Intraoperative Magnetic Resonance Imaging in the Successful Surgical Treatment of an Arteriovenous Malformation
—Case Report—

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Abstract
A 44-year-old female presented with left occipital arteriovenous malformation (AVM) manifesting as sudden onset of severe headache. Magnetic resonance (MR) imaging and conventional angiography showed the left occipital AVM with hemorrhage. Intraoperative MR imaging (iMR imaging) and intraoperative time-resolved imaging of contrast-kinetics (iTRICKS) at 1.5 T revealed complete removal of the nidus of the AVM without conventional catheter angiography. Conventional catheter angiography is commonly used in preoperative and intraoperative examination of AVMs, and for documentation of the surgical outcome, but less-invasive techniques are desirable for both preoperative screening and intraoperative examination. iMR imaging with iTRICKS is less invasive and safer than conventional angiography for both brain tumor surgery and AVM surgery.

Key words: arteriovenous malformation, conventional angiography, intraoperative magnetic resonance imaging, time-resolved imaging of contrast-kinetics, surgery

Introduction
The complication rate of conventional angiography is not very high, approximately 1–2%, but long-term cannulation can cause embolisms.18 Therefore, less-invasive tools are preferable for intraoperative examination, especially for intracranial arteriovenous malformations (AVMs). The successful use of different intraoperative visualization techniques for AVM surgery has been widely reported: catheter angiography, ultrasonography, indocyanine green (ICG) videoangiography, and time-of-flight (TOF) magnetic resonance (MR) angiography. Ultrasonography is easy to use, but the resolution is not satisfactory.2,17 ICG videoangiography is not satisfactory if the AVM vessels are deep seated or not on the surface.7,16 TOF MR angiography is also not adequate for AVM surgery due to poor temporal and spatial resolution.15 Intraoperative MR imaging (iMR imaging) and neuronavigation have substantially changed the principles of neurosurgery.1,3–6 iMR imaging can provide updated information on anatomy and on unanticipated brain events, so allowing safer and more accurate surgery.10–12 Interoperative time-resolved imaging of contrast-kinetics (iTRICKS) can provide high spatial and temporal resolution during iMR imaging. We describe the efficacy of iMR imaging and iTRICKS during AVM surgery with a fully integrated 1.5 T neurosurgical system with neuronavigation and intraoperative imager.

Case Report
A 44-year-old female presented with sudden onset of severe headache. MR imaging showed left occipital hemorrhage (Fig. 1A, B). Cerebral angiography disclosed a Spetzler-Martin grade 2 AVM in the left occipital lobe. The diameter of the nidus was approximately 3 cm. The AVM was fed by the posterior cerebral artery (Fig. 1D). Preoperative TRICKS provided excellent visualization of the AVM (Fig. 1C). Left occipital craniotomy was performed and the nidus was removed. After completion, iMR imaging was performed using an integrated 1.5 T neurosurgical system with neuronavigation and intraoperative imager using flexible heart coils (Surgical Suite®; BrainLAB AG, Munich, Germany and GE Healthcare, Chalfont St. Giles, United Kingdom). The imaging parameters for TRICKS were as follows: repetition time 3.5 msec, echo time 1.4 msec, flip angle 15°, field of view 240 × 240 mm, acquisition matrix 256 × 160, section thickness 3.0 mm (resolution doubled using zero fill interpolation processing) to obtain 6.0-cm volume coverage, bandwidth 62.5 kHz, and excitations per scan 0.5. TRICKS reconstruction generated...
Fig. 1 Preoperative T2-weighted magnetic resonance (MR) image (A), T1-weighted MR image after administration of contrast medium (B), and time-resolved imaging of contrast-kinetics image (C) showing left occipital hemorrhage (arrow). Selective left common carotid digital subtraction angiogram (D) revealing a Spetzler-Martin grade 2 arteriovenous malformation in the left occipital lobe (arrow).

Fig. 2 Intraoperative T1-weighted (A) and T2-weighted (B) magnetic resonance images, and time-resolved imaging of contrast-kinetics image (C) showing complete removal of the arteriovenous malformation.

Fig. 3 Postoperative T2-weighted magnetic resonance (MR) image (A), T1-weighted MR image after administration of contrast medium (B), and selective left common carotid digital subtraction angiogram (C).

Neurol Med Chir (Tokyo) 51, July, 2011

This report describes the successful use of iMR imaging and iTRICKS at 1.5 T for confirmation of complete resection of the AVM. Partial resection does not confer any improvement over the natural history risk of hemorrhage of AVMs, and may actually increase the risk of hemorrhage.\textsuperscript{14)} Postoperative or intraoperative angiography is critical to assess residual AVMs and can also facilitate surgery. The true incidence of residual lesions after resection of intracranial AVMs is not well documented. In one report, a residual nidus was not detected during AVM surgery using intraoperative angiography, but following occlusion of the patient’s femoral artery after surgery. ICG videoangiography was used to detect and totally remove the AVM.\textsuperscript{16)} The spatial and temporal resolution of conventional angiography (typically $0.2 \times 0.2 \text{ mm}^2$ and 1
frame per 0.3–0.5 sec) is superior to that of 1.5 T TRICKS (0.94 × 1.5 mm², 1 frame per 2.0 sec), but false negatives were found in 18% of patients in a series of intraoperative angiography with AVM surgery.¹³) Ultrasonography and ICG videoangiography are useful and easy tools for AVM surgery as there is no need to move the microscope from the surgical field or interrupt the operation.²,⁶,¹⁶,¹⁷) However, ultrasonography has poor spatial resolution. ICG videoangiography can detect only superficial architecture, and may fail to detect residual nidus intraoperatively.⁵,¹⁶) The spatial and temporal resolution of TOF MR angiography images is also not adequate for AVM surgery.¹⁵)

IMR imaging at 1.5 T can be advantageous over the conventional assessments of residual nidus and unanticipated brain events during AVM surgery and can potentially improve the cure rate. The combined use of IMR imaging with iTRICKS is important for verification of the surgical results. IMR imaging can be used to visualize any residual nidus precisely using suitable, commercially available protocols. TRICKS, a new technique, can be used for time-resolved three-dimensional MR digital subtraction angiography because it can achieve the temporal and spatial resolution needed for evaluation of AVMs.⁸) TRICKS at 3 T has various advantages compared to conventional angiography for preoperative assessment of AVMs.⁹) TRICKS achieved 96% sensitivity and 100% specificity both in nidus detection and in early venous filling detection. The Spetzler-Martin grades showed excellent correlation with catheter angiography findings. Compared to lower field strengths, IMR imaging at 1.5 T has several advantages, as the higher intrinsic signal/noise ratio allows the acquisition of images with higher spatial and temporal resolution, and the TRICKS protocol is feasible at this field strength.

This case report demonstrates the efficacy of IMR imaging and iTRICKS at 1.5 T during AVM neurosurgery. IMR imaging with iTRICKS is an excellent technique for intraoperative quality control and documentation of neurosurgical outcomes.

References


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Neurol Med Chir (Tokyo) 51, July, 2011