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Applications of Neuroimaging in the Diagnosis and Study of Brain Diseases

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Abstract

Neuroimaging has revolutionized modern neuroscience, becoming an indispensable tool for investigating brain structure, function, and pathology. By enabling the non-invasive observation of the living brain in real time, neuroimaging has significantly advanced our understanding of the physiological and molecular mechanisms underlying cognitive and emotional functions, as well as pathological changes associated with neurological and psychiatric disorders. Structural imaging techniques like MRI can identify critical alterations such as hippocampal atrophy in Alzheimer's disease, while functional MRI allows for the detection of early brain function changes, often before clinical symptoms manifest. Neuroimaging also plays a vital role in treatment planning, helping to assess disease progression and guide therapeutic interventions in conditions like Parkinson's disease and schizophrenia. The historical evolution of neuroimaging technologies—from early invasive methods like pneumoencephalography to modern, non-invasive imaging modalities such as MRI and fMRI—has paved the way for a more comprehensive understanding of the brain. Furthermore, advanced molecular imaging techniques such as PET and SPECT have facilitated the exploration of disease-specific biomarkers and brain metabolism. Together, these technologies not only enhance the diagnosis and monitoring of brain diseases but also serve as essential tools in clinical research and the development of new therapies.

1. Introduction.

1.1 Importance of Neuroimaging in Modern Neuroscience.

Neuroimaging has become one of the most important tools in modern neuroscience, fundamentally transforming our ability to investigate brain structure, function, and pathology [1,2,3,4,5,6]. It enables researchers to study the living brain in real time, making it possible to observe the physiological processes and molecular mechanisms that underlie cognitive and emotional functions, as well as pathological alterations associated with neurological and psychiatric disorders [7]. The ability to non-invasively observe the brain has opened up a new era in both clinical practice and neuroscience research, where understanding the brain's intricate architecture and activity is crucial to diagnosing, treating, and monitoring disease.

One of the primary advantages of neuroimaging is its ability to directly visualize the brain's physical structure and function, which is critical for understanding a range of conditions [8]. For example, in Alzheimer's disease (AD), structural imaging techniques such as magnetic resonance imaging (MRI) can identify changes such as hippocampal atrophy, which correlates with cognitive decline [9]. Functional neuroimaging, such as functional MRI (fMRI), provides insights into brain activity, allowing clinicians to detect early changes in brain function long before clinical symptoms appear [10]. These capabilities make neuroimaging an invaluable tool for the

early detection of brain diseases, significantly improving the chances of early intervention and potentially slowing disease progression.

Neuroimaging also plays an essential role in treatment planning [11]. In diseases like Parkinson's disease (PD), neuroimaging can help determine the extent of dopaminergic degeneration, guiding the use of specific treatments like dopamine agonists or deep brain stimulation [12]. In psychiatric conditions such as schizophrenia, neuroimaging can help understand the underlying neural circuits that might be involved in the disorder and monitor the effects of medications or therapy [13]. In clinical research, neuroimaging is used to study the brain's response to novel treatments, making it an essential tool in the development of new therapies for brain diseases.

1.2 Historical Evolution of Neuroimaging Technologies.

The evolution of neuroimaging technologies has been nothing short of revolutionary, with each new development offering increasingly sophisticated ways to observe the brain in both health and disease [14]. The earliest attempts at imaging the brain involved relatively crude methods, such as pneumoencephalography, developed in the early 20th century [15]. This technique, which involved injecting air into the cerebrospinal fluid to displace it and reveal the outline of the brain, was highly invasive and risky but marked the first steps toward visualizing the brain's structure.

The true breakthrough in brain imaging came with the advent of X-ray computed tomography (CT) scanning in the 1970s [16]. CT provided a non-invasive way to capture detailed cross-sectional images of the brain, which made it possible to detect and diagnose conditions such as tumors, strokes, and brain hemorrhages [17]. However, CT scans provided limited information about soft tissue structures and did not offer the fine resolution required to detect early neurodegenerative changes.

The real game-changer for brain imaging came with the development of magnetic resonance imaging (MRI) in the 1980s [18]. MRI offered superior soft tissue contrast compared to CT and, crucially, did not involve ionizing radiation [19]. MRI allowed for a much more detailed view of the brain's anatomy and became the gold standard for diagnosing brain tumors, structural abnormalities, and neurodegenerative diseases [20]. The advent of functional MRI (fMRI) in the early 1990s further expanded the field by enabling researchers to measure brain activity in real time, based on changes in blood flow and oxygenation levels during cognitive tasks or resting states [21]. This allowed scientists to observe how different areas of the brain were activated during specific tasks, shedding light on how the brain processes information and responds to external stimuli.

Since then, the integration of molecular imaging techniques such as positron emission tomography (PET) and single-photon emission computed tomography (SPECT) has opened up new avenues for studying brain metabolism, neurotransmitter activity, and disease-specific biomarkers [22]. PET scans, for example, allow for the visualization of amyloid plaques and tau tangles in Alzheimer's disease, offering insights into the biochemical changes that precede clinical symptoms [23]. With the development of advanced techniques like diffusion tensor imaging (DTI) and magnetoencephalography (MEG), researchers can now explore the brain's connectivity, neural networks, and even the magnetic fields generated by brain activity, further expanding the capacity of neuroimaging technologies.

1.3 Objectives of the Review.

The objective of this literature review is to examine the current state of neuroimaging and its applications in the diagnosis and study of brain diseases [24]. The review aims to provide a comprehensive overview of the key neuroimaging techniques and explore their role in understanding various neurological and psychiatric disorders [25]. Specifically, this review will:

Explore Neuroimaging Modalities: Provide an overview of the various neuroimaging techniques, including structural imaging (e.g., MRI, CT), functional imaging (e.g., fMRI, PET), and molecular imaging (e.g., PET, SPECT), discussing their advantages, limitations, and applications in both research and clinical practice.

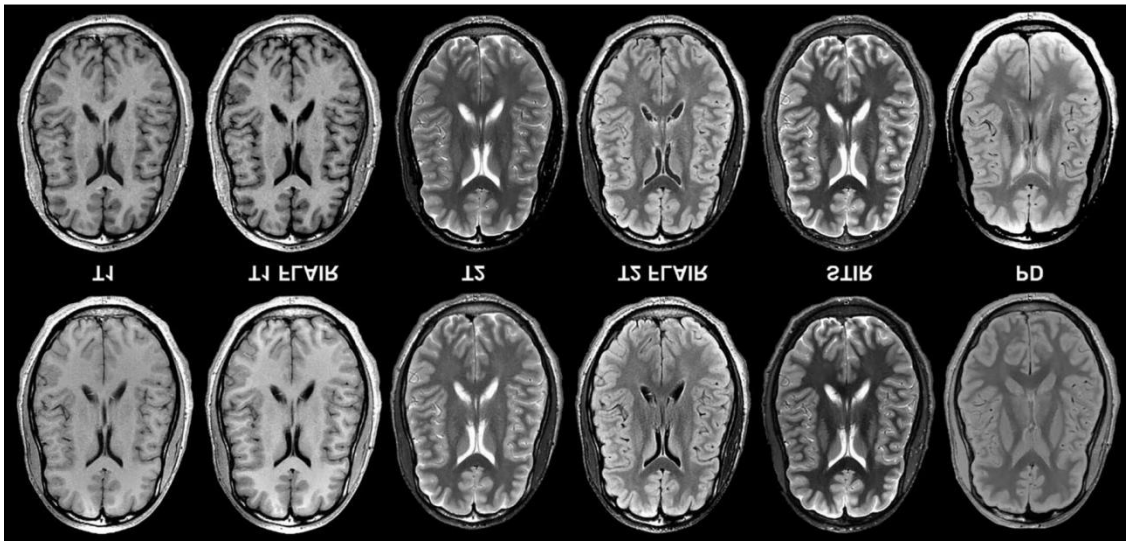
Review Applications in Brain Diseases: Discuss the role of neuroimaging in diagnosing and studying different types of brain diseases, including Alzheimer's disease, Parkinson's disease, epilepsy, schizophrenia, and traumatic brain injury (TBI) [26]. This section will highlight how neuroimaging has enhanced our understanding of disease pathogenesis, aided in early detection, and guided treatment strategies.

Discuss Emerging Trends and Technological Advancements: Investigate the latest advancements in neuroimaging technology, such as multimodal imaging, the integration of AI and machine learning into neuroimaging analysis, and new imaging modalities such as high-resolution functional imaging.

Examine Ethical Considerations: Consider the ethical challenges surrounding the use of neuroimaging in clinical and research settings, including issues related to privacy, informed consent, and the potential for neuroimaging data misuse.

Explore Future Directions: Discuss the future potential of neuroimaging in advancing our understanding of brain diseases, particularly in the context of precision medicine and personalized treatments [27]. This section will also consider the ongoing development of new imaging technologies and their promise for enhancing diagnosis and therapy.

By addressing these objectives, the review aims to offer a comprehensive understanding of how neuroimaging is shaping the future of neuroscience and clinical practice, particularly in the realm of brain diseases.



2. Core Neuroimaging Techniques.

2.1 Structural Imaging.

Structural neuroimaging plays a pivotal role in providing detailed images of the brain's anatomy, allowing clinicians and researchers to observe structural abnormalities and track changes in brain morphology over time [28,29]. These imaging techniques are crucial for diagnosing conditions that affect brain structure, such as neurodegenerative diseases, brain tumors, and traumatic brain injuries.

2.1.1 Magnetic Resonance Imaging (MRI).

Magnetic Resonance Imaging (MRI) is one of the most widely used structural imaging modalities in both clinical and research settings [30]. MRI employs strong magnetic fields and radiofrequency waves to produce detailed images of the brain's internal structures, including gray matter, white matter, and cerebrospinal fluid [31]. MRI is particularly useful in identifying atrophy or shrinkage in specific regions of the brain, which is often a hallmark of various neurological disorders.

The key advantage of MRI over other imaging techniques like CT is its superior soft tissue resolution and the ability to visualize brain structures in high detail [32]. This makes MRI the gold standard for evaluating diseases like Alzheimer's disease (AD), where hippocampal atrophy is a major diagnostic marker [33]. MRI is also

essential for assessing the progression of neurodegenerative diseases, monitoring the effects of treatment, and evaluating the structural impact of brain injuries.

In addition to conventional MRI, there are advanced techniques that enhance the resolution and provide additional functional information [34]. Diffusion Tensor Imaging (DTI), for example, allows for the visualization of the brain's white matter tracts and provides insights into the connectivity between different brain regions [35]. DTI has become a valuable tool for studying diseases that affect white matter integrity, such as multiple sclerosis and Alzheimer's disease.

2.1.2 Computed Tomography (CT).

Computed Tomography (CT) remains an important structural imaging tool, particularly in acute clinical settings where rapid assessment is crucial [36]. CT utilizes X-ray technology to create detailed cross-sectional images of the brain [37]. Although CT is less sensitive than MRI in detecting soft tissue changes, it remains a valuable tool for evaluating acute brain injuries, hemorrhages, and stroke.

In the emergency room, CT is often the first imaging technique employed due to its speed and availability [38]. CT scans can quickly identify brain tumors, hemorrhages, or ischemic changes caused by stroke [39]. However, CT has a significant disadvantage compared to MRI—it exposes patients to ionizing radiation, which limits its use for long-term monitoring, especially in chronic conditions [40]. Furthermore, the resolution of CT images is lower than that of MRI, making it less effective for detecting subtle changes in brain structure.

Despite these limitations, CT remains an essential diagnostic tool in clinical practice, especially for urgent situations [41]. However, its utility in chronic or progressive diseases is often overshadowed by the more detailed and radiation-free advantages of MRI..

2.2 Functional Imaging.

Functional neuroimaging has significantly advanced our ability to study brain activity in real-time [42]. These techniques provide insights into how different regions of the brain engage during various cognitive tasks and at rest, offering valuable information about the brain’s functional organization.

2.2.1 Functional Magnetic Resonance Imaging (fMRI).

Functional Magnetic Resonance Imaging (fMRI) measures changes in brain activity by detecting alterations in blood oxygenation levels, known as the Blood Oxygen Level Dependent (BOLD) signal [43]. When neurons are activated, they require more oxygen, which leads to increased blood flow in the activated brain regions [44]. fMRI detects these changes, allowing researchers to map functional brain networks and observe how different brain areas work together during tasks involving perception, memory, motor control, and cognition.

One of the significant advantages of fMRI is its ability to provide both high spatial and temporal resolution, making it possible to study dynamic brain activity over short time intervals [45]. Unlike techniques like electroencephalography (EEG), which has excellent temporal resolution but poor spatial accuracy, fMRI offers a detailed picture of the brain’s activity while maintaining a reasonable temporal resolution [46]. This makes fMRI particularly valuable in studying complex cognitive processes and diseases that involve alterations in brain function, such as schizophrenia and Alzheimer's disease.

fMRI has proven to be an invaluable tool in cognitive neuroscience, allowing researchers to examine the functional specialization of different brain regions [47]. For example, fMRI studies have demonstrated that language processing is primarily localized in the left hemisphere, with distinct regions such as Broca’s area and Wernicke’s area playing key roles in speech production and comprehension [48]. Similarly, fMRI has provided critical insights into the brain's reward system, helping to uncover the neural mechanisms underlying addiction, motivation, and emotion regulation.

2.3 Molecular Imaging.

Molecular neuroimaging allows for the visualization of specific molecular processes within the brain, providing valuable insights into biochemical changes that occur in the early stages of neurological and psychiatric diseases

[49]. Unlike structural and functional imaging, which primarily focus on anatomical and activity-based changes, molecular imaging detects abnormalities at the cellular and molecular levels [50]. This type of imaging is crucial for understanding the pathophysiology of diseases and for identifying biomarkers that can be used for early diagnosis and monitoring disease progression.

2.3.1 Positron Emission Tomography (PET).

Positron Emission Tomography (PET) is one of the most widely used molecular imaging techniques [51]. PET scans provide images of the brain's biochemical processes by detecting the emission of positrons from a radiotracer injected into the bloodstream [52]. These radiotracers are typically labeled with isotopes that target specific molecules, such as neurotransmitters, enzymes, or amyloid plaques, allowing researchers to study the distribution and activity of these molecules within the brain..

In the context of neurological diseases, PET has been particularly valuable for studying Alzheimer's disease (AD) [53]. Radiolabeled amyloid-binding agents, such as Pittsburgh Compound B (PiB), can detect amyloid plaques, which are one of the hallmark features of AD [54]. PET scans have been used to identify amyloid deposition in the brains of asymptomatic individuals, providing early insights into the development of AD long before clinical symptoms manifest [55]. Additionally, PET can be used to study the distribution of tau tangles in AD patients, another key pathological feature of the disease.

PET also plays a crucial role in studying Parkinson’s disease (PD), particularly by monitoring the dopaminergic system [56]. Radiotracers like 18F-dopa are used to visualize the activity of dopamine transporters in the brain, allowing clinicians to assess the degree of dopaminergic degeneration, which is characteristic of PD [57]. This molecular imaging technique has proven invaluable in the early diagnosis of PD, as well as in monitoring the effectiveness of treatments such as levodopa therapy.

Moreover, PET has become an essential tool in cancer research, where it is used to track tumor metabolism and detect brain metastases [58]. Radiolabeled glucose analogs, such as 18F-fluorodeoxyglucose (FDG), are commonly used in oncological PET imaging to evaluate glucose metabolism, which is often elevated in cancer cells.

2.3.2 Single-Photon Emission Computed Tomography (SPECT).

Single-Photon Emission Computed Tomography (SPECT) is another molecular imaging technique that provides three-dimensional images of brain function by detecting gamma rays emitted from a radiotracer injected into the patient [59]. Although SPECT has lower spatial resolution compared to PET, it is more widely available and less expensive, making it a popular choice for clinical practice in some regions.

SPECT is primarily used to evaluate cerebral blood flow (CBF), which can be altered in a variety of neurological disorders [60]. For example, in stroke, SPECT can detect areas of reduced blood flow in the brain, helping to determine the extent of ischemic damage [61]. Similarly, in conditions such as epilepsy, SPECT can be used to identify areas of the brain that are hyperactive or have abnormal blood flow, aiding in the localization of epileptic foci for surgical planning.

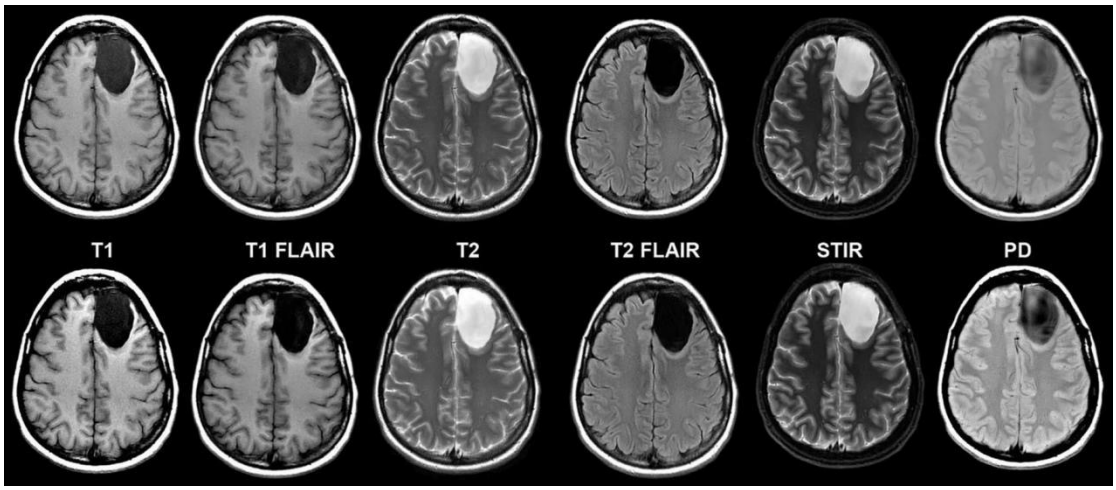
SPECT is also employed in the study of neurodegenerative diseases, particularly Alzheimer's disease [62]. SPECT imaging with radiotracers such as 123I-iodobenzofuran (IBF) allows for the detection of amyloid plaques and the measurement of glucose metabolism in the brain [63]. In Parkinson's disease, SPECT can be used to assess the loss of dopamine transporters, a key feature of the disease..

Although SPECT is not as advanced as PET in terms of resolution and sensitivity, its lower cost and widespread availability make it a valuable tool for clinical diagnosis, particularly in settings where advanced PET imaging may not be accessible..

2.4 Advanced Imaging Techniques and Multimodal Imaging.

In recent years, significant advancements have been made in neuroimaging technology, including the development of high-resolution imaging techniques and the integration of multiple imaging modalities [64].

These advances have enabled researchers and clinicians to gain a more comprehensive understanding of brain diseases by providing detailed information about brain structure, function, and molecular processes simultaneously [65]. The combination of multiple imaging techniques, known as multimodal imaging, is particularly promising for studying complex diseases where various factors interact to cause pathological changes.



2.4.1 Diffusion Tensor Imaging (DTI).

Diffusion Tensor Imaging (DTI) is an advanced MRI technique that maps the diffusion of water molecules in brain tissue, providing detailed information about the brain's white matter tracts [66]. Unlike conventional MRI, which provides only a static image of the brain's anatomy, DTI allows for the visualization of the brain's connectivity and the integrity of its white matter pathways [67]. DTI has become an invaluable tool for studying diseases that affect the brain's white matter, such as multiple sclerosis (MS), Alzheimer's disease, and traumatic brain injury (TBI).

In Alzheimer's disease, for example, DTI can detect disruptions in the integrity of the brain's white matter, which may occur before structural atrophy becomes apparent on conventional MRI [68]. In patients with TBI, DTI can be used to assess diffuse axonal injury, a common and often invisible consequence of head trauma [69]. DTI is also being used to study the effects of psychiatric disorders, such as schizophrenia, on brain connectivity [70]. Researchers have found that individuals with schizophrenia often exhibit abnormalities in the white matter tracts that connect different regions of the brain, which may contribute to the cognitive and functional deficits seen in the disease.

2.4.2 Magnetoencephalography (MEG)

Magnetoencephalography (MEG) is a non-invasive technique that measures the magnetic fields produced by neural activity [71]. MEG offers excellent temporal resolution, making it ideal for studying the brain's dynamic activity [72]. Unlike EEG, which measures electrical activity, MEG detects the magnetic fields generated by the flow of ions during neuronal firing [73]. MEG provides high spatial resolution, allowing researchers to precisely locate the sources of neural activity in the brain.

MEG has been particularly valuable in studying brain function during cognitive tasks [74]. For example, it has been used to examine the brain's response to sensory stimuli, motor planning, and language processing [75]. In clinical applications, MEG is used to localize brain regions responsible for critical functions, such as motor control or speech, prior to surgery for epilepsy or brain tumors..

In addition to its clinical applications, MEG is also being used in research to study brain connectivity and neural oscillations [76]. Researchers are investigating how different brain regions communicate with each other during tasks that require attention, memory, or decision-making [77]. MEG has also been used to study the neural basis

of psychiatric disorders such as depression and anxiety, where abnormal patterns of brain activity are thought to underlie the symptoms of these conditions.

2.4.3 Functional Near-Infrared Spectroscopy (fNIRS).

Functional Near-Infrared Spectroscopy (fNIRS) is a relatively new, non-invasive technique that measures changes in brain oxygenation by detecting the absorption of near-infrared light by hemoglobin in the blood [78]. Like fMRI, fNIRS is used to study brain activity, but it is more portable, less expensive, and more accessible [79]. fNIRS can be used in a wide range of environments, including in clinical settings, during physical activity, or even in mobile settings.

fNIRS is primarily used to measure changes in cerebral oxygenation during cognitive tasks [80]. It is particularly useful in studying brain activity in infants and children, as it is less cumbersome than fMRI and can be used in more naturalistic settings [81]. fNIRS is also being explored as a potential tool for monitoring brain activity in patients with neurological disorders, such as stroke, traumatic brain injury, or neurodegenerative diseases [82]. By measuring changes in brain oxygenation, fNIRS can provide valuable insights into how these diseases affect brain function over time.

3. Applications of Neuroimaging in Brain Diseases.

Neuroimaging technologies have revolutionized the way we understand, diagnose, and treat brain diseases [84]. These tools provide insights into the structural, functional, and molecular alterations in the brain associated with various neurological and psychiatric disorders [85]. From neurodegenerative diseases like Alzheimer's and Parkinson's to psychiatric disorders such as schizophrenia and depression, neuroimaging has become an essential component of both clinical practice and research [86]. This section explores the application of neuroimaging in diagnosing and understanding the pathophysiology of several common brain diseases.

3.1 Alzheimer's Disease.

Alzheimer’s disease (AD) is one of the most prevalent neurodegenerative disorders, characterized by the gradual deterioration of cognitive functions, particularly memory [87]. It is pathologically defined by the accumulation of amyloid plaques and tau tangles in the brain [88]. Neuroimaging has played a crucial role in both the early diagnosis and the ongoing monitoring of AD [89]. The primary imaging techniques used for AD include structural MRI, functional MRI (fMRI), and molecular imaging techniques like positron emission tomography (PET).

3.1.1 Structural Imaging: MRI and Atrophy.

MRI is widely used in the diagnosis and monitoring of Alzheimer's disease due to its high resolution and ability to visualize brain structures [90]. One of the earliest signs of AD that can be detected on MRI is the atrophy of specific brain regions, particularly the hippocampus, which is crucial for memory processing [91]. Structural MRI has been instrumental in tracking the progression of brain shrinkage over time, providing a direct measure of disease progression [92]. Longitudinal studies have shown that hippocampal atrophy correlates with cognitive decline in AD patients [93]. The ability to measure changes in brain volume through MRI is key for detecting early stages of AD, which is crucial for timely interventions.

3.1.2 Functional Imaging: fMRI and Brain Connectivity.

While structural MRI identifies changes in brain anatomy, functional MRI (fMRI) is used to assess changes in brain activity [94]. fMRI measures brain activity by detecting blood oxygen level-dependent (BOLD) signals, which reflect changes in cerebral blood flow associated with neuronal activity [95]. In Alzheimer's disease, fMRI studies have shown altered brain connectivity, particularly in the default mode network (DMN) [96]. The DMN is a network of brain regions active when a person is at rest and is associated with self-referential thinking and memory [97]. In AD, the DMN exhibits decreased connectivity, which has been linked to cognitive impairment and memory dysfunction [98]. fMRI can also assess the brain's response to cognitive tasks, providing valuable insights into the degree of dysfunction in specific brain regions.

3.1.3 Molecular Imaging: PET and Amyloid Imaging.

Molecular imaging techniques like positron emission tomography (PET) have become invaluable tools in Alzheimer's disease diagnosis and research [99]. PET imaging allows for the visualization of amyloid plaques in vivo, which are hallmark features of Alzheimer's pathology [100]. Radiotracers like Pittsburgh Compound B (PiB) bind to amyloid plaques and allow them to be visualized on PET scans [101]. This ability to detect amyloid deposition before clinical symptoms appear has opened new avenues for early diagnosis and monitoring the progression of AD [102]. PET imaging is also used to assess tau tangles, another pathological feature of Alzheimer's [103]. Tau imaging with specialized tracers, such as [18F]AV-1451, has been shown to correlate with cognitive decline and could potentially serve as a biomarker for tracking disease progression.

Moreover, PET imaging has been instrumental in assessing the efficacy of therapeutic interventions [104]. Several anti-amyloid therapies are in development, and PET scans can be used to monitor changes in amyloid burden following treatment [105]. This helps researchers evaluate the effectiveness of these therapies in reducing amyloid deposition and potentially slowing disease progression.

3.1.4 Emerging Techniques and Future Directions.

While the current imaging techniques are invaluable in diagnosing Alzheimer's disease, new technologies are constantly emerging to improve our understanding of the disease and enhance diagnostic capabilities [106]. For instance, advanced MRI techniques such as diffusion tensor imaging (DTI) and magnetic resonance spectroscopy (MRS) are being explored to assess white matter integrity and metabolic changes in the brain, respectively [107]. These techniques offer additional insight into the pathophysiology of AD, particularly in the early stages when structural changes may not yet be evident.

The integration of multi-modal neuroimaging is another promising development [108]. Combining structural, functional, and molecular imaging techniques allows for a more comprehensive understanding of Alzheimer's disease [109]. By integrating data from multiple modalities, researchers can better understand the interactions between amyloid plaques, tau tangles, brain connectivity, and cognitive decline.

Furthermore, the application of artificial intelligence (AI) and machine learning (ML) in analyzing neuroimaging data holds great promise [110]. These technologies can help identify subtle changes in brain structure and function that may be difficult to detect through traditional methods [111]. AI-driven algorithms could enable earlier detection, predict disease progression, and personalize treatment strategies for AD patients.

3.2 Parkinson's Disease.

Parkinson's disease (PD) is a neurodegenerative disorder primarily affecting motor function due to the degeneration of dopaminergic neurons in the substantia nigra [112]. While motor symptoms such as tremor, rigidity, and bradykinesia are the hallmark features of PD, non-motor symptoms such as cognitive decline, depression, and sleep disturbances are also common [113]. Neuroimaging plays a crucial role in the diagnosis, assessment, and monitoring of Parkinson’s disease.

3.2.1 Structural Imaging: MRI and Brain Degeneration.

In Parkinson's disease, MRI is used to assess structural changes in the brain, particularly in the basal ganglia, which are involved in the regulation of movement [114]. One of the most notable structural changes seen in PD is the loss of dopaminergic neurons in the substantia nigra [115]. While this degeneration is not always visible on routine MRI, advanced imaging techniques such as high-field MRI and voxel-based morphometry (VBM) have revealed subtle changes in the basal ganglia and other brain regions [116]. These changes correlate with the severity of motor symptoms and can be used to track disease progression.

Additionally, structural MRI can be used to differentiate Parkinson’s disease from other movement disorders that share similar symptoms, such as essential tremor [117]. In some cases, MRI can reveal characteristic patterns of atrophy that help guide clinical diagnosis.

3.2.2 Functional Imaging: fMRI and Motor Network Alterations.

Functional MRI has provided significant insights into the motor deficits seen in Parkinson's disease [118]. fMRI studies have shown altered brain activity in motor-related areas, such as the primary motor cortex and supplementary motor area, during both voluntary movement and at rest [119]. In PD, there is often hyperactivity in these regions, which is thought to reflect a compensatory mechanism due to the loss of dopaminergic input [120]. fMRI also allows researchers to study changes in brain connectivity in PD patients, particularly between motor-related regions and other parts of the brain involved in executive function and decision-making.

Resting-state fMRI (rs-fMRI) has been used to assess the connectivity of motor and non-motor networks in PD [121]. Studies have shown disrupted connectivity in the default mode network (DMN) and executive control networks, which are linked to cognitive impairment and non-motor symptoms in Parkinson’s disease [122]. These alterations in connectivity may provide important biomarkers for assessing the progression of cognitive decline in PD.

3.2.3 Molecular Imaging: PET and Dopamine Loss.

PET imaging has become a powerful tool in Parkinson’s disease for both diagnosis and tracking disease progression [123]. PET scans can detect the loss of dopaminergic function in the brain by imaging dopamine transporter (DAT) binding in the striatum [124]. The reduced availability of DAT in the striatum is a hallmark of Parkinson's disease and can be quantified using radiolabeled ligands such as [11C]raclopride and [18F]FP-CIT [125]. These molecular imaging techniques are valuable for confirming the diagnosis of Parkinson's disease, particularly in cases where clinical symptoms overlap with other movement disorders.

PET can also be used to monitor the effects of treatment in Parkinson’s disease, such as dopamine replacement therapies or deep brain stimulation [126]. By measuring changes in dopamine receptor availability and brain metabolism, PET provides insights into the effectiveness of these treatments and their impact on brain function.

3.2.4 Future Directions: Imaging for Personalized Treatment.

As with Alzheimer’s disease, advancements in neuroimaging are leading to more personalized approaches to treatment in Parkinson’s disease [127]. The integration of molecular imaging, structural MRI, and functional imaging can help tailor treatments to the specific needs of individual patients [128]. For instance, PET scans can identify patients with residual dopaminergic function who might benefit from dopamine replacement therapy, while those with more advanced degeneration may be better suited for deep brain stimulation.

Furthermore, ongoing research into the use of biomarkers for early diagnosis and prediction of disease progression is critical for the development of disease-modifying therapies in Parkinson's disease [129]. Neuroimaging will play a pivotal role in identifying these biomarkers and guiding the development of new treatments.

3.3 Multiple Sclerosis.

Multiple sclerosis (MS) is an autoimmune disease that affects the central nervous system, leading to inflammation, demyelination, and neurodegeneration [130]. MS can present with a wide range of symptoms, including motor deficits, sensory disturbances, and cognitive impairments [131]. Neuroimaging plays a crucial role in diagnosing MS, assessing disease activity, and monitoring treatment response.

3.3.1 Structural Imaging: MRI and Lesion Detection.

MRI is the gold standard for diagnosing multiple sclerosis due to its ability to detect lesions in the brain and spinal cord [132]. These lesions, which are the result of demyelination and inflammation, can be visualized using contrast-enhanced MRI [133]. MRI scans are particularly useful for detecting new lesions, which are indicative of ongoing disease activity [134]. The presence of contrast-enhancing lesions on MRI can be used to determine whether a patient is experiencing a relapse or if their condition is stable.

Quantitative MRI techniques, such as volumetric MRI, allow for the assessment of brain atrophy, which is a common feature of MS, particularly in progressive forms of the disease [135]. Tracking brain atrophy over time can provide valuable information about disease progression and help clinicians predict long-term outcomes.

3.3.2 Functional Imaging: fMRI and Cognitive Impairment.

In addition to structural MRI, functional MRI (fMRI) has been used to assess the effects of multiple sclerosis on brain function [136]. MS patients often experience cognitive impairments, including problems with memory, attention, and executive function [137]. fMRI studies have shown altered brain activity patterns in MS patients during cognitive tasks, which may reflect compensatory mechanisms as the brain adapts to areas of damage [138]. These functional changes can provide important insights into the extent of cognitive decline and help guide interventions.

Resting-state fMRI has also been used to study the functional connectivity of brain networks in MS patients [139]. Disrupted connectivity in networks related to cognition and motor function has been observed in MS, and these changes may correlate with clinical symptoms [140]. As research in this area continues, fMRI may become a valuable tool for assessing cognitive impairment and evaluating the impact of therapeutic interventions in MS.

3.3.3 Molecular Imaging: PET and Neuroinflammation.

PET imaging has been used to study neuroinflammation in multiple sclerosis [141]. Radiolabeled ligands that bind to activated microglia and macrophages, such as [11C]PK11195, can be used to visualize regions of inflammation in the brain [142]. Neuroinflammation is a key feature of MS, and PET imaging can provide insights into the extent and location of inflammation, which is critical for monitoring disease activity and assessing the effectiveness of anti-inflammatory treatments.

PET imaging has also been used to study the effects of disease-modifying therapies (DMTs) in MS [143]. By tracking changes in inflammation and brain metabolism, PET scans can help determine how well these treatments are working to reduce disease activity and slow the progression of the disease.

4. Advances in Neuroimaging Techniques.

Neuroimaging techniques have undergone significant advancements over the past few decades, improving our ability to study brain structure, function, and molecular processes [145]. These innovations have not only enhanced our understanding of brain diseases but have also paved the way for more accurate diagnoses and personalized treatment strategies [146]. This section will explore some of the latest advancements in neuroimaging technologies, including improvements in spatial and temporal resolution, multi-modal imaging, and the integration of artificial intelligence (AI) and machine learning (ML) to interpret complex imaging data.

4.1 High-Resolution Imaging Techniques.

One of the most important developments in neuroimaging is the increase in spatial resolution, allowing for more detailed and precise imaging of the brain at both the macro and micro levels [147]. Advances in MRI technology, including the development of ultra-high-field MRI (7T and beyond), have provided significantly enhanced images of the brain's microstructure, offering new insights into both normal and diseased brain anatomy [148]. High-resolution imaging is particularly beneficial for studying small structures such as the hippocampus and amygdala, which are implicated in numerous neurological conditions, including Alzheimer's disease and epilepsy.

Ultra-high-field MRI scanners allow for the visualization of finer details of the brain, such as the cortical layers and the organization of neural fibers in white matter [149]. These scanners use stronger magnetic fields to capture high-quality images with much greater detail than standard MRI scanners, enabling the detection of subtle changes in brain structure that were previously undetectable [150]. This advancement has made it possible to study neurodegenerative diseases like Alzheimer's and Parkinson's at earlier stages, which is critical for early intervention and understanding disease progression.

In addition to structural improvements, advancements in functional MRI (fMRI) have led to better temporal resolution, allowing researchers to capture brain activity with increased precision [151]. Functional MRI can now detect changes in brain activity at a finer time scale, improving our ability to track rapid neuronal events and better understand the dynamics of cognitive tasks or brain network activity [152]. This is particularly important when studying diseases like schizophrenia or autism, where brain connectivity patterns can change over time or in response to different stimuli.

4.2 Multi-Modal Imaging.

The integration of multiple imaging modalities has emerged as a key strategy in advancing neuroimaging [153]. Multi-modal imaging combines the strengths of various techniques, providing a more comprehensive view of the brain's structure, function, and molecular processes [154]. For example, combining structural MRI with functional MRI (fMRI) allows researchers to assess both the anatomical changes in the brain and the associated functional alterations, providing a holistic understanding of how disease processes affect the brain.

One powerful example of multi-modal imaging is the combination of PET and MRI, which allows for simultaneous structural and molecular imaging [155]. While PET can detect metabolic activity and molecular markers associated with disease (such as amyloid plaques in Alzheimer's or dopamine loss in Parkinson's), MRI can provide detailed images of brain anatomy [156]. By combining these two modalities, researchers can gain insight into the relationship between molecular changes and structural alterations in the brain, as well as how these changes correlate with cognitive or motor symptoms.

Another promising area of multi-modal imaging is the combination of magnetic resonance spectroscopy (MRS) with MRI or PET [157]. MRS allows for the non-invasive measurement of brain metabolites, such as N-acetylaspartate (NAA), choline, and creatine, which can be used to assess neuronal health and metabolism [158]. When combined with MRI, which provides detailed anatomical information, or PET, which tracks molecular markers, MRS can offer insights into the biochemical changes occurring in the brain during the development of neurological diseases like multiple sclerosis or epilepsy.

The application of multi-modal imaging is particularly promising in the study of neurodegenerative diseases, where complex interactions between structural, functional, and molecular changes must be understood to develop effective diagnostic and therapeutic strategies [159]. By integrating multiple imaging techniques, researchers can obtain a more comprehensive picture of disease mechanisms and track the effects of interventions in real-time.

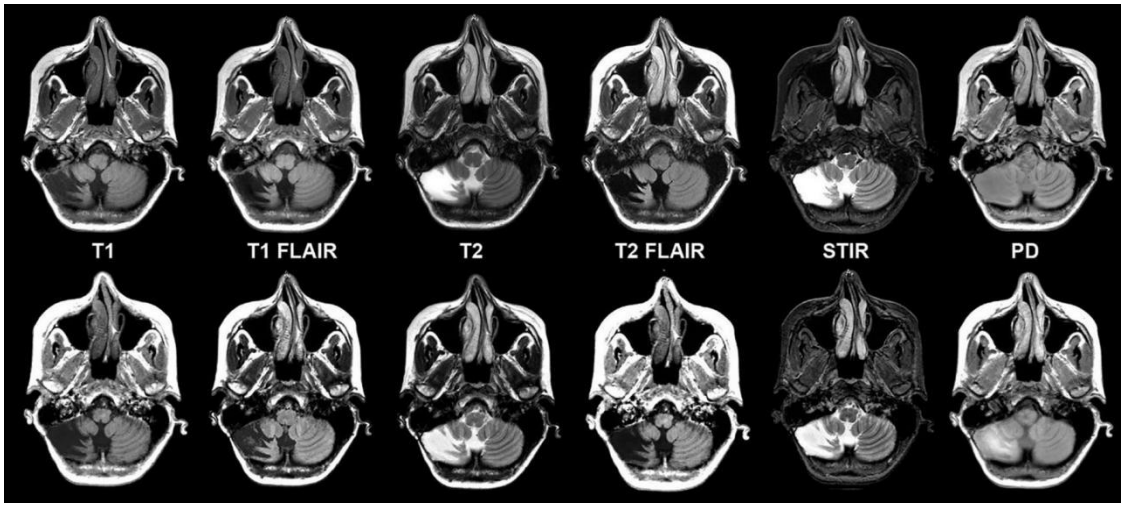
4.3 Advanced Imaging Techniques: Diffusion Tensor Imaging (DTI) and Quantitative Susceptibility Mapping (QSM).

In addition to traditional imaging modalities, several advanced imaging techniques are being developed to probe specific aspects of brain structure and function [160]. One such technique is diffusion tensor imaging (DTI), which is used to study the white matter tracts in the brain [161]. DTI measures the diffusion of water molecules along the direction of white matter fibers, providing valuable information about the integrity of these tracts [162]. DTI has been particularly useful in studying diseases that affect white matter, such as multiple sclerosis and schizophrenia, as it allows researchers to visualize disruptions in white matter connectivity and track changes over time.

In neurodegenerative diseases like Alzheimer's and Parkinson's, DTI has revealed altered white matter integrity, which is often associated with cognitive decline [163]. By quantifying fractional anisotropy (FA), a measure of the directionality of water diffusion, DTI provides an objective marker of white matter integrity, which can be correlated with clinical symptoms [164]. DTI has also been used to study brain plasticity, as changes in white matter connectivity may reflect compensatory mechanisms in response to injury or disease.

Another advanced imaging technique gaining traction is quantitative susceptibility mapping (QSM) [165]. QSM is a form of MRI that measures magnetic susceptibility in the brain, which can provide information about tissue composition, iron deposition, and other pathological changes [166]. QSM is particularly useful in studying neurodegenerative diseases like Parkinson's disease, where abnormal iron accumulation is commonly observed

[167]. QSM can be used to detect iron deposits in specific brain regions, such as the basal ganglia, which are involved in motor function and are known to undergo changes in Parkinson's disease [168]. By providing a more detailed view of tissue composition, QSM can complement other neuroimaging techniques and improve our understanding of disease processes.



4.4 Artificial Intelligence and Machine Learning in Neuroimaging.

Artificial intelligence (AI) and machine learning (ML) have become increasingly important in the field of neuroimaging, particularly in the analysis and interpretation of complex imaging data [169]. These technologies have the potential to revolutionize the way neuroimaging data is processed, analyzed, and used in clinical settings [170]. AI and ML algorithms can assist in identifying patterns within large datasets, enabling the detection of subtle changes that may be missed by traditional methods.

One of the most exciting applications of AI in neuroimaging is the development of automated image analysis tools [171]. These tools can analyze large volumes of brain imaging data quickly and efficiently, reducing the time required for manual interpretation and minimizing human error [172]. For example, AI algorithms can be trained to automatically segment brain structures, such as the hippocampus or gray matter, and detect changes in these structures over time [173]. This could be especially useful for tracking disease progression in conditions like Alzheimer’s disease or multiple sclerosis, where subtle changes in brain anatomy are important for monitoring treatment efficacy.

Machine learning algorithms are also being used to develop predictive models for disease diagnosis and prognosis [174]. By analyzing a combination of structural, functional, and molecular imaging data, ML models can predict the likelihood of developing a particular disease or forecast disease progression [175]. For instance, ML algorithms have been used to predict the onset of Alzheimer's disease based on early neuroimaging biomarkers, such as amyloid deposition and hippocampal atrophy [176]. These models can be trained on large datasets to identify subtle patterns in brain imaging data that correlate with clinical outcomes, enabling earlier and more accurate diagnoses.

Another promising application of AI in neuroimaging is the development of personalized treatment plans [177]. By combining neuroimaging data with patient-specific information, such as genetic and clinical data, AI-driven approaches can help identify the most effective treatment strategies for individual patients [178]. This personalized approach is especially important in neurodegenerative diseases, where treatments need to be tailored to the specific progression and characteristics of each patient's condition.

4.5 Functional Near-Infrared Spectroscopy (fNIRS).

Functional near-infrared spectroscopy (fNIRS) is a non-invasive neuroimaging technique that measures changes in blood oxygenation levels in the brain [179]. It uses near-infrared light to penetrate the skull and assess the absorption of light by hemoglobin in the blood, providing real-time information on brain activity [180]. fNIRS

has been used to study brain function in various clinical settings, including stroke rehabilitation, cognitive decline, and neurological disorders such as epilepsy and schizophrenia.

One of the main advantages of fNIRS is its portability and low cost compared to other neuroimaging techniques like fMRI or PET [181]. This makes it an attractive tool for use in clinical settings or for monitoring brain activity during everyday activities [182]. fNIRS is particularly useful for studying brain function in populations who may have difficulty undergoing traditional neuroimaging, such as young children, elderly patients, or those with cognitive impairments.

While fNIRS does not offer the same level of spatial resolution as fMRI, it provides a more flexible and accessible means of studying brain activity [183]. Researchers are continuing to refine fNIRS technology to improve its spatial resolution and expand its applications in both research and clinical practice.

4.6 Future Prospects of Neuroimaging.

The future of neuroimaging is incredibly promising, with advancements in both technology and analysis techniques continuing to push the boundaries of what is possible [184]. As imaging modalities become more precise and multi-faceted, our ability to track brain changes with greater accuracy and detail will enable earlier diagnoses, more targeted treatments, and a deeper understanding of brain diseases.

In particular, the continued integration of AI and machine learning with neuroimaging is expected to revolutionize clinical practices, allowing for faster, more accurate, and personalized assessments [185]. Additionally, the development of portable and accessible neuroimaging tools will likely broaden the application of these technologies, making brain disease diagnosis and monitoring more widely available and less invasive.

As we move toward a more integrated, multimodal approach to neuroimaging, the future holds immense potential for improving the diagnosis, understanding, and treatment of brain diseases.

5. Neuroimaging in the Early Diagnosis of Brain Diseases.

Early diagnosis of brain diseases plays a critical role in improving patient outcomes [187]. The ability to detect disease at its incipient stages provides an opportunity for early intervention, potentially slowing or even halting disease progression before irreversible damage occurs [188]. Neuroimaging has become a cornerstone of early diagnosis, with advances in imaging techniques allowing for the detection of subtle structural, functional, and molecular changes that signal the onset of neurological disorders.

5.1 Early Detection of Alzheimer's Disease.

Alzheimer's disease (AD) is a prime example of a neurodegenerative disorder where early diagnosis is crucial for improving the chances of successful treatment [189]. In the early stages of AD, patients often experience mild cognitive impairment (MCI), a condition in which they show slight but noticeable memory problems that are not severe enough to interfere with daily activities [190]. However, these early symptoms can be difficult to distinguish from normal age-related cognitive decline, making it challenging to diagnose AD at this stage [191]. Neuroimaging, however, has proven valuable in identifying early biomarkers associated with the disease.

MRI and PET scans have been instrumental in detecting early changes in the brain that signal the development of AD [192]. Structural MRI scans can reveal atrophy in key brain regions, including the hippocampus, which is one of the first areas to be affected in AD [193]. Functional MRI (fMRI) has also been used to detect disruptions in brain network activity, which occur early in AD and are linked to cognitive decline [194]. In particular, changes in the default mode network (DMN), a network of brain regions that are active when a person is not focused on the outside world, have been associated with AD and MCI.

One of the most important breakthroughs in early AD detection is the use of positron emission tomography (PET) to visualize amyloid plaques, a hallmark of AD pathology [195]. PET scans using radiotracers such as Pittsburgh Compound B (PiB) have made it possible to detect amyloid deposition in the brain long before clinical symptoms manifest [196]. The ability to visualize amyloid plaques provides critical insight into the disease's progression and helps to identify individuals at risk for developing AD [197]. More recently, tau PET

imaging has also been developed to visualize tau tangles, which are another key pathological feature of AD [198]. The combination of amyloid and tau imaging can help provide a more complete picture of the disease's development and progression.

5.2 Early Detection of Parkinson's Disease.

Parkinson's disease (PD) is another neurodegenerative disorder where early diagnosis is vital for managing symptoms and improving quality of life [199]. PD is characterized by the progressive loss of dopaminergic neurons in the brain, particularly in the substantia nigra [200]. Early symptoms, such as tremors, rigidity, and bradykinesia (slowness of movement), may be subtle and easily overlooked, making early diagnosis challenging [201]. However, neuroimaging techniques have provided valuable tools for detecting PD at an earlier stage.

Structural MRI is often used in combination with other techniques to assess brain changes associated with PD [202]. While MRI can detect atrophy in certain brain regions, particularly the basal ganglia, changes in the brain's white matter may also indicate the early stages of PD [203]. PET imaging, however, has become one of the most reliable methods for detecting dopaminergic dysfunction in PD patients [204]. Radiotracers such as 18F-dopa are used to visualize dopamine transporter activity in the brain [205]. Reduced dopamine activity in the striatum is one of the earliest signs of PD and can be detected before motor symptoms appear.

In addition to PET, single-photon emission computed tomography (SPECT) has also been used to visualize dopaminergic activity in the brain [206]. SPECT scans using radiotracers such as 123I-FP-CIT can provide detailed information about the integrity of the dopaminergic system, making it possible to detect early signs of PD [207]. Advanced MRI techniques, such as diffusion tensor imaging (DTI), are also being explored for their ability to detect early changes in white matter integrity, which may precede clinical symptoms of PD.

5.3 Early Detection of Multiple Sclerosis.

Multiple sclerosis (MS) is an autoimmune disease that affects the central nervous system, leading to demyelination and neurological dysfunction [208]. The disease often presents with intermittent symptoms, such as numbness, weakness, and vision problems, which can make early diagnosis difficult [209]. Neuroimaging plays a critical role in the diagnosis and monitoring of MS, allowing for the identification of lesions in the brain and spinal cord that are indicative of the disease.

MRI is the gold standard for diagnosing MS, as it can detect the characteristic white matter lesions that are caused by the demyelination process [210]. In the early stages of MS, these lesions may be small and difficult to identify, but advances in MRI technology, including higher resolution scanners and newer imaging sequences, have improved the ability to detect early lesions [211]. Additionally, functional MRI (fMRI) has been used to assess brain activity in MS patients, revealing changes in brain network connectivity that may reflect the early impact of the disease on cognitive function.

In recent years, researchers have also focused on using MRI to detect microstructural changes in the brain that may precede visible lesions [212]. Diffusion tensor imaging (DTI) is one such technique that measures the movement of water molecules along the white matter fibers, allowing for the detection of disruptions in fiber integrity [213]. Changes in DTI metrics, such as reduced fractional anisotropy, have been observed in the brains of MS patients even before visible lesions appear, making DTI a valuable tool for detecting early signs of MS and tracking disease progression.

5.4 Early Detection of Stroke.

Stroke is a leading cause of disability and death worldwide, and early detection and intervention are critical for minimizing brain damage and improving recovery outcomes [214]. Neuroimaging plays a crucial role in diagnosing stroke, determining its type (ischemic or hemorrhagic), and assessing the extent of brain damage [215]. Advances in neuroimaging have significantly improved the ability to detect stroke in its early stages, even before clinical symptoms become apparent.

Non-contrast CT scans are commonly used in the emergency setting to quickly assess for hemorrhagic stroke, as they can rapidly detect bleeding in the brain [216]. However, for ischemic stroke, where there is no visible

bleeding but rather a blockage of blood flow, MRI and advanced MRI techniques are preferred [217]. Diffusion-weighted imaging (DWI) is particularly valuable for detecting early ischemic changes, as it can identify areas of the brain that are at risk of permanent damage due to lack of blood flow [218]. DWI can detect ischemic changes within minutes to hours after a stroke, providing crucial information for determining the appropriate course of treatment.

In addition to DWI, perfusion imaging using MRI or CT can help assess the blood flow to specific brain regions, identifying areas that are at risk of infarction [219]. This information is critical for guiding treatment decisions, such as the use of thrombolytics or thrombectomy in patients with ischemic stroke [220]. Advances in neuroimaging have also enabled the development of predictive models that combine imaging data with clinical information to predict stroke outcomes, allowing for more personalized treatment strategies.

5.5 Early Detection of Epilepsy

Epilepsy is a neurological disorder characterized by recurrent seizures, and its early diagnosis is crucial for preventing further episodes and improving long-term outcomes [221]. Neuroimaging plays a key role in identifying the underlying causes of epilepsy, such as structural abnormalities, brain lesions, or changes in brain connectivity [222]. Advances in imaging techniques have made it possible to detect subtle changes in the brain that may be associated with epilepsy even before seizures occur.

Structural MRI is routinely used in the evaluation of patients with epilepsy, as it can identify brain lesions, tumors, or other abnormalities that may be responsible for the seizures [223]. In some cases, MRI may reveal abnormalities that are visible even in the absence of clinical seizures [224]. Functional imaging techniques, such as fMRI and positron emission tomography (PET), are also being used to study brain activity in epilepsy patients [225]. fMRI can help identify the brain regions responsible for initiating seizures, providing valuable information for surgical planning in patients with refractory epilepsy.

Another emerging imaging technique for early detection of epilepsy is magnetoencephalography (MEG), which measures the magnetic fields produced by neuronal activity [226]. MEG provides high temporal and spatial resolution and can be used to localize the brain regions involved in seizure activity [227]. By combining MEG with other imaging modalities, such as fMRI or PET, researchers are gaining a more comprehensive understanding of the brain’s seizure networks, which can inform early diagnosis and treatment.

6. Conclusion

Neuroimaging has revolutionized our understanding of brain diseases and plays an indispensable role in diagnosing, monitoring, and treating neurological conditions [229]. The ability to observe both structural and functional changes in the brain with high precision has transformed the landscape of clinical neurology [230]. As brain diseases, such as Alzheimer’s, Parkinson’s, multiple sclerosis, and stroke, continue to pose significant challenges to public health worldwide, neuroimaging provides crucial insights that allow for early detection, better disease tracking, and personalized treatment approaches.

The integration of various neuroimaging techniques, including structural MRI, functional MRI (fMRI), positron emission tomography (PET), and diffusion tensor imaging (DTI), has enabled the identification of early biomarkers, which was once impossible with traditional methods [231]. Early detection of diseases like Alzheimer's and Parkinson's, where symptoms may not be noticeable at the outset, can make a significant difference in terms of treatment efficacy [232]. Moreover, neuroimaging facilitates monitoring of disease progression and helps evaluate the effects of therapeutic interventions, thus playing a pivotal role in the development of new treatments and clinical trials.

In diseases like Alzheimer's, where the accumulation of amyloid plaques and tau tangles is central to the pathophysiology, molecular imaging techniques like PET have allowed for in vivo visualization of these protein deposits [233]. This breakthrough has improved our ability to track disease progression and identify individuals who are at risk of developing dementia before clinical symptoms arise [234]. Similarly, the use of PET and SPECT imaging in Parkinson’s disease has allowed for the early detection of dopamine dysfunction, even

before motor symptoms become clinically apparent, which is key for starting treatment early and potentially slowing disease progression.

Furthermore, neuroimaging not only assists in diagnosing brain diseases but also plays a critical role in understanding their underlying mechanisms [235]. Advanced imaging techniques, such as fMRI, allow for real-time monitoring of brain activity and can reveal disruptions in brain networks, particularly those responsible for memory, cognition, and motor control [236]. These insights help scientists and clinicians uncover the specific areas of the brain that are most affected by disease and can inform therapeutic strategies aimed at restoring normal brain function.

In addition to its diagnostic and monitoring roles, neuroimaging provides essential data for assessing the impact of treatments [237]. Whether it is evaluating the effects of drug therapies, surgical interventions, or novel approaches like deep brain stimulation, neuroimaging allows clinicians to visualize the outcomes of treatment and refine therapeutic approaches [238]. As neuroimaging technologies continue to advance, they offer the potential for even more precise and personalized treatment options for patients suffering from neurological disorders.

As the field of neuroimaging continues to evolve, several challenges remain [239]. One key challenge is the development of imaging techniques that can detect diseases at even earlier stages, potentially before structural changes occur in the brain [240]. For example, researchers are focusing on improving the sensitivity and specificity of PET tracers to identify early molecular changes associated with diseases like Alzheimer's and Parkinson's [241]. Another challenge is making these technologies more accessible and affordable, as the cost of advanced imaging methods can be prohibitive for some healthcare systems [242]. In addition, more efforts are needed to integrate neuroimaging data with genetic, clinical, and other biomarkers to create a more comprehensive and accurate understanding of brain diseases..

The future of neuroimaging holds great promise [243]. With ongoing advancements in imaging resolution, machine learning algorithms for data analysis, and the development of novel biomarkers, neuroimaging will continue to enhance the precision of diagnosis and treatment planning for brain diseases [244]. Moreover, as we gain a deeper understanding of the brain's connectivity and function, neuroimaging may enable the identification of previously undetectable pathologies and lead to new approaches for preventing or even reversing brain diseases.

In conclusion, neuroimaging is an indispensable tool in the modern approach to brain disease diagnosis and treatment [245]. By providing unparalleled insight into the structure, function, and molecular biology of the brain, neuroimaging helps clinicians to make more accurate diagnoses, track disease progression, and tailor treatments to individual patients [246]. As the technology continues to evolve and become more accessible, neuroimaging will undoubtedly play a central role in advancing both clinical practice and scientific research in the field of neuroscience.

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