

Study on the Application of Quantitative Susceptibility Mapping in Cognitive Function Assessment

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1. Abstract

This article introduces a novel imaging technique called Quantitative Susceptibility Mapping (QSM), which is used to measure the magnetic susceptibility of brain tissue and is widely used in brain structure and function research within the MRI field. With the aging population and increasing incidence of brain diseases, the evaluation of cognitive function has become increasingly important. QSM not only provides high-resolution brain structural images but also can quantitatively evaluate the relationship between biological markers such as iron content and cognitive function, providing more accurate and reliable evidence for early diagnosis and treatment of cognitive impairments. Increasingly, researches indicate that QSM can be used to assess brain iron content and distribution, further exploring pathological changes related to cognitive function, such as neuronal atrophy and deactivation. The application of QSM in cognitive function assessment has received increasing attention in recent years, with domestic and foreign research institutions applying QSM technology in different areas of neurological disorders and cognitive impairments, achieving some important research progress.

2. Review

With the continuous increase in population aging and the incidence of brain diseases, the assessment of cognitive function is becoming increasingly important. Magnetic Resonance Imaging (MRI) is being widely used in neuroscience, and the Quantitative Susceptibility Mapping (QSM) technique can accurately measure the magnetic susceptibility of brain tissue, making it a useful tool for evaluating cognitive function. QSM is an emerging magnet-

ic resonance imaging technique that can quantify tissue magnetic susceptibility and is widely used in brain structural and functional researches [1]. More and more researches are beginning to explore the relationship between iron deposition and cognitive function in the brain. Iron is a necessary mineral for many biological processes, including neurotransmitter synthesis and myelin formation. However, abnormal iron deposition is associated with a variety of neurodegenerative diseases such as Alzheimer's disease, Parkinson's disease, multiple sclerosis, as well as brain injuries and recovery after stroke [2-4]. Therefore, understanding the role of iron in cognitive function is of great significance for the diagnosis and treatment of these diseases.

From the perspective of scientific research trends, cognitive impairment has become an important component of the health problems of the elderly, and related researches are receiving increasing attention. With the accelerated aging process of the population, the incidence of cognitive impairment will further increase. Therefore, developing effective methods for evaluating cognitive function is of great significance for the health management of the elderly. QSM technology, as a non-invasive and radiation-free imaging technique, has broad prospects for application in cognitive function assessment. This technique can not only provide high-resolution brain structural images but also quantitatively evaluate the relationship between biological markers such as iron content and cognitive function, providing more accurate and reliable evidence for the early diagnosis and treatment of cognitive impairment [5].

In cognitive function assessment, QSM technology can provide more accurate and reliable structural and functional information, supporting the study of the pathological mechanisms of cognitive

impairment. In recent years, more and more studies have shown that QSM technology can be used to evaluate brain iron content and distribution, and explore pathological changes such as neuronal atrophy and inactivation related to cognitive function [6-7]. Some scholars have conducted some exploratory researches and achieved some results in the early diagnosis of cognitive impairment symptoms in the elderly and the correlation between insomnia symptoms and cognitive impairment among others [8-9]. Meanwhile, research institutions have applied QSM technology in different areas of neurological diseases and cognitive impairment and have made some important research progress. For example, in Alzheimer's disease research, QSM technology can be used to evaluate changes in brain iron content and find pathological iron deposition associated with cognitive impairment [10]. Du et al. found that increased iron deposition in the basal ganglia was related to poor performance in attention and working memory tasks in healthy individuals [11]. Another study demonstrated that increased iron deposition in the hippocampus was associated with cognitive decline in the elderly [12].

In addition, QSM has been used to study the relationship between iron deposition and cognitive function in patients with neurodegenerative diseases. A study of patients with Parkinson's disease found that increased iron deposition in the substantia nigra was associated with poorer cognitive function, including executive function and attention [13]. Another study found that QSM could detect changes in iron deposition in the basal ganglia of patients with multiple sclerosis, which was correlated with cognitive impairment [14]. In studies of traumatic brain injury, QSM technology has been used to assess changes in iron metabolism after brain injury and has identified brain tissue iron deposition that is associated with cognitive dysfunction [15].

In addition, some studies have explored the application of QSM technology in other cognitive impairments. For example, in the study of Parkinson's disease, QSM technology can be used to evaluate changes in brain iron content and to discover pathological iron deposition related to movement disorders [16]. In the study of cognitive impairment after stroke, QSM technology can be used to evaluate changes in brain iron content and to discover pathological iron deposition related to cognitive impairment [17].

QSM has also shown potential as a biomarker for early detection and monitoring of cognitive decline in neurodegenerative diseases. For example, QSM can detect changes in iron deposition in the hippocampus and cingulate gyrus of patients with mild cognitive impairment, which is a precursor to Alzheimer's disease [18]. In addition, QSM has been used to monitor changes in iron deposition in multiple sclerosis patients receiving treatment, which is related to cognitive improvement [19]. Furthermore, QSM has been used to study the pathophysiology of various neurological disorders. Sepchrband et al. [20] used QSM to study the relationship between brain iron and Alzheimer's disease progression. The researchers

found that QSM-derived iron content in the basal ganglia and thalamus was associated with Alzheimer's disease progression, indicating that QSM can serve as a biomarker for the disease. Another study by Li et al. [21] used QSM to investigate the relationship between brain iron levels and cognitive impairment in type 2 diabetes patients. The authors found that QSM-derived iron content in the hippocampus was negatively correlated with cognitive performance in these patients, highlighting the potential of QSM in studying the effects of diabetes on cognitive function. Overall, QSM has shown great potential in advancing our understanding of the role of brain iron in cognitive function and its relationship with various neurological disorders. However, further research is needed to validate the clinical utility of QSM in cognitive research and to address its limitations, such as its susceptibility to various influencing factors that can affect its accuracy.

In summary, QSM is a promising MRI technique that can be used to investigate the relationship between iron deposition and cognitive function. It has the potential to provide new insights into the underlying mechanisms of neurodegenerative diseases and serve as a biomarker for early detection and monitoring of cognitive decline. Further research is needed to validate the clinical utility of QSM in cognitive studies.

In the future, the application prospects of QSM technology in the field of cognitive function assessment will become increasingly broad. Firstly, with the continuous advancement of technology, QSM technology will become more accurate and reliable in terms of imaging quality and quantitative measurement. For example, there is ongoing research on QSM image reconstruction methods based on deep learning, which can further improve imaging quality and reduce noise interference [22]. Secondly, as research on cognitive function assessment continues to deepen, more biomarkers will be discovered and combined with QSM technology to achieve more accurate cognitive function assessment. For example, a recent study showed that evaluating the relationship between iron content in the brainstem using QSM technology and cognitive function can help diagnose related diseases such as Parkinson's disease in the early stages [23]. Thirdly, with the continuous development and improvement of QSM technology, its application prospects in the field of cognitive function assessment will also continue to expand. The brain structure analysis methods commonly used in cognitive function assessment are mainly based on 3DT1WI pixel intensity, but this method cannot provide information on biomarkers such as iron content in the brain. In addition, QSM technology can also be combined with other imaging techniques, such as fMRI (functional magnetic resonance imaging), to further study the relationship between cognitive function and brain structure and function. Researchers can study the neural mechanisms of cognitive function and explore the brain regions and networks corresponding to different cognitive function tasks by fusing QSM and fMRI image data. These research results can

not only deepen our understanding of cognitive function, but also provide more accurate and effective means for the early diagnosis and treatment of cognitive impairments. Therefore, QSM technology is expected to become an important supplement, which can improve the accuracy and reliability of cognitive function assessment by quantifying the relationship between biomarkers such as iron content and cognitive function.

In summary, QSM technology has a wide range of applications in cognitive function assessment. With the continuous improvement and refinement of the technology, it will become an important tool to help us better understand the relationship between cognitive function and brain structure, and provide more accurate and reliable evidence for the early diagnosis and treatment of cognitive disorders. At the same time, the development of QSM technology will also promote the continuous deepening and expansion of brain research. Overall, researches on the application of QSM technology in cognitive function assessment are achieving more and more results and have gained widespread attention internationally. With the continuous development and maturity of the technology, the application prospects of QSM technology will become increasingly broad, bringing significant improvements to medical research and clinical diagnosis and treatment.

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