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Perioperative evaluation of blood volume flow in high-flow cerebral arteriovenous malformation using phase-contrast magnetic resonance angiography

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A B S T R A C T

Phase-contrast magnetic resonance angiography (PC-MRA) is useful for the quantitative measurement of blood flow volume (BFV) in the internal cerebral arteries (ICAs) and basilar artery (BA). A 45-year-old man was diagnosed with a non-hemorrhagic high-flow arteriovenous malformation (AVM) in the right temporal lobe. PC-MRA examinations of the bilateral ICAs and BA were conducted before treatment, at five days and at one and three months after the operation. The patient underwent preceding endovascular embolization of the deep part of the nidus and feeders. There were numerous feeders from the superior MCA trunk, which directly passed through the nidus to the normal brain. Therefore, the nidus was completely removed while maintaining the flow of the main superior MCA trunk in a passing artery. The BFV of the right ICA before AVM treatment was extremely high (mean: 675.7, systolic: 896.1, diastolic: 518.5 mL/min). Five days after the nidus resection, the BFV of the right ICA was decreased by almost half of that before treatment, and it was decreased even more at one month after the operation. The BFVs of the left ICA and BA were slightly increased before the operation and returned to normal values after the operation. The diastolic total BFV was immediately decreased after the operation, but the systolic total BFV was not sufficiently decreased at five days after the operation. Therefore, the difference between these systolic and diastolic total BFVs was higher at five days after the operation than before the operation. The systolic and diastolic total BFVs were decreased to normal levels one month after the operation. PC-MRA is a convenient and useful tool for quantifying BFVs in AVMs and can help plan the treatments. More research is needed to establish a definite role for PC-MRA in the quantification of flow changes in the treatment of high-flow AVMs.

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Introduction

The main feature of a cerebral arteriovenous malformation (AVM) is the existence of nidus, which is defined histologically as a tangled cluster of abnormal vessels. The nidus acts as a direct shunt from arteries to veins in the absence of a capillary bed. Cerebral hemodynamic changes caused by AVM influence its clinical features, including intracerebral hemorrhage, subarachnoid hemorrhage, seizure, cerebral infarction or transient ischemic attack, headache, etc. [1,2].

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Phase-contrast magnetic resonance angiography (PC-MRA) is accepted as the gold standard for the quantification of blood flow volume (BFV, ml/min) in the internal cerebral artery (ICA) and posterior circulation [3,4]. Total BFV in AVM cases has been reported to be significantly greater than that in normal volunteers [5]. Additionally, the mean value of BFV in the ICA ipsilateral to the AVM has been reported to be significantly greater than that in the contralateral ICA [5]. However, to our knowledge, no studies on the quantitative measurement of BFVs in surgical AVM cases using PC-MRA have been reported. In this study, we evaluated the perioperative hemodynamic changes in an adult patient with a high-flow temporal AVM using PC-MRA.

Case reports

Disclosure of the patient's data was approved by the ethical committee for human research at our hospital, and informed written consent was directly obtained from this patient. A 45-year-old man presented with a generalized tonic–clonic seizure. MRI and MRA revealed a right temporal AVM close to the Sylvian fissure. A digital
subtraction angiography of the right ICA depicted a high-flow AVM and a small portion of the normal perfusion territories of the right middle cerebral artery (MCA) and anterior cerebral artery (Fig. 1A and B). The main trunk and branches of the right MCA and the Sylvian veins were enlarged due to a flow increase through the AVM. The compact-type nidus had a maximum diameter of 3.2 cm and a volume of 9.5 mL. The surgical risk grade of this AVM case was II based on the Spetzler–Martin grading system (size; 2, deep venous drainage; 0, eloquence; 0), and IV based on the Lawton supplementary grading system (age; 3, unruptured presentation; 1, diffuse nidus; 0) [6,7]. Our therapeutic strategy for the prevention of subsequent intracranial hemorrhage and seizure control was a combined therapy with preceding endovascular embolization and microsurgical nidus resection, and this was chosen based on the previous reports [8,9]. For the first step of treatment, the deep part of the nidus and the relevant feeding arteries supplied from the inferior trunk of the MCA were occluded by embolization using the Onyx 18 and 34 liquid embolic agents (Fig. 2). There were numerous feeders from the superior MCA trunk, which directly passed through the nidus to the normal perfused tempororo-occipital lobe. Complete nidus resection with the maintenance of the flow of the main superior MCA trunk in a passing artery was confirmed by intraoperative indocyanine green videoangiography (Fig. 2E) and digital subtraction angiography one month after the operation (Fig. 1C and D). Postoperatively, the systolic blood pressure was maintained at approximately 100 mmHg with sedation and mechanical ventilation for five days to prevent postoperative normal perfusion pressure breakthrough (NPPB). PC-MRA examinations of the bilateral ICAs and the basilar artery (BA) using the 1.5 T MRI system (MAGNETOM Avanto, SIEMENS, Munich, German) were performed before treatment and at five days and one and three months after the operation (Fig. 3). The sequence parameters of the PC-MRA were as follows: TR/TE, 24/5 ms; flip angle 15°; section thickness, 3 mm; field of view, 140 mm; acquisition matrix size, 256 × 192; number of cardiac phases, 14–16; velocity encoding, 100 cm/s, same as the previously reported protocol [3,4]. The BFV in the right ICA was extremely high before treatment (mean: 676, systolic: 896, diastolic: 519 mL/min), and at five days after the operation, the mean and diastolic BFVs in the right ICA had dramatically decreased, but the systolic BFV in the right ICA remained high (489 mL/min). One month after the operation, the systolic BFV in the right ICA reached a normal level (302 mL/min). Total BFV was calculated as a simple sum of each BFV in the bilateral ICAs and BA. The preoperative total BFV was extremely high (mean: 1109, systolic: 1491, diastolic: 839 mL/min), and although the mean value of the total BFV was dramatically decreased to 656 mL/min at five days after the operation, the difference between the systolic and
Fig. 2. Three-dimensional angiography and microsurgical photograph. Three-dimensional angiograms after endovascular embolization (A and B). Red color indicates arteries and transparent sky-blue color indicates veins. Light-green color indicates the nidus embolized with Onyx and purple indicates the residual nidus. The superficial superior trunk of the MCA branched the numerous feeding arteries and directly passed through the nidus to the normal perfused temporo-occipital lobe. Enlarged superficial Sylvian veins were the main drainer. C shows the temporal surface in the microsurgery. D shows the indocyanine green video-angiogram before cut-off the numerous feeding arteries from the superficial MCA trunk and E shows after microsurgical nidus resection.

Fig. 3. Perioperative blood flow volume measured on phase-contrast magnetic resonance angiography (PC-MRA). The left upper images show the antero-posterior view and the lateral view of the time of flight MRA. Scanning surface for PC-MRA was positioned perpendicular to both ICAs at the level of the vertical segment of the petrous portion of the ICA. The white dotted line indicates the position of the scanning surface for PC-MRA. The left lower image shows the one cardiac phase image of PC-MRA. 1 indicates the cross section of the right ICA; 2, that of the left ICA; and 3, that of the basilar artery. The line graphs show blood flow volumes (mL/min, y-axis) of the right and left ICAs and the BA at the one cardiac cycle (x-axis). Black squares indicate the blood flow volumes before treatment, and white squares indicate those five days after operation. White triangles indicate one month after operation, and white circles indicate three months after operation.
diastolic total BFVs at that time was 823 mL/min, which was higher than that of the preoperative total BFV. $^{123}$I-$N$-isopropyl-piodoamphetamine single photon emission computed tomography (IMP-SPECT) examinations before and five days and one month after the operation indicated normal perfusion around the temporal AVM. The patient was discharged with no deficit (modified Rankin scale; 0) and with no seizures after his initial presentation.

**Discussion**

On the basis of our experience and previous reports, [3–5] we support the view that PC-MRA is effective for evaluating the perioperative dynamic changes of BFVs in cerebral AVMs. The preoperative total BFV in this AVM case was twice the normal mean value of total BFV in patients in their fifth decade of life (600–700 mL/min) [3]. Although the total BFVs in AVMs can be immediately decreased after complete removal of the nidus, the difference between the systolic and diastolic BFVs can increase for a few days after the operation, as was seen in this case. The diastolic BFV is decreased immediately after nidus resection as the result of an increase in vascular resistance caused by the elimination of direct shunts from arteries to veins. However, the systolic BFV cannot be decreased immediately after nidus resection because it is dependent on the diameter of the major arteries, which are relevant feeding arteries that need time to remodel to reduce their diameters. We believe that this temporary increase in the difference between systolic and diastolic BFVs causes arterial congestion and NPPB after nidus resection. Therefore, preservation of a major passing artery and perfusion in the normal brain close to the nidus are critical for preventing NPPB in the treatment of high-flow AVMs. Additionally, we assessed the period of sedation for preservation of postoperative NPPB using PC-MRA and IMP-SPECT. However, we did not obtain any definitive evidence regarding the association of NPPB risk with BFVs or the effect of sedation on NPPB risk. A large number of high-flow AVM cases need to be evaluated in terms of dynamic perioperative changes in BFVs. However, it is difficult to recruit homogeneous types of surgical AVM cases. For example, this was a non-hemorrhagic case in a patient of more than 40 years of age, and surgical treatment was performed even though age and an unruptured presentation have been reported to be significant risk factors for complications during the surgical treatment of AVM [6]. The surgical risk of age might be associated with the time-consuming plasticity of vascular remodeling after the operation [10].

Confirmation of the relationships between age and perioperative dynamic changes in BFV and surgical risks, including NPPB, warrants further research on PC-MRA, a non-invasive and reliable technique for the quantification of BFV.

**Conclusion**

Here, we presented the perioperative dynamic change of quantitative flow volumes in a single case of high-flow AVM. The definition of “high-flow” is unclear because intracranial BFVs have not been objectively evaluated in cerebral AVM cases. Therefore, the known surgical risks for AVMs had not included BFVs or hemodynamic factors. PC-MRA can be used for the future estimation of NPPB risk and lead to the development of a novel, safe method for AVM treatment.

**References**