Postprint: Research Progress on the Prognostic Value of Diffusion Tensor Imaging Combined with Motor Evoked Potentials in Evaluating Motor Function in Hemiplegic Patients with Cerebral Infarction

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Abstract

Limb paralysis is a common sequela of cerebral infarction, imposing both physical disability and heavy psychological burden on patients. In recent years, research on motor function prognosis in cerebral infarction patients has been increasing, with more medical assessment tools becoming widely recognized. Diffusion tensor imaging (DTI) and transcranial magnetic stimulation motor evoked potentials (TMS-MEP) can detect changes in white matter fiber tract structure at the microscopic level. The combination of DTI and TMS-MEP—integrating neuroanatomy, electrophysiology, and neuroimaging—more accurately reflects the degree of motor neuron damage, yielding more objective motor function assessment than clinical functional indicators. This article provides a review of predictive assessment for motor function recovery in post-cerebral infarction patients based on the role of DTI and transcranial magnetic stimulation (TMS) in the corticospinal tract, summarizing the value of commonly used measurement parameters of DTI and TMS in evaluating motor function recovery in hemiplegic patients. It concludes that DTI and TMS-MEP can detect more subtle neural and tissue changes, serving as powerful non-invasive tools for exploring complex brain tissue architecture. Through the combination of DTI and TMS, utilizing different analytical methods to effectively explore injury patterns of white matter fiber tracts, it will facilitate the formulation of appropriate neurological rehabilitation programs for patients, maximizing improvement of their long-term prognosis.

Full Text

Advances in the Prognostic Value of Diffusion Tensor Imaging Combined with Motor Evoked Potentials for Motor Function Recovery in Hemiplegic Cerebral Infarction Patients

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Abstract

Limb paralysis is a common sequela of cerebral infarction that imposes both physical disability and heavy psychological burden on patients. In recent years, research on motor function prognosis in cerebral infarction patients has increased substantially, with growing recognition of various medical assessment tools. Diffusion tensor imaging (DTI) and motor evoked potentials induced by transcranial magnetic stimulation (TMS-MEP) can microscopically detect structural changes in white matter fiber bundles. The combined use of these modalities—integrating neuroanatomy, electrophysiology, and neuroimaging—enables more accurate assessment of motor neuron impairment, yielding objective motor function evaluations that surpass clinical functional indicators. This review examines the prognostic value of DTI and TMS for predicting motor function recovery after cerebral infarction by detecting and quantifying corticospinal tract degeneration. We summarize the prognostic significance of commonly used measurement parameters from DTI and TMS in evaluating motor function recovery in hemiplegic patients. We conclude that DTI and TMS-MEP are powerful noninvasive tools for exploring complex brain tissue structures, capable of detecting subtle neural and tissue changes. Through combined DTI and TMS analysis using different methodologies, white matter fiber bundle injury patterns can be effectively explored, facilitating the development of individualized neurological rehabilitation programs to maximize long-term patient outcomes.

Keywords: Brain infarction; Diffusion tensor imaging; Transcranial magnetic stimulation; Prognosis of motor function; Neurological rehabilitation; Review

Introduction

The burden of cerebrovascular disease in China is increasingly severe. In 2020, the prevalence of stroke in China reached 2.6%, representing a 0.6% increase from 2019 and significantly exceeding the global estimate of 1.2% in 2019. With 343 deaths per 100,000 individuals, stroke has become the leading cause of death [1], with onset age trending younger and neurological deficits drawing greater attention. Limb dysfunction represents the most common sequela [2]. Motor function recovery typically occurs within three months after cerebral infarction, though upper limb recovery is relatively more limited than lower limb recovery. Research indicates that upper limb motor function recovery may not be confined to the first 3-6 months post-infarction, with this critical recovery window potentially extending to 18 months [3]. Accurate prognosis prediction and timely rehabilitation within the effective window are crucial for restoring function in affected limbs. However, current assessments of neurological deficits and rehabilitation remain incomplete and lack specific modalities [4], necessitating exploration of imaging and electrophysiological tools for motor function prognosis evaluation.

The corticospinal tract (CST) constitutes the primary motor output pathway, and its integrity significantly influences motor outcomes. Wallerian degeneration represents the manifestation of CST damage after stroke, encompassing anterograde degeneration of axons and myelin. Early manifestations include distal axonal swelling, rupture, collapse, and myelin relaxation, followed by myelin swelling, thickening, tortuosity, and disintegration [5]. Wallerian degeneration closely correlates with CST dysfunction, though conventional imaging methods fail to reveal these subtle changes in the early post-stroke period. Diffusion tensor imaging (DTI) and transcranial magnetic stimulation motor evoked potentials (TMS-MEP) serve as sensitive tools for early detection of post-stroke Wallerian degeneration, revealing subtle neural and tissue changes and providing objective indicators of motor pathway damage.

1. DTI Principles and Applications

1.1 Basic Principles and Methods DTI is an advanced MRI and post-processing technique developed from diffusion-weighted imaging (DWI), serving as a noninvasive tool for detecting white matter fiber architecture. Both DWI and DTI imaging are based on differences in water molecule diffusion direction and velocity across different structures. DTI enables three-dimensional visualization of white matter fiber trajectories in living brains, achieving refined imaging of neural fibers. DTI reveals subtle early white matter fiber damage that conventional MRI cannot detect, including compression, displacement, and disruption of fiber bundles due to injury [6-7]. Through DTI-based tracking of white matter fibers, researchers can reveal neural tissue morphology and structure while enhancing diagnostic potential for intracranial lesions related to white matter tracts.

1.2 Common Parameters and Significance Processed data can be converted into parametric maps including fractional anisotropy (FA), relative anisotropy (RA), average diffusion coefficient (ADC), and volume ratio (VR). FA and ADC are the most commonly used DTI scalars. Quantitative assessment of white matter microstructural changes at different stages of ischemic cerebral infarction through these scalars enables translation of fiber bundle injury into motor function changes, thereby reflecting long-term outcomes of varying degrees of motor deficit.

FA values represent tissue anisotropy characteristics, reflecting myelin integrity, density, and fiber parallelism. Decreased FA indicates compromised cellular integrity and irreversible damage [8], with changes varying between infarct core and ischemic regions depending on stroke severity and onset time [9]. ADC reflects water molecule diffusion capacity, with temporal changes in cerebral infarction. ADC values decrease in the hyperacute and acute phases, begin rising in the subacute phase, subsequently show pseudonormalization, and gradually increase in the chronic phase, eventually exceeding reference ranges [10]. These changes result from early cytotoxic edema restricting intercellular water movement (reducing ADC), followed by vasogenic edema increasing diffusion space (elevating ADC) [11]. Therefore, combining ADC value changes can further clarify the degree of white matter ischemic necrosis at different time points.

1.3 DTI Applications in Post-Stroke Hemiplegia Early measurement of DTI parameters in white matter fiber bundles has proven valuable for independently predicting functional outcomes and serves as an additional metric in stroke recovery research [12]. A study evaluating CST integrity at 12 hours post-infarction demonstrated that CST integrity closely correlated with motor function at 90 days and outperformed infarct volume and clinical scores in outcome prediction [13]. Research comparing deficit severity at 24-72 hours and 3 months post-infarction found that while hemispheric white matter integrity declined significantly over time, patients with less distal fiber loss showed better motor recovery [14]. Studies have confirmed that the ratio of FA values between affected and unaffected sides (rFA) provides important guidance for evaluating upper limb recovery at 3 months post-infarction [15], with FA values independently associated with poor outcomes [16].

DTI can also evaluate variability in microstructural damage within and adjacent to infarcted tissue, effectively distinguishing infarct core from penumbra and providing new evidence for thrombolytic therapy in acute cerebral infarction [17]. Additionally, ADC values measured during transition from acute to chronic phases reflect disease stage progression, guiding functional outcome evolution while clarifying white matter ischemic necrosis severity [18]. Generally, higher ADC values in the chronic phase indicate progressive liquefactive necrosis, suggesting more difficult recovery [19].

2. TMS Principles and Applications

2.1 Basic Principles of TMS TMS is a noninvasive, painless neurophysiological examination based on Faraday' s principle of electromagnetic induction. Pulsed magnetic field signals pass unattenuated through scalp and skull to the cerebral cortex, generating induced currents that stimulate neuronal excitation and produce corresponding neuroelectrophysiological activities [20].

2.2 Common Parameters and Significance Neurophysiological indicators including motor evoked potential (MEP) amplitude and latency, and central motor conduction time (CMCT) are commonly used TMS metrics that provide insight into post-stroke corticospinal excitability status [21]. TMS-MEP involves applying TMS to cortical motor cells, spinal nerve roots, and peripheral nerves while recording action potentials in corresponding muscles, thereby reflecting central motor pathway function [22]. MEP amplitude provides a measure of excitability changes in polysynaptic pathways from motor cortex to target muscles [23]. MEP latency represents the time from stimulus application to motor response, including cortical excitation, CST conduction, spinal anterior horn excitation, and spinal conduction. Prolonged MEP latency indicates CST damage, while CMCT represents the time for evoked potentials to travel from motor cortex to spinal nerve roots. CMCT prolongation indicates slowed CST conduction, suggesting axonal damage or demyelination [24].

2.3 TMS Applications in Post-Stroke Hemiplegia TMS can quantify CST excitability during stimulation and assess CST neurophysiological integrity through MEP evaluation [25]. In central nervous system lesions, MEP manifestations are determined by the degree of spinal cord damage—more severe demyelination and greater anterior horn cell loss more readily affect MEP latency and amplitude [26-27]. Early post-stroke presence or absence of TMS-MEP provides effective information about cortical motor conduction system integrity [28]. For severely impaired patients, MEP status is significant for distinguishing good versus poor motor recovery. A study of middle cerebral artery infarction with predominant motor dysfunction found that while upper limb deficits were more severe and recovery more difficult than lower limb deficits, patients with upper limb TMS-evoked responses could still achieve meaningful benefits through early identification and 3-year intensive rehabilitation programs [29]. Similarly for the lower limb, early TMS to determine CST preservation helps predict final motor recovery and gait function [30].

TMS detects neural pathway integrity to predict prognosis, making CST integrity a predictor of motor function potential [31]. By assessing CST structural integrity, TMS can diagnose disuse phenomena during recovery due to chronic motor function loss. Even when CST remains intact in post-stroke disuse patients, TMS can stimulate neurons and estimate CST fiber numbers through MEP amplitude measurement to determine motor deficits [32]. Accurate determination of motor function status facilitates individualized rehabilitation planning and identifies patients with significant recovery potential who may benefit from intensive rehabilitation.

3. Combined DTI and TMS Applications in Post-Stroke Hemiplegia

DTI can identify white matter fiber bundle regions for anatomical mapping and investigate brain functional disorders by precisely tracking white matter integrity [33]. Early measurement of white matter diffusion tensor imaging parameters in cerebral infarction patients, observing the evolution of FA and ADC values at different post-stroke stages, and establishing correlations with motor deficit recovery can independently predict functional prognosis. While DTI reflects fiber traction, displacement, and defect severity, its assessment of subtle internal fiber structure lesions has limitations. TMS can evaluate pathway integrity from an electrophysiological perspective, precisely reflecting motor conduction pathway function and microstructural pathophysiological changes within CST. Currently, TMS is primarily used to study correlations between brain anatomy and electrophysiological function related to motor recovery after subcortical infarction, providing more objective and comprehensive assessment of nerve fiber damage than clinical functional indicators [34]. Studies of MEP amplitude, latency, and CMCT under cortical stimulation reflect white matter pathway function and explore excitability and neuroplasticity related to post-stroke motor recovery.

KUMAR et al. [35] evaluated the accuracy of TMS motor evoked potentials and DTI in predicting upper limb motor recovery within 7 days post-infarction, concluding that DTI parameter FA values indicate CST integrity—reduced FA represents interrupted fiber integrity and correlates with motor deficits. Patients showing MEP responses and preserved CST integrity had better upper limb recovery opportunities than those without these features, confirming the prognostic importance of both modalities. OKAMOTO et al. [36] similarly explored the importance of DTI and TMS neurophysiological parameters in stroke rehabilitation. However, poor MEP response does not necessarily indicate irreversible outcomes—studies show that severely impaired stroke patients without MEP responses can still achieve clinically meaningful improvements through neuromodulation and motor rehabilitation training, though responders show better outcomes [37]. This may occur because CST damage reduces corticospinal synaptic excitability, preventing TMS pulses from generating potentials. Thus, DTI can improve prognostic specificity in such cases. Domestic studies by YANG Yaxin et al. [38] similarly found that MEP waveform absence and DTI scalars can assess severe limb dysfunction, with combined testing significantly improving diagnostic efficacy. However, limb dysfunction can occur despite CST preservation—TANG et al. [39] observed that in mild hemiparesis from precentral gyrus infarction not involving the original CST region, TMS showed electrophysiological changes despite intact CST. LI et al. [40] reported similar findings where post-treatment DTI showed no significant improvement while MEP amplitude and latency improved markedly. This suggests CST structural integrity does not equate to functional integrity, highlighting the importance of neurophysiological changes in cortical lesions.

4. Summary and Outlook

White matter fiber bundle injury is a key factor affecting neurological function and recovery in cerebral infarction patients. DTI and TMS-MEP can detect subtle neural and tissue changes, serving as powerful noninvasive tools for exploring complex brain structures. Combined DTI and TMS analysis using different methodologies can effectively explore white matter fiber bundle injury patterns, facilitating development of individualized neurological rehabilitation programs to maximize long-term outcomes. Current research hotspots remain focused on exploring central nervous system fiber pathways, with quantitative analysis enabling visualization of brain injury and latent lesions in various neural tracts relevant to clinical treatment. DTI and TMS offer tremendous advantages in neuroanatomy, fiber connectivity, and brain development research, with broad application prospects for neurological disease and brain function studies. As technology improves and better post-processing tools become available, these modalities will be applied more fully and effectively in clinical practice and research.

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