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The role of Neuroradiology in Neuroplasticity: New advancements

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Abstract

- Neuroplasticity, the brain's capacity to adapt to internal and external environmental changes, occurs physiologically throughout growth and in reaction to damage. Many MRI studies of neuroplasticity have shown strong evidence that the brain changes quickly and extensively when people have new experiences.
- In this paper, we review the most advancement in the role of neuroradiology in neuroplasticity and using biomarkers.
    - Detecting neuroplasticity in global brain circuits in vivo is critical for understanding various processes such as memory, learning, and injury healing.
    - MRI-biomarkers can be used to check for corticospinal integrity and how well motor resources are used. White matter neuroplasticity is studied via MRI. It has been used to study structural changes using diffusion tensor imaging (DTI)
    - The ultrafast fMRI (ufMRI) technique allows for high spatiotemporal sensitivity and resolution in dispersed brain circuits to detect fMRI signals more connected with the underlying neural dynamics.
    - White matter hemodynamics may change over time, explaining functional neuroplasticity in this tissue.

Keywords: Neuroradiology; Neuroplasticity; MRI; fMRI; Rehabilitation; Cognition Science

1. Introduction

Neuroplasticity, or the brain's capacity to adapt to internal and external environmental changes, occurs physiologically throughout growth and in reaction to damage. Neuroplasticity is an important underlying component of skill acquisition in healthy people and functional recovery after damage. Synaptic plasticity occurs at the subcellular level, whereas system and network plasticity occurs at the system and network levels [1]. Several neurological symptoms can occur in neurodegenerative, neurovascular neuroinflammation disease. These symptoms become essential even in patients recovering from COVID-19 [2]. Several treatments have been applied for neuroplasticity in cognition disorders, from drgus, to novel neuromodulators such as Repetitive transcranial magnetic stimulation (rTMS) [3] and Photobiomodulation [4]. In this paper, we review the most advancement in the role of neuroradiology in neuroplasticity and using biomarkers

2. Neuroradiology in Neuroplasticity

Non-invasive approaches in neuroradiology can be utilized as a first-line screening tool to detect neurodegenerative and neurovascular diseases [5]. Over the last two decades, many MRI studies of neuroplasticity have shown strong evidence that the brain changes quickly and extensively when people have new experiences. Until now, most of these

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studies have looked for differences in structural or functional images and did not pay much attention to the fact that they do not have much biological specificity. In recent reviews and public debates, people have said that more advanced imaging techniques are needed to understand better the nature of these differences – how big they are in time and space and how they work biologically and in networks. This article will look at some new imaging methods for studying neuroplasticity [6].

Detecting neuroplasticity in global brain circuits in vivo is critical for understanding a variety of processes such as memory, learning, and injury healing. Functional Magnetic Resonance Imaging (fMRI) is useful for such in vivo mappings, although it often relies on mapping changes in spatial extent of activation or signal amplitude modulations, which can be difficult to interpret. Notably, one of the most important aspects of neuroplasticity is the alteration of neuronal activity temporal characteristics. As a result, this temporal dimension may serve as a novel neuroplasticity marker. The ultrafast fMRI (ufMRI) technique allows for high spatiotemporal sensitivity and resolution in dispersed brain circuits to detect fMRI signals that are more connected with the underlying neural dynamics. When neuroplasticity in the rat visual system was established by dark rearing, ufMRI could track temporal modulations over the whole visual pathway. As a result, our findings reveal a new dimension for studying neuroplasticity in vivo [7].

There has been a lot of progress and evidence that brain injuries like stroke, traumatic brain injury, and epilepsy are caused by changes in functional connectivity and structural abnormalities in the brain. There is still much confusion about whether these changes can be used as a biomarker to establish prognostic models, develop targeted treatments, and stratify patients for interventional trials [8].

3. Chronic Stroke Patients' Structural Neuroplasticity

Acute stroke generally causes physical and cognitive impairments that can be corrected through therapy. Chronic stroke patients have only partial recovery and lingering deficits following therapy. In four chronic stroke patients, Lazaridou et al. assessed cortical thickness with VBM and white matter integrity with DTI. The research involvement was more than 6 months after the beginning of left-sided ischemic subcortical middle cerebral artery stroke. In an 8-week program, patients squeezed an exercise ball with their paretic hand for 1 hour 3 days a week. MR scans were done at baseline, 4 weeks, 8 weeks, and 4 weeks afterward. For DTI fiber reconstruction, deterministic tractography was used with visual inspection. The pons, posterior limb of the internal capsule, and motor cortex were chosen as seed areas (CST). The number of CST fibers and average tract length increased significantly in the damaged hemisphere. CST fibers of a sample patient before, during, and after motor training. The CST fibers (blue) got closer to the motor cortex and became denser as training progressed. The cortical thickness of the ventral postcentral gyrus grew considerably following training compared to the baseline. They showed that rigorous motor training led to structural neuroplasticity in the sensorimotor system in chronic stroke patients, and they established a new method for assessing rehabilitation success [9].

U. Horn and his team did a very detailed review of MRI-biomarkers that can be used to check for corticospinal integrity and how well motor resources are used. Corticospinal integrity evaluation by structural imaging was more reliable and accurate than the functional connectivity parameters. This was true for patients with different levels of impairment. It will be easier to find the best treatment for a specific group of patients when the group is more defined. They also suggested using a combination of different measures in an algorithm to classify fine-graded groups of patients.[10]

White matter: White matter function is a part of neuroplasticity that hasn't been looked at very much. It's important to know how learning-based changes in the brain affect the whole brain to get a complete picture. In one study, twelve healthy, right-handed people used an MRI-compatible computer mouse to do fine and gross motor tasks with both hands. Analysis looked at how the right and left hands changed due to training. Motor task score went up a lot for the left-hand condition, but not for the right-hand condition. Similarly, there was a change in how long it took for white matter hemodynamics to change in only the right corticospinal tract [11].

White matter neuroplasticity is studied via MRI. It has been used to study structural changes using diffusion tensor imaging (DTI). The functional MRI neuroplasticity studies were limited to gray matter (GM). The internal capsule and the corpus callosum are well-known WM areas of neuroplasticity change. MRI-based neuroplasticity alterations supported this in the internal capsule for DTI fractional anisotropy, fMRI hemodynamic response functions, and low-frequency oscillations (LFOs). DTI fractional anisotropy, fMRI hemodynamic response functions, and low-frequency oscillations all showed stronger behavioral gains in the non-dominant hand following training than in the dominant hand (LFOs). LFOs, DTI, and functional correlation tensors showed neuroplasticity alterations in the corpus callosum (CC) (FCT). The LFO results showed considerable amplitude decreases, suggesting an improved transmission

mechanism via myelination. Indirect WM research into mapping connectomes and improving MRI clinical applications is now possible [12].

X. Fan et al. compare left and right mesial temporal lobe epilepsy patients to matched healthy controls to examine the differential brain anatomical and effective connectivity abnormalities within the semantic cognition network. Because hippocampal sclerosis patients' seizures were more targeted than random, left mTLE had more gray matter degeneration than right mTLE across the whole brain, especially inside the contralateral semantic cognition network. This study found that left HS patients were more prone to seizures, indicating a compensatory strategy. This may explain the more severe name-finding difficulty but strong understanding abilities [13]. According to the literature, several approaches have been proposed so far for neurodegenerative disorders such as Parkinson's disease (PD). However, there continue to be controversies over the most effective options [14].

4. Neuroplastic Network Changes in TBI

Attention, working memory, speech, and executive functions such as planning, inhibition, and cognitive control are typically affected after a traumatic brain injury. Caeyenberghs et al. [15] used functional imaging and graph theory to solve the latter issue. They employed an event-related fMRI paradigm previously used to assess cognitive control in young and older individuals and in TBI patients. Participants used a joystick to make temporally linked circular hand. Visual signals suggested switching from asymmetric to symmetric movement patterns or keeping moving. Medial frontal, anterior cingulate, dorsolateral prefrontal, bilateral inferior frontal (BA 44), basal ganglia, cerebellum, right and left premotor cortex, bilateral insula, and right superior and inferior parietal cortex made up the network. The average time series for each ROI of each individual was then submitted to a partial correlation analysis. A metric for functional linkages was obtained by quantifying the unique correlation between two ROIs and content filtering the effects of all other ROIs. Important connections between nodes (i.e., ROIs) were weighted matrices for theoretical graph analysis. Weighted matrices were utilized to compute the mean node and network connection strength. It was used to examine global network design and nodal features.

Yan et al. studied the episodic memory network of mild traumatic brain injury survivors. Compared to normal controls, moderate TBI enhanced bilateral and decreased effective ipsilateral connectivity in the episodic memory network. The over recruitment of the right anterior PFC induced disruption of the strategic component of episodic memory, causing episodic memory decline in mTBI survivors [16]

S. Zhang et al. investigated cortical thickness and white matter integrity in children with mild-moderate hydrocephalus. These youngsters had thinner cortical layers in the left middle temporal and left rostral middle frontal gyrus, and their corpus callosum had lower diffusion measurements than normal controls. This study shows that structural brain alterations can be utilized to track long-term results in mild-to-moderate hydrocephalic kids.[17].

5. Neuroplasticity in Multiple sclerosis (MS)

MS is a chronic illness marked by inflammatory and neurodegenerative damage to the central nervous system. FMRI is a tool that permits in vivo functional changes connected to disease and evolution. Several investigations have indicated that aberrant brain activation occurs early in MS during task execution. More functional activation during certain tasks has been regarded as an adaptive plasticity mechanism to counteract greater tissue damage. The radiologic manifestations of a neuroinflammatory illness might reveal themselves in any sequence and without provocation [18]. MS causes gradual brain atrophy in the early stages of the illness, resulting in physical and cognitive impairment. Brain atrophy can be detected indirectly using neuroradiology, such as Trans Cranial Sonography (TCS) , for the Third Ventricle Diameter [19].

Recent fMRI research on resting brain activity has generated mixed results, suggesting that alterations in functional brain connections indicate adaptive or maladaptive plasticity mechanisms. It's also been utilized to explore plastic changes generated by medication or rehabilitation, albeit unknown whether these alterations are a surrogate of neuroplasticity [20].

Neuroplasticity in Neonates: Neural plasticity promotes the repair and remodeling of the brain in premature newborns with high risk of brain injury induced by so-called extrauterine and endogenous determinants of cerebral immaturity. Neuroplasticity confers compensatory (regenerative) brain function. Impaired or delayed brain maturation can affect subsequent neuropsychiatric development in preterm newborns [21]

Neuroimaging can detect structural brain injury in infants and patterns of cerebral maturation and adaptability [22]. CUS and MRI are now frequently utilized to diagnose brain abnormalities in newborns. MRI scans of preterm newborns show the degree of regression of the sub-ependymal germinal matrix of the brain lateral ventricles [23]. Premature newborns with sub-ependymal germinal matrix regression disease have impaired cerebral physiological development [24]. Using CUS, the sub-ependymal germinal matrix can be recognized as hyperechoic regions in the anterior lateral ventricle (in the Monro foramen projection) until week 29 [22]. MRI can show the germinal matrix as hypointense signals on T2 weighted images and hyperintense signals on T1 weighted images up to week 30 [25].

The importance of neuroplasticity isn't fully understood, so more attention should be paid to reporting complete and granular racial and ethnic profiles to keep track of how modern neurology problems, such as stroke trials represent people in different groups [26]. Neuroradiological biomarkers can be used as biomarkers for personalized neurology and cognition problems [27-30].

6. Conclusion

- Many MRI studies of neuroplasticity have shown strong evidence that the brain changes quickly and extensively when people have new experiences.
- Detecting neuroplasticity in global brain circuits in vivo is critical for understanding various processes such as memory, learning, and injury healing.
- MRI-biomarkers can be used to check for corticospinal integrity and how well motor resources are used. White matter neuroplasticity is studied via MRI. It has been used to study structural changes using diffusion tensor imaging (DTI).
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Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest for the authors in this paper.

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