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**Echo-Planar Perfusion MR of Moyamoya Disease**

Kazuhiro Tsuchiya, Sayuki Inaoka, Yoshiyuki Mizutani, and Junichi Hachiya

**PURPOSE:** Our goal was to assess the value of perfusion MR imaging by using a single-shot echo-planar technique to evaluate the hemodynamics of moyamoya disease.

**METHODS:** We performed echo-planar perfusion studies in 19 patients with a 1.5-T unit, using a free-induction-decay echo-planar sequence for 14 examinations and a turbo-gradient-spin-echo echo-planar sequence for five examinations. After a bolus injection of contrast material, 30 consecutive scans were done in 10 sections every 2 seconds. The data were analyzed to yield time-intensity curves for a region of interest set in the territory of the bilateral middle and/or anterior cerebral arteries in all examinations and to produce semiquantitative flow maps of each section, representing the signal decrease due to passage of contrast material in 17 examinations. The semiquantitative flow maps were compared with single-photon emission CT (SPECT) findings in 11 cases.

**RESULTS:** We detected differences between the cerebral hemispheres and/or focal perfusion abnormalities by the time-intensity curves and semiquantitative flow maps in 15 of the 19 examinations and in 11 of the 17 examinations, respectively. Results of one or both these examinations corresponded with the SPECT findings in nine of the 11 examinations.

**CONCLUSION:** Our results indicate that single-shot echo-planar perfusion MR imaging can sensitively depict hemodynamic abnormalities in moyamoya disease.

In the diagnosis of ischemic cerebrovascular disease, magnetic resonance (MR) imaging can depict lesions readily and accurately. MR angiography is capable of noninvasively delineating the status of the major intracranial arteries. However, it is not possible to obtain adequate information on changes in hemodynamics by these techniques. Such information can be obtained by single-photon emission computed tomography (SPECT) or positron emission tomography (PET), but perfusion MR imaging is another option to examine cerebral blood flow. By using T2-weighted imaging that is sensitive to magnetic susceptibility, perfusion MR imaging shows signal changes that occur in the brain during the first pass of gadolinium-based contrast material (1–3). For this purpose, gradient-echo sequences have commonly been used. Recently, it has become possible to apply the single-shot echo-planar technique to perfusion MR imaging. As is well known, extremely fast scanning is possible, because this technique acquires sufficient echoes after the application of a single radio-frequency excitation pulse. In the present study, we assessed the value of single-shot echo-planar perfusion MR imaging in the evaluation of hemodynamics in moyamoya disease.

**Methods**

We performed perfusion MR imaging in 19 patients with moyamoya disease diagnosed by conventional angiography between September 1995 and February 1997. The group consisted of 13 female and six male subjects ranging in age from 9 to 59 years (mean, 24 years).

MR examinations were done with a 1.5-T unit (Magnetom Vision). For 14 examinations, we used a free-induction-decay echo-planar sequence with the following imaging parameters: echo time, 54; scanning time per section, 102 milliseconds; imaging matrix, 128 × 128; and section thickness, 7 mm. For the remaining five examinations, we used a turbo-gradient-spin-echo echo-planar sequence. The imaging parameters were as follows: echo time, 18; scanning time per section, 140 milliseconds; imaging matrix, 128 × 128; and section thickness, 3 mm. For each sequence, we did 30 scans every 2 seconds, with 10 sections in each scan. The 10 sections were set to cover an area from the base of the posterior fossa to the high convexity. A bolus of contrast material (0.1 mmol/kg) was manually injected via the antecubital vein at the start of imaging.

We analyzed the acquired data in three ways. First, time-intensity curves were calculated for two regions of interest (ROIs) of the same size (4 cm² or more) in the territory of the middle cerebral artery (MCA) and/or anterior cerebral artery bilaterally (19 examinations). The ROIs were thus placed because moyamoya disease involves the internal carotid artery. The location and size of the ROIs varied case by case based on...
findings on conventional or MR angiograms. Second, semi-
quantitative flow maps of each section were created by the
software incorporated into the MR unit (17 examinations).
These maps were created on the premise that a bolus of
gadolinium-based contrast agent produces a decrease in signal
intensity of perfused brain tissue on T2*-weighted images. The
flow maps showed differences both in the degree of signal
drop due to passage of contrast material and in the time
between the start and the peak of the signal. In these maps, the
longer the time between the start and the peak of signal
decrease and/or the smaller the degree of signal drop, the
darker a pixel became. Thus, these maps reflected not only the
regional cerebral blood volume but also the difference in ar-
rival time of the contrast material. Therefore, they represented
the relative status of the regional cerebral blood flow. Third,
the semiquantitative flow maps were compared with axial
SPECT scans obtained with 123I-iodoamphetamine (five exam-
inations) or 99mTc-ethylcysteinate dimer (six examinations), for
a total of 11 examinations. We used two SPECT scanners of the
same type (GCA-9300A/HG) with a low-energy, super-high-
resolution fan-beam collimator with resolution of 8-mm full
width at half maximum. The MR and SPECT studies were
performed within an interval of 4 weeks.

Results

Differences between the cerebral hemispheres and/or focal perfusion abnormalities were detected with at least one of the three methods of analysis in all except two patients (cases 10 and 15), in whom the
time-intensity curves, flow maps, and SPECT scans were unremarkable (Table). In these patients, we believe that, as discussed later, several factors, including the compensation of blood flow due to collateral
circulation, were responsible for the perfusion MR imaging findings. Although flow maps of sections near the skull base tended to be distorted by suscept-
tibility artifacts, we could obtain results not degraded by other factors, such as patient motion.

<table>
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<tr>
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<td>L MCA/ACA peak delay</td>
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<td>Corresponding findings</td>
</tr>
<tr>
<td>19</td>
<td>10/F</td>
<td>FID</td>
<td>Intraventricular hematoma</td>
<td>R = L</td>
<td>R MCA peak delay, R MCA heightened peak</td>
<td>Hypoperfusion in R MCA area</td>
<td>Corresponding findings</td>
</tr>
</tbody>
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Note.—TGSE indicates turbo-gradient-spin-echo; FID, free-induction decay; MCA, middle cerebral artery; and ACA, anterior cerebral artery.
FIG 1. Case 11: 14-year-old boy with moyamoya disease affecting both sides almost equally. The patient had several lacunar infarctions in the bilateral frontal lobes and the right parietal lobe on conventional MR images.

A, Free-induction-decay echo-planar image (echo time, 54; flip angle, 90°; field of view (FOV), 22 × 22 cm; matrix, 128 × 128) shows circular ROIs in the bilateral MCA territories.

B, Time-intensity curves show a delayed peak time and washout as well as a decreased peak height in the right MCA territory (solid line) compared with the left MCA territory (dotted line).

C and D, Flow maps show hypoperfusion in the left temporal, right frontoparietal, and left frontal regions (arrows). This abnormality was depicted only on the perfusion study.

FIG 2. Case 4: 31-year-old woman with moyamoya disease predominantly affecting the left side. MR images showed a small infarction in the right frontal subcortex.

A, Free-induction-decay echo-planar image (echo time, 54; flip angle, 90°; FOV, 22 × 22 cm; matrix, 128 × 128) shows circular ROIs in the bilateral MCA territories.

B, Time-intensity curves show an increased peak height and a delayed peak time in the left MCA territory (dotted line) compared with the right MCA territory (solid line). The baseline on the right side is lower than that on the left side, because the ROI on the left includes more of the hyperintense cerebrospinal fluid in the sulci than does the one on the right.

C, Flow map shows hypoperfusion in the left MCA and posterior cerebral artery territories, probably reflecting the peak time delay. The hypoperfusion was not seen on conventional MR images, but was suspected at MR angiography.
Time-Intensity Curves (n = 19)

We detected abnormalities in 15 studies (79%). In either of the cerebral hemispheres, the peak was delayed in 13 studies (68%) and washout of contrast material was delayed in three studies (16%) (Fig 1). We noticed decreased signal drop on one side in five studies (26%). In three studies (16%), however, signal drop was increased on the side on which the stenosis was more prominent on conventional or MR angiograms (Fig 2).

Semiquantitative Flow Maps (n = 17)

The flow maps showed focal abnormalities corresponding to infarcted areas on MR images in four studies (24%) (Fig 3); noncorresponding abnormalities were detected in seven studies (41%) (Fig 1). In six studies (35%), the flow maps were normal (Fig 4). Five of these six patients were asymptomatic, and one patient (case 2) had mild hemiparesis.

Comparison of Semiquantitative Flow Maps with SPECT (n = 11)

The flow maps and the SPECT findings corresponded well in nine studies (82%) (Figs 3 and 4), but did not correspond in two studies (18%).

Discussion

Moyamoya disease is a rare cerebrovascular occlusive disorder most often encountered among the Japanese (4–6). It is characterized by progressive occlusion of the supraclinoid portion of the internal carotid artery and the proximal portions of the anterior cerebral artery and the MCA. These occlusive changes are accompanied by the formation of extensive collateral vessels in the basal ganglia and thalamus, together with leptomeningeal and transdural collateral vessels. As a result, cerebral ischemia tends to occur in children, whereas intracranial hemorrhage is more frequent in adults. Although the usefulness of CT, MR imaging, and MR angiography for the diagnosis of moyamoya disease has already been established (7–9), conventional angiography is still necessary for a definitive diagnosis. To evaluate hemodynamic changes in moyamoya disease, SPECT is the method used most widely (10, 11). SPECT findings, especially those of hypoperfusion, generally correlate well with clinical symptoms (10). PET with H215O or C15O2 is also used at institutions in which it is available (12). The information obtained by these techniques significantly influences assessment of the prognosis and the need to perform bypass surgery.

Currently, perfusion MR imaging is performed us-
ing fast T2*-weighted imaging to detect signal changes that occur during the first pass of contrast material. The value of perfusion MR imaging as well as of diffusion-weighted MR imaging in acute stroke has been described (13, 14). Meanwhile, the efficacy of SPECT and PET in the evaluation of regional cerebral blood flow has been established. However, if perfusion MR imaging can provide comparable information at the same time as standard MR imaging and MR angiography, it would be quite advantageous clinically. Furthermore, perfusion MR imaging is superior to SPECT and PET in the evaluation of blood flow in the white matter. If not postprocessed and displayed properly, the data generated by these techniques cannot demonstrate white matter perfusion well because of the relative hyperperfusion of the gray matter and basal ganglia. Additionally, perfusion MR imaging causes no radiation exposure, which is an advantage over SPECT and PET, because patients with moyamoya disease need repeated examination during a long follow-up period. In the present series, the time-intensity curves revealed a difference between the hemispheres in 79% of the patients. Although moyamoya disease usually involves both hemispheres, its severity is not always symmetric. Presumably, the excellent temporal resolution of single-shot echo-planar sequences allowed us to detect differences between the hemispheres. It is also noteworthy that some patients showed a more marked signal drop on the side on which stenotic change was more prominent on conventional or MR angiograms. We assume that this may be explained by the rich collateral flow in these patients being reflected as seemingly increased perfusion caused by a high sensitivity to magnetic susceptibility. A method of calculating regional blood flow from time-intensity curves obtained by echo-planar perfusion studies has already been proposed (15). Such a quantitative technique would make echo-planar perfusion MR imaging a more valuable tool for patients with various ischemic cerebrovascular disorders, including moyamoya disease. However, setting a proper ROI remains a problem in relation to generating time-intensity curves in moyamoya disease.

Semiquantitative flow maps showed areas of hypoperfusion that either did or did not correspond to infarction in two thirds of our patients. We consider that the multisection capability of echo-planar contributed to the detection of these abnormal foci. Hypoperfusion in the noninfarcted regions thus detected is of clinical importance, because these areas are vulnerable to ischemia. Even the apparently normal flow maps in six (35%) of the 17 examinations may at least partly be attributed to well-developed collateral flow. Thus, the ability of single-shot echo-planar perfusion studies to reveal the whole brain appears to be quite advantageous in moyamoya disease, in which a complicated collateral circulation develops. The flow
map method used in this study is not ideal for visual assessment of perfusion, but quantitative assessment of perfusion may become possible with further developments in software for postprocessing. The fact that two patients with lacunar infarctions on MR images had normal perfusion studies is somewhat noteworthy. We think well-developed collateral flow was the main cause of the discrepant findings. However, inadequate spatial resolution of flow maps and improperly sized ROIs for the time-intensity curves may also have affected the results.

Echo-planar perfusion MR imaging has several disadvantages. Image degradation by susceptibility artifacts is a problem near the skull base or paranasal sinuses. At present, the spatial resolution is also inadequate. Additionally, although each scan is performed in a very short time, useful data cannot be obtained from patients who do not remain still during the whole imaging examination (about 1 minute).

Conclusions

Our results indicate that single-shot echo-planar perfusion MR imaging can sensitively detect abnormalities of hemodynamics in patients with moyamoya disease. We think that the multisection capability and excellent temporal resolution of this technique are most advantageous. In this study, it was unfortunate that only a limited number of examinations could be compared with SPECT. Additionally, a more sophisticated method of data analysis may be required. Nevertheless, our results suggest that echo-planar perfusion MR imaging has the potential to become an effective diagnostic tool comparable to SPECT or PET in evaluating moyamoya disease.

Acknowledgments

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References