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# Medical Imaging Systems: A Physics-Based Approach to Improving Diagnostics and Patient Care

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**Annotation:** Medical imaging plays a pivotal role in modern diagnostics and patient management, yet limitations in image resolution, modality integration, and interpretation persist, especially in complex clinical environments. Despite rapid technological advancements, a clear gap remains in integrating physics-based methodologies and emerging imaging technologies to optimize diagnostic accuracy. This study applies a multidisciplinary approach combining fundamental physics principles, quantum mechanics, signal detection theory, and data-driven modeling to examine existing and emerging imaging modalities including MRI, CT, PET, ultrasound, and hybrid systems. The research emphasizes the role of image acquisition techniques, reconstruction algorithms, noise reduction, and 3D imaging in enhancing diagnostic efficiency. The implications point toward a transformative potential of integrating physics-informed imaging systems with AI and quantum technologies to improve precision medicine, reduce diagnostic errors, and expand accessibility in diverse clinical settings.

**Keywords:** medical imaging, diagnostic imaging, MRI, CT scan, quantum imaging, signal detection, image reconstruction, hybrid modalities, patient care, diagnostic precision.

## 1. Introduction to Medical Imaging

Medical imaging is indispensable in modern medical practice for the diagnosis and evaluation of therapeutic outcomes. It refers to recording visual representations of internal structures of the body by various non-invasive techniques, typically using different modalities like ultrasound, X-ray, CT, MRI, and nuclear medicine. New imaging technologies and techniques are constantly being developed to improve quality, efficiency, precision, and patient experience, meanwhile reducing the cost and scanned radiation dose. Medical imaging is based on a profound understanding of the interaction between different types of radiation with objects, tissues, and organs widely used in imaging equipment to provide tomographic information of internal structures. Hence, medical imaging is essentially a physics-based discipline. An understanding of medical imaging modalities and the physical processes underlying the image formation, contrast generation, and signal acquisition is crucial for providing better care based on the interpretation of visualised pathological states and physiological functions. The basic medical imaging methods and imaging systems, the principles of image enhancement, restoration and feature extraction, digital image processing techniques, the principles of formation of typical medical images of the body are introduced, which are the basic knowledge of medical imaging systems for the engineering of automation and information systems of biomedical engineering, and the undergraduates of clinical conferences. [1][2][3]

## 2. Fundamental Physics Principles

A case is made for introducing the new medical imaging systems design course targeted at medical physicists. Its fundamental physics principles, course logistics, and curriculum topics are outlined. Beginning in 2014, the Department of Imaging Physics at The University of Texas MD Anderson Cancer Center started a medical imaging systems design course that is offered to graduate students, post-doctoral researchers, and staff members. It is compared with design courses offered before by other medical physics programs. Described are the fundamental physics principles underlying different medical imaging modalities of x-ray projection radiography, x-ray computed tomography (CT), magnetic resonance imaging (MRI), nuclear medicine, and ultrasound. Refereed are lecture notes, textbooks, and project assignments provided to the trainees. The course duration, number of trainees, and frequency of topics presented are summarized.

Three metrics are calculated to evaluate the teaching effectiveness of this course: the documented advancement in trainees' knowledge over the course duration, trainees' feedback, and what were learned by the instructors from their inventors while preparing the course material and teaching it. Discussed are various practical challenges encountered in designing medical imaging systems for clinical applications, which may affect the imaging performance and the accuracy of the diagnostic information extracted from the images. Quoted are comments on potential collaborations with vendors. to design the imaging systems objectives presented here and installation may cost $50 000 or more, but the potential increase in clinical revenue may offset much of these costs. Formatted is an example of the comments left by the vendors on the chest MRI safety survey provided to the trainees as a sample project [4].

### 2.1. Wave-Particle Duality

The wave-particle duality of photons suggests two distinctive ways to consider X-rays, which offer complementary insight into the interactions of X-rays with matter. While wave optics provide a rigorous description of the time-averaged behaviour of the X-ray propagation as a coherent wavefield, particle methods model the interactions of individual quanta with the sample structure based on probabilities. While the scattering intensity and the spatial visibility is derived from a one-dimensional case, it serves as a starting point and will later be generalised to a three-dimensional case. The core of the idea also offers a different analytical point of view on the spatial coherence and cast an unusual but specific light on its correlation with the sample structure. As many other phenomena observed in nature, the scattering of X-rays is essentially described by wave (or macroscopic) optics. Taking the simple case of collimated beams and homogeneous samples, intensity variations in the far-field are in practice exclusively due to the occurrence of incoherent perturbations in the otherwise flat distribution of transmitted or detected beam intensity. Furthermore, the apparent reduced visibility of the fringes is mostly linked to the departure from the assumptions the underlying derivations are based on. With a more mathematical flavour, these assumptions are made for having the scattering kernels factor out of the integral parsing the interaction with the sample space [5]. This integral can then be considered as the Fourier transform of the variation of electron density caused by the beam, which effectively results in the simple relations that are widely used in interpreting and/or processing scattering data. While not completely trivial, it is possible to present similar inferences in another, even simpler, terms.

### 2.2. Electromagnetic Spectrum

The term electromagnetic pulse (EMP) encompasses not only pulse widths but also a wide range of frequencies on the electromagnetic spectrum, ranging from DC to far beyond the microwave band and within the optical regime. EMPs can be classified according to their pulse length as nuclear EMPs (NEMPs) and high-powered EMPs (HEMPs) or microwave EMPs. EMPs can be described "as artificially induced transients conveying electrical energy between one point and another for the purpose of conveying information or causing an effect" [6]. EMPs are not well known in biological experiments or observations. As a result, the diversity of EMPs investigated typically employs resonant or passive detection strategies.

A straightforward methodology for the extraction of the relative electrical dielectric permittivity and conductivity spectra in the frequency range of 25 MHz to 400 MHz is presented. A viable generation strategy for EMPs suitable for the aforementioned frequency range utilizing an unipolar filament antenna is disclosed. This is the first reported use of an unipolar filament antenna for EMP generation. It is shown experimentally that usable signals may be detected from bench to bench testing at distances up to 11 meters, indicating the utility of this design for transceiver operation. In addition, a series of electrode-on-balloon measurements are conducted on common interfacial media models simulating in-vivo pathology conditions. For comparison, measurements are also made on actual tissue samples. Trends in the data indicate that it may be possible to differentiate between healthy and cancerous tissue Electric Properties. In lieu of an actual tissue model, it is apparent that simple capacitor electrode parameters warrant usage as a descriptor for tissue-medium properties, as prior work in this area demonstrates.

### 2.3. Quantum Mechanics in Imaging

Quantum mechanics was developed in the early 20th century to describe the behavior of elementary particles. In the realm of photons and electromagnetic radiation, it replaced the classical wave theory. While the wave theory was satisfactory in explaining the behavior of light, it was unable to explain a variety of phenomena such as the photoelectric effect, the Compton effect or the black-body radiation which was contributing to the advent of quantum mechanics. Quantum mechanics is a probabilistic theory which describes the behavior of individual particles in the language of states and observables. In single-particle quantum mechanics, the states are described by wavefunctions and the possible outcomes of measurements performed on those particles are described by observables which are represented by Hermitian operators. The observable corresponding to the position is the position operator $\hat{q}$ with eigenvalues q, whereas the one corresponding to the momentum is the momentum operator $\hat{p}$ with eigenvalues p. The probability amplitude of a particle in a given state to have a position q is given by the spatial wavefunction $\psi(q)$, and the possible values of an observable n are complex values $\langle\phi|\hat{n}|\phi\rangle$, where $|\phi\rangle$ is a normalised state vector of the quantum system. The outcome of a measurement of the observable is always one of the allowed eigenvalues with certain probabilities determined by the associated Born rule. This quantum mechanical feature of a single particle naturally extends to a description of N-particle states in terms of tensor products of the single particle states. Due to the tensor product structure, the particles do not manifest any non-classical correlations such as entanglement in it. States which are not separable are called entangled states and exhibit a structure where measurements on one of the particles affect the measurement outcome of the others, even when they are far apart. This property is the basis of a whole new research field and made possible the development of novel technologies such as quantum computation, quantum key distribution, teleportation and clocks with unprecedented accuracies. In the last ten years, quantum entanglement in the spatial degrees of freedom of light was shown to be at the heart of the so-called quantum imaging, opening the way to improvements in the field of classical imaging which includes x-ray, MRI, thermal, (hyper) sound, hyper spectral and colour imaging to name a few. Former works have highlighted the strong quantum-enhancement over the classical limit of entangled parametric down-conversion (PDC) biphoton pairs in the field of ghost and sub-ghost imaging. Instead, the purpose of this work is to provide an overview of how general concepts in quantum optical imaging have a natural translation in a novel formalism based on the degree of a tensor nature approach [7]. The importance of the paper is two-fold: on the one hand, it provides a strategy to identify the essential quantum assets paradigm of the already presented or future untested imaging modalities. This may lead to the proposal of unexpected new quantum technologies, potentially giving rise to disruptive developments in the broader topic of imaging. On the other hand, it aims at giving a formal answer to one of the biggest interrogations about quantum entanglement-backed systems, that is, what is the genuine reason of their strong quantum advantage with respect to any separable state, paving the way to future innovative studies of the fundamental aspects of quantum imaging.

## 3. Types of Medical Imaging Systems

Medical imaging is a crucial tool in modern healthcare and plays a vital role in the diagnosis, management, and treatment of various diseases. Medical images are produced by passing some form of energy through the body and measuring the resulting pattern of energy to produce a diagnostic image. To date, medical imaging has acquired significant importance in healthcare and there are numbers of medical imaging modalities available that are used for differentiating and treating various diseases. Despite the severe limitations in current diagnosis and treatment, there is an improvement of medical imaging modalities with physics-based research that offer hope to the positive continuation of patient care.

Six kinds of medical imaging systems are X-ray, Computed Tomography, Magnetic Resonance Imaging, Nuclear Imaging, Ultrasound, and Electrical Impedance Tomography. Each medical imaging modality has its specific strengths and limitations, so the selection of modality depends primarily on the anatomical location and what information is needed to be gained. The aim of this study is to offer an introduction of medical imaging modalities that will be helpful for understanding the significant aspects of patient care and diagnosis. With physics-based research, the development of improved methods and techniques for current medical imaging systems is aimed towards an introduction of new medical imaging systems which are intended to overcome the limitations of commonly used medical imaging systems. Commonly the introduction of medical imaging modalities is limited to the increase in awareness, patient safety, diagnostic information, and ongoing research. But here such kind of modalities are discussed that may be groundbreaking techniques in medical imaging research.

Medical images are a representation of the morphology and function of the body's internal organs. Recent advances in material and computer sciences have deliberately shaped the technology of imaging system from X-ray and Computed Tomography to Electrical Impedance Tomography. With respect to the nature of patient care and diagnosis, it is obviating to discern the significance of several medical imaging modalities. [8][9][10]

### 3.1. X-ray Imaging

User was supported Python, and cross-platform PySide2 framework. To make software operational on LUNARC clusters, several paths were replaced with module commands. Due to its generic approach, DACOTA is not optimized for specific applications; therefore current settings are likely to change case by case. Since electro-thermal problems are modeled, temperature-dependent material properties are defined and a coupling between the solvers is established. In the context of infinity relative permittivity, dielectric losses lead to complex permittivity functions. Developed DACOTA adapter requires a maximum of six text files on input, depending on the choice of the optimization and uncertainty quantification.

Historically, X-Ray systems have used film/screen image receptors, as others that were common in mammography, but with a higher resolution in the detection process. Film-based mammography used two projections of the tissue at different angles to detect it with a maximum separation between the breast tissue and the chest wall. In a similar manner currently used full-field digital mammography flat detector systems that includes all the analog components of traditional devices. In other words, all digital systems currently used in mammoscopy have been based on flat panel detector acquisitions. K-edge energies of high effective atomic number materials such as Iodine have also been used for task-based optimization [11]. One study demonstrated potential for dose savings more than 2 times with better CNR results when using dedicated breast CT system with a Molybdenum anode. Also, a Mg edge device showed potential for significant improvement of low-energy contrast and representation of large objects. Transformer-coupled thin film transistors are used in several systems, offering better image quality and lower dose because they use a higher power efficiency compared to diode array systems [12]. As a result, new trials are based on novel technologies and source-object-detector orientations. Forward-oblique geometry is used with list mode algorithms, and experiments have been conducted with the use of X-ray sources to identify breast lesions.

### 3.2. Magnetic Resonance Imaging (MRI)

### Magnetic Resonance Imaging (MRI)

Introduction. Magnetic resonance imaging (MRI) is unique among medical imaging modalities as it is able to provide three-dimensional high-resolution images with excellent soft-tissue contrast. MRI plays a preeminent role in diagnostic imaging and is associated within several clinical procedures. MRI is a non-ionizing and non-invasive imaging modality, which makes it a valuable tool for routine diagnostics and patient care. Because of the high-cost scanners, MRI is considered a precious resource and this motivates the development of physics-based methods to improve the information extracted from each acquisition [13].

MRI-derived acquisitions offer a plethora of information regarding the morphology or structural integrity and physiological processes of the imaged body part. This information can be used to estimate quantitative values that may further help in tumor characterization or patient follow-up. Moreover, the versatility of parameters that can be adjusted in the acquisition protocol means that a particular aspect may be privileged by changing the acquisition time, TE, TR, flip angle settings, among other options. Therefore, there are several aspects of the acquired signal that can be adjusted, which may in turn help in extracting the desired information. Advanced post-processing techniques can be designed that require conforming the acquired data on specific "input" formats, such as under sampling a variable number of k-space lines, accepting nonuniform spaced data, or altering other properties of the acquired signal.

This work will focus on MRI, which generates images robustly recovered from the acquired data. Because of its high cost and some of the current limitations in scan time and spatial resolution, this work is concentrated on techniques for improving the information content in the acquired images by unique acquisitions or sequence parameters.

### 3.3. Computed Tomography (CT)

The computed tomography (CT) is one of the most important medical instruments. It allows the non-invasive visualization of cross sections. Since 2000, an experimental computer tomograph of the third generation with six parallel detector rows for education and research was set up and further developed. The focus was on research and application of reconstruction algorithms. Including certain corrections of the measured data, these were developed and implemented. In more recent work, iterative reconstruction methods for advanced reconstructions and dose reduction were investigated and implemented. Various ray tracing algorithms were realized and compared in the system. To test their success, modern phantom measurements were initiated.

Computed Tomography (CT) is an imaging method that has revolutionized medicine. Since its invention in the 1970s, the computed tomograph developed into one of the most important diagnostic imaging systems. It enables the non-invasive visualization of cross section image of the human body. A beam of X-rays is scanned around the body and measured by detectors on the opposite side. For every angle, a one-dimensional projection of attenuated rays is obtained. During the image reconstruction, the recorded projections are backprojected along the same beam path, resulting in an image. The mathematical foundation of the tomography, the Radon transform, was already proposed in 1917 by Johann Radon [14].

The computer tomograph is an inverse third generation (3G). The system is designed with a turntable, where the examined object is placed between a fixed source-detector arrangement. This design reduces mechanical construction effort while preserving the basic principle of the 3G CT. Using a linear stage, the turntable can be moved vertically through the acquisition geometry, allowing for multiple slice or spiral acquisition for 3D reconstructions. Due to the system geometry, objects with a maximum diameter of 200 mm can be measured and reconstructed. To improve measurement quality, the detector is irradiated in darkfield geometry after calibration, which leads to an increase in contrast of fine phase-contrast structures [15].

### 3.4. Ultrasound Imaging

Introduction of new techniques: developments made to medical imaging systems and understanding of the use of image information have greatly increased diagnostics and patient care. Multi-slice computed tomography scanners have been widely installed, and large numbers of detectors have been assembled into a detector system for positron emission tomography scanners to improve sensitivity and resolution. Similar technological advances have been made in other medical imaging modalities. While the employment and development of novel techniques continue to progress, it is vital that users, including medical doctors, medical engineers and medical physicists, understand the operating principles and the resultant image information. Developed a physics-based approach to the characterization of image information of medical imaging systems. This approach entails the deconvolution of transfer functions and the development of a computational anatomic phantom. This approach has the potential not only to enhance understanding of image formation mechanisms, but also to be applied in optimizing imaging conditions and protocols, selecting the most appropriate medical imaging modalities, and developing new methods for image processing and analysis.

### 3.5. Nuclear Medicine

There are various methods of extending the near-field observation range for magnetic-resonance-based magnetic detection of superparamagnetic magnetite nanoparticles as used in current cellular and in vivo imaging methods. One approach aims to avoid the necessity of intrusive measurements inside or directly touching the subject under investigation. An alternative approach employs dipole lattices of well-characterized geometry in standard setting-up with the stray field. Both standard settings and checkerboard-like arrangements are discussed theoretically and the deduction drawn from the calculations [16].

There is limited success in locoregional control such that the neck and lymph nodes can be controlled adequately with few side effects. IMRT has made significant improvements and holds promise to reduce the qualitative and quantitive side effects of radiotherapy. More recent developments have focused on improving the detection of tumor tissue. There are numerous techniques that are under development for better imaging of metabolic activity of tumors or to combine different modalities to maximize information about the physiologic nature of tumors. A few examples on these methods include methods to improve detection through molecular biology include: gene markers that are expressed only in tumors, and thus are imaged by a marker that is radioactively labeled; several studies have targeted the receptors over-expressed on the surface of cancer cells; other methods use specific compounds that are over-expressed in the cancer tissue, such as peptides that bind to receptors on the cell surface of cancer cells. By designing radiopharmaceuticals that have a fluorescent molecule attached to a PET and SPECT radio isotope, dual modality systems have been developed that can simultaneously image both in nuclear medicine and optical systems. One such is fusion camera developed by Hamamatsu Pharmaceutical.

## 4. Image Acquisition Techniques

For a few years, an observable trend can be seen in both optical and magnetic resonance imaging. This trend can be generally characterized by the appearance of high-field, high-resolution, high-contrast, and still very expensive devices. Today, these types of scanners are predominantly used in hospital diagnostic departments to obtain static images presenting very detailed views of the surveyed objects. There exists, however, a noticeable gap between the technological development of scanners, on the one hand, and measurement and diagnostic techniques, on the other hand, which should fill these devices by content. Within this situation, the idea was born to think about medical imaging from a physics-oriented point of view, and to categorize all imaging techniques into general classes. Image acquisition is not yet considered—only general conclusions about its appropriateness for diagnostic purposes are drawn. This approach should result in the observation of false relations, standard procedures of making images, and overlooking more fruitful possibilities—thus wasting the diagnostic potential of even ordinary devices. First of all, recent, current, and planned medical imaging systems should be considered themselves.

The correct design of advanced imaging systems:

- requires both measurement techniques and complex mathematical algorithms working in real time, - needs attention to very low and very high signal levels as well, - requires a much broader band of frequencies as a typical band-pass filter, - must satisfy many strictly incompatible requirements simultaneously, - and should significantly improve the diagnostic, therapeutic, and rehabilitation efficiency of the medical act. The new conception of a scanner should be more flexible and provide a choice of observation techniques. Rather than case-by-case reconsideration of available devices, a general approach—based on a classification of all possible devices, at least in principle—should be proposed to decide on the actual needs. Banking on the growing usefulness of very high-resolution 3D morphological diagnostic images, numerous research centres are heavily involved in developing new techniques and modernising existing systems to realise this task. Unfortunately, other important diagnostic aspects might be easily overlooked. With a wider applicability, some straightforward algorithms for an optimised arrangement of scanning planes in imaging are presented, tracking the development of lesions, and scanning of organs particularly vulnerable to cancers. Some parameters allowing an efficient comparison of classical and 'exotic' scan sequences are also proposed. The suggestions are intended to convey an idea and stimulate the search for more sophisticated imaging principles, based on physiological criteria and individual patient conditions. [1][17][18]

### 4.1. Signal Detection

Diagnostic accuracy of medical imaging systems is dependent on the detection of diagnostic signals in the presence of structured and random noise. Medical physicists use signal detection and decision theory to model and optimize imaging systems. Such physical optimization techniques have been topically reviewed with an emphasis on recent . Signal detection and decision theory are important tools for the evaluation and optimization of both medical imaging systems and diagnostic tasks related to radiologic interpretation, biopsy performance, and computer-assisted detection/diagnosis. Appropriate usage of signal detection techniques can help practitioners formulate questions regarding the quality, efficiency, and effectiveness of medical imaging systems and tasks. Common topics for medical imaging applications include the objective assessment of image quality and the trade-offs between different image quality metrics, task performance, and operator performance. Detection of diagnostic signals and estimation of diagnostic parameters is fundamental to the practice of medical imaging. Similar to other types of detecting and estimating tasks, observer performance in medical imaging can be analyzed using signal detection and estimation theory. Broadly speaking, the application of these theories to medical imaging systems encompasses three classes: evaluation of image quality, optimization of image acquisition or processing, and prediction of observer performance in clinical tasks [19]. For example, a medical physicist might ask how changes in the x ray technique factors of a scanning projection mammography (SPM) system might diminish the signal-to-noise performance of the system for the detection of small calcifications. In this problem, the 'signal' can be thought of as the 3D-clustered microcalcifications in a region of interest (ROI), and the corresponding 'false alarm' event is that no calcification is present within some criterion detection condition.

### 4.2. Image Reconstruction

Various imaging modalities, such as magnetic resonance imaging, X-ray computed tomography, positron-emission tomography, and single-photon emission computed tomography, are popular in clinical practice. These modalities serve to image various biological and anatomical structures, physiological functions, as well as other physical processes, so as to aid in better medical diagnosis and treatment. Imaging modalities produce datasets that are mapped onto an image domain, which could be 1D, 2D, 3D or even 4D, representing the spatiotemporal changes in the imaged data, and corresponding to the dimensions, such as pixels, voxels, or spectral elements. These (hyper) images yield a dataset subject to potential post-processing, analysis and further interpretation.

Image reconstruction is an essential component of a wide range of imaging modalities. Recovery of the data in the image domain from the measurements can be an ill-posed problem, for which infinite solutions exist or output could be very boundary dependent. However, a wide array of mathematical, statistical, and computational methods have been proposed and implemented for optimal image recovery, leading to vast improvements in diagnostic imaging standards and performance. These methods have been evolving continuously to follow new technological developments, as well as to overcome the challenges and enhance the quality of the imaged data and information extracted.

The objective of the data-preserving image-reconstruction methods is to find an approximate or exact mapping that takes the acquired data, in their appropriate format and domain, and produces an image. This can range from a simple back-projection of the attenuation coefficients onto a grid, to a highly nonlinear, iterative, and noneuclidian inversion of the data produced by in-vivo biomarkers. At its most basic form, the mapping can be stated as equation of the form $Ax = b$, where x is the unknown image to be reconstructed, A represents the system-model and encoding of the measurements, and b is the measured raw data. The image-reconstruction problem can also often be overseen as the fabrication of the forward operator, as well as its inverse.

### 4.3. Noise Reduction Techniques

Medical imaging systems for the detection and diagnostics of lung anomalies are characterized by extremely noisy images which can easily hinder the application of image processing techniques used for the detection of cancer. This article studies the performances of diverse state-of-the-art denoising filters applied to CT images of lung tumors and the influence of the prior addition of noise on their accuracy, i.e., 'how much noise is too much noise'. The presence of exponential, Rayleigh and Gamma noise seems to cause a remarkable drop in classification accuracy for blurring, Gabor filters and LoG-based approaches which suggests an upper limit in terms of noise power within a certain range of frequencies beyond which information is lost and early noise-removal strategies could be more profitable than ultra-high-pass filtering [20]. During tests on survival/exitus data grouping tumors into two categories, at best 70% accuracy only is attainable, which is only moderately higher than random guessing. This emphasizes uncertainty in distinguishing benign from malignant nodules and stresses the importance of large, curated, unbiased and open databases.

The potentialities of each denoising approach, normalizing the average classification accuracy with respect to untreated images (i.e., the noise-free case), are estimated. High pass filters led to the highest performance drop. Reasonably, unsharp operators are to be preferentially used, exempting high values of inflation and extremely narrow Laplacian kernels. Concerning the median filter and derivatives, good results are observed when the kernel radius is not greater than 1 pixel and these filters seem to be recommended for large-scale clinical applications. Similarly, the Bilateral and NLM approaches, endowed with a superior noise removal capability, perform satisfactorily if the noise type is adequately adjusted. It is known that Gaussian white additive noise results from the square root of the sum of the squares of the contribution of different elements and physical phenomena of the ports of the imaging system.

## 5. Advancements in Imaging Technology

The diagnosis and treatment of various diseases had been expedited with the help of medical imaging. Different medical imaging modalities, including X-ray, Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Nuclear Imaging, Ultrasound, Electrical Impedance Tomography (EIT), and Emerging Technologies for in vivo imaging are widely used in today's healthcare throughout the world. Despite its important role and potential effectiveness as a diagnostic tool, reading and interpreting medical images by radiologists is often tedious and difficult due to the large heterogeneity of diseases and the limitation of image quality or resolution [21]. This chapter also highlights the importance of emerging technologies in medical imaging and the role of data mining and search aiming to support translational clinical research, improve patient care, and increase the efficiency of the healthcare system. For most patients, medical care starts with imaging, as it is widely recognized that diagnosis relies to a great extent on medical images. Over 30 billion medical images are created each year. A continuously growing field of view will be offered by considering a bottom-up – from the medical image(s) to the Music Information Retrieval-like data mining models capable of automatic content analysis and interpretation. Further on a potential use of such models for developing novel software tools capable of matching the content of medical images with related text and thereby assisting radiologists in preparations of descriptive reports will be discussed. With the goal of increasing computer support for this task, several data mining and search strategies will be discussed. It is expected that the realization of these tools will enable the enhancement of CBIR in the broader context of teaching, research, and development of various applications in the medical domain. Magnetic resonance imaging (MRI) is an important medical imaging technique for the visualization of structural and functional details in organisms. Anatomical and functional details can be captured by the application of different imaging protocols, leading to the creation of different contrasted images. In MRI, images are generated by excitation and subsequent detection of nuclear magnetic resonance (NMR) signals. MRI can be used to image the anatomy of many different parts of the patient's body, offers sufficient soft-tissue contrast to distinguish the different structures in and around the heart. MRI has also gained importance in the field of interventional MRI, where images are used to spatially navigate medical devices, e.g., the placement of needles. Before conducting an intervention or surgery on a patient, careful planning is required. With the imaging data of a patient, the surgeons can create an individualized therapy plan by simulating the upcoming medical intervention. For this purpose, computational models of surgery have been developed for a variety of interventional procedures, which can predict the result of a planned intervention.

### 5.1. 3D Imaging Techniques

In current study a novel technique of ‘cryogenic sequenced layering’ (CSL) is proposed for 3D image reconstruction of biological samples transparent or semitransparent in visible or near-infrared spectrum utilizing previous cryogenic embedding [22]. The compatible polymer-embedded tissue model is exposed to cold gas vapor and photo-documented. The cold phase of the polymerized sample provides the acquisition of high-quality images. Thus, the developed technology facilitates the creation of detailed visual data for high-resolution 3D models of samples. The sample visual data are the input for software layering using a patented algorithm, which generates ‘3DL’ vector 3D model of the sample. This computer-assisted vector-based modeling is potentially a new step in imaging analysis since similar models have only been applied to inedible materials and do not have a utilization patent. Initially, a mathematical basis is briefly outlined, followed by a detailed protocol for the preparation and documentation of biological samples compatible with software applications.

Three-dimensional (3D) imaging generates great interest in medical diagnosis, robotics, computer vision, and other applications [23]. With the advent of advanced computer technology, visualization of 2D images in the 3D format has become possible. The volume rendering of Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), and other 3D datasets have caught the attention of researchers and introduced new applications in their respective areas which are not feasible with 2D imaging techniques. When the scanned object is transparent, a 3D imaging system is employed to capture its internal structure. A 3D imaging system could be B-mode ultrasonic imaging, a conventional tomographic system, or a 3D optical imaging system. A three-dimensional acquisition and display system for ultrasonic imaging is developed. Under such systems, the captured data is a sequence of 2D images, forming a B-scanned stack of the object at different angular orientations. Efforts have been made to come up with useful findings with CSL, B-mode, and stereo technologies, but these techniques were inadequate in many cases and produced only partially satisfying results.

### 5.2. Functional Imaging

Functional imaging techniques aim to study changes in physiology, typically through measurements of structures or dynamic systems such as blood flow or metabolism [24]. Functional methods have the potential to improve the quantitative accuracy and clinical significance of structural and biological measurements. They enhance the diagnosis of functional changes associated with diseases, and help to monitor the effectiveness of medical treatments. The range of available functional methods is broad, and continues to grow rapidly. These methods include both invasive and non-invasive techniques, and can be used to study many different physiological parameters.

#### 5.2.1. Perfusion imaging

Perfusion imaging techniques seek to obtain spatial distributions of the blood flow in various tissues and organs within the human body. Perfusion is fundamental to tissue viability, because it is through the blood that tissues derive their oxygen and glucose, and that they remove metabolic waste products. As a result, quantitative perfusion measurements are potential indicators of particular physiological or pathophysiological processes within tissues.

### 5.2.2. Mitochondrial imaging

Functional imaging technologies are now actively being developed for applications in dosimetry, radiobiology, and oncology. One particularly important target in the study of cancer is the dysfunction of mitochondria, since it has been known for some time that mitochondria play an important role in determining the difference in metabolic pathways between normal cells and cancer cells [25]. Specifically, it has been observed that cancer cells seem to prefer certain metabolic pathways that result in the production of nitrogen-based compounds.

### 5.3. Hybrid Imaging Systems

Physicians and physicists are constantly in search of ways to improve the quality of imaging, better characterizing internal structures and leading to earlier diagnosis. Hybrid imaging systems, which combine modalities, have been developed with the aim of providing complementary information in a single noninvasive measurement. Most of these systems are used in medicine (nuclear medicine with CT or MRI), and simple combinations in pre-clinical imaging and clinical radiological instruments. An overview of the hallmarks behind such combined systems is given, particularly focusing on the most well-known PET/CT. Patents describing the mechanical aspects of PET/CT and SPECT/CT systems, to protect the manufacturers of the imaging systems from becoming involved in patent disputes, are given. Although the focus is on PET/CT, PET/MR systems are also discussed.

A PET/CT scanner typically consists of a full ring of detectors that encircles the patient’s body, recording coincidence events of the two 511 keV gamma rays emitted in positron annihilation. Coincidence events are used to retrospectively deduce a line of response along which annihilation occurred. Making an image involves stacking many of these lines of response acquired from different positions of the detectors around the patient to produce a 3D image volume. While a CT x-ray study provides the greatest anatomical detail, it is unable to visualize some soft tissues [26]. PET also provides information that is otherwise unobtainable but can miss small lesions, classifying PET/CT as a synergistic pair.

## 6. Physics of Imaging Modalities

The diagnosis and treatment of various diseases had been expedited with the help of medical imaging. All over the world, the contribution of medical imaging is increasing in the healthcare system for the improvement of patient care. There are different medical imaging modalities for diagnosis of diseases such as X-ray, CT (Computed Tomography), MRI (Magnetic Resonance Imaging), Nuclear Imaging, Ultrasound, EIT (Electrical Impedance Tomography), and Emerging Technologies are used in the healthcare system. Despite the importance and potential effectiveness of medical images in the diagnosis of disease, reading and interpretation of medical images by radiologists is often tedious and difficult due to the limitations of current medical imaging modalities and their usage. Additionally, it is not possible to read all types of abnormalities or findings in medical images, most of the time it is missed. Most importantly, interpretation of medical imaging is extremely difficult for less experienced radiologists. In order to improve patient care and increase the efficiency of the healthcare system by categorizing the abnormalities and findings in the medical images, it is important to develop advanced search techniques by considering data mining and the importance of emerging technologies in medical imaging system [21]. The diagnosis and treatment of various diseases had been expedited with the help of medical imaging. All over the world, the contribution of medical imaging is increasing in the healthcare system for the improvement of patient care. There are different medical imaging modalities for diagnosis of diseases such as X-ray, CT (Computed

Tomography), MRI (Magnetic Resonance Imaging), Nuclear Imaging, Ultrasound, EIT (Electrical Impedance Tomography), and Emerging Technologies are used in the healthcare system. A review of medical imaging modalities is presented. In addition to this, advanced imaging modalities such as contrast-enhanced MRI, which are not currently available in the public healthcare system, are also discussed. Despite the importance and potential effectiveness of medical images in the diagnosis of disease, reading and interpretation of medical images by radiologists is often tedious and difficult due to the limitations of current medical imaging modalities and their usage. Additionally, it is not possible to read all types of abnormalities or findings in medical images, most of the time it is missed. Most importantly, interpretation of medical imaging is extremely difficult for less experienced radiologists. In order to improve patient care and increase the efficiency of the healthcare system by categorizing the abnormalities and findings in the medical images, it is important to develop advanced search techniques by considering data mining and the importance of emerging technologies in medical imaging system.

### 6.1. Principles of X-ray Imaging

X-ray imaging has led to major advancements in both the quality of diagnostics and patient care, revolutionizing medical technology. The emergence of digital imaging systems has made substantial improvements in patient throughput, detection sensitivity, modality integration, and diagnostic accuracy. This compendium of multi-disciplinary techniques addresses the operating principles of medical imagers and four key modalities: X-ray, computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET). Each section will provide a physical description of the system and convey a solid understanding of the underlying physics, engineering, and mathematical design – detailing both intrinsic patient scanning parameters and extrinsic operational considerations for system optimization.

The manual will rigorously explain the physics of medical imaging systems. As the most typical modality, X-ray imaging will be discussed in great detail, starting with the description of X-ray tube components, generation, and detection [11]. This will be followed by a study on radiography, chest radiography, digital radiography, fluorscopy, CT, bone densitometry, mammography, and angiography. Alterations in modulation techniques, electronic control panels, and beam alignment will be highlighted to give budding technologists the wherewithal to configure scanners properly. The mechanics of X-ray imaging will be compared to other systems to provide a comprehensive look at a broad range of modalities, beginning with a detailed explanation of the principles and components of X-Ray imaging systems. There will be discussions of X-ray transmission, contrast, noise, and spatial resolution. Finally, conventional radiography, digital radiography, fluoroscopy, and Computed Tomography (CT) will be studied, addressing both the hospital and clinic settings [12].

### 6.2. MRI Physics

MRI physics is a complex and heavy topic in medical imaging. Nevertheless, the knowledge of MRI measurement principles is important for researchers in the field of MRI. From measurements to the produced images, one can distinguish between the spatial distribution and contrast of parameters. These can, however, be linked: the image contrast can then be understood by the unique sensitivity profile of each measurement. The focus is made on static (i.e. non-dynamic) measurement of the system. It is first described how images are produced from measurements of a particular quantity (T1, T2, magnetic susceptibility effect). The encoding of the position is also explained, as well as some acquisition strategies for MRI. Finally, we show how the image contrast actually relates to the differences in some of the underlying physical parameters (T1, T2, and proton density). As a brief summary, MRI physics describes how MRI measurement can be linked to the underlying parameters of the image to produce.

Regardless of specific interests in image contrasts (T1, T2, proton density (PD), diffusion, flow), knowledge of the basic physics leading to the coupling between MR signal and the anatomy is necessary. The aim of this chapter is to give a comprehensive view of MR physics and related imaging aspects. Physiochemical and other technologies are considered as peripheral material and seldom treated in detail; attention is mostly paid to the MRI scanner and pulse sequences. Both scientific principles of MR physics and possible optimization in the software and hardware manners of a clinical or research scanner are emphasized. An MRI scanner is comprised of three basic components: magnet, radio frequency (RF) systems, and gradient coils. The formation of an MRI image involves the following key steps: magnetization, precession, absorption and emission of radiofrequency, gradients, and image reconstruction. At each step, the underlying physical processes are described to provide the basis for an understanding of MR signal generation. Consideration is also given to factors that can optimize and equip the behavior of sequences of images for different applications.

### 6.3. Ultrasound Physics

To visualize non intrusively human internal organs has intrigued mankind for centuries. The invention of Computed Tomography (CT) and other three dimensional techniques have revolutionized radiology . Clinical phased array systems were first constructed in the early 1980's; and in subsequent years 2D array systems have been the focus of an increasing amount of research. Three-dimensional techniques are gaining importance in diagnostic imaging today. Three-dimensional (3D) display techniques have been studied extensively for medical applications for the past several years. In addition to providing diagnostic information, they are also being studied for applicability in providing physicians with 'virtual surgery' capabilities. Recently, special techniques have also been proposed for multi-modal images with combinations of PET and MRI data. In medical and diagnostic imaging, three-dimensional data may be obtained in several ways. For example, Magnetic Resonance Imaging (MRI) may survey the subject with three-dimensional gradients, or Computer Tomography (CT) may sample the subject from all angles. Alternatively, in time-centred modalities, such as Ultrasonic Imaging, three-dimensional data may be collected over time, or a fixed time interval. In practical terms, acquiring three-dimensional data in Ultrasonic Imaging is complex, but three-dimensional display of an interpreted two-dimensional image is relatively simple. One advantage that Ultrasonic Imaging possesses is that it is non invasive and does not pose any radiation related risks to the patients. In ultrasonic imaging systems, the fastest method of acquiring two dimensional (2D) images is through a linear phased array system similar to RADAR. However, commercial 3D ultrasonic imaging systems are not available yet, and the medical imaging industry awaits the development of 2D phased array and associated electronics. Scanning with a 1D linear array with translation of the array in a perpendicular direction has been attempted to produce images in 3D. An efficient 3D Acquisition and Display System for Ultrasonic Imaging and a novel type of three-dimensional image that has the potential to be used as a hybrid 2/3D display is presented.

### 6.4. Nuclear Medicine Physics

NIBIB-Radiation-based quantitative bioimaging program is currently on a path to expand into new arenas of quality assurance: computed tomography, positron emission tomography, and PET-MRI. The states of current developments and future directions are summarized here: X-ray Computed Tomography: A plethora of follow-up efforts to the currently more mechanically oriented efforts to develop man phantoms made of solid material have continued to make advances. With the first patient equivalent CT dose metrology standard under consideration, the need will develop the metrology tools to use this standard is described. A smaller cohort effort to address specific aspects of CT (such as contrast measurements) is also outlined, in addition to a plan to develop the software tools necessary for a wider audience to perform “routine” image quality metrology. Positron Emission Tomography and Computed Tomography: A number of efforts began in 2004 for the Instruments, Materials and Reference Data program to expand into nuclear medicine, with three year efforts extending the development and just beginning new reconstruction engine, count-rate, and other standards projects. A relatively new project to develop standard phantoms complementary to the more custom developed phantoms that mimic tissue equivalent materials is described. A plan to open the calibration facility for nuclear medicine is outlined. Future efforts including individual projects are noted, with brief discussion of potential expanded resources. PET-MRI: A somewhat preliminary vision of how the advances already completed could extend from PET-CT into PET-MRI are discussed, where a prime focus is to use these advances to quickly and effectively develop PET standards are open for manufacturers. NIBIB-Radiation-based quantitative bioimaging program is poised to expand these efforts to include computed tomography and a significant problem in nuclear medicine over the next three to five years.

## 7. Clinical Applications of Imaging

A multitude of diagnostic medical imaging modalities can be used to probe the human body. However, these modalities need to be complimented by sophisticated computational techniques in order to ensure that the full diagnostic value of the image data is realized. While image processing methods have been deployed for a long time to enhance visual interpretation of images, image analysis methods have also been developed that offer automated or semi-automated tissue detection, measurement and characterisation of features [27]. The conceptually simplest and perhaps the most common example of image analysis is the detection of structures in an image, be it in two or three dimensions. This implies segmentation of an image into foreground and background regions, or the further assignment of multiple labels such that, for instance, each tissue type can be separately identified in an MR image. In biomedical image analysis the structures of interest will typically be anatomically related, and will represent either healthy tissue, or some or other pathological condition. Complex image analysis operations are often decomposed into a series of less complex operations that are more easily implementable, each of which acts on intermediate representations of the data [21]. This assumption underlies the majority of hierarchical and modular approaches to building systems for image analysis. Given the complexity and diversity of medical image data it is to be expected that multiple transformations will be needed in order to extract the data of interest from an image. Often these are performed sequentially, but more sophisticated tasks will require feedback of parameters determined at the high level from later steps back to preceding ones.

### 7.1. Cancer Detection

Throughout the past few decades, significant progress has been made in the field of medical imaging, resulting in widespread clinical applications. Medical imaging modalities have become routine tools in clinical healthcare to non-invasively observe the inner structure and function of the human body. In the meantime, advanced artificial intelligence technologies, such as deep learning, provide great opportunities in extracting informative features and patterns inside the acquired medical images. Therefore, it is urgent to promote investigations on the advanced fusion of AI technology and medical imaging systems for comprehensive utilization in early diagnosis and patient care.

Cancer is a leading cause of death worldwide, making early detection essential to enhance the prognosis and treatment of the disease. Multiple medical imaging modalities, including ultrasound, X-ray, computed tomography, and magnetic resonance imaging, have played a critical role in early detection, diagnosis, and treatment response prediction of cancer. Early detection of cancer is divided into screening and early diagnosis. The combination of screening and improved early diagnosis could ultimately lead to improved outcomes. Cancer screening tools like digital mammography, computed tomography, and positron emission tomography do not work by detecting small amounts of a cancerous tumor in the body. Instead, they provide information about changes in tissue composition and other characteristics that indicate the possibility of disease. However, because of differences in the disease, the location of the tumor, and/or the timeframe in which the changes happen, false positives and/or false negatives can arise. The accurate determination of the likelihood that a tumor is present in the examined patient is a well-posed binary classification problem. Traditional computational tools fail to provide a clear solution to the problem due to the high-dimensionality of data, uncertainty about the size and number of actual lesions, and clinical uncertainty about how best to model and interpret what is seen. Modern data-driven computational approaches, such as machine learning and artificial intelligence, have shown promise in providing novel solutions to complex health and biological problems.

### 7.2. Cardiovascular Imaging

Recently medical radiology has significantly progressed in the context of holistic approach to the patient management associated with imaging, thanks to the technological improvement of image acquisition and data processing and, more recently, to the integration of artificial intelligence [28]. Cardiovascular imaging is one of the fastest-growing radiological subspecialties, this possibly related to the increase in the aging population, which is more often evaluated for cardiac or ischemic brain events, and the referral to the imaging of asymptomatic subjects and the image follow-up of treated patients because of neoplastic or vascular diseases [29]. In 2018, the European Society of Cardiology and the European Association of Cardiovascular Imaging published a study on computed tomography (CT) and magnetic resonance (MR), focusing on how and why they have gained a I class indication in most cardiovascular diseases and on the potential impact of the tissue and functional characterization by CT photon counting and quantitative MR mapping. The common final cardiovascular outcome under the screening evaluation for cardiovascular risk reasons is acute event (myocardial infarct, stroke, aortic aneurysm rupture, etc.) causing a sudden hospitalization and knockout or aggravating conditions in terms of imminent vital danger, encouraging inappropriate treatment. Cardiovascular diseases are the leading cause of mortality worldwide. Diagnostic and therapeutic management of patients with cardiovascular diseases have been revolutionized, and continue to grow, by continuous technological improvement of assessment techniques. At the same time great progress has been made in the understanding of pathophysiological mechanisms that underlie the structure of the heart chambers and arterial vessels. From the 1995 to 2015, in Europe, the use of CT of the heart has experienced an 84% increase in the use of cardiac magnetic resonance imaging has experienced a 125% increase. So it is reasonable to think that the new technologies of cardiac CT and cardiac MR should necessarily be used with common sense, knowledge of the peculiarities of the patient, and always compatible with ethical and social connotations.

### 7.3. Neurological Imaging

Clinical applications in brain science have progressed at a glacial pace compared to other medical disciplines [30]. Treatments for most neurodegenerative brain diseases (NBD) are limited, and cure strategies remain underdeveloped. Pressure to improve clinical outcomes in neurological sciences is exacerbated by an aging population at risk for degenerative brain diseases (DBD). In recent years, technical advances in neuroimaging offer new promise, with enhanced characterization of microstructural anatomy, network connectivity, and functional biomarkers of health and disease. Neuroimaging applications targeting these outcomes are described using diffusion tensor imaging, diffusion-based tractography, and positron emission tomography. The glymphatic system is reviewed as a target for future neuroimaging investigation in clinical populations such as those with Alzheimer’s disease. Still, the technical advances in neuroimaging over the past 20 years overwhelmingly exceed expectations at their initiation. Moreover, treatment strategies have begun to benefit from applications in imaging technology. Various clinical applications have successfully utilized these methods to enhance surgical planning and improve procedural outcomes. Further methodologies are under development. Movie comprehension in the human brain has been analyzed in several studies using functional magnetic resonance imaging, near-infrared spectroscopy, and magnetoencephalography. In addition, others have demonstrated reliable correspondence of observational correlates of quantitative measures. These requirements from the scientific perspective are challenging in neuroimaging applications. However, previously unapproachable targets are propelling recent success. Paravascular transport mechanisms recently described in murine brain demonstrate waste clearance pathways at the microscopic level facilitated by channels that expand with increasing tissue compression. Glymphatic clearance of the cerebrospinal fluid consists of para-arterial CSF flux that directs along arteries and eventually diffuses into interstitial fluid or CSF.

### 7.4. Pediatric Imaging

#### Radiation dose to paediatric patients

CT and MRI offer valuable, often essential modalities for paediatric patients despite availability of the emerging bargain techniques like US and RX. Paediatric patients have an increased risk of radiation-induced cancers. Sharply increased risk of radiogenic cancers is estimated in children exposed to CT, which continues to experience highest increase in paediatric population. The ALARA principle should be followed strictly in the paediatric population with its own modification due to the increased radiosensitivity of children. MRI, the most rapidly developing imaging modality, is nearly free of ionizing radiation. However, in children, available routine technology requires sedation or general anesthesia. To be prepared for the lowest rate of accidents leading to the potential liability, and to minimise the use of sedation while addressing the clinical indication, practising to cut short the scan time is crucially important in paediatric radiology. [31]

Patient dose in diagnostic radiology has to be reduced to the extent possible without compromising diagnostic image quality. Radiation risks for paediatric patients are higher than for adults, thus the "as low as reasonably achievable" (ALARA) principle should always be strictly followed in paediatric X-ray examinations. Medical exposure contributes to the natural radiation burden of the human being. Intensive application of radiation has been a good reason for monitoring and investigating radiation doses for decades. Diagnostic reference levels are in use. They are useful for monitoring exposure from X-ray machines. [32]

## 8. Patient Safety and Ethics

Patient safety and improved diagnosis and monitoring of patient response also directly convey a consideration of the role of medical responsibility. An acute response to a biodistribution of radiopharmaceuticals can be caused not only by the pharmacological action of the substance but also by the administration of the radionuclide. Consequently, guidelines recommend immediate availability of life-saving drugs, and also emergency measures. In this context, guidance on the roles of national and international authorities, on the training of staff and personnel involved, and other specific issues are discussed. Radiation protection guidelines relating to the practice of medical imaging are discussed, including issues regarding protection principles, personnel dosimetry, source dosimetry, and public exposure. Non-radiation safety issues which are subordinate to national requirements and guidelines are not considered, for example, those involving general laboratory or other safety matters. Questions concerning the potential for a conflict between radiation protection requirements and obligations implicit in the conduct of a medical trial fall outside the scope of this document. Radiopharmaceuticals are a ready source of radiation exposure to people who are either treated with or who come into contact with patients treated with these substances.

Furthermore, the energies of the gamma radiation from the decay of some radionuclides used as radiopharmaceuticals are higher than those of the gamma radiation used for diagnostic imaging, and greater penetration of tissues and hazard to internal organs can occur from contamination. In diagnostic nuclear medicine, the actual absorption of radiopharmaceuticals is usually expressed in terms of the amount of radionuclide activity administered (dose). Practitioners generally limit the administered dose of radiopharmaceuticals to the smallest amount commensurate with obtaining the necessary clinical information while maximizing the statistical quality of the imaging study, restricting the usage of certain radionuclides to therapeutic circumstances, due to the associated risks of radiopharmaceuticals and the potential harm to patients, healthcare workers and the general public. Although this trend seems reasonable, the discussion is usually open and without a precise consensus. An analogous situation is prevalent in diagnostic radiology. The practice of keeping radiation doses as low as reasonably achievable while maintaining the diagnostic information provided by the imaging examination was introduced in the early 70–80s. Possible unintended exposure of patients in the use of non-imaging system imaging techniques, such as interventional procedures or in the context of other practices, led to the application of the as-low-as-reasonably-achievable principle; the practice of using imaging modalities that did not provide adequate image quality for the detection of abnormalities or did not provide sufficient coverage for the clinical examination also represents a significant improvement and a reduction of the potentially applied radiation dose. On the other hand, the implementation of planning protocols supported the choice of device settings and the optimization of image acquisition, reducing the applied dose without losing image quality; some other technological innovations have also revolutionized the way of performing diagnostic imaging examinations. Despite this paradigm shift and the unprecedented growth in the frequency of performances, the effective dose of the population has remained relatively constant. However, in clinical reality, the level of attention given to minimize patient dose is not the same in all imaging departments and the strategies used for dose reduction may vary significantly. Although the levels of proof may be insufficient, some observational results suggest that ionizing radiation epidemiological studies may be responsible for an increased risk of certain benign conditional morbidities after radiation exposure. With a global increase in the frequency of diagnostic imaging due to the innovative applications of this powerful diagnostic tool, the radiation burden of the population is expected to grow. The goal of improving the quality and accessibility of the imaging test must be combined with the goal of minimizing the associated radiation risk for the patient population. [33][34][35]

### 8.1. Radiation Safety

Radiological operations and procedures require sufficient knowledge and strict consideration. The operators should be competent in safety procedures, particularly controlling ionizing radiation exposure to patients and staff, in order to meet the performance standards for equipment and facility. It may require the operators to have knowledge and understand the principles of physics and instrumentation connecting to the modality, understand effects of recording media on principles of imaging physics and optical density, and make exposure adjustments to produce the intended images within acceptable error or tolerances. There are basic safety tools can be employed to minimize exposure, shield, and monitoring the dose. Modern imaging systems measure the radiation dose received by the patient, absent parts, or scanner components. Recently, with the advent of the latest machine learning artificial intelligence used on image processing, a significant progress has been made to implement a radiation dose module on a workstation that can predict the radiation dose of X-ray images produced on many different imaging modalities and physical locations as well during the X-ray procedure or treatment [36].

Radiation scatter is the primary mechanism of operator and staff exposure. Various strategies can be applied to reduce shield scattered radiation. Of these, the most effective technique is virtual collimation, a method by which an image processing tool can adjust and crop the anatomical region of interest on stored images. In a typical fluoroscopic operation room, the image intensifier is usually close to the patient, while the operators and staff are positioned on the opposite side. The X-ray tube can come from the same side as the image intensifier, or from the other side, creating a C-arm geometry. The intensity of scattered radiation captured by the image receptor is significantly higher and with a wider scatter angle at shorter source-to-image distance.

### 8.2. Ethical Considerations in Imaging

Medical imaging is a key component of the modern healthcare system. The development and use of imaging systems have seen significant growth over the last few decades. Many diagnostic tests are performed routinely through such systems. For many medical conditions, imaging plays a critical role in diagnosis and treatment. Finally, clinical labs bring advances in other areas of healthcare. It is also widely used in screening for early detection of disease, in treatment, and in monitoring the progression of individual medical conditions. In recent years, AI and machine learning algorithms have shown exciting results in many fields, including medical imaging. Diagnostic imaging applied in medical diagnostics is an integral part. The development of high-throughput technologies led to the storage of larger and larger datasets of high-resolution data, such as images. A paradigm case is found in diagnostic imaging, where clinicians have to make decisions based on a combination of text descriptions and images. In medical imaging, AI and machine learning techniques are applied in automated analysis and thus assist healthcare professionals in classifying and detecting pathological findings more accurately than considered techniques. Still, most diagnostic infrastructure within the medical imaging domain is based on a single hospital, multimodal, single-patient dataset. For the analysis of novel data modalities, the development of new kinds of AI algorithms is essential.

However, some concrete problems of a much more applied nature still need to be solved, including the automation of all image analysis aspects of diagnostic imaging. The integration of such techniques into more general tools depicting the overall medical record is also demanding. The extensive legislation exists that regulates the proper use of these technologies in clinical practice. In such a scenario, the main aim is to present the initial steps for a software programming development to implement a diagnostic support AI system from scratch, originally created modeling the real one used in the radiology department. This, to the best of the knowledge, is to date not available in the most specialized literature. [37][38]

### 8.3. Informed Consent

Acquisition of ionising image is a primary option for the diagnostic assessment of a lot of diseases, a fundamental task of forensic medicine, and it is used in the follow-up of many clinical conditions. Broad diffusion of these imaging techniques in medicine requires several instrumental devices. Approximately 100 millions of examinations are performed in the 5 principal European countries, involving a total of about 10 millions citizens, and the overall cost is around 15 billions of euros. The comparison with the previous years shows a continual growth of this medical practice. However, the exposure divided by the number of citizens gives a very useful index to follow the time trend of the National Medicine [39]. From the legal point of view, the medical imaging with ionising radiations can be considered as part of a new scenario. This is also the current priority in the field of imaging technology. So losing for sure the traditional role of the merely party expert witness, the physician involved in a trial accusation of malpractice will become an active figure that can exploit the results of the research. The statistic distribution on 15 years base of the number of trials with forensic medical consulting and that of trials condemned in favour of the patient confirms such a hypothesis. The latter display a normal distribution with a wide peak located in the periods 1991-1995, with a return to the original level of activity in the previous years.

## 9. Conclusion

Medical images have achieved a significant status in modern medicine since the first X-ray diagnostic image was taken in February 1896. Medical images constitute a crucial source of information essential for disease diagnosis, treatment and follow-up in clinical practice. In the years that followed, new imaging modalities including nuclear medicine, computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound allowed for obtaining detailed images of human anatomy and physiology. Medical imaging has reached then an extremely advanced state. However, vast amount of data demands matching technologies for advance post-processing, visualization, and, consequently, image understanding. There is a growing need for specialized analysis and efficient interpretation of the image information within the clinical environment.

Recent consensus regarding the use of large digital database systems has provided an impetus to electronically store, and offer access to vast amounts of information, including imaging, which up until now had been recorded in paper form in individual patient files. The development of the digital imaging protocol led to the DICOM standard, which now allows images to be read and manipulated on different imaging platforms and workstations. Further advances in medical imaging technology in the development of higher magnetic field, gradient performance, and MR-compatible interventional devices suggest that the growth in demand for interventional MR studies can be met and will improve physicians' ability to diagnose and treat patients.

Real-time intraoperative guidance will be applied to MRI of graft patency in diverse vascular and perhaps other interventional procedures. These approaches will extend the use of MR to new applications, providing an important adjunct to X-ray imaging. Equally important, the evolution of software for the planning of the interventional procedures means that optimized procedures will be developed in the future using 3D MR anatomy of the target anatomy.

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