Advances in Medical Imaging Equipment: A Review of Research Progress and Clinical Applications

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Abstract. Medical imaging equipment plays a crucial role in medical diagnosis and health screening. These devices utilize various physical principles and technological means, such as X-rays, magnetic resonance, ultrasound, and radioactive isotopes, to produce non-invasive or minimally invasive images of the internal structures and functions of the body. This provides doctors with a clear and accurate understanding of the anatomy and physiology of the body. With the progress of science and technology, it provides doctors with rich diagnostic information through various advanced imaging technologies, and greatly improves the diagnostic accuracy of diseases. Therefore, this paper explores PET / MRI imaging, MR diffusion tensor imaging, and 5T ultra-high magnetic field resonance imaging through a literature review. The research progress, clinical application, limitations, and future development of three cutting-edge imaging technologies are comprehensively analyzed. This study not only provides an in-depth analysis of existing cutting-edge imaging technologies, but also looks into the future of how these technologies shape healthcare and provides directions for future developments in medical imaging technologies.

Keywords: PET/MRI imaging technology; magnetic resonance diffusion tensor imaging technology; 5T ultra-high magnetic field resonance imaging technology.

1. Introduction

With the vigorous development of medical science and technology today, medical imaging technology has also been rapidly improved. PET / MRI imaging technology, magnetic resonance diffusion tensor technology, and 5T ultra-high magnetic field resonance technology, these three technologies show advantages over traditional medical imaging equipment in major clinical diseases such as tumors, nervous systems and cardiovascular diseases. This paper will discuss the progress, clinical application, limitations, and future development of these three advanced medical imaging technologies.

2. Research Progress and Clinical Application of PET / MRI Imaging Technology

PET / MRI imaging technology is an advanced medical imaging technology that combines positron emission tomography (PET) and magnetic resonance imaging (MRI). PET imaging, or positron emission tomography, uses the tracer principle to display biometabolic activity in the body. The basic principle of PET imaging is to use a radioisotope as a tracer release positron, positron in the surrounding tissue constantly scatter and slow down, when they rest combined with an electron, annihilation reaction, positive and negative electrons disappear, and their mass into two equal energy, the opposite direction of photons. By detecting the photons, PET can determine the annihilation position of the position of the positrons, and the computer can reconstruct the radioactivity distribution in the body. MRI imaging is a medical imaging technology that uses the resonance of the frequency magnetic field after the magnetization of the human body in the static magnetic field. MRI imaging has the advantages of no radiation, high soft-tissue contrast, and multiplanar imaging. PET / MRI imaging technology is a cutting-edge technology in the world. In the application of clinical medicine, it mainly focuses on the three fields of malignant tumor, nervous system, and cardiovascular system, and has become the best method to diagnose and guide the treatment of various malignant tumors, coronary heart disease, and brain diseases.

2.1. Application of PET / MRI in Malignant Tumors

Radiotherapy is a method of treating tumors using the ionizing radiation effect of high-energy rays to kill cancer cells. PET / MRI imaging technology is widely used in radiotherapy, which provides more precise tumor localization, more effective treatment planning, and earlier evaluation of efficacy. Gross tumor volume (GTV) is usually described by the tumor morphology seen on MRI. However, by combining the tumor biological information provided by PET, the risk of edge error can be reduced, which may affect the change of GTV [1]. The difference between GTV-MRI and GTV-PET expanded as tumor volume increased. Although approximately 90% of GTV-PET overlaps with GTV-MRI, 10% of tumor and lymph node volumes are only identified by PET, and the advent of PET / MRI holds great promise for achieving precise target delineation.

Patient monitoring plays a key role in the survival of cancer patients. Local recurrence is often the root cause of unsuccessful treatment, and therefore timely and precise restaging of patients with suspected recurrence is essential to ensure that optimal management strategies can be implemented. However, the anatomical changes, scarring, and radiation-induced inflammation induced by radiotherapy or surgery make it difficult to distinguish active tumor tissue, leading to incorrect restaging and thus influencing further treatment decisions. Sawicki et al showed that in patients with suspected pelvic tumor recurrence, PET / MRI correctly diagnosed 100% of malignant lesions, while MRI had only 74.6% [1]. Moreover, compared with PET / CT, the non-radiation activity of PET / MRI reduces the possibility of cumulative radiation damage in patients.

2.2. Application of PET/MRI in the Field of Neurology

Parkinson's disease, also often known as "tremor paralysis," is a degenerative disease of the nervous system. In the past, the diagnosis of PD mainly relied on the clinical symptoms and history, however, this diagnostic process often lacked sufficient accuracy due to individual differences between patients. With the development of medical imaging in recent years, MRI and CT play an important role in the diagnostic evaluation process of Parkinson's patients. However, the sensitivity of MRI to detect lesions is not high, and the resolution of soft tissue imaging of CT is low, resulting in a single MRI and CT can not explain the problems of the brain well. The emergence of PET / MR makes it possible for researchers to deeply explore the pathogenesis, differential diagnosis, and efficacy evaluation.

Application of PET / MR in the differential diagnosis of PD [2]. Because of the overlapping symptoms of PD and other atypical Parkinson's syndrome, it is difficult to differentiate by clinical manifestations. PET / MR can be further identified by PET-associated metabolic patterns combined with MR anatomical information (including volume changes, perfusion information, etc.). Barthel et al [3] used 18F FDG PET / MR in two patients with Parkinson's syndrome: a single DAT single photon emission computed tomography failed to identify both. All of these showed decreased striatal uptake. However, after performing PET / MR imaging, it was found that one of these cases showed brain atrophy in the MR images and showed decreased glucose metabolism in the striatum and thalamus on 18F FDG PET imaging. This case was diagnosed as having a progressive supranuclear palsy, another case showed no.

2.3. Limitations and Future Directions of PET / MRI

PET / MRI equipment is expensive and relatively expensive for maintenance, limiting its popularity in some healthcare facilities. PET components can affect the efficiency of the gradient magnetic field and reduce the signal-to-noise ratio of MR images. At the same time, the rapid switching of the gradient magnetic field will make the PET components generate additional heat, affecting the operation of the temperature-sensitive devices.

In the future, PET / MRI devices are expected to see a series of significant improvements and upgrades as the technology continues to evolve and innovate. First, the miniaturization and performance optimization of PET detectors will make the device more compact, while improving the detection sensitivity and image resolution, resulting in more accurate biochemical information. Secondly, the high field strength of MR systems and the development of rapid imaging technology will greatly improve the imaging speed and shorten the waiting time of patients during the examination process, while providing clearer and more detailed images of the anatomical structures. These technological advances will not only significantly improve the overall quality of imaging and diagnostic accuracy, but also help reduce medical costs, making this advanced imaging technology more popular and allowing more patients to benefit from this efficient means of medical examination. Furthermore, as the accessibility of devices increases, healthcare facilities will be able to deploy PET / MRI devices more widely, improving the overall level of healthcare services, especially in early disease diagnosis and treatment planning.

3. Research Progress and Clinical Application of MR Diffusion Tensor Imaging Technology

3.1. Diffusion Tensor Imaging

Magnetic resonance diffusion tensor imaging (DTI) is a new technique used to describe the structure of the brain. It is a special form of nuclear magnetic resonance imaging (MRI), which probes the microstructure of tissues based on the diffusion properties of water molecules in tissues. The DTI technology is based on the diffusion movement of water molecules in biological tissues, which exhibit different properties in different tissues. In brain white matter, the arrangement of nerve fibers leads to the diffusion of water molecules exhibiting anisotropy, that is, the diffusion speed along the nerve fiber direction that is perpendicular to the nerve fiber direction. By applying diffusion-sensitive gradients in multiple directions, DTI can quantify this anisotropy and generate tensors describing the direction and degree of diffusion in water molecules.

3.1.1 Application of MR diffusion tensor imaging in preoperative grade diagnosis of glioma

Glioma is the most common primary central nervous system tumor, with the characteristics of high malignancy, high recurrence rate, and poor prognosis, and different treatment options mean different prognosis. Therefore, it is crucial to accurately determine the pathological grade of glioma before surgery. At present, the graded diagnosis of preoperative glioma mainly relies on imaging methods, but the graded diagnostic ability of conventional MRI is limited. DTI parameter values are often used for glioma assessment [4]. FA map of DTI parameters can show the compression passage of cerebral white matter fibers, and color FA map can show the invasion and destruction of cerebral white matter. CAI Zhichao et al. [5] graded glioma using DTI quantitative parameters ADC value and FA value and found that the tumor body and peritumor ADC value were significantly different between high and low-grade glioma, which could be used to grade glioma.

3.1.2 Application of MR diffusion tensor imaging in spinal cord lesions

The spinal cord is a lower part of the central nervous system, located in the spinal canal, and the structure of the spinal cord is also divided into white and gray matter. Spinal retreat Progressive disease is generally considered as the most common cause of myelopathy, especially the cervical spinal cord, and the difference between symptoms and conventional MRI imaging results in patients with myelopathy ranges from 15% to 65% [6]. According to the quantitative information provided by the literature [7]. DTI evaluates the severity of myelopathy, facilitating patients to choose early decompression surgery. The most common manifestation of compression myelopathy is increased MD values and decreased FA values, and FA values in the spinal cord have been shown to somewhat predict surgical outcomes [8] in patients with chronic compression myelitis. In the research field of cervical myelopathy, the latest study was conducted by Takamiya et al. [9], who successfully predicted the neurological status of patients using preoperative DTI parameters as indicators after cervical cord decompression surgery. Studies have found that spinal cord compression changed RD values but had minimal effect on AD values. Postoperative improvement in neurological function was negatively correlated with preoperative AD values, independent of other DTI parameters. This finding confirms that preoperative AD values can be used as a valid indicator of predicting postoperative neurological improvement in patients with cervical myelopathy.

3.1.3 Application of MR diffusion tensor imaging in the diagnosis and treatment of craniocerebral trauma diseases

Diffuse axonal injury (DAI) is a traumatic brain injury (TBI) caused by blunt brain injury, mild, moderate, and severe according to the Glasgow Coma Scale. Mao et al reported a case of DAI presenting with speech impairment, a DTI study of the patient [10]. By measuring FA values in the region of interest and DTI white matter tractography showing the reduced white matter integrity of the left frontal and medial temporal regions and found that white matter damage identified by DTI and functional magnetic resonance imaging (Functional Magnetic Resonance Imaging, of fMRI) and language impairment as assessed by neuropsychological examination. These findings demonstrate the role of DTI in differentiating the white matter alterations secondary to TBI. In terms of functional recovery after DAI, Han et al used DTI technology to study the recovery process of corticospinal tract DAI and found that the FA value of both brain stems increased significantly 24 months after DAI onset, along with motor function, which well-illustrated the recovery of corticospinal tract DAI [11].

3.2. Limitations and Future Directions of DTI

Although the DTI technique is highly sensitive to the movement of water molecules within the tissue structure, it is low, and the combination of clinical history and other imaging examinations improves its diagnostic specificity. DTI is very sensitive to artifacts, such as physiological activities such as patient movement, breathing and heartbeat, as well as artifacts caused by magnetic field inhomogeneity, which may affect image quality and analysis results. In addition, DTI assumes that only one fiber travels in each voxel, but in fact, there is the possibility of multiple fibers crossing in a single voxel in the tissue, so DTI does not accurately describe the direction of cross fiber bundles in the tissue.

In the future, DTI (diffusion tensor imaging) technology is expected to become an important tool for the study of white matter fiber networks in the brain, which can describe the direction and structure of nerve fibers in detail, and thus reveal the complex connectivity patterns within the brain. With the continuous progress of technology and the increasing maturity of data analysis methods, DTI technology will provide more precise studies of white matter fiber characteristics, including the density, integrity and directionality of fibers. This will greatly advance the field of neuroscience and provide more in-depth insights into clinical diagnosis and treatment. Clinically, DTI technology can help doctors more accurately diagnose various neurological diseases, such as multiple sclerosis, brain injury, schizophrenia and Alzheimer's disease. By observing the changes of white matter fibers, doctors can better understand the pathological mechanism of the disease, so as to develop more personalized treatment plans. It will play an increasingly important role in future clinical diagnosis, disease treatment, and neuroscience research.

4. Research Progress and Clinical Application of 5T Ultra-high Magnetic Field Resonance Imaging Technology

The principle of 5T ultra-high field MRI is based on nuclear MR phenomena, in which radio frequency energy is used to excite hydrogen nuclei inside the body. At strong magnetic fields, these hydrogen nuclei interact with the magnetic field to produce MR effects. When the RF pulse stops, these nuclei return to their original energy state, while releasing energy that is detected by the MR imaging system and converted into images. The 5T MRI uses the magnetic field strength of 5.0 Tesla, which is much higher than the 1.5T and 3T MRI systems commonly used in clinical practice. According to the principle of magnetic resonance physics, the image signal-to-noise ratio and spectral resolution increase with the enhancement of the magnetic field intensity, thus improving the sensitivity, resolution, signal-to-noise ratio, contrast, and image clarity.

4.1. Application of 5T ultra-high Magnetic Field Resonance Imaging in Cerebrovascular Disease

Wei et al [12] reported that at the field strength of 5.0 T MRI technology, the average SNR value in the lateral plane of the brain was 1.6 times that of 3.0T MRI, indicating that the image quality is higher, and the signal stability is better under the 5.0 T MRI technology. Furthermore, with 5.0 T MRI, the technical 48-channel head coil has higher parallel acceleration capability and faster imaging speed than the 3.0 T MRI 32-channel head coil.5.0 TTOF-MRA defined the arterial dissection location, morphology, and involvement of perforators, while 3.0 TTOF-MRA cannot not. In the application of the anterior choroidal artery, the 5.0 TTOF-MRA showed higher subjective image quality scores, signal-to-noise ratios, and contrast noise ratios than the 3.0 TTOF-MRA, providing clearer images that can aid in the clinical diagnosis and treatment of cerebrovascular diseases related to the anterior choroidal artery.

4.2. Application of 5T Ultra-high Magnetic Field Resonance Imaging in Cardiovascular Diseases

Compared with 3.0 T MRI, 5.0 T MRI is better in resolution and signal-to-noise ratio, which can better balance the field strength and quality of cardiac imaging, provides richer detail of cardiac anatomy and clearly shows small myocardial infarction. Thus, it will improve the accuracy of assessment and diagnosis. For example, high-resolution movie imaging acquired by gradient echo sequence, with a resolution of 1.0 mm*1.0 mm, can clearly display the heart cavity contour, papillary muscle and trabecular muscle. Gadolinium contrast delayed enhancement imaging by phase-sensitive reversal recovery sequence, with a resolution of 0.88 mm *0.88 mm, enables high-resolution and high-contrast cardiac imaging, which is particularly suitable for the identification and quantitative analysis of changes such as myocardial infarction, fibrosis or inflammation. Lin et al study compared gradient echo movie imaging under 5.0T MRI, technique and 3.0 T MRI techniques [13]. They compared the imaging results of the 5.0 T MRI technique with the balanced steady-state free-process movie images of the 3.0 T MRI technique result display. The gradient echo movie image of 5.0 T MRI technology shows an equivalent or better effect than the gradient echo movie imaging of 3.0 T MRI in terms of image quality. In addition, the signal-to-noise ratio (SNR) and contrast noise ratio (RR) of the gradient echo cine imaging images with 5.0T MRI technology are significantly better than those with 3.0T MRI technology. Consequently, at high field intensity, the 5.0 MRI technology system can obtain clearer and more accurate images.

4.3. Limitations and Future Developments of 5T Strong Magnetic Field Resonance Techniques

Although 5T ultra-high field magnetic resonance imaging technology has significant advantages in the field of medical imaging, it also faces some limitations and challenges. The first is the cost problem. Due to the 5T MRI equipment adopting advanced technology and complex hardware design, its manufacturing cost is high, which leads to relatively high purchase and maintenance costs. The second is the technical challenge. MRI equipment with ultra-high field strength may produce high magnetic field strength and RF energy during the operation process, which puts forward higher requirements for the safety, stability and reliability of the equipment.

5. Conclusion

PET / MRI, as an advanced multimodal imaging technique, has shown significant advantages in the precise diagnosis, staging, and assessment of treatment response, as well as in the differential diagnosis of neurological diseases. This technique provides more comprehensive and precise biochemical and structural information by combining the molecular imaging capability of PET with high-resolution anatomical imaging of MRI. DTI technology provides a powerful tool to study the microstructure of brain white matter fibers by analyzing the diffusion patterns of water molecules in tissues. The DTI technology has demonstrated its unique value in the preoperative grading of brain glioma, the assessment of spinal cord lesions, and the diagnosis of craniocerebral trauma.5 TMRI technology, with its higher signal-to-noise ratio and resolution, provides clearer images and more detailed anatomical information in the diagnosis of cerebrovascular disease and cardiovascular disease. This ultra-high field strength MRI system is able to reveal more minor pathological changes, thus improving diagnostic accuracy. In the future, they are expected to provide more precise and comprehensive imaging information in the early diagnosis, treatment planning, and prognosis evaluation of the disease.

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