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Development of Medical Imaging Techniques: A Review of Technological Advances in the Field of Medical Imaging, Such as Magnetic Resonance Imaging (MRI), Computed Tomography (CT), and Ultrasound Imaging (Ultrasound)

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Abstract

In contemporary times, medical imaging is becoming more significant in several therapeutic processes, as well as in the identification and diagnosis of various human illnesses. Not too much of the body has to be opened in order to access the inside sections. Magnetic Resonance Imaging (MRI), CT (Computerized Tomography) scanning, and ultrasound have replaced X-ray imaging in the ability to observe and picture the three-dimensional view of the body. The patient has no discomfort throughout the process of identifying the body's problematic area using the CT scanner. Computed tomography (CT), ultrasound imaging, and magnetic resonance imaging (MRI) are examples of medical imaging technologies that have advanced technologically and will be covered in this research.

Keywords: *technological, magnetic resonance imaging, computed tomography, ultrasound imaging, development.*

Introduction

In contemporary times, medical imaging is becoming more significant in several therapeutic processes, as well as in the identification and diagnosis of various human illnesses. Not too much of the body has to be opened in order to access the inside sections. Magnetic Resonance Imaging (MRI), CT (Computerized Tomography) scanning, and ultrasound have replaced X-ray imaging in the ability to observe and picture the three-dimensional view of the body. The patient has no discomfort throughout the process of identifying the body's problematic area using the CT scanner. Classifying and detecting abnormalities of the glands is the primary application of ultrasound imaging. Less costly, less intrusive, and very simple to utilize is ultrasound imaging. Various image processing methods, including segmentation, pre-processing, feature extraction, selection, and classification, may be used for ultrasound imaging [1].

Rapid, more accurate, and less intrusive instrumentation is causing a massive change in medical imaging. In the medical profession, precision in clinical procedures and equipment development is essential. More information has to be made public in order to unlock the hidden knowledge found in big data—or medical big data—and to analyze enormous data more effectively. Medical practices benefit from the link between data items and hidden data. In the healthcare business, medical imaging is becoming more and more important as efforts are made to reduce costs and achieve early illness diagnosis in pathology. As a result of advanced technology and a variety of imaging modalities, interpreting and analyzing large amounts of pictures for the purpose of diagnosing and treating illness has become increasingly difficult [1].

Medical imaging utilized to make pictures of human or animal bodies, either in part or in whole, for a variety of clinical objectives, such as medical procedures and diagnosis, or for medical research, which includes the study of normal anatomy and function, is known as scientific and diagnostic imaging. Broadly speaking, medical imaging is a subset of biological imaging and includes Positron Emission Tomography (PET), Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Microscopy, Ultrasonography, and radiography.1–5 Medical imaging methods provide researchers, doctors, and patients a thorough anatomic and physiologic view of the many human organs and tissues [2].

The technique of visually representing the composition and operation of the various human tissues and organs for clinical reasons and scientific research into the normal and pathological architecture and physiology of the body is known as medical imaging. Medical imaging methods are used to identify anomalies, cure illnesses, and reveal interior structures hidden behind the skin and bones. Healthcare science has evolved from medical imaging. It's a crucial component of biological imaging and encompasses radiology, which makes use of imaging technologies like thermography, medical photography, electrical source imaging (ESI), digital mammography, tactile imaging, magnetic source imaging (MSI), medical optical imaging, single-photon emission computed tomography (SPECT), endoscopy, magnetic resonance imaging (MRI), magnetic resonance spectroscopy (MRS), positron emission tomography (PET), and ultrasonic and electrical impedance tomography (EIT) [3].

The primary application of medical imaging technology is in diagnosis. The process of identifying a patient's illness and associated symptoms is known as medical diagnosis. The information regarding the illness or condition that is gathered from the patient's medical history, physical examinations, and surveys is provided by the diagnosis, which is necessary for therapy. A disorder's diagnosis becomes a difficult stage in medical research because of the disorder's many indications and symptoms, none of which are precise. For instance, erythema, or skin redness, may be a symptom of many different illnesses. As a result, many diagnostic techniques are required to identify the origins of various illnesses and to treat or prevent them [4].

Aim of study

The purpose of this research is to examine technology developments in medical imaging, including computed tomography (CT), ultrasound, and magnetic resonance imaging (MRI) (Ultrasound).

Literature review

Medical imaging creates visual representations or images of the interior or exterior tissues of the human body, or a portion of the body, using physical phenomena like light, radioactivity, electromagnetic radiation, nuclear magnetic resonance (MR), and sound. This can be done non-invasively or through an invasive procedure. In clinical medicine, computed tomography (CT), MR imaging (MRI), ultrasound, and digital pathology are the imaging modalities most often utilized. Since imaging data make up about 90% of all healthcare data, it is a crucial source of evidence for clinical analysis and treatment planning [5].

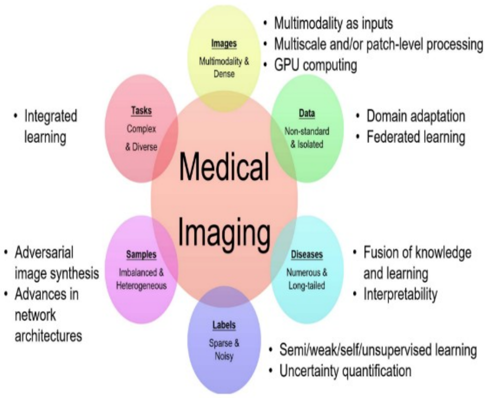


Figure (1) traits of medical imaging and the associated technological trends [5].

Medical pictures are dense in pixel resolution and feature numerous modalities. Imaging modalities are widely available, and new ones are constantly being developed. One such modality is spectral CT. The information density has grown, and even for widely used imaging modalities, the pixel or voxel resolution has improved [5].

Medical imaging data are collected in non-standard environments and are separated. Despite the fact that medical imaging data are collected in vast quantities in clinics, there is a great deal of diversity in scanning settings and equipment since there are no standard collecting processes in place. This results in the phenomenon known as "distribution drift." Images are dispersed among several hospitals and imaging centers due to patient privacy and clinical data management regulations, and fully consolidated open-source medical big data are uncommon [5].

A crucial component of medical diagnosis and therapy is often medical imaging. A radiologist typically examines the obtained medical pictures and compiles their results into a summary report. Based on the radiology report and the pictures, the referring physician determines a diagnosis and course of therapy. Medical imaging is often requested as part of a patient's follow-up to confirm that their therapy was effective. Furthermore, pictures are becoming a crucial part of invasive operations since they are used for real-time imaging throughout the process as well as for surgical planning [6].

Magnetic resonance imaging

In the medical field, magnetic resonance imaging, or MRI, is a potent non-invasive imaging method that has played and will continue to play a significant role. With little patient risk, it may help doctors diagnose patients and arrange preoperative procedures in clinical settings. It may assist neurologists and other biologists in their laboratory studies by revealing new fundamental physiological concepts and anatomical structures. Since magnetic resonance imaging (MRI) does not involve subjecting the patient to ionizing radiation, unlike certain other imaging modalities such as computed tomography (CT), it is regarded as safe. Because MR signals are sensitive to a variety of tissue characteristics, it also offers more information than other imaging modalities. MRI is one of a number of methods that are based on the nuclear magnetic resonance (NMR) phenomena. Bloch and Purcell discovered this phenomena in bulk materials in 1946. In a static magnetic field, certain atomic nuclei will take on one of two states: one with a greater energy level and the other with a lower energy level. The intensity of the applied magnetic field has a linear relationship with the energy difference between the two states. The Zeeman effect is the term for this [7].

Because MRI is totally non-invasive and produces pictures with exceptional soft tissue contrast, it is appealing in clinical medicine. Although MRI was initially mainly utilized for anatomic imaging, its capacity to offer physiological and functional parameters has allowed it to play a larger role in biomedical research during the last 15 years. Despite MRI's increasing maturity, advancements are continuing to be developed, which bode well for the technology's future expansion to numerous previously unthinkable uses [8].

High-Field MRI

The enhancement of the magnetic field strength is perhaps one of the most important developments in magnetic resonance imaging (MRI). Several factors lead to the utilization of high magnetic fields for in vivo magnetic resonance. Benefits include improvements in spectral resolution, blood-oxygenation level-dependent contrast, and signal-to-noise ratio. Drawbacks include the possibility of contrast loss in anatomic imaging due to T1 prolongation and high field susceptibility. High-field MRI can now give fine morphological and functional features in clinical and research contexts because to technological advancements in a number of MRI-related areas [8].

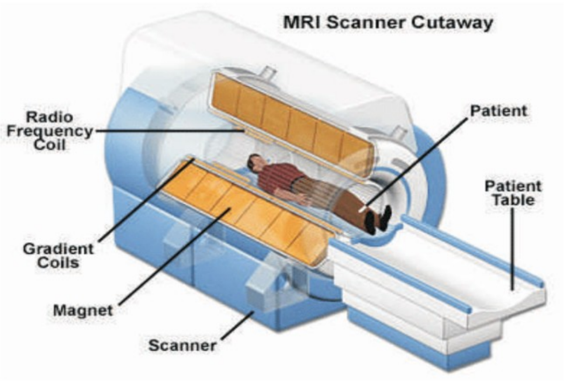


Figure (2) Basic Compartments of the Magnetic Resonance Imaging MRI System [14].

Functional MRI (fMRI)

Prior to statistical analysis, functional magnetic resonance imaging (fMRI) pre-processing entails a number of processes to clean and standardize the data. For each dataset, researchers often develop custom preprocessing algorithms based on a vast tool inventory. Rapid advancements in capture and processing have resulted to an exponential increase in the complexity of these procedures. We provide fMRIPrep, an analysis-neutral program that tackles the problem of reliable and repeatable fMRI data pre-processing. The unique characteristics of almost every dataset are automatically accommodated by fMRIPrep's best-in-breed methodology, guaranteeing excellent pre-processing without the need for human interaction. Through the integration of visual evaluation checkpoints into an iterative software testing integration architecture, we demonstrate that fMRIPrep consistently generates high-quality findings across a variety of fMRI data collections. Additionally, compared to routinely used pre-processing methods, fMRIPrep provides less uncontrolled spatial smoothness. With the aid of fMRIPrep, neuroscientists may verify the validity of inference and the interpretability of data by having access to an intuitive and transparent pre-processing procedure [9].

FMRI is a method that's often used to map brain activity in humans. But the blood-oxygen-level-dependent (BOLD) signal that fMRI measures is usually muddled by fluctuation from non-neural sources. Pre-processing handles specific imaging artifacts and the anatomical localization of signals in addition to identifying the bothersome sources and mitigating their impact on the data. For example, co-registration and spatial normalization deal with signal localization, whereas slice-timing6 correction, head-motion correction, and susceptibility distortion correction (SDC) handle specific artifacts. In order to guarantee the validity of inference and the interpretability of outcomes, a signal that faithfully represents the underlying brain activity must be extracted. Pre-processing's main objective is to lessen the sources of false positive mistakes while minimizing the number of false negative errors that result. Most researchers are acquainted with the example of a false positive error: activity seen outside the brain as a result of improper spatial normalization. More practically, systematic correlations that may be mistaken for functional connectivity can be produced by head motion that is not taken into account in resting-state fMRI data. On the other hand, a variety of pre-processing errors, such as anatomical misregistration between individuals, may lead to false negatives, which lower statistical power [9].

Magnetic Resonance Spectroscopy (MRS)

Magnetic resonance spectroscopy (MRS) is the term used to describe in vivo NMR spectroscopy. MRS has been used to find anomalies that are apparent or invisible in both clinical and scientific settings. Because of MRS's versatility, a method may be developed to examine a broad range of metabolic applications in various tissues. While MRS is primarily employed on brain tissue, it may also be used to the detection, localization, staging, assessment of tumor aggressiveness, and evaluation of tumor response in hepatic, breast, prostate, and other malignancies. This article reviews the medicinal uses of MRS in the brain, including tumors, studies of neurological and psychiatric disorders, and studies of the breast, prostate, hepatic, gastrointestinal, and genitourinary systems [11].

NMR spectroscopy is a tool for molecular recognition and biophysical feature specification. In health centers, nuclear magnetic resonance (NMR) is mostly used to obtain magnetic resonance imaging (MRI) anatomic pictures of the body. The combination of NMR spectroscopy and MRI has several uses in biomedicine and clinical settings. In clinical settings, NMR spectroscopy is referred to as magnetic resonance spectroscopy (MRS). Similar to its use in chemistry, spectroscopy makes it possible to find small molecules in both extracellular and intracellular environments. The obtained spectra provide comprehensive information on the metabolic pathway and its changes; hence, MRS may be used to monitor metabolic differences brought on by illnesses and evaluate the efficacy of therapy [10].

MRS was initially not a common clinical choice for medical imaging, mostly due to its lack of sensitivity. However, sensitivity has significantly increased with the introduction of high intensity magnetic field scanners, such as 3 Tesla (T) clinical magnetic resonance (MR) scanners, as well as better radio frequency pulse designs and evolved coils. As such, in vivo MRS is becoming a technology that is used in the clinic more and more. In contrast to MRI, MRS often does not provide strong signals of fat and water, which are typically of interest. Smaller signals from metabolites are more significant in MRS applications. Consequently, a strong enough magnetic field is required since the signal is too feeble. Thus, 1.5 or 3 T MR equipment are used to do several MRS measurements. Some therapeutic benefits of the 3 T field strength include an improvement in the signal-to-noise ratio (SNR) and the capacity to give spectra from smaller voxels [11].

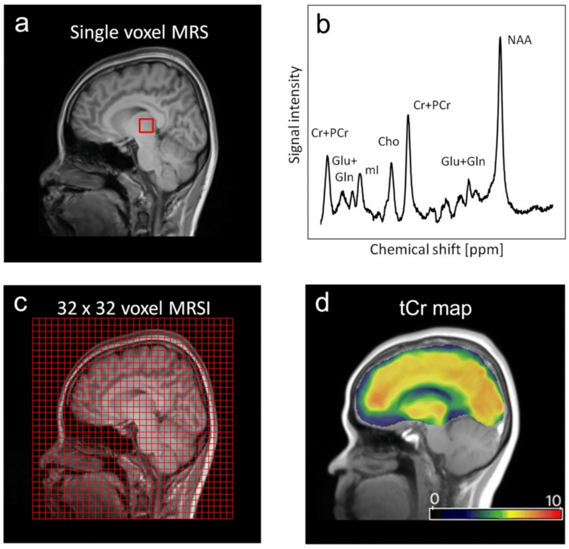


Figure (3) Magnetic resonance spectroscopy (MRS) and spectroscopic imaging (MRSI) [19].

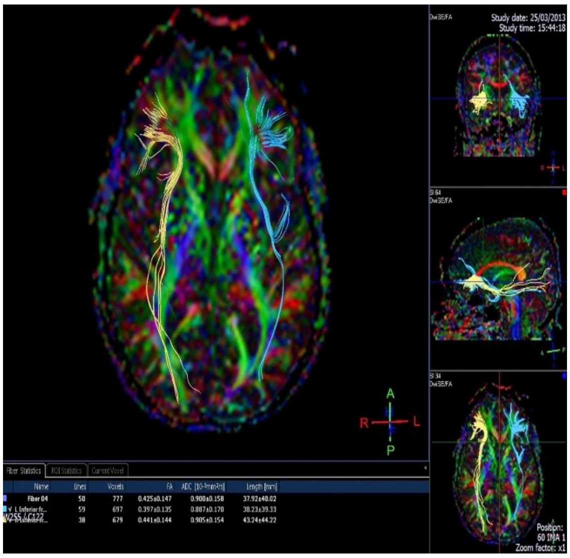
Diffusion Tensor Imaging (DTI)

Spreading With the use of an MRI method called tensor imaging, the translational motion of water may be measured in vivo without causing any harm and can provide details about the anisotropy of the material in various tissues. The white matter tracks of the brain, which typically provide substantial anisotropy to water motion in healthy brains, are among the tissues whose integrity may be quantitatively measured using DTI and have been employed extensively in this regard. But when there is axonal or neuronal injury, this anisotropic impact is lessened. When water and other tiny molecules move randomly and microscopic due to heat causes, it's referred to as molecular diffusion (i.e., Brownian motion). Since the molecules travel randomly and may come into contact with fibers, cell membranes, or macromolecules, diffusion-driven displacements of the molecules allow for a microscopic probe of tissue structure. Thus, observing this displacement pattern may provide special hints about the geometry and structure of tissues [12].

It enables the in-vivo, non-invasive mapping of molecular diffusion—primarily of water—in biological tissues. Water molecule diffusion patterns may therefore provide microscopic information on tissue architecture in both healthy and pathological states. In 1985, the first diffusion MRI pictures of healthy and sick brains were released to the public. Diffusion MRI has been very successful since then. Its primary therapeutic use has been in the investigation and therapy of neurological conditions, particularly in the acute stroke patient population [13].

A magnetic resonance imaging (MR) method called diffusion tensor imaging (DTI) may be used to describe the orientational characteristics of the diffusion process of water molecules. To create neural tract pictures, DTI makes it possible to assess the limited diffusion of water in tissues. Typically, the data is reduced to two categories of parameters: the orientation of the axis that water molecules flow preferentially along and diffusion anisotropy, which indicates the degree of directionality [13].

A number of metrics, including apparent diffusion coefficient (ADC) and fractional anisotropy (FA), are produced by diffusion tensor imaging and may be used to investigate both diseased and normally looking brain regions. Diffusion tensor imaging is quickly taking the place of other radiological techniques for the evaluation of white matter diseases because it may show anomalies in the structure of white matter fibers and give models of brain connections [13].



Name	Lines	Voxels	FA	ADC [10-3mm²/s]	Length [mm]
Fiber 04	50	777	0.425±0.147	0.900±0.158	37.92±40.02
√ L Inferior fr...	59	697	0.397±0.135	0.887±0.170	38.23±39.33
[illegible]	38	679	0.441±0.144	0.905±0.154	43.24±44.22

Figure (4) diffusion tensor imaging (DTI) of brain [20].

Computed Tomography (CT)

Accurate tissue/organ separation between the different bodily compartments, such as adipose tissue, skeletal muscle, bones, and organs, is made possible by the high-resolution CT imaging. In clinical investigations, the imaging modality's additional capacity to differentiate between visceral and subcutaneous fat, as well as between cortical and trabecular bone, is very valuable. Important details on the constituents of subcutaneous adipose tissue and the infiltration of muscle or liver fat may also be obtained using CT. With the use of CT data, it is possible to determine the skeletal muscle attenuation and bone mineral density in relation to metabolic diseases efficiently. CT scans may be used to determine the area and volume of each human body compartment with a high degree of accuracy and repeatability. The techniques of manual planimetry, semi-automated tissue segmentation, stereological point-counting methodology, and geometrical models based on linear or area measurements may all be used to carry out these calculations. An important component of the in-vivo evaluation of body composition at the tissue/organ level is computed tomography, or CT. CT is a popular and readily accessible non-invasive imaging technique. This modality is often regarded as the gold standard for validating alternative field techniques for measuring human body compartments [15].

Cone-Beam CT Compared to Multi-Slice CT

When a patient has conductive hearing loss, multislice computed tomography (MSCT) is usually the standard imaging technique utilized to evaluate them. Nevertheless, not every clinically significant structure is very evident with MSCT. Pathology of the ossicular chain in particular might be difficult to diagnose. Clinically, this MSCT limitation results in individuals with conductive hearing loss, making it unable to precisely identify the disease that already exists [16].

Cone-beam computed tomography is often utilized to image the maxillofacial and dental regions for diagnostic purposes. A cone-shaped x-ray beam is rotated around the patient in CBCT, a modified form of computed tomography (CT). Since the technology was originally presented in the late 1990s, CBCT's diagnostic efficacy has significantly increased. Compared to MSCT, CBCT offers a few distinct benefits. Generally speaking, CBCT results in fewer metal artifacts, a greater spatial resolution, and a far lower radiation dosage. Based on these benefits and the information that is currently available, CBCT could be a good substitute for MSCT [16].

Dual energy computed tomography (DECT)

Dual energy computed tomography, or spectrum CT, is a computed tomography method that employs two distinct x-ray photon energy spectra to examine materials with varying attenuation characteristics at various energies. Dual-energy CT (attenuation values at two energy spectra) yields many picture types that may be reconstructed, whereas traditional single-energy CT only generates one image set [17].

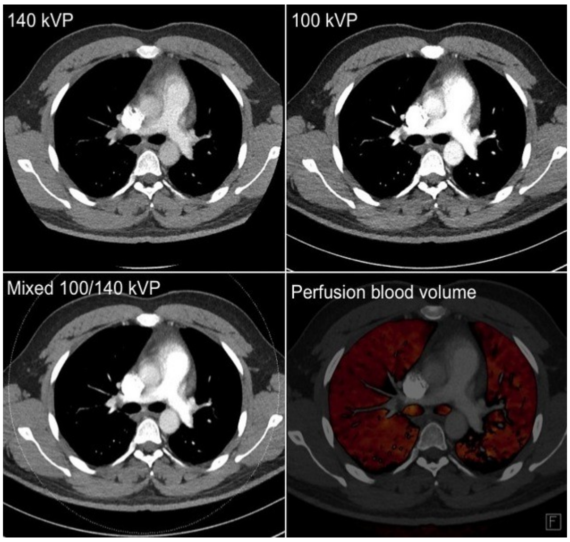


Figure (5) dual energy CT chest [17].

Iterative reconstruction algorithms

Since CT examinations always involve exposing patients to ionizing radiation, the growing number of clinical applications and some recent technological advancements have also contributed to the CT examinations' ever-increasing role in the overall radiation exposure of patients. As a result, it is crucial to reduce radiation exposure while using CT imaging, and methods for doing so are highly sought after when it comes to clinical practice. Various approaches have been developed so far to reduce the radiation dose in CT. These include technical approaches like automated tube current modulation and tube potential selection, as well as dynamic beam collimation, and specific examination techniques that are used in clinical practice across all body regions. Recent developments in processing power have made it possible to create software-based techniques for CT iterative image reconstruction (IR). The common technical principle of IR algorithms is the iterative improvement of measured projection and/or reconstructed image data by application of filters based on statistical data models or mathematical models of the CT imaging process. This is different from established analytical image reconstruction methods such as traditional filtered back projection (FBP) [18].

Ultrasound Imaging

One kind of imaging technology used to identify, track, and manage a wide range of medical disorders is ultrasound. It creates sonograms, or real-time pictures of your organs, tissues, and fluids, using sound waves. Additionally, it may be utilized to alter or eliminate cells, such as those seen in tumors. Ultrasound does not use radiation, in contrast to imaging procedures like computed tomography (CT) and positron emission testing (PET) scans. Additionally, preparatory and post-procedural instructions are usually not necessary [21].

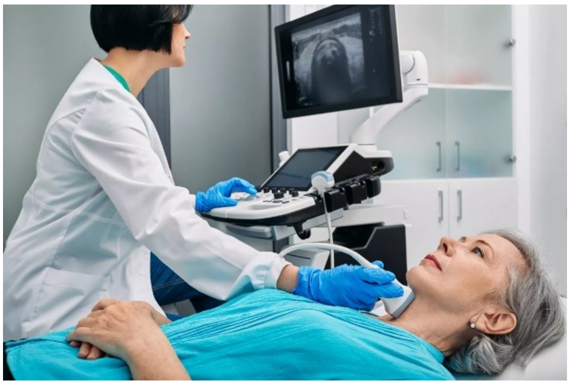


Figure (6) medical ultrasound [21].

3D and 4D Ultrasound

The most quickly developing fetal ultrasonography method and technology in recent years has been three-dimensional (3D) ultrasound. Prenatal ultrasound diagnosis has led to enormous technical advancements that are unparalleled in other medical fields. With the advanced technology of today, we can quickly collect not only high-quality photos but also 3D and 4D photographs. Furthermore, modern 3D ultrasound technology can save the data acquired in 3D/4D for processing at a later time, enabling patients to undergo tests in less time. When evaluating examples for teaching and research reasons, this is incredibly beneficial [22].

CEUS

Contrast-enhanced ultrasonography methods as a whole are referred to by the abbreviation CEUS. In order to evaluate treatment response in oncology and assess activity in inflammation of the bowel wall in inflammatory bowel disease, dynamic contrast enhanced ultrasound, or DCE-US, refers to quantitative time intensity curve (TIC) analysis using either bolus injection of microbubbles or intravenous infusion with disruption-replenishment technique. Data volume picture capture is referred to as 3D CEUS. While it is still being researched, 3D CEUS, which was first introduced in 2002, is accessible in certain systems. Through the course of several minutes, CEUS enables the real-time recording and assessment of the ultrasonic contrast agent's (UCA) wash-in and wash-out phases. This allows the various circulatory phases to be dynamically seen while looking at the liver. Three distinct phases—the arterial (AP), portal venous (PVP), and late (sinusoidal) phases—have been identified as a result of the liver's unique blood supply (LP) [23].

Elastography

First established in the 1990s, ultrasound elastography (USE) is an imaging technique sensitive to tissue stiffness. In recent years, it has undergone more development and improvement to allow for quantitative evaluations of tissue stiffness. Techniques for elastography capitalize on the altered elasticity of soft tissues brought about by certain physiological or pathological processes. For example, it is well known that many solid tumors mechanically vary from the surrounding healthy tissues. In a similar vein, the liver stiffens up compared to normal tissues due to fibrosis linked to chronic liver disorders. Thus, afflicted from normal tissue may be distinguished using elastography techniques for diagnostic purposes[24].

Conclusion

Diagnostic imaging methods facilitate the study, diagnosis, and treatment of many illnesses by providing precise anatomical or physiological pictures of the body. Registered Allied Health Professionals, such as radiologists and health lab technicians, develop and analyze pictures largely from microscopes, ultrasounds, radiographs (such as CT and PET), MRIs, and other sources. Physicians such as radiologists and other medical professionals help diagnose and treat patients depending on the interpretation of radiologists and technicians. The ongoing advancement of various imaging modalities has greatly improved patient care, increased diagnostic precision, and created new opportunities for medical study and therapy.

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