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Medical Imaging Devices: Current Technologies and Future Trends

Tariq Abdullah Tariq
Al-Hadba University, College of Engineering Technology Medical Instruments Technology

Salam Adel Abdel Razzaq
Al-Hussein University, College Medical device technology engineering

Sara Wisam Wahab
AL-Esraa University College Medical Instrumentation Engineering

Ahmed Saleh Kazem
Shanan Engineering Technologies Medical Devices Hilla College

Reda Ghanem Kazem
Medical lnstruments Tech Al-Hilla University College

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Abstract: The role of medical imaging modalities in modern healthcare: An overview. Medical imaging modalities are crucial in the diagnosis, management, and treatment of diseases in modern healthcare. Medical imaging non-invasively visualizes internal structures and functions of the body, enabling numerous tasks, including the early detection and management of diseases, monitoring of treatment outcomes, guidance in medical procedures, and drug delivery. Various medical imaging modalities, such as X-ray imaging, computed tomography (CT), magnetic resonance imaging (MRI), ultrasonography (US), nuclear medicine imaging, and cardiovascular imaging, have been developed with different physical principles and clinical applications. Nowadays, most medical imaging modalities are digitally performed, and digital imaging results are stored and transmitted, providing easy access to data. In addition, newly emerging technologies, such as computational and artificial intelligence (AI), further improve medical imaging practice. AI can assist medical experts by rapidly processing and analyzing large amounts of medical imaging data. AI algorithms can identify and detect patterns, predict disease onset, and propose the optimum treatment plan. Therefore, AI implementation may revolutionize medical imaging and greatly improve healthcare.

Medical imaging is broadly defined as the non-invasive visualization, representation, and analysis of internal structures and functions of the body . The visual representations are called medical images or images; these are stored in the digital format and managed by Picture Archiving and Communication System (PACS). The health professionals skilled in interpreting medical images are called radiographers. While the field of medical imaging encompasses a wide range of applications and technologies, it is traditionally divided into modalities. Each modality has its physical principles and is suitable for different clinical tasks. A great deal of research and development focuses on generating more sophisticated imaging equipment, new contrast media, and analytical methods to improve the diagnostic capabilities of already existing imaging devices. Of course, much attention is also drawn to completely new imaging capabilities.

Keywords: non-invasive, modern healthcare, modern healthcare, Ultrasound, Computed Tomography, Gastroscope

Introduction

In 1895, The Wilhelm Conrad Roentgen discovered the X-ray which is the origin of medical diagnostic imaging. In 1971, first recorded the X-Ray by exposing 23 minutes. Later, multiple equipments have been developed because of the purpose of image studies and clinical diagnostics. Brief overview of medical imaging is the complicated modalities such as X-ray, Magnetic Resonance Imaging (MRI), Computed Tomography (CT), Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET), Ultrasound, and Fluoroscopy beginning from standard one. Medical diagnostic imaging is an unquestionable diagnostic tool that is used to obtain the detailed information of clinical aspects. Because of the revolutionary medical imaging technology, the necessity of enduring the tech in the area of medical devices. There are multiple complications as well as innovations of medical diagnostic imaging. Besides the important role of diagnostic, medical imaging tools can play the necessary role in the treatment and are more compatible with other assistive devices and certain ergonomics innovations in the area of medical diagnostic imaging. Medical imaging technology had very fast development starting from X-ray. Current boost in development of electronics, miniaturization of device elements, increment of computing's power, and economical factors. As for that, the devices had become smaller, faster, smarter, and inexpensive. On contrary, the development of some innovative tools such as non-SEMR, OCT, T-RMS, Hybrid-scope that in association with Gastroscope, Urology and Coloscope would explain the ambitions of medical diagnostic imaging field. Although the compelling technological innovation in the area of medical devices, there are tremendous demands for advanced impact. The devices are yet not fully desirable in some characteristics. Based on the surveys, radiological imaging evidences that the vast majority of standards X-ray diagnostic devices are behind the equipment's replacement requirements. Depending on the acquired data, only the up to 17 % of radiological institutes and the up to 23 % on X-ray devices equal to MR, CT, and so long. These statistics that manifold arguing stronger fundamental role of medical diagnostic imaging in lead diagnosis. On this group of investigation, it was acquired that the medical devices also need adaptation in size and extreme compatibility with other devices. Therefore, in one hand, the diminution of implementing medical devices to the "palm side" could be a technology purport direction. It is not unsung and innovative features that are coming to play . Consequently, less space is required and on the other hand, closer association the devices with robotics is desirable. In spite the chest X-ray is the standard and most frequently occurred medical diagnostic image examination, it is very polemic, if is it a necessary examination before EGN (endogenous) and LIT (liver tomography) and telemetry device implantation. Several hospitals do not have the technical ability to perform the query of medically diagnostic automatons that would be important for LIT (liver tomography). Progress on medical diagnostic imaging is nowadays sweeping comprehended as a broad terminology. Currently, many new vast innovative imaging plexus techniques are undertaken the study. These innovative imaging technique has the process to evolve pathological cardiology, oncology treatment, anesthesia monitoring, neurological disorders, multi parametric functional and assay diagnosis. With kind help of Fetal, Ultrasound and MRT imaging . Innovation is the "key single key" to solving any of the recent challenging and the complex issue today's image based "single vision" can the corner window to upgrading image outcome, thus further pointing medical diagnostic imaging. When retrenchment and commenting all the factors mentioned above, only him attended a challenging time ahead for the continued illustrious transformation of medical diagnostic imaging.

[1][2][3][4][5][6][7][8][9][10]

2. Fundamentals of Medical Imaging

In recent years, the development of numerous medical devices and technologies has been part of a vast, progressive change in healthcare. In the medical field, the term "medical imaging" pertains to quite a few distinct technologies that are used to visualize the human form, especially in disease diagnosis. Injected radiology can permit these images to manifest not only formation of the human body but similarly its operation, as an instance blood flow from the heart. Interference by radiology might also be utilized to guide minor, non-invasive medical operations. The medical imaging is lately a rapidly advancing field. Although X-ray has existed because of an image-producing tension somewhat longer than echography, TC, MRI, PET, SPECT, and several diverse new technologies, are down development. Additionally, the creation of contrast representatives is a powerful field that's gradually growing. Each of these imaging technologies generates images of different sections of the human form, at a particular measurement, using somewhat various flesh inoculations and technique instrument. This section will provide a brief insight of the fundamental scientific principles underlying each of the main imaging techniques by first building the foundation of the most known imaging modality, X-ray, and continue with 3-channel imaging in medicine. The principles of echo, directory tomography, multiple-photons emision avoidance, multiple gamma emision, optical satisfying, infrared, topographic, holography, functional magnetic resonance, photoacoustic imaging, thermal imaging, diffused optics, captor terminography, tactiligraphy, electric impedance tomography, radio-enhanced non-ionizing radiation thermal scene, etc., will not be discussed, however, the mechanism of these imaging techniques can very well be understood by the reader. [11][12][13][14][15][16][17][18]

2.1. X-Ray Imaging

Medical imaging is one of the most sought after ways of visualizing and diagnosing a variety of diseases. Medical imaging is also a renowned way to visualize the physical validation of various diseases and their treatments. The medical imaging technique uses several imaging equipment to detect diseases. Medical Imaging Equipment or Devices produces several difficult types of images. The compressed results of different entry scans help diagnose diseases easily. Different medical imaging devices are MRI, ultrasound, X-ray, PET-CT, CT scan, and so on. There are other new techniques that work with medical imaging, such as thermography and elastography. Among all the medical imaging techniques, the image created using X-ray is commonly used. X-ray is the eldest medical imaging technique and it is now widely used in many medical organizations throughout the world. Some enhanced techniques such as computed tomography (CT) create more comprehensive images that provide more diagnostic information to the radiologist to diagnose diseases. Further, with the advancement of the image processing techniques, the radiologist can interpret the diseases from the images more efficiently. The medical imaging that is recommended will appear in the modalities of different diseases or the affected parts of the body [19]. [12][19][20]

2.2. Computed Tomography (CT)

Computed Tomography (CT) is a clinically sophisticated imaging technique. The basic idea is to probe the interior of an object by mathematically reconstructing it from multiple X-ray measurements made from many different directions [19]. In contrast to X-ray examinations, which illuminate the entire body surface, CT images are cross-sectional "slices" that correspond to the distribution of average X-ray attenuation within the body. The revolution in engineering and computer technology has driven the development of such CT scanners that are capable of rapid scanning around the patient with ever-improved detail in the images. The advancement in spiral CT technology first makes it feasible to continuously rotate the X-ray source and rapidly move the table to acquire volumetric images. Subsequently, multi-slice CT records multiple rows of data at each rotation of the gantry, further increasing the speed of imaging while not sacrificing the detail in the images. These technologies are a technological breakthrough, provide important clinical applications in emergency settings and oncology, and are rapidly becoming a standard instrument in hospitals. Compared to other medical imaging technologies, the market of CT scanners is extensive because of their low cost, instant scanning capacity, and high convenience. However, the CT technology is somewhat less cost-effective when applied to lower income healthcare organizations and developing countries than in industrialized ones. One potential reason is the concerns of radiation dose; the other is the extensive application of contrast materials. CT is also a popular modality in tumor detection and treatment, including computed aided detection, monitoring, biopsy, and follow-up imaging in oncology. There have been extensive studies on CT for different purposes. For example, some studies aim to assess the impact of technical parameters on the image quality; other research is about developing new techniques to minimize the radiation dose while keeping the image quality equivalent. Although the main focus of this section is on diagnostic CT, CT is also frequently integrated with other imaging modalities, such as with x-ray for fluoroscopy, with PET for in-situ attenuation correction, and with ultrasound for 3D imaging. [21][22][23][24]

2.3. Magnetic Resonance Imaging (MRI)

Magnetic Resonance Imaging (MRI) is an interesting parallel case to previous differentiation of general principles because it is significantly more complex than other imaging modalities. MRI is based on strong magnetic fields and radiofrequency waves, and depending on the properties of their tissue, the energy that the nuclei release has a characteristic distribution frequency range.

When these electromagnetic waves with the same frequency as that of the nuclei are imposed, the nuclei capture them and retransmit them. This emission is what is measured and what gives rise to the image [19]. The process starts with the imposition of a strong magnetic field that forces the alignment of the magnetic nuclei of hydrogen atoms. Then, through the RF pulses, it is tried to tilt that alignment. The uncertainty of the nuclei will produce a precession that will be detected by the coil. Lastly, computer processing is done to convert the signal into tomographic images. The capacity of the MRI to obtain a good image between structures difficult to distinguish with other imaging techniques like X-ray or tomography is because it uses soft contrasts. This means that what is compared is the emission of energy between a tissue and its adjacent one, and not between a tissue and the empty background, like X-rays. For this reason, MRI is clinically relevant in nervous imaging, where it contrasts with the bones. Also, it has a widespread presence in other sophisticated techniques such as the footprint of routine medical actuation of public healthcare in cases of fear of x-ray absorption syndrome and carcinogenesis. MRI technology, specifically for its ease of development of Arctic coils and the improvements in sequences and postprocessing introduced by non-manufacturer scientific community. Although initially, its clinical use was almost entirely destined for neuroradiology, nowadays, it is increasingly extended to traumatology, oncology, and other medical specialties to become versatile to any part of the anatomy of MRI systems. Finally, though being far from other imaging modalities in dose levels, being harmless from magnetic fields, and not emitting ionizing radiation has also guided strong growth, wanting to be used in biochemistry fields [25]. However, factors such as the patient's accessibility and cooperation, the duration of exploration and teaching resources, and its great specificity in the high cost and ergonomics of the equipment, have so far limited the leap to reach other modalities. There are attempts to develop MRI systems that do not fill the body, working with open magnets, but limited by the homogeneity of the magnetic field, which needs strong and low dome systems. All these features have made the MRI a growing effort in the development of making portable miniaturization systems to make it a part of the ambulance's medical emergency kit. MRI technology has improved both in hardware and post-processing, expanding its applications to the study of body functions. This paper shows recent findings on the functional MRI or fMRI, a technique that allows the mapping of the areas of greatest brain activation, which is directly proportional to its metabolism. This mapping is due to the quantification of the magnetic resonance signal associated with the proliferation of deoxyhemoglobin, the substance responsible for catalyzing oxygen. This influence is not consistent with the electrical excitation of the neurons, which increases its energy consumption and local blood flow. Functionality of MRI has long been used as a probe in research and psychopathological framing. The evolution of the technology was based on the different magnetic resonance sequence techniques, and it started with the simplest, the Echo-Planar Imaging sequence (EPI). Since then, the development of new more efficient sequences has made the MR become faster and better in spatial resolution. However, it is still a major effort in post-processing the raw fMRI data to obtain images where non-brain signals such as heartbeat, respiratory fluctuations, and image noise have been eliminated. This has driven the emergence of a multitude of programs for fMRI functional mapping. This development has led to start a commercial focus with the appearance of software like the Paz Circumflex system, which allows software assistants capable to guide step by step in the processing of the data of raw MR images. Despite these improvements, fMRI remains a functionally indicative technology with limitations. It provides an indirect measure (local blood flow) of brain metabolism (neuronal activity), and the delayed time for the code makes it inappropriate for applications in intraoperative neurosurgical innovation, which requires real-time cartomapper technology. However, there are still improvements, many of which are based on parallel imaging technology applied to sequences for functional mapping. Nor should it be forgotten that the development of MR is very active in the always critical for science for the development of detectors and coils with greater sensitivity. This high interest to build a light, sensitive, and high spatial resolution modality has also propelled the exponent technological development. One of the recent technologies that offer a promising effect of power is the self-array detection system that allows simultaneously acquiring images from an extensive grid of small elements. MRI is complex without being inherently harmful in terms of ionizing radiation and biological effects. The progress in the technology could enhance this modality in order to expand its applications in medical imaging. There are ways to improve strategies in the future for MRI systems. The improvements for MRI involve from important design considerations like gradients and RF sources to the easily adapted changes like bed rotation that permits reducing the stress on the subject's body. MRI systems were designed and refined since 1973, the first magnetic efficiency concept, is necessarily the union of different factors to produce images. Measures application in the resonant paradigm can be considered from the general to some other specific in research about the improved MRI and even other applications not directly concerned with the imagery. The possibility of creating advanced research-level pulse sequences has been enhanced by recent development of API magnetic resonance interface software package. This enables detailed specification of gradients, RF interactions, and data signal processing. Developed such as devices or methods are based on NMR education and analysis. [26][27][28][29][30][31]

2.4. Ultrasound Imaging

Ultrasound imaging is a safe, flexible and often-used technique for visualization of internal organs of the body. In ultrasound high-frequency sound waves are transmitted into the tissue. The sound waves are reflected by the tissue as echoes. The returning echoes are collected by the ultrasound probe and used to create an image. Ultrasound has a widespread use in the medical environment due to its safety and real-time imaging capabilities. The methods and approaches are continuously evolving, making ultrasound a versatile imaging device. Diagnostic possibilities have been demonstrated in areas ranging from guide intervention, characterization of tissue, regional blood flow, and Doppler imaging, fetal ultrasonography, contrast tissue enhancement, elasticity imaging, 3D and 4D imaging to telerobotic ultrasound systems [32]. Most commonly known hospital applications of ultrasound imaging are centered around abdominal and obstetric examinations. Ultrasound imaging is also a commonly used method in cardiology. Besides the proven diagnostic value in the abdominal, obstetric and cardiology fields the method is also used in applications in urology, musculoskeletal system, gynecology, breast diagnosis, eyes and the brain (including neonatal applications). Traditionally, large cart-based systems have been used. However, the development of hand-carried and portable systems has made medical services utilizing ultrasound imaging more available in developing countries and other areas where the requirements of cart-based systems are met with less success than the light counterparts. Although the interpretation of the ultrasound images is to a certain degree subjective and operator dependent, training programs have been found to increase the diagnostic capabilities of the practitioner. The training of the practitioner is mostly directed at increasing the quality of the images, while the use of ultrasound technology is provided as part of the medical background of the practitioner. With the continuous development of new hardware and methods, the practitioner needs to engage in ongoing training programs. [33][34][35]

3. Advanced Imaging Techniques

The decent and distant future of medical diagnostics consists of moving beyond old technologies. Fatefully, recent technology has grown the realm of imaging beyond what it is often, embedding various potent imaging modalities. These procedures are frequently presented in duration to the point where the long and illustrious past of plain, old X-rays is merely footnoted. Moreover, the extension of existing imaging modalities has also been much-enhanced, delving ever deeper into the inner physiological turmoil and confrontation unseen to those not bearing the burden of an array of fancy degrees from expensive institutions of pedagogy. The future of diagnostic medical imaging apparently lies not in an uneasy seat upon the idyllic laurels of x-ray imaging, but within the clasp of impressive new strategies. Recently the radiographic portion of the medical imaging hospital department was eliminated altogether — saddened only by misty reminiscence from corporations with vested interests in the purely traditional. Some of a glimpse at what kept endowing hospital enquiries together with another distinctive peak at technology might eventually come to be found within an increasingly homogeneous field of truly impressive new diagnostic imaging technologies. It would be incautious to label this a definitive list, as the future of medical imaging is surely anything but definitive — the future of diagnostic medical imaging almost as surely lies enshrined within those new technologies not yet perfected nor currently quite perfected. However, there are a few shining examples where the detective technology has greatly accelerated in recent months and years, enlightening insight into what the tractor beam's eye view of the future of diagnostic medical imaging will likely reveal — at least as it may presently be forecast. Appearing prominently amid this funeral march to the past are the “nuclear medicine” imaging technologies, in particular spectacular Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT) systems [19]. And these in combination with the rapid evolution of truly portable magnetic resonance imaging systems and elegantly useful new detection/imaging techniques such as fluorescence imaging and elastography have allowed the outright replacement of many traditional often less revealing tests. Areas such as the early detection of difficult-to-treat forms of cancer open new possibilities through technologies to be found arguably truly displaying dimensions never before suspected. Indeed, the ability to detect many diseases at much earlier (and frequently less hectic) stages continues to grow, thus allowing for careful and efficacy-targeted treatment with less hardship and greater hope for the patient. Answering previously hopeless lines of clinical enquiry, towards which even the most diligent and learned of medical practitioners formerly advise to simply make the best of (or ignore entirely), have thus fortuitously expanded their perceptive potential. Thus through careful research and the necessity for practice with these board yet potent new technologies can significant improved patient outcomes worshipfully be expected. Efforts towards complementary and increasingly merging imaging modalities continue almost unabated as a result; though largely still in realms of experimental research, it seems probable that many of these new techniques will continue to mature, eventually entering routine practice themselves, to be replaced by even newer and more insightful technologies: this the archetype of advancement that has characterized the human pursuit of technology throughout history. In this light, the modern expansion of diagnostic medical imaging options far from representing the end of innovation, merely a passing peak on an asymptotic curve of technological perfection and omnipresence, might be seen instead of this as a high water mark of a transient victory, which while presently most fearful and gratifying still can and will erode, refine and transform, yielding in time to yet newer and even more potent technologies. [36][37][38][39]

3.1. Positron Emission Tomography (PET)

The Positron Emission Tomography (PET) is a non-invasive imaging technique that produces three-dimensional colored images of processes and the change in cellular activity within the body. It uses a radio-pharmaceutical as a means of evaluation. Current state-of-the-art cameras have high resolution, count rate performance, and sensitivity as well as time of flight capability. The imaging is exquisite and beautifully highlights regional metabolism. Often PET receives CNC recommendation. The ability to differentiate between artifacts and significant findings such as in oncology provides invaluable information. In addition, it is an essential piece of imaging in cardiology and neurology and can frequently provide information not easily achievable with alternate imaging modalities [40]. As new treatments to pathology are developed, this not only occurs but also significantly alters the roles of radiology imaging. PET-CT came into maturity and dramatically changed there understanding and practice of imaging. This was through the innate quantitative and superb sensitivity of the PET data and also through the synergy when it is obtained with CT as well as its high resolution and specificity. With the advent of a large number of new treatments the roles and requirements of PET-CT have continued to change. The ability to quantify treatment response early is now essential yet challenging. As further modifications to traditional practice standard treatments are proposed, the ability to diagnose and monitor disease progression and response is critical. However, much pathology occurs within respiring tissue. Whilst respiratory gating has been used on PET data it is less effective than with CT data given the usually noisy PET data [41]. However, the Revo system connects the patient with its Siemens CT using Bluetooth providing deep respiratory values detected which are then incorporated into the PET acquisition. This then produces true respiratory gated PET data, removes the limitations of respiratory gating PET data, and has the added advantage of avoiding additional further dose to the patient from repeat planning CTs. So, it is important to pick up that PET may not only be used but used in combination with hyper fractionation and an understanding of the new technologies to pursue relentlessly cost-effective advances. [42][43][44]

3.2. Single-Photon Emission Computed Tomography (SPECT)

Single Photon Emission Computed Tomography (SPECT) is a medical imaging technique that uses gamma rays emitted from a radiopharmaceutical to provide a detailed 3-dimensional image of functional processes occurring within the body. Emanating gamma rays are detected by a gamma camera which enables 3D imaging of the functional processes in organs or tissues. In SPECT, the gamma camera rotates around the patient acquiring multiple planar images, and later data is reconstructed into 3D using an iterative algorithm. Images can be fused with anatomical modalities like CT further enhancing the clinical interpretation of the findings. SPECT imaging is based on different kinds of radiopharmaceuticals that accumulate in organs according to their biological process. The significance of SPECT is continuously increasing in the field of medical imaging and the use of the SPECT system is growing day by day. The development of SPECT as the most advanced technology has changed the history of the treatments and considerable variations in the physiology of humans. SPECT is used in a wide range of clinical applications and has the biggest role in the field of nuclear medicine. The primary application of the SPECT system includes oncology, cardiology, and neurology. SPECT system can be employed in a combined manner with CT and an MRI system. Relevance of SPECT system is increasing because it provides precise data for the detections of tumors and detailed anatomy of the organs which is very useful for the treatments of diseases like cancer. The technical growth in SPECT systems adds a model for the therapy planning of the procedure to monitor the manner and the reaction of the body to the following healing process. As normal medical imaging strategies can be replaced, the SPECT system is widely used. Once the alterations occur in the body, the SPECT system is used as a conventional tool to detect them in an early stage. In the field of nuclear medicine, SPECT is getting very popular as the system provides more precise data in comparison to the other devices like PET, CT, and MRI. Amplifying the clinical data and the recognition of the high-speed imaging market are the main causes of the prosperity of the SPECT system [45]. [46][47][48]

3.3. Fluorescence Imaging

New innovative technologies are revolutionizing medical diagnostics which is a vital part of disease prevention. These techniques are non-invasive, painless and fast. In the last decade, great progress has been made in extending the limits of imaging localization, outperforming the diffraction limit using fluorescence imaging. By using the antibody-antigen interaction it is possible to target to a specific cell or molecule. This opens new horizons in the study of various diseases and in the development of novel therapies. [49]

Fluorescence imaging belongs to biomedical optical imaging. It is not harmful for the human body because no ionizing radiation is used. A fluorescent marker generates light in the visible and infrared regions, and it enables to visualize biological processes on the cellular level. This kind of imaging is often used in combination with other methods to enhance the obtained results. Many scientists attempt to use fluorescence imaging in investigating a number of non-infectious diseases. Fluorescence imaging is a powerful tool to study cancer as it is possible to make an early diagnosis. Moreover, fluorescence imaging aids in finding the tumor during the surgery; it may be visible even through the bones cleanly distinguishing between normal and malignant tissues. [50][51]

It is possible to evaluate the functional and dynamic properties of an object by this technique. Image processing software is used to extract all the information from the obtained images. It is useful to investigate the dynamics of a marked process by using real-time imaging, as this is high time-yielding process-monitoring. Fluorescence light scattering phenomenon is used in various techniques; one of them is optical biopsy. The progressing of a variety of diseases may be precluded by studying their effect on the immune system. Stimulated by specific diseases, the immune system generates auto-antibodies which may be detected using fluorescence imaging. [52][53]

3.4. Elastography

Elastography is an emerging imaging technique based on the detection of the mechanical property of tissues. It assesses the elasticity of soft tissues, providing diagnostic information not available with conventional imaging methods. Elastography has the potential to improve the characterization and the evaluation of disease progression, including cancer, liver diseases or fibrosis, and more. Elastography is used to assess the mechanical properties of tissues. Stiffness is the mechanical property that is typically measured and quantified with other imaging methods. In a metastatic involvement of cholangiocarcinoma, liver showed a high tumor stiffness in comparison with surrounding liver tissue. Commercial machines have been developed with various techniques such as strain and shear wave elastography. The former technique induces compression of the tissues of interest and uses the recorded data to generate tissue's elasticity mapping. In compression-based methods, ultrasound is used; radiofrequency data are obtained before and after manual compression. The difference between the two datasets is used to calculate the displacement [54]. There are two techniques to evaluate cancer stiffness with shear wave measurement: TE and ARFI elastography. TE and ARFI elastography are used in predicting gastric cancer metastasis in lymph nodes. ARFI is superior to TE for this purpose. The operator independence of ARFI is helpful for quantitative evaluation of gastric cancer stiffness. The differences in analysis methods and operator dependency were suggested as reasons for this variability. ARFI elastography is another ultrasound-based method for tissue elasticity measurement. A push pulse generates an acoustic radiation force in tissue, resulting in shear wave propagation. The speed of propagation of the resulting shear wave is used to construct a map of tissue elasticity. [55][56][57]

4. Emerging Technologies in Medical Imaging

Emerging technologies in medical imaging are deeply reshaping the landscape of diagnostics and patient care. Artificial intelligence and machine learning have a significant impact on the analysis and interpretation of medical imaging. 3D and 4D medical imaging technologies, in combination with advanced visualization techniques, bring unprecedented insights into the structure and physiology of anatomical objects from in vivo imaging data. Nanotechnology is cross-disciplinary and promotes the use of emerging technologies and tools in medical domains to allow a more advanced study and healthier responses to complex practical issues. Medical imaging has proven to be a potent noninvasive tool for diagnosing diseases. X-ray, ultrasound, computed tomography, magnetic resonance imaging, positron emission tomography, and so on, have been used in disease diagnostics. [12][58]

Integration of these and other technology to come with new initiatives is considered a new paradigm in the diagnostics approach. It will no longer focus on diseases causing imaging. Nevertheless, a more comprehensive, more personalized, and more targeted approach, looking from macroscopic object to cellular, subcellular and molecular levels. Over the last two decades, the growing generation of a variety of imaging modalities has radically improved our knowledge of the functioning of the life cycle. Despite the multifaceted diagnostic and pathophysiological information it gives, further efforts are still needed to understand the existing constraints and advance the diffusion of these new methods to clinical practice. In the panel of emerging technologies in the medical field, both nanotechnology and image analysis are given particular consideration. Opportunities for and challenges in this context are evoked, with examples of innovative developments. [15][59][60][61]

4.1. Artificial Intelligence and Machine Learning

Artificial Intelligence (AI) and Machine Learning (ML) have transformed medical imaging practices. Particularly in sophisticated imaging modalities, AI-based algorithms can automate tedious image data multi-dimensional analyses, which is becoming increasingly critical with the increasing complexity and data size of these modalities [62]. Scenario analyses have revealed that the number of medical images that exist in the world today is expected to grow at a two-digit rate, and that the total image data volume will become so large that it cannot be interpreted by radiologists using conventional methods. AI-based image diagnostic tools curbed this situation, holding the promising potential to work synergistically on patient management along with prevention and treatment of diseases. [63]

In medical imaging, the image data that are subjected to interpretation are described as a multitude of image data units in which numerous values are meticulously poured into a configuration that manifests within a picture frame on a two-dimensional plane, all of which aligns with the intricate positional information regarding the object being analyzed. Consequently, a radiologist is required to deftly maneuver through an enormous quantity of data in order to interpret the images comprehensively and accurately. The process of disease recognition stands out as one of the most intricate and time-consuming undertakings in this regard. Moreover, the practice of viewing medical images may change unexpectedly from time to time due to various factors. Although a physician possesses clinical expertise, fluctuating feelings and emotional states may significantly alter his or her observations during diagnosis. In contrast, automated image diagnostics powered by artificial intelligence (AI) and machine learning (ML) operate on a foundation of purely rule-based algorithms, which have the distinct advantage of maintaining consistent application of the same rules across different cases. In addition, the diseases that are evaluated radiographically are the result of a variety of examination designs, each possessing its own unique visual representation characteristics. As such, the intricacies involved in visual diagnosis can become overwhelming, making it essential that only skilled radiologists, equipped with ample experience, are able to achieve satisfactory and accurate results in their analyses. The AI-based image diagnosis systems, with their capability to minimize various visual perception limitations and to control all eventual viewing angles, have significantly increased their automotive robustness and reliability in clinical settings. It is critical to formulate such advantageous systems to serve as a formidable aide-memoire for clinicians who are faced with isolated or rare opaque radiography scenarios, thereby substantially contributing to more informed clinical decision-making processes. The increasingly thorough investigation of AI-based image diagnostics within the medical field not only depicts the myriad directions for insightful research but also aids in establishing clinical applications that are both practical and effective in enhancing patient care. [64] [65][66][67]

4.2. 3D and 4D Imaging

Since the introduction of computed tomography (CT) and MRI, conventional two-dimensional (2D) imaging technologies have significantly advanced the ability to visualize both anatomical detail and disease within the human body. A few decades after the emergence of CT, an advancement was made in imaging technology; researchers and clinicians began to develop and use three-dimensional (3D) imaging. The emergence of 3D imaging can be seen as a giant leap in medical imaging technology that greatly enhances the interpretation of complex anatomical structures. Today, medical imaging technology enthusiasts have gone beyond 3D and started the 4D imaging technique. 4D imaging captures anatomy, which is 3D imaging in nature, as well as a dimension incorporating time; the fourth dimension. The time component in the scan session provides an understanding of the dynamic physiological process in 3D anatomical detail which could potentially be an interesting and important input for systematic clinical management in several medical specialties. [68][12][69]

Three-dimensional – 3D – and even four-dimensional – 4D – imaging are a giant leap forward in the visualization of anatomical details and the functional nature of the human body that paves the way for a wide array of newer technologies and creates a large number of new ‘roads’ for image-based research. Since then, 3D imaging has become increasingly common on a wide range of medical imaging instruments and the technology is widely available. Additionally, the last decade has been marked by the rapid development of 3D imaging technology. Developments in 3D imaging of the human body are almost directly influenced by the development and expansion of computer-based and voxel data processing techniques. The majority of clinically available 3D techniques are post-acquisition methods, where 2D image sequences are used to generate 3D structures [70]. At present, most imaging modalities, including both major modalities, CT and MRI, offer the possibility of post-processing data into 3D. Furthermore, 3D has been integrated into imaging systems to facilitate application. 4D imaging can provide new and dynamic insights into physiology and raise the possibility to treat organ movement. Like with most new technologies, the dynamic time for the treatment of biological motion bodies is challenging and warrants technical and procedural validation. A more extensive research agenda helps to ensure the continued growth and diffusion of 4D technology. For instance, the analysis of the cycle and the implementation of appropriate countermeasures can enhance the effectiveness of 4D’s lead-time. With the expansion of 4DCT clinical access, musculoskeletal research in 4DCT is of interest that many comprehensive reviews are provided. [12][71][72]

4.3. Nanotechnology in Imaging

Nanotechnology is revolutionizing the field of medical imaging. Many novel contrast agents and imaging probes are currently being developed to enhance image quality and resolution. Among these are injectable nanoparticles that either target diseased tissues or rapidly clear the body to increase image contrast. Several other nanoparticle imaging agents are being designed to improve detection and characterization of disease at the cellular or molecular level. Additionally, many nanoscale materials are biocompatible and have negligible toxicity, which makes them much safer in vivo than molecular or organic contrast agents that persist in the body for long periods. Wide variety of nanoparticle imaging agents are under development, but the number of molecular imaging agents currently available for clinical imaging remains scarce, largely due to regulatory approval and the difficulty of producing complex materials in a scalable manner [73].

Nevertheless, the convergence of nanotechnology with more traditional imaging modalities such as magnetic resonance imaging (MRI), computed tomography (CT), nuclear imaging, ultrasound, and optical imaging stands to yield a number of significant advances. Here, the principles of nanotechnology are introduced that suggest that massive gains in sensitivity and specificity can be achieved through appropriate handling of the scale of matter. How this is playing out in research and innovation to yield a new generation of diagnostic and theranostic imaging solutions are touched on. It is widely recognized that progress in many fields of science and engineering comes about through the miniaturization of technology. Such advantages are keenly needed in medicine, where there are significant challenges for existing diagnostic techniques [74].

5. Hybrid Imaging Systems

Hybrid imaging systems have emerged by combining several imaging modalities, offering the unique possibility of collecting comprehensive diagnostic information in a single examination. There are basically two approaches to create hybrid systems: the first one consists of the development of specific systems, with dedicated and generally more advanced software, able to combine data coming from different scanners. The second solution relies on the physical integration of standard, or even outdated, systems . Hybrid devices work in the same session, thus shortening examination times, undoubtedly one of the most relevant objectives of the scientific research in this field during the last years. Hybrid systems are able to unity anatomical and functional techniques, accurately localizing and characterizing pathological regions, consequently expanding disease diagnostic accuracy. [12][16]

As a result, hybrid imaging is expected to provide a major advancement in patient management. Metastatic lymph nodes and/or extracapsular lymph node spread are critical parameters in tumor staging, respectively associated with poor prognosis. In the presence of previous radiotherapy, evaluation of mediastinal lymph nodes can be controversial, as size criteria may not be accurate. Considering the importance of correct diagnosis and treatment decision, many other areas could take advantage of the multimodal simultaneous approach offered by hybrid systems. Besides broadly explored oncology, emergent and growing application fields for hybrid imaging are cardiology, neurology, and psychiatry. [12][15]

6. Point-of-Care Imaging Devices

Introduction

The emergence of point-of-care (POC) technology offers the promise of rapid and potentially even real-time diagnostic result with the testing and imaging being done within reach of the patient [75]. This has the potential to support timely patient management and even theranostics in a variety of clinical settings, thereby bypassing the potentially protracted timescales resulting from the necessity of samples being obtained and sent off for analysis elsewhere. For medical imaging in particular, this can facilitate its use beyond the traditional imaging department and extend further into emergency medicine, primary care, and remote healthcare settings. [76]

At the same time, a number of challenges exist, including typically a trade-off in image quality and/or marker resolution when compared with conventional ex-situ systems. User interfaces and training for healthcare personnel are additional challenges, as well as regulatory constraints on providing sophisticated diagnostic volition such systems. All of these will be examined in the article. Notwithstanding these difficulties, efforts are being made to address the many technical challenges by a variety of inventive and portable imaging technologies. Moreover, an advanced and connected society is well placed to take advantage of modern telemedicine solutions, which can further enhance the utility of POC devices. [77]

7. Image-Guided Interventions

Introduction: Image-guided interventions (IGIs) are minimally invasive medical procedures under the guidance of medical imaging. Various imaging modalities, such as computed tomography (CT), magnetic resonance imaging (MRI), and X-ray, could be used in IGIs to help locate the pathology or target concerning regions. Generally, imaging is utilized either to display the patient's internal structures or to project the treatment device and the target on the patient's images. Therapeutic interventions guided by imaging include biopsy (tissue sampling), drainage, ablation, embolization, cryoablation, and radiation therapy. Many of these interventions are usually performed with needle-like devices. Medical complications of needle-like IGI procedures commonly occur, such as tissue injury, bleeding, and treatment failure [78]. Proper imaging guidance is thus required to minimize the risk of complications and to increase the success rate of intervention. In the case of IGIs, real-time imaging equipment is necessary for therapy device navigation and targeting. [79][80]

Better accuracy of these procedures can reduce the chance of complications to patients. IGIs can be performed with different imaging equipment, such as computed tomography (CT), fluoroscopy, ultrasound (US), and magnetic resonance imaging (MRI). The accuracy of the procedures depends on the accuracy of the guidance given by the images. At the same time, the characteristics of the guidance determine the procedure's quality. The more such technology is integrated into a procedure, the greater the need for a very high standard of technology. The integration of advanced imaging techniques, such as magnetic resonance imaging (MRI) and ultrasound (US) guidance, is a key to the success of these procedures. As these procedures are associated mainly with imaging guidance and clinical decision-making, the role of the operator is also particularly important. This is why skilled operators are needed in this group of procedures. Some complications and damage may be related to the examinations themselves, or to the materials used in the procedures. These complications, typically associated with more risky procedures, which would be difficult without imaging guidance, are largely unavoidable. However, due to mishandled properties, some complications can be avoided; hence, the development of procedures and technology is gradually approaching this goal. The aim of this paper is to review interventional procedures stratified by the complexity groups of medical materials, and to analyze ongoing technological advancements for patient safety and procedure quality improvement. Case studies will be presented in the second part of the paper to better illustrate the role and the value of imaging in these procedures. [12][15][11]

8. Radiation Safety and Dose Optimization

Radiation safety and dose optimization are primary concerns in the use of all medical imaging devices. The principles of justification (strong clinical grounds), optimization of radiation protection, and the use of diagnostic reference levels are now universally accepted for medical exposures. Consideration of these three principles is critical for the use of both existing and new and emerging technologies, since the effective dose for a prescribed diagnostic task from a given imaging device could vary by more than an order of magnitude. Optimization of radiation protection can involve both caregivers and patients, and both of these groups should expect specific doses to organs or tissues that fall within a defined range and be made aware of the reference levels [81][82]. This consequently underpins the responsibilities of both imaging referrers (mainly clinical personnel who request an examination and responsible for providing clinical information) and imaging providers (mainly involved in the imaging process and responsible for the technical quality of an examination). Medical imaging is a rapidly developing area within healthcare, with a large and increasing number of imaging examinations now being undertaken. Most imaging techniques involve the use of non-ionizing radiation, but the use of radiation exposure is increasing due to the expanded use of computed tomography (CT), nuclear medicine, and interventional radiology [12]. Growth in the development and use of hybrid imaging methods is accelerating this increase. In this context the radiation safety of patients and healthcare providers is of paramount importance, as a survey found that radiation safety for patients and healthcare providers was considered the most important subject in the training of both groups across a broad range of imaging providers. Effective use of diagnostic reference levels and good application of the dose audit process can contribute to improvements in protective optimization. Automatic exposure control (AEC) systems are important in reducing the scatter radiation doses and in optimizing image quality, both reducing exposure. Optimisation should be undertaken in conjunction with the utilization of dosimetry and an awareness of diagnostic reference levels (DRL) [83]. Dosimetry is a method of direct measurement or calculation of the radiation dose that is received by an individual patient or phantom during a particular examination. The two areas where dosimetry is most important are the implementation of guidance or reference levels over an extended period of time and assurance that the dose is effectively reduced in the case of dose-intensive examinations, whilst image quality is maintained. Dosimetry may be particularly important in the pediatric population, where there are concerns that the dose from certain examinations may be higher for children than for adults. It involves measurement of the dose-length-product (DLP) and use of this quantity as a surrogate for effective dose. It is recommended that supplementary dosimetric measurements for CT be undertaken at least once a year and that the results be compared with local and international DRLs. A further important focus of the optimization of radiation protection is education and training of operators and other healthcare workers on radiation protection issues. The multidisciplinary team essential in optimizing radiation protection must be the cooperation of the radiologists, physicists, radiographers, and regulators. Patient education should also be recognized as important as there is evidence that many patients have limited awareness of medical radiation, and are not aware of the different levels of radiation risk between x-ray modalities. Reducing noise can assist interpreters and phantom detectability, and image quality should be slightly increased with patient size. This can be achieved in a number of ways such as by increasing the FOV, slightly increase the tube current, or reducing the pitch. Optimal adjustments of kVp and mAs prior to IR will be necessary based on patient BMI, or on EFW when BMI is not available. Area DLP should also be multiplied by a site-specific conversion factor. It is important to strike a balance between patient safety and the necessity of acquiring diagnostic images. This is particularly important for emergency and inpatient imaging in scenarios where duplicate examinations have been performed. This should be kept in mind, however it's also emphasized that patient safety and diagnostic quality take priority over dose optimization and it may not be possible to exceed the dose limits without further compromising essential clinical information. The diagnostic efficacy of the examination should not be reduced to achieve a dose in accordance with defaulted DRLs. Special consideration will then need to be given to challenging high BMI and/or EFW categories so that patient size is not a reason patient dose above the established DRLs. It is anticipated that individual dose thresholds will become important at this point, requiring site-specific and maybe even protocol-specific criteria. Configuration of MRI machines and related equipment such as coils should be optimized prior to the examination. Reducing noise can assist radiologists in their interpretation of the examination and phantom detectability. Using the minimum TE and TR is advised in most cases as this generally reduces noise. The degree of parallel imaging should also be considered – increasing this factor will often increase noise. Sens and AC should be employed where they will not compromise the diagnostic information. Raising the kVp can also slightly increase the noise in the image, and therefore a slightly increased image quality should be accepted with larger patients. This can be achieved by increasing the FOV, increasing the number of signal acquired, or increasing the SENSE Factor. A lower pitch should also be considered. The ability to customize the IR strengths is one of the chief recommendations of IR at all points where its use is system implement. Gain further training in kVp modulation if available. More widespread execution of this feature can lead to standardized patient dosing and potentially a higher quality in final images. [81][84][82][85]

9. Regulatory and Ethical Considerations

The development and operation of medical imaging devices are subject to rigorous regulatory and ethical standards to ensure the safeguard of patients and clinical efficacy. Any medical device, including medical imaging technologies, must comply with the relevant legislation and protocols. This is overseen by designated regulatory bodies [86]. Any use of radiation is also subject to special regulations, with diagnostic exposure to ionising radiation closely monitored. All imaging carried out as a part of a patient's treatment should follow existing guidelines and protocols; any research requiring imaging should similarly safeguard the patient. [87]

The ethical implications of the use of new technology are just as pressing as the legal side of equipment use. Even if a patient has been referred for imaging, they should still be informed of its purpose and consequences. Safeguarding the privacy of that patient also extends to the data produced by imaging. The continued role of the British Radiological Council in monitoring and enforcing high standards of professional practice will hopefully lead to the ethical implications of imaging data in research being more widely reported. Nevertheless, the potential for imaging to be misunderstood, or producers selectively taken up, is large, and future research practice should aim to either ameliorate these problems or at least report on the precautions observed. Unfortunately, legal and practical guidelines for the use of AI in the planning of research are sorely underdeveloped; a programme of continuous professional development may help to address these issues as they develop. There is a duty of contractual and professional communication between healthcare provider, researcher, and patient; as in much else, transparent communication, both symptomatic and diagnostic, may be the best response. [88][89][90]

10. Challenges and Future Directions

The key to the above transformative vision is to balance advanced solutions with accessibility. While high technology advancement rates produce numerous new instruments and engineering achievements, they may significantly elevate the cost of medical tools, diagnostics, and analytic solutions. It is highly desirable to democratize these impressive technologies to expand public availability and maintain current healthcare diversity. Particular attention should be paid to imagine services because they are costly and not equally accessible everywhere. Similarly, efforts in data storing, management, and exchanging problematics are growing along with the appearance of new methods and tools. Hence, standard, shared, and consistent rules for useful medical data handling and acquisition should be continuously improved. Individual clinical healthcare professionals must pursue lifelong education endeavors and apply novel techniques, systems, and equipment in perhaps unmatched quantitative terms. This perspective embraces a variety of EP as well, which take similar considerations. [91][92][93]

Nowadays, the development of various AI-based solutions is very intensive. A lot of effort is being put into creating medical-imaging-compatible AI algorithms. Despite this, the resolution of medical imaging systems is still being elevated. A new trend may consist of introducing patient-individual imaging protocols. Undoubtedly, the most crucial issue is the growing economic differentiation between and within countries, which hampers equal access to medical technologies. Beyond those subjective considerations, further considerations of the development of imaging technologies are listed. Although they seem hyperdeveloped, their implementation is crucial for further escalation and egalitarian access. The same applies to the joint or collective solution of challenges, which contributes to multilateral practices and international cooperation, particularly within the framework of research and innovation [19].

Conclusion

Advancements in medical imaging design, technology, and use have not only enabled improved diagnostics and treatment but have also contributed to expanding the reach and efficacy of healthcare practices. It is important for healthcare professionals in the modern era to have an understanding of the full range of traditional imaging technologies available, as well as to stay informed regarding new and emerging imaging devices. This will allow professionals to critically assess their patients' needs and recommend the most effective and minimally invasive imaging practices to achieve optimal patient outcomes. With the increased focus on patient-centered, personalized healthcare, the imperative of this understanding becomes even more pressing, for both experienced practitioners, as well as for students entering the field. The peculiar impact of emerging imaging technologies, as well as the ethical and infrastructural challenges to their integration into healthcare practices must also be highlighted.

Throughout the history of medical imaging and up until today traditional technology dominates the medical imaging market. Despite this, a plethora of new imaging technologies and designs with yet undiscovered medical applications and therapeutic possibilities emerge. The vast majority are research prototypes and even with those that have already stepped on the ground of practicality under-market testing protocols. With healthcare practices under growing pressure to lower costs, the pressures have accentuated to "objectify" the benefits of the use of emerging imaging technologies, measured in terms of improved outcomes related to well-defined diseases and conditions. Already many examples exist of medical imaging technologies that have found use in specific healthcare applications and contribute to widening the therapeutic options available to the clinician. Equally, many imaging methods see routine use but make relatively modest contributions to improved outcomes. With growing pressure on medical costs, practices must focus their use. Desirable from the point of view of pharmaceutical and medical-equipment vendors is a situation in which prescriptive use based on evidence-based trials could be introduced, giving them a focus for selling; yet while pressure is applied by clinicians and professional groups, they are not necessarily equipped to provide a body of rigorous trials. Decisions as to the purchase and installation of equipment are often carried by administrators and decision makers without medical knowledge and typically with no understanding of the clinical application of the technology concerned. With the reduction of healthcare costs a global concern, practices are more reluctant than ever to invest in technology unless a robust therapeutic case can be made and strong evidence provided to support the likely return on investment. In the local, national, and international contexts, the development of interdisciplinary, patient-focused research projects involving both academics and clinicians are considered the best way to address the interests of all relevant stakeholders.

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