# 7T MRI for Intracranial Vessel Wall Lesions

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Intracranial vessel wall lesions are involved in a variety of neurological diseases. The advanced technique 7T MRI provides greater efficacy in the diagnosis of the pathology changes in the vessel wall and helps to identify potential subtle lesions.

Keywords: 7T MRI ; ultra-high resolution ; brain ; vessel wall

## 1. Introduction

Intracranial vessel wall lesions are involved in a variety of neurological diseases, including intracranial atherosclerotic disease (ICAD), aneurysm, arterial dissection, vasculitis, and moyamoya disease. They account for the majority of the intracranial large vessel diseases [1][2], which are closely related to stroke. Characteristics of vessel wall lesions are eccentric wall thickening and enhancement in ICAD [3], enhancement of the aneurysm wall in intracranial aneurysm [4], and concentric enhancement in vasculitis [5], as well as concentric thickening and enhancement without remodeling in moyamoya disease [6]. Information about the specific vessel wall features enables clinicians to better understand the pathology changes, make an accurate diagnosis, and monitor disease prognosis.

Conventional vessel imaging modalities such as magnetic resonance angiography, computed tomography angiography, and digital subtraction angiography provide information about the lumen and show common morphologic changes, e.g., stenosis in the major proximal intracranial arteries, but they fail to assess the vessel wall and to reveal the pathological etiology. Compared with previous neuroimaging methods, vessel wall-magnetic resonance imaging (VW-MRI) is a diagnostic imaging technique that enables specific visualization of the actual intracranial arterial walls. This allows a more direct evaluation and differentiation of the intracranial vasculopathy.

Current technical challenges at 3T VW-MRI are incomplete cerebrospinal fluid (CSF) suppression and limited scan coverage, hindering the full assessment of arterial wall changes [7]. With the advent of more powerful imaging equipment, 7T MRI provides a higher signal-to-noise ratio (SNR), allowing for complete suppression of CSF signal and whole-brain imaging [8]. The SNR increases with the static magnetic field strength (B0), which can be translated into higher spatial resolution and enhanced tissue contrast within clinically reasonable scan times [9], allowing researchers to obtain more information about abnormalities within the arterial wall, and detect more arterial wall lesions.

As a result, this advanced technique evaluates a wider spectrum of intracranial vascular disease, gives insights into the pathogenesis of intracranial vessel wall lesions, aids the clarification of how vessel wall abnormalities contribute to the onset and progression of neurological disorders, and helps to identify potential subtle lesions.

## 2. Intracranial Atherosclerosis Disease

Intracranial atherosclerosis is a major cause of ischemic stroke [10]. It could lead to atheroma, emboli, and abnormal cerebral blood flow. It is not surprising to find that intracranial atherosclerosis was the most common disease reported using the 7T VWI MRI technique. However, the wider and various spectrum of the associated neurological disorders identified were noteworthy. For example, intracranial atherosclerosis was associated with cerebral small vessel disease imaging markers, including lacunes, white matter hyperintensity, and cortical microinfarcts. The possible pathway may be the impaired large artery leading to the downstream ischemic lesion. In addition, both post-mortem studies [11][12] and in vivo studies [13][14] confirmed intracranial atherosclerosis was related to cognitive abnormality and dementia. Applying the 7T VWI MRI enabled further evaluation of the premorbid cognitive function and artery-specific relationships. The underlying mechanism is possible due to the strategic brain regions involved with the specific cognitive domains. Apart from that, researchers found that intracranial atherosclerosis was related to extracranial atherosclerosis markers, reflecting the advantages of 7T MRI—namely, allowing more potential associations to be fully assessed and found in vivo. By directly visualizing the actual pathology in the vessel wall beyond stenosis, 7T MRI facilitates a more complete and

accurate assessment of ICAD, enabling the detection of more subtle changes and relationships. A major limitation of the reviewed atherosclerosis papers is that the evaluation methods of vessel wall lesions remained various, implying the lack of consensus. Future research developing a standardized qualitative and quantitative approach, and a multiparametric scoring system may be useful to accurately and comprehensively measure the vessel wall lesions.

## 3. Intracranial Aneurysm

Aneurysm rupture could cause subarachnoid hemorrhage, a subtype of stroke with a poor prognosis [15]. The exact mechanism prompting the formation, growth, and rupture is not fully illuminated. Early identifying the population with a high risk of aneurysm rupture is essential to guide prevention and clinical therapy. One major advantage of investigating intracranial aneurysms at 7T lies in the improved image quality, with higher spatial resolution and signal-to-noise ratio; furthermore, direct visualization of aneurysmal wall and investigation of the associated pathological process by a noninvasive method may be possible. Most of the reviewed articles used ultra-high-field MRI at 7T to delineate the structure, morphology, location, and enhancement features of the wall of intracranial aneurysms, and correlated these vessel walls' lesional characteristics with blood flow parameters, inflammation, and vasculopathy process, which provides a unique opportunity to estimate the risk of aneurysm development and growth and to better identify novel markers of intracranial aneurysm instability, and will lead to an accurately personalized approach to risk prediction. The limitations of the papers reviewed here are the inconsistent pulse sequence and protocol design. Consensus on defining a minimum clinically achievable 7T imaging quality with appropriate technical parameters and tolerable scan time, as well as attaining good reproducibility and reliability, would be beneficial to generalization.

## 4. Moyamoya Disease

No papers studied the use of 7T MRI for moyamoya disease to determine the vessel wall changes, which may be accounted for by the less availability of 7T MRI. Although less common than ICAD, moyamoya disease is particularly important clinically because it is predominant in juvenile patients under 10 years of age [16], causing severe disability due to the development of ischemic stroke [17]. The relatively low proportion of patients may contribute to this deficit. In addition, 7T MRI/MRA has been shown to have higher sensitivity and specificity than 3T MRI/MRA for detecting flow voids in the basal ganglia [18]. Whether 7T MRI is superior to 1.5T/3T MRI for the investigation of vessel wall changes and related neurological disorders remains unclear.

Prior VWI-MRI studies on moyamoya were limited and primarily focused on Asian populations [19][20][21][22]. These studies showed that patients with moyamoya had smaller outer vessel wall diameter and wall thickness, compared with ICAD. One study [23] recruited North American moyamoya patients and applied VWI-MRI to investigate the characterizations in the vessel wall, as well as with moyamoya disease clinical severity. The results showed smaller internal carotid arteries lumen and outer vessel wall diameter in patients with moyamoya, compared with controls, and the diameters decreased with increasing modified Suzuki scores. However, no significant change was detected in vessel wall thickness. Future 7T MRI vessel wall studies with various moyamoya populations on the vessel wall changes may provide more information about the vascular features. In addition, a full evaluation of the characterizations in vessel wall measurements with disease status is necessary to better manage the disease in clinical practice.

## 5. Cerebral Small Vessel Disease

Cerebral small vessel disease refers to a series of pathological processes damaging the perforating arterioles, capillaries, and venules [24][25], and it has a crucial role in stroke, dementia, and aging [25]. Though the clinical manifestations and neuroimaging markers were well recognized and studied [26], the exact mechanisms remain incompletely understood and characterized. Conventional neuroimaging markers include white matter hyperintensities, enlarged perivascular spaces, cerebral microbleeds, and lacunes [26]. None of the reviewed articles reported the vessel wall lesions of cerebral small vessel disease at 7T MRI, which is essential to understanding the etiological mechanisms. With advances in MRI vessel wall technology, increasing lines of evidence suggest the role of intracranial vessel wall lesions in the pathogenesis and progression of cerebral small vessel disease. For example, atherosclerotic stenosis with an eccentric plaque and intraplaque hemorrhage of the middle cerebral artery has been noted in CADASIL on magnified T1-weighted imaging [27]. In addition, intramural patchy gadolinium enhancement of the subcortical and leptomeningeal vessels was found in a CADASIL patient who underwent intracranial VWI-MRI [28]. Recent advents in 7T MRI technology may open a new window for scientists to study cerebral small vessel disease, which may help expand the capability to elucidate pathogenesis from the perspective of vessel wall changes.

## 6. Central Nervous Vasculitis

Central nervous vasculitis is characterized by vessel wall inflammation, and its diagnosis is challenging and often requires an invasive procedure [29]. VW-MRI promises valuable imaging approaches for a fast and accurate diagnosis. The commonly reported conventional imaging features included vessel wall enhancement and thickening [30] and were shown to have good agreement with histology results [30]. No paper studied the use of 7T MRI for central nervous vasculitis to illuminate the vessel wall lesion and its related neurological disorders, which may be explained by the rare condition that vasculitis affects the central nervous system, and the diagnosis is challenging [31]. Recent case reports showed that 7T MRI could detect the vasculitic changes in the superficial temporal artery and demonstrated superior image quality than 3T [32], and the pathological examination confirmed the 7T MRI results. These lines of evidence suggest that 7T MRI could have a good diagnostic utility for central nervous vasculitis and assist clinical diagnosis and decision making. Moreover, dynamic observations of changes in vessel walls by examination of neuroimaging findings during treatment may aid develop biomarkers, finding more subtle associations, assessing treatment response, and monitoring disease prognosis.

These studies have several main limitations. First, the patient population is largely confined to intracranial atherosclerotic disease and aneurysm, and none of the vessel wall studies use 7T MRI in other conditions such as moyamoya disease, small vessel disease, vasculitis, and dissection. This lack of other investigations may reflect the novelty of 7T MRI vessel wall imaging, its limited availability, and the relatively small number of patients diagnosed with these types of cerebral vascular disease compared with ischemic stroke and aneurysm. Second, the study enrollment is not large, which limits the power of the research. Third, most of them have not conducted longitudinal research to monitor the changes and trajectory of the vessel wall lesions. Fourth, there is a paucity of histological validation of vessel wall lesions. Finally, a lack of consensus on 7T MRI protocols and variability in selecting neuroimaging endpoints may result in differences in detecting neuroimaging features and reproducibility.

Several limitations of the present review need to be acknowledged. By including various study designs for various intracranial vessel wall lesions and their associated neurological disorders, researchers compiled a heterozygous collection of studies. They did not carry out a risk-of-bias analysis. It is likely that several studies would be susceptible to selective reporting bias. Differences in patient populations, intracranial vessel wall abnormalities, and outcome definitions prevent the performance of a pooled analysis.

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