Surgical Simulation with Three-Dimensional Fusion Images in Patients with Arteriovenous Malformation

Takayuki Hara and Masanori Yoshino

Introduction

In AVM surgery, evaluation of angiostructure is essential to make a good surgical strategy. With conventional two-dimensional digital subtraction angiography (DSA), it is sometimes difficult to understand AVM structure stereoscopically. Three-dimensional rotational angiography (3D-RA) gives us much more precise information about the relationships of each feeder, drainer, and nidus, but when the AVM is supplied by a multiple vascular territory (e.g., middle cerebral artery and posterior cerebral artery), all the details cannot be seen in one image. For the surgical simulation, the location of the nidus in the brain is also important so as to decide the surgical approach. Recent image fusion technologies have helped surgeons create virtual surgical fields, especially in brain tumors [1–3]. In this article the authors introduced 3D fusion images in AVM surgeries and evaluated their clinical use.

Methods

Image data, including 3D-RA, 3D-rotational venography (RV), comported tomography (CT), and magnetic resonance imaging (MRI), was obtained from AVM patients. Three-dimensional-RA and RV were performed with a C-arm angiography unit (Allura XperFD 20/10; Philips Medical Systems, Best, the Netherlands). The C-arm rotated through 240° at 55°/s and obtained 120 images on a 17-in. FOV during contrast injection. MRI was performed with a 3.0-T system for the head (Ingenia 3.0T; Philips Healthcare, Andover, MA.). Fluid-attenuated inversion recovery (FLAIR) in MRI was acquired with an eight-channel head coil. CT was done with a 64-section CT scanner (Aquilion; Toshiba Medical Systems, Tokyo, Japan). The slice thickness was 1 mm.

Image data was coded in digital imaging and communication in medicine (DICOM) format and was imported to the two different imaging applications. In this study, we used iPLAN cranial (BrainLab, Germany) and Avizo (Visualization Science Group, Bordeaux, France) for 3D image reconstruction using a previously reported method [1, 2]. In iPLAN, the 3D model was constructed with a volume rendering method with autosegmentation, whereas Avizo used a hybrid method combining surface- and volume-rendering methods, and manual segmentation was used to distinguish the small anatomical structures, such as the feeding arteries, from surrounding noise.

Results

The 3D fusion images of the right parietal lobe AVM for a representative patient are illustrated in Fig. 1. The fusion image with iPLAN has lower resolution and the feeders, nidus, and drainers are not distinguishable because these three vasculatures are visualized in the same time phase in case of arterio-venous shunting disease. Avizo created higher resolution images, and feeders, drainers, and normal vessels are visualized clearly with different colors. Also, each feeder and its supplying territory in the nidus are distinguished, and surgical simulation becomes possible after adding the MRI (FLAIR) and CT images (Fig. 2). On the other hand, the time required for creation is much shorter in iPLAN (approximately 1 h) than Avizo (more than 3 h).

Discussion

In AVM surgery, understanding the angiostructure is essential for planning good surgical strategy. In principle, feeders should be occluded before the dissection and obliteration

T. Hara (✉) · M. Yoshino
Department of Neurosurgery, Toranomon Hospital, Minato-ku, Tokyo, Japan
e-mail: takayuki_hara@syd.odn.ne.jp

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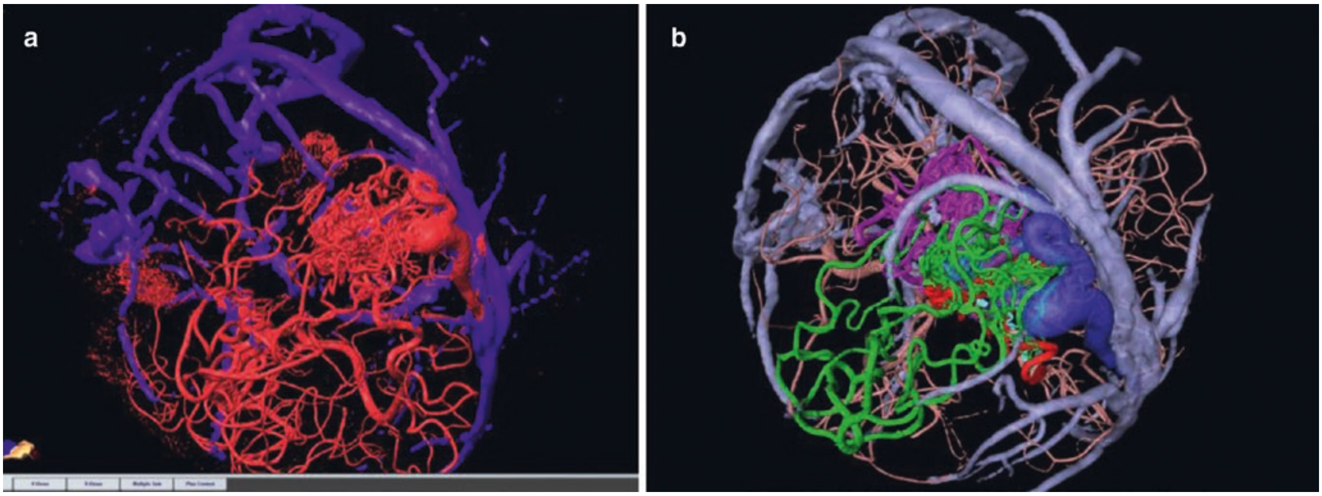

Fig. 1 Three-dimensional fusion images in an 18-year-old female with right parietal AVM. (**a**) Fusion image by iPLAN. Feeder, nidus, and drainer are visualized in the same color. (**b**) Fusion image by Avizo. Each feeder, drainer, and surrounding normal vein is identified separately with high resolution

of the gliotic tissue around the nidus. However, in conventional angiography, and especially with high-flow AVMs, it is sometimes difficult to identify each feeder and its anatomical relationship with the nidus and drainers. Three dimensional-RA images give us much more precise information about the angiostructure of AVMs, and have become prerequisites for the surgery. However, in the real surgical field, we have to dissect the nidus from the brain, and the feeders may be found on the brain surface or in the sulci or fissures; therefore it is also necessary to evaluate the anatomical relationship between the AVM and the brain. Surgeons must currently use their experience and knowledge to mentally reconstruct 3D fusion images from different modalities for this purpose. In this study, we created two types of 3D fusion images in AVM patients with different imaging software and compared their efficacy in the surgical simulations. Images by iPLAN were easily created without much time or AVM surgery experience, because this software enables the automatic segmentation of DICOM data. The resultant 3D fusion image is highly versatile, the quality is similar between creators, and it can be introduced to the navigation system (BrainLab), all of which make surgical simulation easier for less experienced surgeons. On the other hand, the resolution is not so high and each feeder and its supplying territory in the nidus are not distinguishable. Moreover, it is difficult to find "hidden feeders" existing just behind the drainer, which we sometimes encounter in a clinical setting, because feeders and drainers are recognized in the same color. In contrast, 3D fusion images by Avizo are created by both surface and volume rendering methods, so that they have a much higher resolution and the contrast between feeders, nidus, and drainers are much better than with the images by iPLAN. Therefore, we can identify all feeders even if they are close to the drainers or "en passage" arteries (Fig. 2). Avizo can also discriminate not only each feeder but also its supplying territory in the nidus with different colors, helping us to understand which feeders impinge more on the nidus (Fig. 2). According to these data, we can then decide which feeders have priority for surgical or endovascular occlusion. Adding MRI data to the Avizo images produces a virtual surgical field and surgical simulation (positioning, craniotomy, exposure of the brain, and the dissection of the nidus) becomes easy.

AVM surgical simulation with other virtual reality technologies has also been published [4, 5]. In these articles, the authors created 3D fusion images with a virtual reality simulator (Dextroscope), but they used only MR-angiography (MRA) and MR-venography (MRV) as vessel images, so the resolution of each vessel was not as high and classification of each feeder and its supplying territory in the nidus was impossible. To our knowledge, only Avizo provides adequate detail to distinguish individual feeder territories, so it may have an advantage especially in the surgical simulation of large, complex AVMs. On the other hand, the limitation of the Avizo imaging technique is that it is time-consuming because the segmentation of DICOM data and extraction of each feeder must be done manually and requires some knowledge of AVM surgery.

Conclusions

To make the surgical simulation of AVM easier, it is important to visualize all vasculatures sterically. Recent technologies have made this level of detail possible with 3D fusion

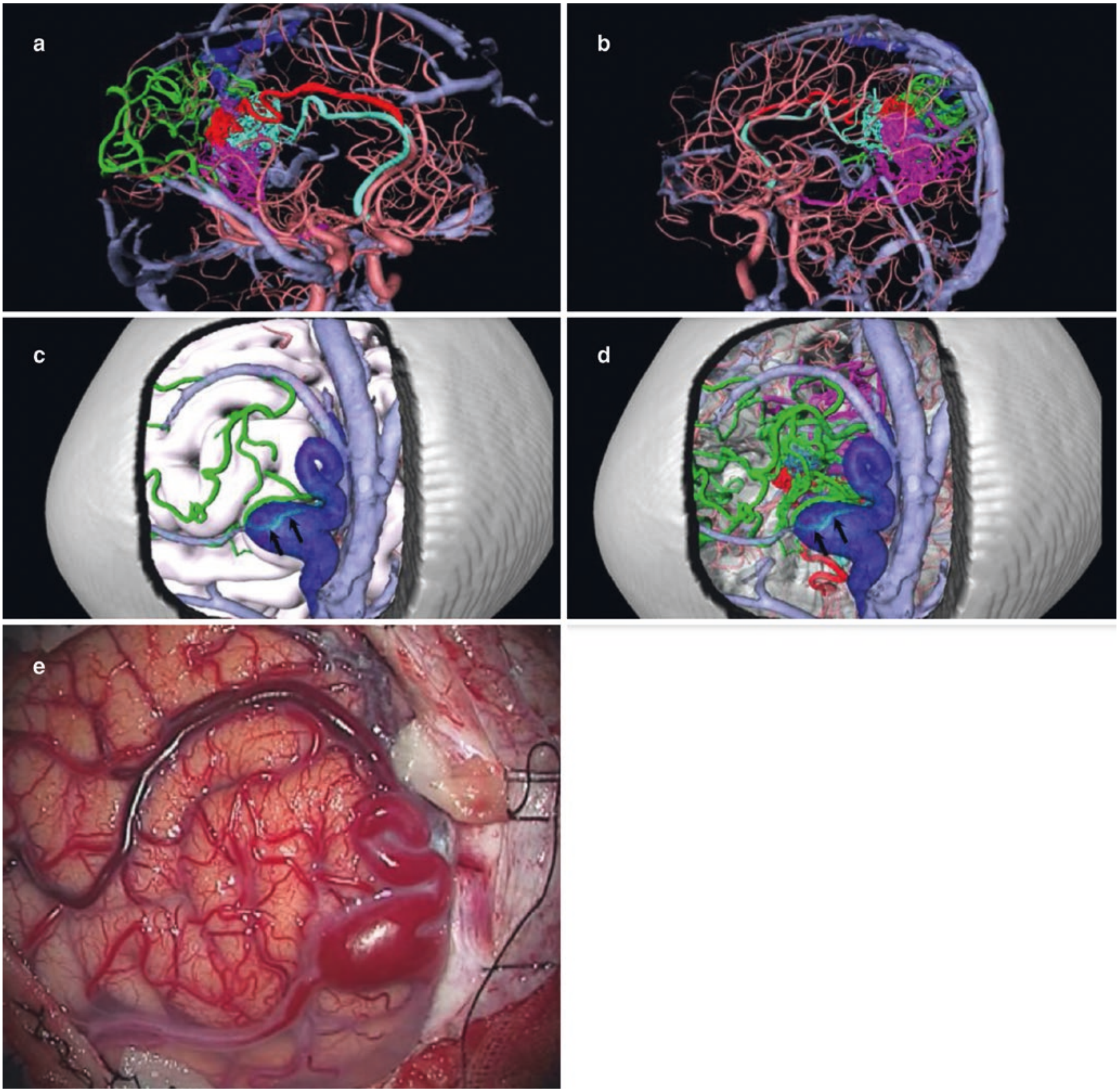

Fig. 2 Three-dimensional fusion images of the same patient by Avizo and comparison to the surgical field. (**a**, **b**) Not only each feeder but also its supplying territory in the nidus is well demarcated. Feeders from anterior cerebral arteries are colored red and cyan, those from middle cerebral arteries are green, and those from posterior cerebral arteries are pink. (**c**, **d**) Surgical simulation using fusion images. The feeder existing just behind the main drainer (arrows) is well recognized. (**e**) Real surgical field in the same patient. The cortical artery feeders were quite similar to fusion image (**c**)

images. Our study demonstrates that the Aviso 3D fusion images may be especially useful in surgical simulations for large, complex AVMs, and adoption of this technology may contribute to safer AVM surgeries.

Conflict of Interest The authors declare that they have no conflict of interest.

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