

# Application of magnetic resonance imaging technology in the diagnosis of brain diseases

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**Abstract.** Every year, more than 20,000,000 patients were plagued by brain diseases worldwide. Brain diseases include stroke, brain tumors, alzheimer's disease, parkinson's disease and many other diseases. Common diagnostic methods include computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography, etc, and among these methods, MRI is the diagnostic method with the best safety, the highest detection rate and the best reproducibility. As an advanced imaging technique, MRI has the advantages of non-invasive, non-radioactive, multi-parameter imaging, which means MRI has an indelible role in diagnosing brain diseases. MRI can be divided into perfusion weighted imaging (PWI), diffusion weighted imaging (DWI) and functional magnetic resonance imaging (fMRI). This paper focuses on the technical principles, characteristics and clinical applications of these three methods, for the purpose of promoting the development of magnetic resonance technology and the advancement of clinical diagnosis and treatment of brain diseases.

**Keywords:** Magnetic resonance imaging (MRI), perfusion weighted imaging (PWI), diffusion weighted imaging(DWI), functional magnetic resonance imaging(fMRI), brain diseases.

## 1. Introduction

Brain is an important organ of the human body, the lesions of the brain pose a great threat to human health. Common brain diseases include acute stroke, cerebral hemorrhage, brain abscess, brain tumor, moyamoya disease, alzheimer's disease, etc. Light cases can cause functional impairments such as limbs and speech and cognitive impairment, and severe cases cause death. Therefore, timely and accurate diagnosis and treatment are of great value for patients with brain diseases. Traditional brain disease detection methods include X-ray imaging, computed tomography (CT), and so on. However, those methods have drawbacks such as low sensitivity, poor specificity, and slow imaging speed. For example, it is difficult for traditional methods to detect small bleeding, early strokes, and cannot distinguish early cerebral infarction and transient ischemic attacks[1]. With the deepening of research on brain imaging, MRI, a highly sensitive and specific rapid diagnostic method, has emerged. It is currently recognized as one of the most effective brain imaging techniques in clinical practice. A comparison chart of imaging methods for brain diseases showing the imaging quality of X-ray, CT, PET, MRI, magnetic resonance angiography(MRA)(Figure 1).

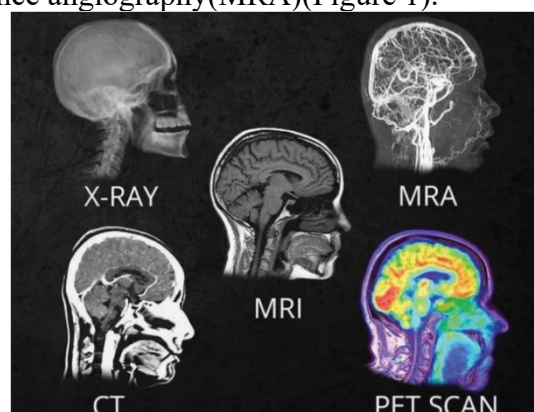


Figure 1. Comparison chart of imaging methods for brain diseases

MRI is a biological magnetic resonance imaging technique, which utilizes the spin characteristics of atomic nuclei within the human body to generate a signal by applying radiofrequency pulses in an external magnetic field. The signal is detected, processed, and used to display sectional images of the human body. MRI has the advantage of non-ionizing radiation compared to CT, and has higher tissue image resolution. It can rely on multiple scan sequences to accurately observe brain tissue and understand its degree of damage through tissue windows, allowing clinicians to obtain a clear diagnosis in the shortest possible time and win the best treatment opportunity[2]. The commonly used MRI techniques in clinical practice include perfusion weighted imaging (PWI), diffusion weighted imaging (DWI), and functional magnetic resonance imaging (fMRI). Among them, PWI can reflect the microvascular structure and blood flow perfusion of brain tissue, thus effectively extracting hemodynamic information. For example, PWI can more accurately reflect pathological manifestations and has obvious advantages in determining tumor grades[3]. DWI can reflect the micro-movement status of water molecules in living tissues, and can effectively monitor the pathological and physiological status of brain lesions, which is valuable for the diagnosis of brain lesions[4]. For example, the research conducted by Li Zhi et al. [5] shows that DWI has an accuracy rate of up to 90% in diagnosing acute ischemic stroke patients, which is significantly higher than the 70% accuracy rate of traditional MRI, indicating a clear advantage. FMRI is currently one of the most effective imaging methods for living organisms, and is very valuable for early diagnosis and treatment of traumatic brain injury[6].

In the diagnosis and treatment of brain diseases in clinical practice, selecting appropriate imaging methods based on the patient's condition is beneficial for accurately displaying lesion information such as the location, severity, and structure of the brain, reducing imaging and diagnostic time, lowering misdiagnosis rates, and securing valuable time for patients. This article mainly discusses the characteristics, advantages, and clinical applications of PWI, DWI, and fMRI, aiming to improve the effectiveness and safety of treatment.

## **2. The application of PWI in the diagnosis of brain diseases**

Perfusion refers to the function of delivering oxygen and other substances carried by circulating blood through capillary networks and other exchange vessels to surrounding tissues. Cerebral perfusion refers to the process by which blood passes through the blood-brain barrier to deliver oxygen and nutrients to brain tissue and utilize them, which is generally equated with the process of blood flow. PWI is a magnetic resonance imaging technique used to reflect tissue blood perfusion and microvascular distribution[7]. PWI is based on ultrafast MRI scanning and paramagnetic contrast agents, and quantitatively measures hemodynamic information by detecting endogenous or exogenous markers in the body. PWI has high consistency, high cost, and high spatial resolution, and its imaging methods are usually divided into two types: endogenous indicator imaging method and exogenous indicator imaging method. Endogenous imaging methods using contrast agents include arterial spin labeling (ASL), chemical exchange saturation transfer (CEST) techniques, and intravoxel incoherent motion (IVIM). These methods use flowing blood as the contrast agent, taking advantage of the natural sensitivity of proton spin motion in MR signal to mark flow of blood as an endogenous magnetic contrast agent. Exogenous contrast imaging methods include dynamic susceptibility contrast MRI (DSC-MRI) and dynamic contrast enhanced MRI (DCE-MRI), which are divided into intravascular contrast agent technology and diffusive tracer technology. The former uses paramagnetic contrast agent Gd-DTPA to mark the substance in the blood flow without diffusing into the tissue, which has the advantage of high signal-to-noise ratio[8]. The latter injects exogenous markers into the body and diffuses into the tissue to measure the MR signal of non-proton nuclei, but the signal-to-noise ratio is relatively low. Figure 2 illustrates the fundamental principles of these two techniques ( Figure 2). The advantage of PWI technology lies in its ability to measure hemodynamic parameters such as regional cerebral blood volume (rCBV), regional cerebral blood flow (rCBF), and

regional mean transit time (rMTT). These parameters are critical for early detection and diagnosis of ischemic cerebrovascular disease.[9]

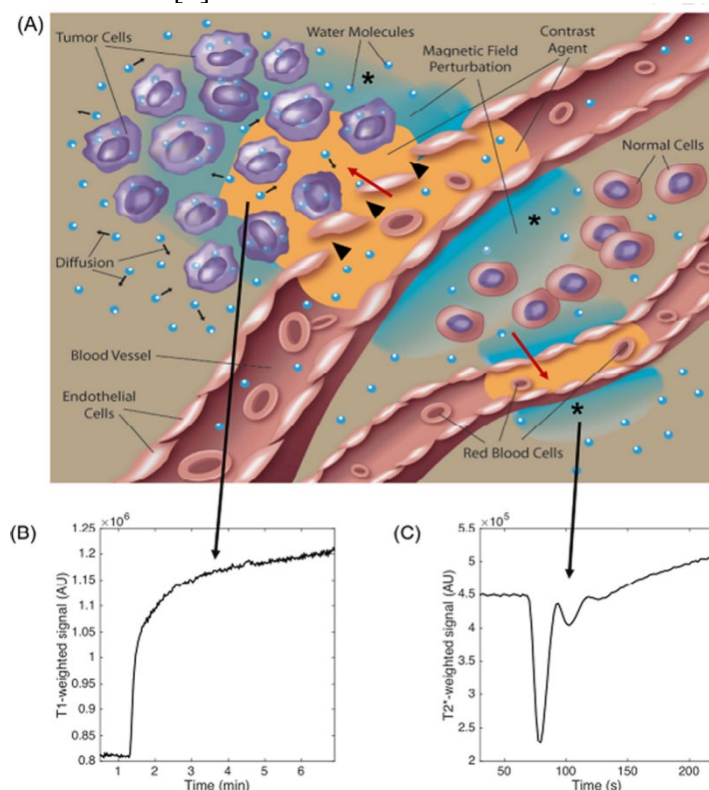


Figure 2 Illustration of CA distribution within tissue, its interaction with water protons (A) and the induced  $T_1$ -weighted (B) or  $T_2^*$ -weighted (C) signal changes[10].

In clinical practice, PWI plays an indispensable role in detecting pathological conditions in the early stage of cerebral infarction. The principle of DSC-MRI is to inject a paramagnetic contrast agent, usually Gd-DTPA, when the blood-brain barrier is undamaged, and calculate perfusion parameters based on the strong  $T_2^*$  effect of the contrast agent. The concentration-time signal curve is obtained through  $T_2^*$ -weighted images, in order to monitor the flow direction and changes in blood flow volume of the contrast agent in the blood, in order to evaluate tissue blood flow status and perfusion[11]. The principle of DCE-MRI is based on  $T_1$ -weighted imaging and the absorption and metabolism of contrast agents in the body after injection. It reflects the dynamic changes of contrast agents between the target area and surrounding tissues. With the help of medical image algorithms, DCE-MRI is used to infer the microenvironment and metabolic level of the target area and obtain hemodynamic parameters[12]. DSC-MRI and DCE-MRI have advantages such as non-invasiveness, no radiation, and high resolution. Table 1 compares the principles, display objects, application ranges, examination time, and safety of DSC-MRI and DCE-MRI( Table 1)

Table 1 Comparison of DSC-MRI and DCE-MRI.

	Principle	Display object	Application range	Examination time	safety
DSC-MRI	Strong $T_2^*$ effect of ferromagnetic contrast agents	Hemodynamic parameters	Multiple diseases	30-60min	There are risks of drug allergies and kidney damage.
DCE-MRI	Permeation effect of contrast agent.	Organizational metabolism and functional status.	Neurological or metabolic disorders	10-20min	Relatively safe

DSC-MRI can measure local cerebral blood flow and is widely used to diagnose ischemic and hemorrhagic stroke in clinical practice. In addition, DSC-MRI can measure the vascular morphology, distribution, blood flow velocity and blood volume of tumors, which helps to evaluate the malignancy

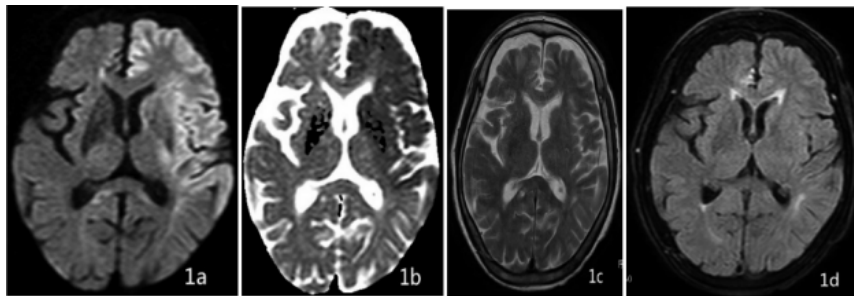
and growth characteristics of tumors. Additionally, DSC-MRI can differentiate between pseudoprogression or recurrence of high-grade gliomas[13], used for monitoring the effectiveness of tumor treatments. DCE-MRI can determine the vascular morphology, blood flow velocity, blood capacity, and permeability of tumors. Research and applications based on DCE-MRI are widespread in clinical settings, including cardiovascular diseases, liver cancer, brain tumors, and so on. With the continuous development and improvement of MRI technology, DCE-MRI will play an increasingly important role in clinical diagnosis and treatment.

Besides, PWI has considerable value in evaluating the degree of cerebral ischemia in patients with Moyamoya disease. Moyamoya disease is a chronic progressive cerebrovascular occlusive disease that can cause stenosis of the intracranial arteries, leading to local cerebral hypoperfusion and delayed perfusion, and in severe cases causing cerebral ischemia and infarction. By semi-quantitatively studying changes in blood flow after cerebral infarction, PWI can provide parameters such as rCBV, rCBF, and rMTT, thereby identifying the specific blood supply situation in the infarcted area. Thus, PWI is valuable for evaluating cerebral ischemia in patients with Moyamoya disease[14].

### 3. The application of DWI in the diagnosis of brain diseases

Diffusion refers to the irregular random movement of molecules, which typically describes the microscopic movement of particles such as molecules from high concentration regions to low concentration regions. The unit is  $\text{mm}^2/\text{s}$ . DWI currently is the only imaging method that can measure and image the diffusion of water molecules in vivo. Its high signal reflects the restricted diffusion of water molecules in ischemic regions, and can detect cellular edema, reflecting the functional status of brain cells[1]. DWI can use the echo planar imaging (EPI) technique to image the information of water molecule diffusion in tissues. In DWI, adjusting the gradient size and direction is used to determine the diffusion rate of water molecules in tissues, providing a non-invasive method of measuring the rate, also known as the diffusion coefficient. The diffusion coefficient provides a means of analyzing the micro-scale variations in vibration, movement, and expansion within an organization. In DWI images, the apparent diffusion coefficient (ADC) of each pixel is presented through color coding, which represents the rate of water molecule reverse diffusion at that location[8]. Therefore, DWI images can identify various abnormal conditions in tissues, including stroke, spinal cord injury, tumors, and other lesions. DWI has high spatial resolution, but slight motion can cause serious artifacts interference. However, the EPI pulse sequence can shorten the imaging time to 30ms and significantly reduce motion artifacts, increasing the accuracy of measured MR diffusion coefficients[15].

In clinical practice, DWI is usually used to detect ischemic stroke. In the early stage of ischemic stroke, brain tissue experiences ischemia and hypoxia, resulting in imbalanced intracellular sodium ions and water, as well as high osmotic pressure within cells. This leads to cytotoxic edema, restricted diffusion of water molecules in brain tissue, and bright high signals on DWI. The decrease in diffusion caused by the narrowing of extracellular space results in a decrease in ADC value and signal intensity[1]. DWI can detect neuronal damage and cell death within minutes after ischemia, providing important basis for early diagnosis and treatment. Through DWI images, doctors can determine the size of the ischemic penumbra and the perfusion state of local brain tissue. This information can help doctors predict patients' condition and prognosis, and choose appropriate treatments. The detection effects of DWI, ADC, T2WI and FLAIR for an early stroke patient can be compared in Figure 3(Figure 3). Traditional MR techniques have limited ability to determine the scope and severity of acute stroke, while DWI combined with PWI can effectively detect hyperacute stroke. By obtaining parameters such as rCBV, rCBF, rMTT through PWI, comparing the area of abnormal perfusion area on PWI with the area of abnormal signal area on DWI is helpful for inferring the type of ischemic penumbra and the size of the final stroke area, and is conducive to accurate selection of indications for thrombolytic therapy which makes the individualized treatment of stroke feasible.



**Figure 3** Illustration of a comparison of DWI, ADC, T<sub>2</sub>WI, FLAIR in early cerebral infarction diagnosing[1]. Patient, woman, 86 years old, unconsciousness for 30 minutes, blood pressure 190/124 mmHg, no abnormalities found in head CT. 1a: DWI shows abnormal high signal in the left frontal lobe and basal ganglia in a patchy pattern. 1b: The lesion appears as a low signal on ADC (b=1000). 1c: T<sub>2</sub>WI and 1d: FLAIR do not show any abnormal signal in the left hemisphere of the brain.

In addition, DWI has specificity in the diagnosis of brain abscesses, with the abscess cavity showing obvious diffuse restricted high signal[4]. Brain abscess refers to the formation of a local abscess in the brain tissue caused by brain infection. Brain abscess is usually caused by bacterial, fungal, or viral infections, which can cause brain tissue necrosis and decay, increase intracranial pressure, and lead to brain edema, neurological dysfunction, and death. Common symptoms include headache, fever, vomiting, and consciousness disorders. The treatment plan generally includes antibiotics and surgical treatment to relieve symptoms, restore neurological function, and prevent complications. This disease needs to be treated promptly to avoid serious consequences. In 2021, Anjali et al. [16] reported that brain abscesses appeared as high signal on DWI. The pus cavity of a brain abscess contains a viscous fluid consisting of a large number of inflammatory cells, necrotic tissue, bacteria, protein secretions, and other substances, which brings about a high viscosity inside the pus cavity. This high viscosity restricts the diffusion of water molecules within the pus, resulting in a high signal on DWI and a low ADC value. The high signal on DWI of a brain abscess is distinct from the obvious low signal of cystic degeneration and necrosis on DWI, which aids in the diagnosis of the disease.

#### 4. The application of fMRI in the diagnosis of brain diseases

fMRI uses measurements of brain blood flow and metabolism to observe differences in blood flow and metabolism between different regions of the brain, allowing for the inference of the structure and function of each area. It can accurately locate targeted brain tissue and quantitatively measure physiological parameters within the targeted area. For example, in diagnosing brain injuries, fMRI can evaluate the severity of damage to functional and structural brain regions, and show alterations in brain network structure[6]. Specifically, the neuronal activity in each brain region can cause changes in blood flow, which can be detected by blood oxygenation level dependent (BOLD) functional MRI. BOLD signals are closely related to changes in the ratio of oxygenated and deoxygenated hemoglobin concentrations, and increased blood flow leads to an increase in oxygenated hemoglobin and a decrease in deoxygenated hemoglobin, resulting in an enhanced BOLD signal[17]. fMRI is non-invasive, non-radioactive, and has high spatial resolution and good repeatability. In comparison to other imaging techniques such as PET and SPECT, the results of fMRI are also more replicable, making it an important tool in studying brain function and neuroscientific research. However, the main limitation of fMRI is its lower temporal resolution, as it takes several seconds to minutes (depending on the scanning equipment and experimental techniques) to observe changes, limiting its ability to rapidly detect brain activity in a short amount of time[18].

Susceptibility weighted imaging (SWI) is an fMRI technique that uses the differences in magnetic susceptibility between tissues to enhance the contrast of images and reveal tissue details. SWI takes advantage of the effect of iron elements in tissues to increase image contrast, which allows for better

observation of subtle brain structures such as cerebral microbleeds (CMBs). SWI can display more detailed blood vessels and richer networks of smaller blood vessels, as well as track lesions such as vascular tumors. In clinical practice, patients with traumatic brain injury (TBI) often present pathological changes primarily in the form of CMBs, which makes this technique important for the diagnosis of TBI, and has a higher detection rate for CMBs after TBI compared to CT and DWI. Compared to traditional MRI, SWI can improve image contrast and resolution and is a more advanced imaging technology.

Diffusion tensor imaging (DTI) is an fMRI technique that reflects the microstructure of tissues by measuring the diffusion direction and velocity of water molecules within the tissue. It can provide information on the direction, length, thickness, and shape of white matter fibers, and is used to study the physiological and pathological processes of the nervous system. In DTI, diffusion coefficients are decomposed into three directions to establish the diffusion tensor of each voxel. Based on the main direction and eigenvalues of the diffusion tensor, the texture, direction, and connectivity of the tissue can be quantitatively described, and the 3D distribution of connected fiber bundles can be obtained by spatial interpolation. The evaluation parameters of DTI include fractional anisotropy (FA), mean diffusion coefficient, axial diffusivity, and radial diffusivity. In clinical applications, DTI is mainly used to detect the integrity of white matter fibers after traumatic brain injury [19, 20], and the FA value is positively correlated with axonal integrity[18]. The FA parameter obtained from DTI is an important indicator for evaluating the severity of brain white matter injury, and provides great help in the diagnosis and treatment of brain white matter injury in clinical practice.

## 5. Summary and Outlook

As a diagnostic tool, MRI has advantages such as non-invasiveness, high resolution, multi-parameter imaging, multi-angle imaging, high safety, and good repeatability. PWI has high consistency and spatial resolution, and can help doctors evaluate the blood perfusion of organs or tissues, making it very helpful in assessing conditions such as stroke, tumors, and infections. The advantage of DWI lies in its ability to provide high-resolution images for detecting diseases such as tumors, infections, strokes, as well as neurodegenerative diseases like cerebellar ataxia and leukoencephalopathies. fMRI can monitor real-time brain function activity, identify blood perfusion in specific brain areas, and assist doctors in diagnosing conditions such as syncope, psychiatric disorders, and cognitive diseases.

The advantages of MRI are very obvious, but the equipment is expensive and the maintenance and operation costs are also relatively high. In addition, MRI scanning takes a long time, usually ranging from 30 minutes to 1 hour, which may be very painful for some patients. MRI equipment generates a lot of noise, which may interfere with patients and doctors. Signal undersampling can be used to combine deep learning algorithms and image reconstruction algorithms to reconstruct images, thus shortening the scanning time without reducing the imaging quality. Developing open and miniaturized MRI equipment will also benefit the development of MRI.

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