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Application of high-resolution MR imaging in intracranial diseases

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Abstract: In recent years, imaging technology has developed rapidly. In identifying cerebrovascular diseases, in addition to traditional imaging techniques such as magnetic resonance angiography (MRA), computed tomography angiography, digital subtraction angiography (DSA), high resolution magnetic resonance imaging (HR-MRI) uses its advantages to stand out in recent years. HR-MRI uses specific sequences to generate images of intracranial vessel walls that allow simultaneous wall and luminal imaging. This helps to identify a variety of intracranial vascular diseases, including intracranial atherosclerotic disease (ICAD), central nervous system vasculitis (ACNS), Moyamoya disease (MMD), intracranial artery dissection (IAD), aneurysms, etc.[1]

1. Introduction

DSA is the "gold standard" for the diagnosis of intracranial vascular lesions, which is highly operational demanding and invasive. The CTA examination is radioactive and only reflects the degree of stenosis of the vascular lumen alone[2]. Compared with conventional imaging, high-resolution magnetic resonance imaging (HR-MRI) is more suitable for detecting the arterial wall status and distinguishing tissue characteristics. This paper discusses the diagnostic value of high-resolution magnetic resonance imaging (HR-MRI) in a variety of intracranial vascular diseases.

2. Arterial dissection

Spontaneous intracranial artery dissection (ICAD) is an important cause of stroke in young and middle-aged people, and is more common in the Asian population[3]. Carotid artery dissection is usually defined as a mural hematoma. The wall cavity haematoma can occur secondary to an intimal tear, or by direct bleeding into the arterial wall due to vessel rupture, resulting in the only anatomic hematoma presenting without other specific signs. It is located below the intima or adventitia, the former can lead to secondary vascular stenosis and occlusion, while the latter is easy to cause lumen dilatation.

Head and neck carotid artery dissection (CAD) is an important cause of ischemic stroke in young and middle-aged people in Asia. Due to the lack of specificity in the clinical presentation, the diagnosis of arterial dissection largely depends on the imaging examination. Although digital subtraction angiography (DSA) is considered the criterion for the diagnosis of intracranial vascular disease, the condition of the vessel wall itself could not be observed. Therefore, it has limited diagnostic value for arterial dissection with normal or nonspecific stenosis or occlusion in the lumen. Based on this, the researchers recommend the use of arterial wall combined with luminal imaging to diagnose arterial dissection, and indicate that the diagnosis of dissection disease requires evidence of intramural hematoma or features of dynamic imaging changes. According to the results of MR vascular imaging (TOF MRA), the morphology of anatomical vessels was divided into stenosis and occlusion, aneurysm expansion and pearl string. Aneurysm expansion and increased vessel diameter, visually defined as increased vessel diameter compared to normal appearing arteries, were also assessed for the presence of anatomical flap, double lumen signs, posterior cerebellar artery involvement, length, and remodeling index on the TOF-MRA, PD, and pre-and postcontrast T1 weighted magnetic resonance (MR) images. There was a relationship between the interval between symptom onset and HR-MRI and T1 signal intensity of intramural hematoma[4]. A study by Wang et al. found that intramural hematoma (61% of patients), double cavity (50% of patients) and endometrial flap (42% of patients) were considered characteristic changes in high-resolution MRI anatomy[5].

High-resolution magnetic resonance imaging sequence with ideal tissue contrast and spatial resolution (HR-MRI) can not only obtain luminal morphological information, but more importantly, directly visualize characteristic intramural hematoma, intimal flap and double cavity features caused by arterial dissection through wall imaging. Therefore, HR-MRI is recommended as the first choice for the diagnosis of arterial dissection[6].

3. Aneurism

Digital subtraction angiography is the standard criterion for the diagnosis of intracranial aneurysms, but does not show the full size of the TIA, and the technique is invasive. Computed tomography angiography (CTA) is the most commonly used examination method for intracranial aneurysms, but the detection of thrombosis in aneurysms is challenging using this method. These two methods of aneurysm detection can lead to a diagnostic omission or misdiagnosis of TIA. High-resolution magnetic resonance imaging (HR-MRI) using a black angiography sequence has been successfully used to accurately display vascular wall plaques in the head and neck region. It is currently the standard standard for imaging plaque of vessel walls and plays a decisive role in developing the clinical treatment plan for head and neck plaques. For the diagnosis of aneurysms, HR-MRI with the aneurysm wall enhancement (AWE) technique has been used to predict the risk of aneurysm wall rupture. HR-MRI not only identifies the true circumference of the aneurysm, but also clearly shows the morphology and distribution of the aneurysm wall and thrombus, as well as vascular thrombosis, without interference by the blood flow[7]. Several studies have evaluated the association between wall enhancement in HR-VWI and typical risk factors for aneurysm rupture, and gadolinium-enhanced HR-VWI studies also demonstrated a significant correlation between aneurysm wall enhancement, inflammatory changes, and instability.

The HR-MRI scan sequence includes 3D T1-weighted images (3D-T 1 WI), 3D T2-weighted images, 3 D time-of-of-flight MRA (3 D-TOF-MRA) and 3 D rapid imaging with steady-state acquisition (3 D-FIESTA). These methods are non-invasive and reproducible and exhibit high resolution of anatomical structures (e. g., intramural hematoma and flaps).

4. Atherosclerosis

With an improved quality of life and an aging population, ICAS-induced cerebrovascular diseases are increasingly prevalent in clinical practice[8]. Atherosclerotic plaque is the most important cause of stroke and is often associated with unstable plaques[9]. Intracranial atherosclerotic disease (ICAD) is defined as atherosclerotic lesions affecting the large intracranial artery at the bottom of the brain, including the intracranial carotid artery (ICA), middle cerebral artery (MCA) and basilar artery.

Atherosclerosis is a progressive disease. Its occurrence and development are associated with local hemodynamic stress, usually caused by changes in vascular geometry[10]. ICAS has unique features, such as a dense internal elastic layer (IEL), little absence of an external elastic layer (EEL) and the relative lack of vessels in the foreign phase. ICAD was once considered one of the most common subtypes of stroke worldwide, particularly in Asians and Hispanics.

Routine imaging methods include magnetic resonance angiography (MRA), computed tomography angiography, and digital subtraction angiography commonly used for ICAS identification in clinical practice. In these vascular imaging, the degree of lumen stenosis is considered the primary indicator for assessing disease severity and predicting stroke outcome. However, data from several large trials suggest that luminal stenosis is not the only risk factor for adverse outcome in patients with ICAS[11]. Various intraplaque factors, such as plaque morphology, plaque components, and inflammation, are also closely associated with the vulnerability of atherosclerotic plaques. In this regard, high-resolution magnetic resonance imaging (HR-MRI) is an appropriate tool to directly depict the vessel wall and exhibit pathological changes, including the morphology (eccentricity and remodeling) and plaque characteristics (number, volume, distribution and components)

HR-MRI has several advantages over conventional MR imaging. In addition to visualization of submillimeter arterial walls, it achieves high signal-to-noise ratio and shortest scan duration. The degree of stenosis is no longer the only predictor of susceptible atherosclerotic lesions. Traditional luminal images are limited to displaying plaques, but HR-MRI is able to directly display plaque features[12]

In the field of neurointervention, the characteristics of intracranial arterial lesions are important for many reasons. The characteristics of atherosclerotic lesions have been described as the major factors affecting the incidence of perioperative complications and can therefore be used to select patients for percutaneous transluminal angioplasty and stenting, as well as to design individualized surgical plans.

Fortunately, HR-MRI in intracranial arteries is a good benchmark model based on previous studies involving MRI of the carotid wall. Based on extensive clinical studies with carotid endarterectomy, carotid wall MRI is becoming the best candidate for evaluating carotid stenosis and with other diagnostic features relevant to patient management.

Intracranial artery calcification (IAC) is considered representative of intracranial atherosclerosis (ICAS). The IAC may involve two main layers: the intima and the medium. IAC can be detected by HR-MRI by demonstrating hypotension. HR-MRI reveals the ultrastructure of the vessel wall, allowing neurologist to identify calcium deposits at different locations (e. g., superficial and deep) and their positional relationships to other plaque components. By comparing necropsy with HR-MRI, a significant distinction between the lipid core (isosympathetic / high score), fibrous cap (isofen) and calcification (low precision) was made on the T1 sequence by Jiang et al. The combination of HR-MRI and CT may be beneficial for the diagnosis and differentiation of IAC, also indicating the need to classify IAC located in different layers (intima and media) of the vessel wall[13].

5. Plaque

Currently, among all commonly used non-invasive clinical imaging methods used to evaluate carotid plaques, carotid ultrasound is widely used in clinical practice for its simplicity, convenience, non-invasive and low cost. However, the accuracy of ultrasound in assessing the nature of carotid plaques decreases due to spatial, temporal, and resolution limitations. Therefore, carotid ultrasound has a limited ability to identify vulnerable plaques. Numerous comparative studies on imaging and pathology show that HR-MRI produced results in the identification and quantitative analysis of carotid atherosclerotic plaques are highly consistent with those from histopathology, with levels of sensitivity and specificity already reaching 90 – 100% accuracy. With the development of imaging techniques, it has been previously demonstrated that high-resolution magnetic resonance imaging (HR-MRI) shows high sensitivity and specificity in detecting carotid artery vulnerable plaques[14]. HR-MRI can be used to qualitatively and quantitatively assess plaque location, load, enhancement ratio, size, length and area, and remodeling index. Detailed assessment of the plaque component is more important for the assessment of luminal stenosis alone, as the formation and destruction of atherosclerotic plaques may cause some hemodynamic changes in the vessel wall before the acute ischemic event[15].

The PH (with or without intratular hemorrhage) is caused by the rupture of the fragile and tortuous new blood vessels formed within the plaque. Is considered as an important atherogenic stimulus that promotes macrophage infiltration, thus making the plaque more unstable. IPH is highly correlated with plaque progression. As the plaque progresses, the fibrous cap covering it becomes thinner and causes active inflammation. Inflammatory factors such as macrophages accumulate in the plaque and cause ischemic stroke upon rupture, and the basic parallel anatomical scan (BPAS) is a method to identify the vertebral OBA by using a fast spine echo sequence， Using T2-weighted imaging is a relatively simple method, and the results of this test can be obtained relatively quickly (within two minutes). High-resolution MRI takes longer than the BPAS method, and it uses contrast agents. However, it is expected that it can improve diagnostic accuracy by identifying the internal condition of the vessel profile as well as the internal and external profile of the vessel[16].

6. Nodular vasculitis

Central nervous system (CNS) vasculitis is an inflammatory vascular disease that involves the CNS. The clinical manifestations are not very clear, so it is difficult to diagnose CNS vasculitis. Imaging can make a valuable contribution to this, especially being able to determine the extent of the disease and the number of affected vessels. Classical imaging methods such as CT (CTA) or MR angiography (MRA) and digital subtraction angiography (DSA) focus on changes in lumen diameter that usually do not adequately demonstrate the vessel wall. Ultrasonography can assess the lumen and vessel walls, but can only measure select extracranial vessels with sufficient resolution. Because vasoactive substances are mainly based on changes in the vessel wall, the luminal changes found are usually nonspecific and may occur in other diseases. With high-resolution MRI of the neck and intracranial vessels, a promising new approach is feasible that can noninvasively display the inflamed vessel wall in detail without the use of ionizing rays[17].

MRI of CNS vasculitis showed that the vessel wall was mostly non-focal stenotic lesions with smooth concentric thickening and prominent enhancement. High-resolution magnetic resonance (HR-MRI) technology can not only help to diagnose central nervous system vasculitis, but also effectively evaluate its therapeutic effect. HR-MRI allows simultaneous wall and lumen imaging and accurate assessment of the extent and extent of vascular stenosis. Meanwhile, HR-MRI can provide important information to determine the cause of vascular stenosis according to the changes of vascular wall structure [18].

7. Moyamoya disease

Moyamoya disease (MMD) is a rare cerebrovascular disease characterized by a progressive stenosis of the fuzzy network of the large intracranial arteries (including the distal internal carotid artery) and the basal collateral called the moyamoya vessels[19]. Mainly occurred in the Asian population[20]. MMD maintains the classical bimodal age distribution pattern. The first peak occurs around the age of five and the second at around 40. Ischemic characteristics predominate in the paediatric age groups. In adults, both ischemia and intracranial hemorrhage (ICH) are possible.

Although digital subtraction angiography (DSA) is recommended for the definitive diagnosis of MMD and MMD staging (known as the grade 6 Suzuki staging system), especially among candidates for surgical revascularization, this procedure is known to have a potential risk of persistent neurological deficits. A definite diagnosis can also be provided when using a 1.5 Tesla scanner, magnetic resonance angiography (MRA). However, the TOF MRA has no temporal resolution. It would be ideal to non-invasively display dynamic flow patterns within the cerebral vasculature to monitor the clinical course of MMD. Increasing evidence suggests that 3.0-Tesla MR scanners provide a higher signal-to-noise ratio, allowing for higher spatial resolution and fine visualization of intracranial neural and vascular structural features, including the pathological vasculature of MMD patients. Recently, non-contrast-enhanced time-resolved four-dimensional MRA was developed using arterial spin labeling technology (ASL-4 DMRA) to depict dynamic flow patterns within the cerebral vascular system[21].

8. Conclusion

The advantage of HR-MRI is its high spatial resolution in displaying the vessel wall, thus improving the ability of MRI to help understand the pathogenesis of cerebrovascular diseases. HR-MRI facilitates the diagnosis of intracranial atherosclerosis, arterial dissection, moyamoya disease, vasculitis, reversible cerebral vasoconstriction syndrome, and radiation therapy-induced intracranial vascular lesions. In contrast to several other imaging methods, HR-MRI has no radiation effect on patients. However, because the scanning time of HR-MRI is long and it is conducted in a closed space, the patient tolerance is extremely high.

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