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Analysis of Traditional Medical Imaging Methods and their Comparison with Ultra-Weak Magnetic Field Imaging

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ABSTRACT

Human structural imaging methods such as Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) are essential to modern clinical medicine. These non-invasive tools allow doctors to clearly observe hidden internal organs, bones, and soft tissues, greatly improving diagnosis rate and survival rate. Detailed structural scans also support personalized treatment: surgeons use reconstructed images to plan precise surgery and avoid damaging vital tissues, while radiotherapists pinpoint lesions and limit damage to healthy areas. Serial image comparison can objectively track the development of the disease and treatment results, so that the plan can be adjusted in time. Ultra-weak magnetic field imaging is an emerging medical functional information imaging method. It detects the magnetic field of human body through shielding the earth's magnetic field. The magnetic field of human organs is extremely weak, so the quality requirements for ultra-weak magnetic medical equipment are extremely high. This paper introduces the applicability and other aspects of ultra-weak magnetic field imaging, highlighting its advantages over traditional medical imaging methods. Finally, the future development prospect of ultra-weak magnetic field imaging is proposed and its importance in safeguarding human health is emphasized.

KEYWORDS

Medical imaging; CT; MRI; Ultra-weak magnetic field imaging

1. INTRODUCTION

Human structural imaging and functional imaging are both essential fields of medical and biological research, playing pivotal roles in revealing and treating diseases. Structural imaging focuses on capturing detailed images of the body's physical structure, such as bones, organs, and tissues. Technologies like Computed Tomography (CT) [1], and Magnetic Resonance Imaging (MRI) [2] provide comprehensive views of the body, helping physicians to diagnose diseases, injuries, and abnormalities in real-time. These imaging technologies allows early detection of conditions such as tumors, fractures, and neurological disorders. The information gathered through structural imaging is crucial not only for clinical diagnosis but also for pre-surgical planning and monitoring the progress of certain treatments.

On the other hand, functional imaging is concerned with the dynamic processes within the body, such as brain activity, blood flow, and metabolic changes. Methods like Functional Magnetic Resonance Imaging (fMRI) [2], Positron Emission Tomography (PET), Single Photon Emission Computed Tomography (SPECT) [3], Electrocardiography (ECG) and Electroencephalography (EEG) are utilized to monitor real-time physiological activity. Ultra-weak magnetic field imaging is a new functional imaging method [5]. Functional imaging plays a key role in understanding the brain's functioning, diagnosing neurological disorders such as Alzheimer's or epilepsy, and even in exploring

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the effects of various treatments. It also helps in studying metabolic processes and assessing the function of vital organs like the heart.

Together, structural and functional imaging allow for a holistic view of the human body, providing critical insights that guide medical interventions, improve patient outcomes, and enhance our understanding of human health at an intricate level. This paper analyzes the traditional medical imaging technologies and compares them with ultra-weak magnetic field imaging, emphasizing ultra-weak magnetic field imaging's advantage over traditional medical imaging methods.

2. TRADITIONAL MEDICAL IMAGING METHODS

2.1. Computerized Tomography

The landscape of human structural and functional imaging has witnessed remarkable advancements, helping medical diagnostics, research, and patient care. In structural imaging, CT scanners, as shown in Figs. 1-2, now integrate iterative reconstruction algorithms and dual-energy capabilities, reducing radiation doses while enhancing the differentiation of soft tissues and minerals. Furthermore, 3D printing based on structural imaging data enables personalized anatomical models for surgical planning, as seen in complex cranial or cardiac interventions [1].



Figure 1. The CT equipment

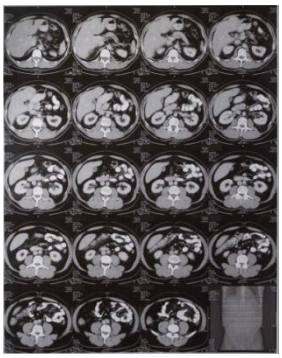


Figure 2. CT image

2.2. MRI and fMRI

Magnetic Resonance Imaging, known as MRI [2], is a radiation-free technology widely used in hospital diagnoses. Its main purpose is to helps doctors observe soft tissues including the brain, spinal cord, joints, abdominal and pelvic organs to detect hidden illnesses. Its basic principle centers on hydrogen protons inside human water molecules: under a powerful static magnetic field, disordered hydrogen nuclei align uniformly; after receiving radio frequency pulse stimulation, these protons absorb energy and get excited. Once the radio wave stops, protons generate detectable signals during their recovery to a steady magnetic configuration. Combined with gradient magnetic fields for spatial positioning, computers convert different signal intensities of various tissues into intuitive high-resolution cross-section images for accurate disease screening. Technologies like MRI have evolved with higher field strengths such as 7T MRI, delivering sub-millimeter anatomical resolution to visualize fine structures such as cortical layers and white matter tracts.

Functional magnetic resonance imaging (fMRI), shown in Figs. 3-4, meanwhile, has expanded its horizons. fMRI has moved beyond blood-oxygen-level-dependent (BOLD) imaging [2], with arterial spin labeling and resting-state MRI uncovering brain connectivity and perfusion patterns in neurological disorders like schizophrenia.



Figure 3. fMRI equipment

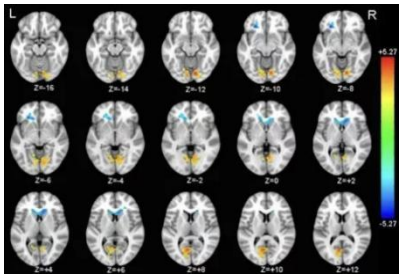


Figure 4. fMRI image

2.3. PET and SPECT

Positron emission tomography (PET) [3] technology has made tremendous advances, thanks to newly developed specific tracers that can be bound to unique biomolecules in human tissues, shown in Fig 5. A classic example is tracers that target amyloid plaques, a key pathological marker of Alzheimer's disease. These agents allow clinicians to identify early brain pathological changes before overt clinical symptoms develop. For SPECT imaging, modern equipment uses an all-in-one hybrid system combined with a CT scanner. This combination provides functional and anatomical data to help physicians accurately locate abnormal functional areas within vital organs such as the heart and brain [4].



Figure 5. PET equipment

2.4. Electrocardiography

Electrocardiography remains one of the most fundamental and widely adopted diagnostic modalities in contemporary cardiovascular medicine, shown in Figs. 6-7. It functions not only as an independent diagnostic tool but also serves as an indispensable complement to advanced cardiac imaging techniques. First introduced into clinical practice more than a century ago, ECG non-invasively captures the heart's electrical activity via cutaneous electrodes. It converts myocardial depolarization and repolarization processes into characteristic waveform tracings, namely the P wave, QRS complex and T wave, which encode vital information regarding cardiac rhythm, intracardiac conduction and myocardial functional status. Conventional 12-lead ECG acts as the primary screening test for numerous cardiovascular disorders, ranging from acute coronary syndromes to various arrhythmias and conduction defects. Beyond static resting recordings, evolving variants include ambulatory Holter monitoring and wearable ECG sensors, enabling long-term continuous surveillance outside hospitals and supporting home-based remote cardiac management [5]. Additionally, ECG provides essential gating signals for cardiac magnetic resonance imaging and computed tomography, mitigating motion artifacts during image acquisition to enhance the clarity of reconstructed cardiac images. Although novel high-resolution structural imaging approaches have emerged rapidly, ECG retains irreplaceable clinical value owing to its low cost, excellent portability and exceptional temporal resolution. It can detect electrical abnormalities that might escape identification by structural

imaging, consolidating its enduring position in routine cardiac diagnosis across primary care and emergency settings.



Figure 6. ECG equipment

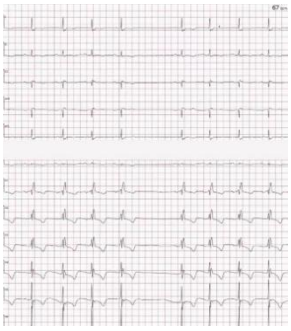


Figure 7. ECG image

2.5. Electroencephalography

Electroencephalography is a fundamental neurophysiological technique widely applied in clinical neurology and neuroscience, functioning as both an independent diagnostic platform and a vital auxiliary tool for advanced brain imaging modalities, shown in Figs. 8-9. Developed nearly a century ago, EEG non-invasively captures the summed electrical potentials generated by cortical neuronal assemblies via scalp electrodes. It converts synchronous neuronal depolarization and repolarization into distinct oscillatory waveforms, including delta, theta, alpha, beta and gamma rhythms, which carry essential information about brain arousal states, neural network activity and pathological electrical discharges [6].

In routine clinical practice, standard scalp EEG serves as the primary examination for diagnosing epilepsy, localizing seizure foci, evaluating sleep disorders and detecting encephalopathy following brain trauma. Further technical innovations have spawned long-term ambulatory monitoring and high-density EEG arrays to improve spatial precision. Importantly, EEG is frequently combined with functional magnetic resonance imaging for multimodal brain investigations, merging its millisecond-scale temporal resolution with the superior spatial localization capability of haemodynamic imaging.

Even amid the rapid advancement of modern brain imaging technologies [6], EEG holds irreplaceable value. Its low cost, flexible portability and capacity to capture transient electrical abnormalities that structural imaging cannot identify ensure its sustained importance in neurological diagnosis and translational neuroscientific research.



Figure 8. EEG equipment

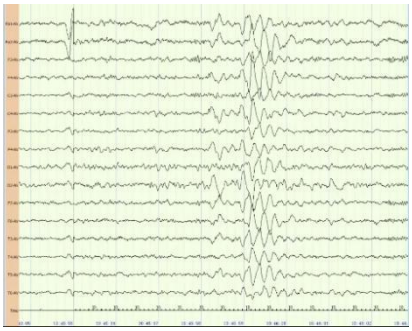


Figure 9. EEG image

2.6. Limitations of Traditional Medical Imaging Methods

Existing technologies such as MRI and PET are not applicable to young children and pregnant women, and the detection takes a relatively long time, and they mostly can only obtain static structural

anatomical information, and cannot capture the subtle dynamic functional changes of human cells and nerves and ultra-weak biological electromagnetic signals.

Challenges remain, such as balancing spatial resolution and acquisition time in functional imaging or the inconvenience of detection, for example, an MRI requires a long wait. Yet, on-going innovations - from ultrafast MRI sequences, PET, SPECT, ECG, EEG to ultra-weak magnetic field imaging - continue to push the boundaries, ensuring structural and functional imaging remain at the forefront of medical science, driving discoveries and improving health outcomes.

3. ULTRA-WEAK MAGNETIC FIELD IMAGING METHOD AND FUTURE DIRECTIONS

3.1. Ultra-weak Magnetic Field Imaging Method

Ultra-weak magnetic field imaging [7] is an innovative interdisciplinary branch integrating quantum precision measurement, magnetic shielding engineering and clinical medicine, as shown in Fig. 10 [8]. By constructing an ultra-weak magnetic environment to isolate geomagnetism and environmental magnetic interference, it adopts ultra-sensitive quantum magnetometers such as atomic magnetometers and SQUIDs to passively capture the picotesla-level ultra-weak biomagnetic signals spontaneously generated by the electrical activities of the human heart, brain and other organs. Without ionizing radiation, external magnetic excitation or contrast agents, this technology delivers functional imaging with millisecond temporal resolution and millimeter spatial resolution, enabling detection of early functional lesions like microcirculatory ischemia long before organic structural damages emerge. As a complementary tool to CT and MRI structural imaging, it has achieved clinical applications in magnetocardiography (MCG) and magnetoencephalography (MEG), providing non-invasive solutions for early screening of cardiovascular diseases, preoperative localization of epileptic lesions and postoperative rehabilitation assessment, and stands as a key domestic innovation track of high-end medical devices empowered by quantum technology.

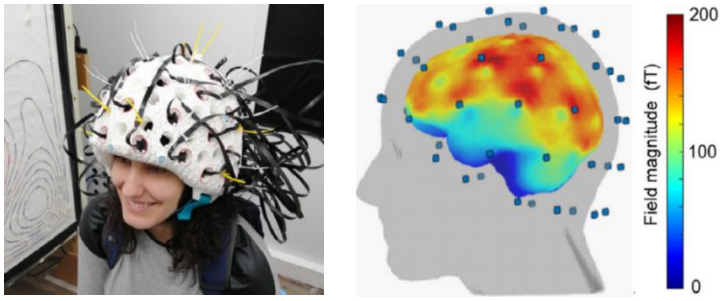


Figure 10. Ultra-weak magnetic field imaging

3.2. Future Directions

With the continuous innovation between disciplines and the continuous iteration of technology, the development of ultra-weak magnetic field imaging has a broad prospect. It will focus on promoting multimodal information fusion to realize collaborative detection and interactive analysis of human core physiological systems, including heart-brain synchronous monitoring, as well as in-depth exploration of the bidirectional regulation mechanism of heart-brain axis, so as to realize a more comprehensive and accurate perception of human physiological state.

Ultra-weak magnetic detection equipment can develop in the direction of miniaturization, wearable and family, break through the limitations of traditional professional magnetic shielding barrels, and expand the clinical and popular application scenarios. Portable home coil devices and flexible wearable detection terminals will realize frequent, convenient and real-time physiological monitoring

in communities and homes, and greatly improve the accessibility and flexibility of ultra-weak magnetic field imaging testing.

In terms of improving diagnostic accuracy, future research and clinical practice of ultra-weak magnetic field imaging will adhere to the integration of structural information and functional information, and combine high-precision magnetic signal detection technology with electroencephalogram, functional magnetic resonance imaging, and other neuroimaging and neurophysiological techniques. Thus, it complements the structural morphological characteristics and functional dynamic changes of human tissues and organs, and optimizes the ability of disease identification and early diagnosis.

In addition, ultra-weak magnetic field imaging will be deeply integrated with medical big data and artificial intelligence technology to build a standardized and systematic database, and through intelligent algorithm modeling, the raw magnetic signal data and clinical research results will be transformed into intelligent disease diagnosis and auxiliary treatment tools. This multidisciplinary integration of magnetic biology, clinical medicine, information technology and artificial intelligence will drive the continuous upgrading of the theoretical system and technical model of ultra-weak magnetic field imaging.

4. SUMMARY

In summary, various medical diagnostic techniques are available for clinical use, including, CT, MRI, fMRI, PET, SPECT, ECG, EEG and laboratory tests. Radiation-based scanning methods, such as CT, excel at rapid screening of bone and acute internal injuries, whereas MRI avoid ionizing radiation and can safely examine soft tissues. However, traditional imaging methods are often not applicable to children, and cannot be applied to both the heart and brain simultaneously.

Ultra-weak magnetic field imaging overcomes the core defects of contemporary mainstream medical technologies, and shows unique comprehensive advantages in early diagnosis, detection mode, application scenarios, diagnostic logic and intelligent development. Unlike existing medical technologies that rely on static structure examination, contact detection and radiation interventional imaging, ultra-weak magnetic field imaging supports the capture of subtle dynamic physiological signals with high sensitivity through an ultra-low magnetic interference environment, realizes the organic integration of human structure and functional information, and greatly improves the accuracy of early lesion screening and physiological state assessment. It has completely non-invasive, non-radiation and extremely safe testing conditions, which is suitable for all ages, including children and infants who are sensitive to the existing medical technologies examination stimuli. It can be repeatedly implemented in children health screening without potential health risks. It can be monitored for a long time, frequently and repeatedly, and can be extended to wearable and portable scenarios in the community and home, breaking the limitations of traditional clinical examinations. Ultra-weak magnetic field imaging has great clinical transformation value and broad future development potential.

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