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REVIEW ARTICLE

Imaging Technique is Amazing for Unraveling Neurological Diseases

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ABSTRACT

To see the inside of the live brain, to image the structure and function of the brain, neuroimaging technique is used. To explore the brain function and activity of normal human brain as well as various neurological disorders, imaging techniques revolutionized our understanding dramatically. Starting from basic tools used for researchers to the diagnosis, neuroimaging techniques provided valuable noninvasive methods to study and analyze the neurological disorders. The essential imaging tools used for research are cellular microscopy, histochemistry and cytochemistry. For diagnosis innovative neuroimaging techniques are computed tomography (CT) scan, magnetic resonance imaging (MRI),functional magnetic resonance imaging (fMRI), positron emission tomography (PET), neuro-sonography, electroencephalogram (EEG), magneto-encephalogram (MEG) and near infrared spectroscopy (NIRS). Every technique has their own strength and shown to be crucial for better diagnosis, characterization, and treatment of various brain diseases. Regardless of notable progresses in the field of imaging, there is a greater need to boost spatial and temporal specificity, resolution and sensitivity.

KEYWORDS

• Computed tomography scan (CT) • Electroencephalogram (EEG) • Functional magnetic resonance imaging (fMRI) • Magnetic resonance imaging (MRI) • Neuro-sonography • Positron emission tomography (PET)

INTRODUCTION

Since few decades, advances in imaging techniques have indispensible application in health care and medical sciences and research enabling disease detection, diagnosis, characterization, and treatment decisions.

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Antonie van Leeuwenhoek is considered as father of microscopy[1] and his ground breaking discovery of microscopic techniques provided remarkable achievement in magnification of the single brain cells. Gradually highly sophisticated zeiss and confocal microscopes were evolved. Imaging techniques of brain and the whole nervous system employ an interaction between brain tissue and various types of electromagnetic radiations to capture the physiological and anatomical data that represent the corresponding structure and function of the nervous system. Dr William Oldendorf is regarded as father of neuroimaging.[2] Significant achievements obtained while monitoring the progress of patient during the course of treatment and after cure. Methodological advancements in imaging techniques beheld remarkable progress with accuracy as well as in efficacy. To study the brain, to detect the disease and diagnose the status of neurological disorders various neuroimaging tools used are positron emission tomography (PET), computed tomography (CT), magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI). To obtain the critical insights into neurological diseases progress imaging modalities allow for the intense imagining of multiple anatomical and functional aspects and these techniques (PET, CT, MRI, fMRI) have shown to be central for better treatment and exploring the basis.[3] Generally, neuroimaging procedures are painless. But patient may experience discomfort while remain still for extended period. Diagnostic imaging techniques have revolutionized the field of medicine, providing healthcare professionals with invaluable tools for accurate diagnosis, treatment planning, and monitoring. From X-ray imaging to CT scans, MRI, and sonography, each modality offers unique benefits and applications. As technology continues to advance, emerging trends such as AI integration, 3D and 4D imaging, and molecular imaging are pushing the boundaries of what is possible in medical imaging. Most of the neurodegenerative diseases like Parkinson's disease (PD), Alzheimer's disease (AD), multiple sclerosis (MS), amyotrophic lateral sclerosis (ALS) and Huntington's disease (HD) share common cellular phenomenon at the cellular level, protein level and tissue level. At various level of miss-folded protein aggregation, disturbances in transport within cellular compartment and aggregation of cellular proteins changes the cellular plasticity of neuron. These cellular changes/modifications are studied through live-cell imaging of either at cellular compartment or single protein. By understanding the principles and applications of different diagnostic imaging techniques and considering patient-specific factors, healthcare professionals can choose the most appropriate imaging modality for specific conditions, ensuring ultimate precision and accuracy in patient care[4].

Cellular imaging and microscopy:

Scientists and engineers are developing cutting-edge cellular imaging tools that offer advanced understanding of dynamic neuronal cell systems across scales in healthy and diseased states. For the brain cell analysis cellular imaging, capturing image of single cell, visualizing cells using transmitted light or florescence imaging channels usually done by varieties of microscopy. For secondary cellular analysis like signal transduction, DNA damage, tumor invasion, evaluation of cytoplasmic structures various types of software modules are available with advanced applications for specific analysis such as for single object tracking, neurite out growth, modulation of neural spines, kinetic scratch wound healing assays, spot counting automatic region of interest identification. The microscopic lenses are available with various special features for metallurgical applications, ensuring high resolutions with fully focused images with different heights. Laser based autofocusing along with z-stacking are available to visualize greater areas and depth of a sample. Also the kinetic image capture is possible using microplates or across vessel over minutes, hours or days. Cellular imaging become a faster technology by combing the high content screening (HCS) combines high-throughput automated image analysis and it provides greater depth of understanding of the neurological cellular architecture, quantify phenotypic changes at individual cells, functional screening and high-throughput screening (HTS) that helps in drug discovery and drug screening approaches. For a better understanding of molecular mechanism of neurodegenerative diseases, live cell imaging and detail study at cellular level shows promising effect by visualization through microscopy that allows imaging the steps

of transport, accumulation and turnover at different compartment of cells.[5,6]

Computed Tomography (CT)

The term computed tomography (CT) refers to computerized x-ray imaging procedure. X-rays are the ionizing radiations because of its very short wavelength and large energy. It begins with the emission of x-ray beams from an X-ray tube. These beams pass through the patient's body and their absorption and scattering varies depending on the density of the tissue encountered. The greater x-ray attenuation results in regions of high density such as bones absorbs greater degree of radiations and the reduced amount of the radiation detected by scanner on opposite side of the body, whereas low density soft tissues such as lungs (air-filled cavities) have weak attenuation of x-rays, absorbs the radiations to lesser degree and the greater signals are detected by the scanner in opposite side of the body. CT is a noninvasive imaging tool that provides detail of the skull and brain. CT scan is used to show the stroke related damages in brain, blood vessel changes in dementia and shrinkage of brain (brain atrophy)[7]. For visualization of fine bone detail CT is superior to MRI.CT scans are particularly valuable in emergency neurological medicine, as they can quickly identify traumatic injuries, internal cerebral bleeding, or other life-threatening conditions in brain.[8]

Magnetic Resonance Imaging (MRI)

Among other global healthcare issues, neurodegenerative disorders carriage a tough challenge. Roughly 15% of the worldwide population suffers from both cognitive and neurological impairment.[9] The progressive degeneration of the neuron and glia leads to gradual dysfunctions of nervous system. Various parts of the nervous system get affected and decline of cognitive symptoms gradually worsen the brain. Advancements in MRI techniques provide the high-resolution images of brain, spinal cord and peripheral nerves.For identifying spinal abnormalities like tumors and abscess MRI is especially the valuable imaging. It provides excellent contrast resolution that makes distinction between normal healthy and diseased tissues for detecting demyelinating plaques and abnormalities of the brain. The non-ionizing radiations used for high resolution imaging of MRI technique is harm less and painless. The potent magnetic field and radio waves of MRI are used to generate particularinternal structure and images of the brain in Alzheimer's diseases and Parkinson's disease.[10] In some brain MRI, gadolinium is used as injection and this contrast material alters the properties of nearly water molecule which enhances the quality of the images. This advanced contrast imaging used in MRI help for better diagnose of stroke, multiple sclerosis, brain infection and dementia. Studies show gadolinium may deposit at various part of the body and their accumulation may cause side effects in patients which are now under consideration for using non-gadolinium agents.[11,12]

Functional Magnetic Resonance Imaging (fMRI)

Functional MRI (fMRI) represents a refined imaging technology used in current age neurological study and disease diagnosis. fMRIs used to study the functional activity of the brain while performing the tasks and the disease pattern can be distinguished from the normal brain pattern. This technique helps to reveal abnormal condition or dysfunction of the area of the brain during disease process and identify the progress during neurotherapeutic treatments. fMRIs detects change in blood oxygenation and flow of blood to the parts of the brain are active during specific tasks. fMRI measures neuronal activity by detecting oxygenation of blood flow to that area of brain. The core principle of fMRI associates with nuclear magnetic resonance and the differences in magnetic properties between oxygenated and deoxygenated blood. The key to fMRI is the Blood Oxygenation Level Dependent, which is commonly called as BOLD Contrast.[13] fMRI identifies the difference in magnetic properties between oxygenated (oxyhemoglobin) and deoxygenated (deoxyhemoglobin) blood. In general when a brain area is active, that needs more oxygen leading to increased blood flow and higher concentration of blood. The changes in the magnetic properties of the blood create a map of brain activity and the fMRI scanner detects it. Higher activity appear brighter on the fMRI scan which corresponds to the higher oxygenated blood levels. Any small changes in the signals those are associated with neuronal activity in the brain can be well detected by fMRI. It is non-invasive, safe and repeatable

and has widespread potential uses. It is producing unique and valuable information for applications in both basic, clinical neuroscience, brain physiology in aging and neurodegeneration.[14]

Positron Emission Tomography (PET)

In neurological diseases, sometimes in clinically challenging patients, it is difficult to identify and diagnose among different neurodegenerative disorder when they show alike symptoms. To overcome these difficulties, positron emission tomography (PET) is used. PET plays a crucial role in monitoring the progress of treatment and evaluating the effectiveness after treatment. The disease like Alzheimer's and frontotemporal dementia are identical advent where PET helps in distinction diagnosis.[15] PET scan provides the underlying mechanism of neurodegeneration and also assists in early detection of abnormal protein deposition. The distinct pattern of glucose metabolism and deposition of abnormal proteins such as tau and beta-amyloid can be identified. To visualize metabolic processes and recognize abnormalities in brain function, PET scan is used which is low dose of radiation. PET gives apparent image that intricate neural network of disease brain. For imaging of blood flow patterns in the brain single-photon emission computed tomography (SPECT) imaging is used whereas to distinguish neural connection in brain's white matter diffusion tensor imaging (DTI) scan is used. From the symptom based diagnosis to biomarker based diagnosis, PET imaging helps in understanding the neurodegenerative disorder to establish quantification of molecular targets.[16]

Neurosonography

Neurosonography is a safe diagnostic tool and also known as neurological ultrasound. High-frequency sound waves are used to visualize the brain, spinal cord and peripheral nerves. Neurosonography does not use any ionizing radiation and is a versatile technique that uses high-frequency sound waves to produce real-time images of the brain, blood brain barrier and brain's internal structures. Being suitable for patients of all ages, it provides valuable information about the size, shape, and function of organs, blood flow patterns, and the presence of abnormalities such as tumours or cysts in brain. Neurosonography is used to demonstrate a prototype design of a low-frequency multiple channel hemispherical ultrasound phased-array system for trans-cranial BBB disruption.[17] A multiple-channel low-frequency ultrasound driving system was designed to provide a suitable acoustic output for BBB opening.[18] Focused ultrasound with the presence of microbubbles has been shown to temporarily open the blood-brain barrier (BBB), which offers the potential to improve central nervous system disease treatment. Neurosonography is used for BBB opening and using this technique treatment of brain can be done by implementing the construction of passive mapping of BBB-opening.[19] Parkinson's disease (PD) results due to impairment in neuronal function of the basal ganglia and due to the deep location of basal ganglia inside the brain, conventional treatment is challenging. Hence for the treatment of movement disorder (PD) and dystonia, the non-invasive neurosonography treatment approaches are used for therapeutic treatment for reversible permeabilization of the BBB and targeting delivery of drugs deep into the brain and neuromodulation.[20]

Choosing the Right Imaging Technique for Specific Conditions

Selecting the most appropriate imaging technique for specific neuronal conditions and medical situations requires careful consideration of various factors. These factors include the suspected condition, the part of the brain being examined, and the required level of detail, patient safety, and cost-effectiveness. The initial point is to determine the specific information required to answer the clinical question. For example, first, the goal is to visualize the brain, soft tissues, and blood vessels in the brain. Then, patient safety should take into account along with any patient-specific factors that may influence the choice of imaging technique, such as pregnancy, allergies, or previous adverse reactions to contrast agents. To consider factors such as radiation exposure, contrast agent administration and potential adverse effects matters a lot. By carefully considering these factors, healthcare professionals can ensure that the most appropriate diagnostic imaging technique is chosen for each patient, maximizing the chances of an accurate diagnosis and optimal treatment outcome.

Concluding remark & future perspective:

Neurological imaging is a crucial component of modern medicine that gives structural and functional status of brain to healthcare professional to diagnose the disease. Specific cellular and molecular target validation is possible due to advancement of synthetic molecular probes. Integration of multimodal imaging techniques and combinations of more than two techniques for making hybrid methodologies may improve molecular visualization at the site of neurological injury. The excellent achievement can be done in the field of neurological disorder diagnosis, prognosis and treatment by using the innovative methodologies of data fusion, image analysis and visualization. Every technique has their own strength and shown to be crucial for better diagnosis, characterization, and treatment of various diseases. Despite notable advancements in the field of imaging, there is a greater need to boost spatial and temporal specificity, resolution and sensitivity. The integration of artificial intelligence (AI) and machine learning algorithms may potentially to revolutionize the neuroimaging field.

Conflict of Interest: There is no conflict of interest.

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