

Correlation between Clinical Presentations and Hemodynamic Parameters Measured by Dynamic Susceptibility Contrast Magnetic Resonance Imaging in Adult Patients with Moyamoya Disease

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Background: The examination of cerebral hemodynamics is indispensable for the clinical management of patients with moyamoya disease (MMD). In this study, we examined the correlation between clinical presentations and hemodynamic parameters measured by dynamic susceptibility contrast magnetic resonance imaging (DSC-MRI) in adult patients with MMD. *Methods:* One hundred fifty-seven hemispheres in 122 adult patients with MMD were examined by DSC-MRI to measure the regional relative cerebral blood volume (CBV) and relative mean transit time (MTT). The patients were divided into 4 groups based on their clinical presentations: a nonsymptomatic (NS), hemorrhagic (H), infarction (I), and transient ischemic attack (T) group. The regional CBV and MTT values were compared among the 4 groups. *Results:* The relative value of CBV was significantly higher in groups T and I than in the NS group ($P < .01$). The CBV of group H was higher than that of the NS group only in the frontal lobe cortex. There were no significant statistical differences among the 3 symptomatic groups. Prolongation of the MTT in comparison with the cerebellum (MTT delay) was significantly higher in groups T and I than in the NS group in all regions of the cerebral cortex ($P < .05$). The MTT delay was significantly lower in group H than in group T in the frontal lobe and the Rolandic area ($P < .05$). *Conclusions:* Hemodynamic factors measured by DSC-MRI reflected the variable clinical presentations of patients with MMD. DSC-MRI is a useful modality for evaluating the clinical conditions of individual adult patients with MMD. **Key Words:** Moyamoya disease—DSC-MRI—cerebral hemodynamics—clinical presentation.

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Introduction

Moyamoya disease (MMD) is a progressive, occlusive, cerebrovascular arteriopathy characterized by bilateral

stenosis of the terminal segments of the internal carotid arteries, accompanied by the development of compensatory collateral vessels.^{1,2} Patients with MMD present with various manifestations, most prominently transient ischemic attacks (TIAs), cerebral infarction, and cerebral hemorrhage.^{3,4} With the wider adoption of screening by magnetic resonance angiography (MRA), moreover, the number of more patients are being diagnosed as having MMD even in the absence of neurological ischemic symptoms.⁵ Such variability in clinical presentations is observed more extensively in adults than in juvenile patients.^{3,6} The hemodynamic status of MMD varies, and ¹⁵O gas positron emission tomography (PET) reveals severe hemodynamic stress in selected subgroups of patients.⁶

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The examination of cerebral hemodynamics and metabolism is therefore indispensable for the management of MMD, especially for decision-making on surgical revascularization.

Several authors have recently reported on the utility of dynamic susceptibility contrast magnetic resonance imaging (DSC-MRI) for evaluating cerebral hemodynamic status.⁷⁻⁹ DSC-MRI provides parameters such as cerebral blood flow (CBF), cerebral blood volume (CBV), and mean transit time (MTT), and does so with higher spatial resolution, better accessibility in clinical practice, and less invasiveness than PET.⁷⁻¹³ It remains unclear, however, if these parameters measured by DSC-MRI show variability among clinical subtypes of MMD comparable with the variability found in measurements by ¹⁵O gas PET.⁶ The purpose of the present study was to evaluate the correlation between the clinical presentation of adult patients with MMD and hemodynamic parameters measured by DSC-MRI in order to accumulate further evidence on the utility and validity of DSC-MRI as an alternative for ¹⁵O gas PET in the clinical management of MMD.

Materials and Methods

Subjects

One hundred and fifty-seven hemispheres in 122 consecutive adult patients with MMD (30 males and 92 females; mean age, 34.2 years; range, 15-60 years) were treated from April 2001 to October 2014 (the patient selection process will be described later). The patients were divided into 4 groups based on their clinical presentations: nonsymptomatic (NS), hemorrhagic (H), infarction (I), and TIA (T) (the group selection criteria will be described later). A total of 157 hemispheres were classified by the MRA stage grading for MMD and also evaluated by the presence of posterior cerebral artery (PCA) lesion.¹⁴ All patients underwent DSC-MRI to measure the regional CBV and MTT.

Nonsymptomatic Patients

Sixty-two hemispheres of 31 nonsymptomatic patients (NS group, 9 males and 22 females; mean age, 37.2; range, 16-60 years) were examined. By the MRA stage classification, 6 hemispheres were classified as stage 1, 25 hemispheres were classified as stage 2, 26 hemispheres were classified as stage 3, and 5 hemispheres were classified as stage 4. PCA lesions were observed in 7 hemispheres (11.3%). The NS patients were free of focal neurological symptoms and diagnosed incidentally on magnetic resonance imaging (MRI) and MRA. None of these patients showed infarcted or hemorrhagic lesions on fluid-attenuated inversion recovery or T2-weighted MRI images. The definition of nonsymptomatic MMD in this study was based on the study criteria from the Asymptomatic Moyamoya Registry. Briefly, patients were assessed as

nonsymptomatic if they had bilateral or unilateral MMD on cerebral angiography or MRA but no episodes suggestive of TIA, ischemic stroke, hemorrhagic stroke, or quasi-MMD.⁵

Symptomatic Patients

Symptomatic patients were categorized into 3 groups: a hemorrhagic group (H), infarction group (I), and TIA group (T). Only the affected hemispheres were examined in this study. Group H (3 males and 13 females; mean age, 34.1; range, 18-56 years) consisted of 16 patients with hemorrhagic onset in 16 hemispheres ipsilateral to the bleeding points. In the MRA classification, 1 hemisphere is stage 2, 13 hemispheres are stage 3, and 2 were stage 4. PCA lesions were observed in 4 hemispheres (25%). All of the group H patients had well-preserved activities of daily living after intraventricular bleeding or minor intracerebral hemorrhages. None suffered severe deficits or massive parenchymal damage. Group H was examined by DSC-MRI after acute stage care and rehabilitation. The mean interval between the onset of the hemorrhagic stroke and the examination of DSC-MRI was 10.1 (range 1-54) months.

Group I (10 males and 13 females; mean age, 37.9 years; range, 15-58) consisted of 23 patients. The mean interval between the onset of cerebral infarction and the DSC-MRI was 8.5 (range, 2-36) months. Cerebral infarction caused neurological deficits originating in bilateral hemispheres in 1 group I patient, so 24 hemispheres of 23 group I patients were included in the study. Three hemispheres were classified as stage 2, 15 hemispheres were classified as stage 3, and 6 hemispheres were classified as stage 4. PCA lesions were observed in 13 related hemispheres (54%).

Group T (8 males and 44 females; mean age, 30.9 years; range, 15-57 years) consisted of 52 patients. The mean interval between the last TIA and the DSC-MRI was 1.5 (range, .5-5.0) months. All had transient motor, sensory, visual, or language deficits but were free from neurological deficits during the examination period. Three group T patients had symptoms of TIA originating in bilateral hemispheres at different times within short periods, so 55 hemispheres were examined in the study. All of the group T patients were free from large cortical infarcted lesions on T2-weighted MRI. MRA stage was classified as follows: 9 hemispheres were classified as stage 2, 34 hemispheres were classified as stage 3, and 12 hemispheres were classified as stage 4. PCA lesions were observed in 18 related hemispheres (33%).

All study protocols were approved by the ethics committee of our institute.

DSC-MRI Protocol

The DSC-MRI studies were performed with a 1.5-T magnetic resonance (MR) scanner (Magnetom Vision, Siemens

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