITAL SUBTRACTION ANGIOGRAPHY)

Digital subtraction angiography (DSA) is a modern fluoroscopic radiographic technology used to diagnose vascular diseases. The DSA technique successfully acquires the images of the bone and vessels located in the several segments of the body and have proven its efficacy in representing the arterial information present within the background of dense bones and soft tissues. The basic principle idea of the DSA can be understood as the working of a CT scanner. The usability of DSA for human subjects came into commercialization in 1980. DSA has established its usefulness in the recognition of vascular abnormalities, for example stenoses, aneurysms, occlusions, and ulcerated plaques [26]. A large section of the primitive measures related to arterial information processing and cardiac processing are being rapidly replaced by DSA. Digital subtraction angiography has also been employed for the generation of abdominal, pulmonary, carotid, cardiac and peripheral vessels. The commercial DSA systems work on the basic principle of digital subtraction. The fluoroscopic contrast medium is intravenously injected into the subject under study. The image obtained before the injection of the contrast i.e. mask image is subtracted from the series of the contrast induced images so as to enable the visualization of arterial structures. So a DSA machine makes it achievable to view arterial structures without arterial punctures. Hence the contrast is available on the monitors for successive viewing to detect the abnormalities. An example of DSA machine is Allura Xper FD20/10 biplane DSA Machine. The DSA images and mask images can further be fused together to generate a comprehensive view vascular and non vascular information i.e. arteries, blood vessels, bone and soft tissues in a single composite image. Fig 6 shows the pre-contrast mask image, a contrast image and the DSA image

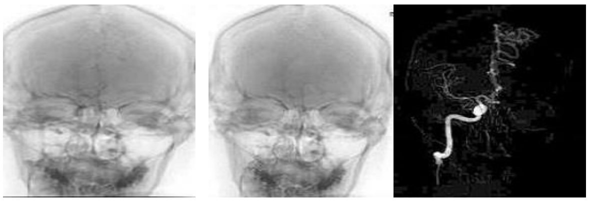

Fig 6 Mask image; Contrast image; DSA image [13]

VI. MAGNETIC RESONANCE IMAGING

Since its development in early 80's MR has emerged as a very useful imaging technique. Magnetic resonance imaging is based on the scientific fact that certain atomic nuclei emit radio waves when subjected to external magnetic field. The MRI makes use of strong magnetic fields to generate images of the organs under study. Certain abnormalities or regions which are not visible in CT or X-ray imaging, may become visible in MRI. Though MRI systems are uncomfortable as they stipulate the patient to enter narrow machine tubes, they are less hazardous as compared to CT and PET. MRI scans enable themanagement and treatment of various diseases without exposing the patients to ionizing radiations. The hydrogen atoms present naturally in the human body organs generate detectable radiations which are detected by the antenna surrounding the anatomical objects under study. These pulses received generate a spin of nuclear energy transition and therefore resulting in localization of the signal in space [27].

	X-RAY	CT	PET	SPECT	DSA	MRI	ULTRASOUND
Basic principle	generates 2-D projections of the subject understudy by exposing it to the X-ray	Scan body organs by producing of cross sectional X-ray images.	nuclear substance imaging where radioactive tracer is used	several cross sectional images with the tracer in	Uses a fluoroscopic contrast medium to generate arterial	Produces slices of human body organs by subjecting them to	High frequency temporal signals are received as echo signals which are used to project real time images of

	radiation		to diagnose ailments	body are taken	images by digital subtraction	gradient magnetic fields.	the subject under study
Contrast level	high	very high	-	-	high	high	high
Cost	intermediate	intermediate	high	Very high	high	high	low
Radiation source	X-rays	X-rays (Ionizing)	positron	photons	Fluoroscopic material	Magnetic field	Sound waves
Application	Anatomical	Anatomical Functional	Anatomical Functional metabolism	Functional	Anatomical Functional	Anatomical Functional molecular	Anatomical Functional

Table 1. A comparison of various radiographic techniques [17]

MRI generates images of soft tissues even at slight variation in contrast in a non-invasive manner. By regulating the magnitude of the radio pulses, image contrast can be varied to depict various anatomical structures or pathologies. When a tissue is excited under the magnetic field it returns to its equilibrium state by phenomena of spin lattice (T1 weighted) or spin–spin (T2 weighted) relaxation. If the excitation is allowed to reach its equilibrium state prior to the measurement of the MR signal by changing the time for repetition cycles a T1 weighted MRI is generated. In T2 weighted imaging the magnetization is allowed to decay by varying the echo time. T1 weighted MRI is used for the assessment of cerebral cortex, lesions in liver and provides information about post-contrast morphology, whereas T2 weighted image is used for visualization of anatomy in uterus and prostate and reveals white matter lesions. The MRI can be used for detection of tumours in brain, aneurysm, nerve injury or stroke. MRI can also be employed for visualization of coronary blood vessels, arteries and veins. MRI also helps in the management or bone health and spine such as spinal tumour, stenosis and arthritis [28]. Fig 7 shows the MRI scan of axial and sagittal view of the brain.

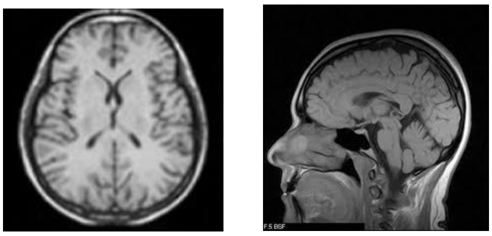

Fig7. MRI scan for axial and sagittal view of brain (L-R) [29]

VII. ULTRASOUND

Ultrasound is the sound wave which is not audible to the human ear with frequency ranging between 20Khz to gigahertz. Ultrasound imaging with the help of high temporal frequencies provides the instant real time imaging of the subject under study. An ultrasound image is generated by the transmission of small pulses into the body. These waves penetrate into the body and tissues with varying acoustic impedances. The waves which are reflected back (the echo signals) from various coplanar surfaces are used to generate an image. The transducer used in the Ultrasound imaging can be used both as a speaker phone and a microphone.
This is why the ultrasound enables the hearing of the sound of heartbeat of a fetus inside female body [17].

The US technology can be made use of in several applications like cancer diagnosis, detection and treatment, prostate and conformal radiation therapy [17]. Fig 8 depicts the striking visualization of fetus inside the female body.

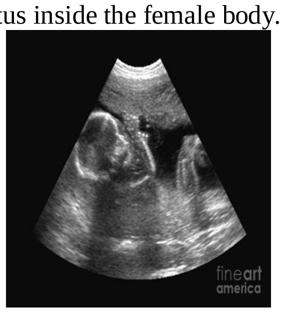

Fig8. ULTRASOUND scan of fetus inside female body [30]

A brief insight into the primary image modalities which finds numerous applications in medical imaging is given. Some of major differentiating characteristics of various imaging modalities were given by Zahraa et al. in [17] which is presented in Table 1.

VIII. CONCLUSION

Radiology is an indispensable division of medical sciences. The accurate and precise readability of medical imaging radiographs forms the basis for precise and accurate diagnosis. The fusion of these modalities together provides high degree of comprehension for the medical practitioner. While designing an effective image fusion algorithm one needs to be acquainted with basic principle, outlook, contrast levels and application of these imaging modalities. In this manuscript a brief and concise review of anatomical and functional imaging modalities has been given. Each imaging modalities presents a specific type of information of the subject under study. Each ailment requires various kinds of radiographs to given an accurate diagnosis. CT presents the contrast gradient more easily as compared to X-RAY and PET and SPECT depicts the spread of the radioactive tracer in space. These medical imaging systems need to be handled extremely carefully pertaining to their harmful effects.

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Ayush Dogra has attained his B.tech from Guru Nanak Dev University. He has done his M.tech from Punjabi university, Patiala. After that he has done his MBA from IGNOU, delhi. Now currently he is pursuing his Ph.D from Panjab University, Chandigarh. He has many papers to his credit which consists of SCOPUS and SCIE indexed papers. His research interests are image registration, image fusion, image enhancement and image denoising. He is also serving as editor and reviewer of many reputed journals. He was awarded the annual research award by UIET, Panjab University Chandigarh.

Bhawna Goyal received her B.E. degree in electronics and communication engineering from GNDU Amritsar in 2012 from India. She did her M.tech in ECE from PEC University of technology, Chandigarh in 2014. Currently she is pursuing her doctorate degree from Panjab University Chandigarh. She has published a lot of papers in SCIE and SCOPUS indexed journals. Her research interests are image denoising, image enhancement, image fusion and optical communication.

Dr. Sunil Agrawal is currently a professor in UIET, PU Chandigarh. He has attained his master's degree in engineering from Thapar University Patiala. He has attained his doctorate degree from Panjab University Chandigarh. He has many publications to his account out of which many are SCIE and SCOPUS indexed articles. His main areas research is wireless communication, artificial intelligence, image processing and optical communication.

.Prof. B.S. Sohi is currently holding the position of pro-vice chancellor in Chandigarh University. He has done incredible contribution to the field of research and served as the director of the UIET, Panjab University Chandigarh. His research interests are electromagnetics, image processing, wireless communication and basic electronics