DOI 10.1007/s10527-018-9772-5
Biomedical Engineering, Vol. 52, No. 1, May, 2018, pp. 14-18. Translated from Meditsinskaya Tekhnika, Vol. 52, No. 1, Jan.-Feb., 2018, pp. 10-13.
Original article submitted December 3, 2016.

A Hybrid Neurosurgical Operating Room: Potentials in the Treatment of Arteriovenous Malformations of the Brain

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This article presents a novel technical solution to the surgery of cerebrovascular diseases – a hybrid neurosurgery operating room. Operation rooms of this type represent a state-of-the-art neurosurgical operating room including an angiography instrument, a surgical microscope, and a neuronavigation system. Hybrid operation rooms combine endovascular and microsurgical methods within a single operative procedure. We present the technical and organizational points, advantages and disadvantages, and results from the treatment of patients with complex cerebrovascular diseases in hybrid operating rooms.

Introduction

Contemporary invasive methods for the treatment of cerebrovascular pathology include microsurgical and endovascular methods, which are often applied sequentially and separately, dividing procedures into stages performed in different parts of the hospital and often with significant time intervals between them. Digital subtraction angiography (DSA), in contrast to magnetic resonance angiography (MRA) and computerized tomography (CT), provides highly precise imaging of normal and pathological brain vessels. Thus, DSA is used diagnostically for precise planning of microsurgical procedures and for imaging in endovascular closure of arterial aneurysms and arteriovenous malformations (AVM) of the brain. In addition, DSA is also performed to monitor the extent of treatment in the early and later post-operative periods [1].

The concept of hybrid operating rooms [2, 3] consists of combining endovascular and microsurgical methods of diagnosis and treatment in a single operating room. The fixed X-ray angiography system provides a smooth transition between the main microsurgical stages and the use of digital subtraction angiography. Angiographic studies are performed without changing the positions of the patient's head and body by movement of the C arch.

The main advantage of having the angiograph in the operating room is perioperative provision of high-resolution angiographic images with immediate evaluation and interpretation by the neurosurgeon of hemodynamic changes after stepwise removal of AVM nodes from the circulation [4]. The key point is that this allows the greatest possible removal of vascular lesions during a single surgical procedure and in a single operating room.

The planning and design of hybrid operating rooms presumes integration of any medical equipment and provision of the appropriate specialists required for effective and timely diagnosis and treatment of patients with complex cerebrovascular pathology.

The aim of the present work was to describe the concept of a hybrid operating room and its capacities in relation to the treatment of AVM in the brain. This study was performed as part of the scientific-applied collaboration between the Irkutsk State Medical University and Fukui University, Japan.

Technical Equipment for Hybrid Operating Rooms

The hybrid operating room is fitted with a Magnus operating table (Maquet Getinge Group, Germany),

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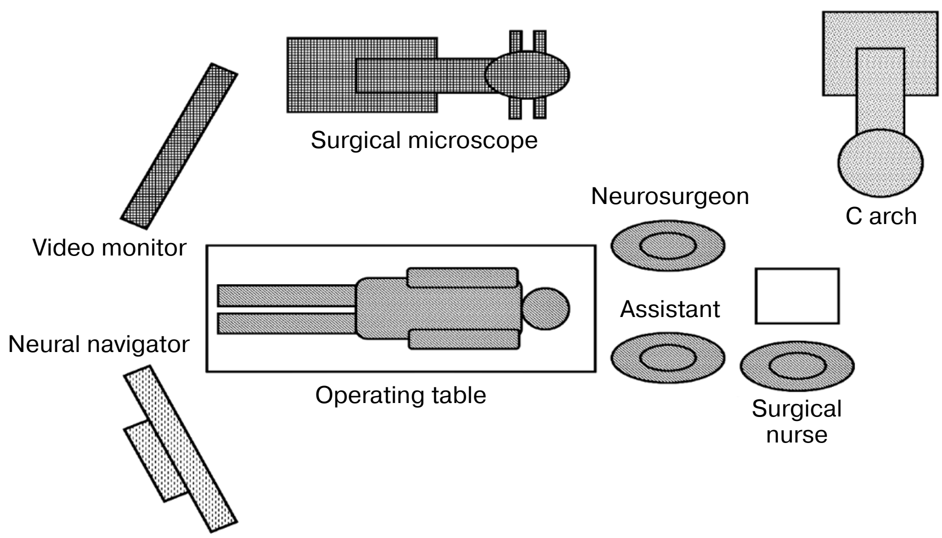

Fig. 1. Diagram of hybrid operating room (see text for explanation).

which can be placed in three positions: for induction of anesthesia and for the angiographic and surgical stages of operations. The patient's head is fixed in an X-ray-transparent three-point clamp (Mayfield® Integra Infinity XR2, USA) and is recorded using a Curve frameless neuronavigation system (BrainLab, Germany). Neurophysiological monitoring is carried out using a Neuropack MEB-2208 apparatus (Nihon Kohden, Japan).

The Allura Xper FD20 (Phillips, Netherlands) X-ray surgical angiographic system consists of a C arch with a flat panel detector, the working field size of 30 × 40 cm, and a high-resolution matrix of 2560 × 2048 points. DSA images are displayed on a 56" color LCD display (FlexVision XL, Phillips, Netherlands). Suspension from the ceiling allows motorized movement of the C arch and display to provide rapid imaging in different projections and compact accommodation of the arch in the room.

The microsurgical stages of surgery are performed under magnification using a Leica M720 OH5 operating microscope with an FL400/800 fluorescence module (Leica Microsystems, Germany/Switzerland) for intraoperative videoangiography with indocyanine green (Fig. 1).

Technique for Removal of AVM in a Hybrid Operating Room

We will consider the technology for the surgical treatment of AVM in a hybrid operating room using the example of the treatment of a female patient aged 46 years with a grade II (Spetzler–Martin classification) AVM of the right temporal lobe. The AVM was asymptomatic and was detected on a brain MRI scan performed for convulsive seizure (Fig. 2, a and b). The patient underwent total microsurgical resection and clipping of the AVM in the right temporal lobe via subtemporal craniotomy with intraoperative cerebral DSA.

Preparation in the operating room. After initiation of anesthesia, the patient was placed on the operating table with the head fixed in the clamp. The operation field for craniotomy was marked, treated, and delimited, and access to the femoral artery was obtained.

Diagnostic cerebral DSA. The first step was catheterization of the right femoral artery by the Seldinger method. Standard methods were used for sequential selective cerebral DSA of the branches of the internal carotid and vertebral arteries in the direct and lateral projections (Fig. 2, c-e). Maintenance of the intravascular guide catheter required continuous irrigation of the lumen with heparinized physiological saline (5000 U of heparin and 1000 mL of physiological saline) until subsequent intraoperative angiography.

Microsurgical stage of surgery. The frameless navigation system was used, along with pre-operative DSA data, for targeted right-sided subtemporal craniotomy with visualization of the base of the surface of the anastomosis of the pathological AVM. Fluorescent videoangiography was performed with indocyanine green to identify the location of the vascular node and the main pathological incoming and outgoing vessels of the AVM. Microsurgical dissection and removal of the node were

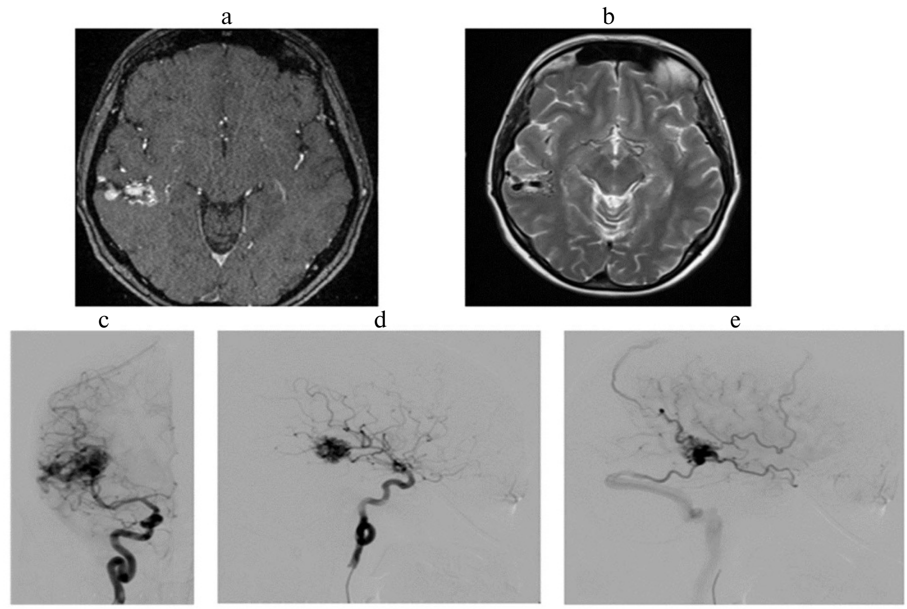

Fig. 2. Pre-operative MRI brain scans: MR angiogram (a), T2 regime (b), and intraoperative angiograms in the direct (c) and lateral (d, e) projections show the AVM nodule in the right temporal lobe, with a blood supply from branches of the middle cerebral artery and pathological release into the superficial venous system.

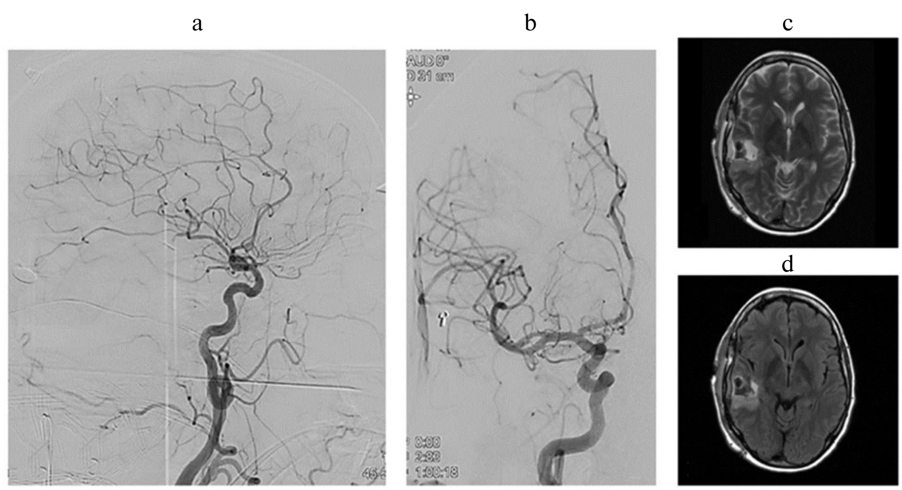

Fig. 3. Intraoperative DSA images in the lateral (a) and direct (b) projections after clipping of the branches of the anterior choroid artery supplying the AVM and post-operative MRI images in the T2 (c) and T1 (d) regimes show complete removal of the malformation from the circulation.

performed, with stepped clipping of the incoming anterior and middle temporal arteries. Control videoangiography with indocyanine green using the surgical microscope identified the flow of contrast into the AVM node but did not visualize the source of the blood supply.

The endovascular stage of surgery. Intraoperative DSA was performed by the neurosurgery team using the previously formed access. The C arch was brought into position in place of the surgical microscope. A standard method was used to employ the existing femoral access for selective catheterization of the right internal carotid artery (ICA). The high resolution of the resulting images of the basin of the right ICA allowed the incoming right anterior choroidal artery supplying the AVM node to be identified.

Continuation of the microsurgical stage. The presence of residual incoming vessels, which were branches of the anterior choroidal artery, was an indication for clipping. To decrease the risk of invasiveness and to prevent the risk of hemorrhage associated with dissection close to the node, selective transtemporal access to the anterior choroidal artery was obtained. The neuronavigation system and intraoperative angiograms were used to verify the right anterior choroidal artery. Microsurgical dissection with removal and clipping of the AVM-supplying branches was performed, and the AVM was completely resected.

Endovascular monitoring. Control DSA was performed and showed radical removal of the AVM from the circulation (Fig. 3, a and b). The femoral catheter was removed and a pressure dressing was applied.

The patient was transferred to the neurosurgery department on day 2 without neurological deficit and was discharged on day 8 in satisfactory condition. MRI follow-up demonstrated radical removal of the AVM (Fig. 3, c and d).

The Place of the Hybrid Operating Room in Current Approaches to the Treatment of AVM

Making intraoperative images is now an obligatory stage in any operative procedure in vascular neurosurgery. Despite the active development of neuroimaging methods (CT and MRI angiography), DSA continues to be the gold standard for the diagnosis of vascular malformations of the brain and spinal cord [5]. Improvements in fluoroscopic techniques using flat screen detectors have provided significant improvements in the quality of DSA images. Furthermore, the neurosurgeon can use a programmable system built into the C arch system to obtain a rotating 3D model of the brain vessels [6]. It is important to note that the combination of microsurgical and endovascular methods is one of the optimal means of treating complex aneurysms of the brain vessels and AVM. The combined use of contemporary neuronavigation systems, a surgical microscope, microsurgical instrumentation, and intraoperative DSA provides for safe microneurosurgical procedures on brain vessels. In parallel with this, the development of endovascular techniques also provides for effective and safe removal of vascular anomalies from the circulatory system. Ideally, all operations for complex AVM and vascular aneurysms of brain vessels should be performed using DSA, 3D models, microneurosurgical instrumentation, and endovascular treatment methods (removable coils, balloon catheters, stents, glue composites) [7].

Advantages and Disadvantages of the Hybrid Operation Room in the Treatment of AVM

The advantage of hybrid operating rooms in the treatment of vascular anomalies, including AVM, has been demonstrated in a whole series of studies. For example, Iihara et al. demonstrated the advantage of a hybrid operation room over a standard mobile DSA in the treatment of complex vascular anomalies in the brain [8]. A study reported by Fandino et al. also demonstrated the efficacy of hybrid surgical methods in the treatment of complex aneurysms of brain vessels [9].

However, hybrid operating rooms do not lack drawbacks. For example, the cost of the equipment and organization of a hybrid operating room requires enormous investment, while complex vascular anomalies are not encountered particularly frequently in the population. Yamakawa et al. analyzed the costs of treatment of complex vascular anomalies using hybrid operation rooms and came to the conclusion that operation rooms of this type are economically disadvantageous. The authors explained these conclusions in terms of the fact that a hybrid operating room is not used frequently and the clinical efficacy of hybrid surgical procedures is in some cases dubious [10]. Murayama et al. came to the same conclusions [11].

Conclusions

The concept of a hybrid operation room is assessed from the point of view of the equipping and organization of adjacent units during neurosurgical procedures for cerebrovascular pathology. This organization is based on a clear interaction between neurointerventional specialists and neurosurgeons during the surgical procedure.

Data obtained by intraoperative DSA on the supplying branches and residual drainage vessels of an AVM make a significant contribution to the efficacy of surgical treatment, monitoring the extent of radical removal of AVM from the circulation, and exclusion of the need for repeat surgery. Despite the significant cost of the equipment and provision, the concept of a hybrid operation room is effective and has potential as a technical solution in the treatment of patients with complex cerebrovascular pathology, which is illustrated by a clinical example and published data, and provides a decrease in the frequency of detecting post-operative residual nodes and, thus, repeat operations.

REFERENCES

1. Byval'tsev, V. A., Belykh, E. G., and Stepanov, I. A., "Selection of a method for the treatment of cerebral aneurysms in different locations with the development of contemporary endovascular techniques: a meta-analysis," Vestnik Ross. Akad. Med. Nauk, No. 1, 31-40 (2016).
2. Oded, G., Stephen, J., Moshe, H., Mati, B., and Sagi, H., "Modern intraoperative imaging modalities for the vascular neurosurgeon treating intracerebral hemorrhage," Neurosurgical Focus, **34**, No. 5, 122-124 (2013).
3. McCormick, W., "Pathology of vascular malformations of the brain," in: Pathology of Vascular Malformations of the Brain, Williams & Wilkins, Baltimore (1984), pp. 44-63.
4. Kim, H., Su, H., Weinsheimer, S., Pawlikowska, L., and Young, W., "Brain arteriovenous malformation pathogenesis: A response-to-injury paradigm," Acta Neurochir. Suppl., **111**, 83-92 (2011).
5. Haydon, D. H., Chicoine, M. R., and Dacey, R. G., "The impact of high-field-strength intraoperative magnetic resonance imaging on brain tumor management," Neurosurgery, **60**, No. 1, 92-97 (2013).
6. Leng, L. Z., Rubin, D. G., Patsalides, A., and Riina, H. A., "Fusion of intraoperative three-dimensional rotational angiography and flat-panel detector computed tomography for cerebrovascular neuronavigation," World Neurosurg., **79**, 504-509 (2013).
7. Byval'tsev, V. A., Preventive Revascularization for the Prophylaxis of Ischemic and Hemorrhagic Strokes [in Russian], Author's Abstract of Doctoral Thesis in Medical Sciences, Moscow (2010).
8. Iihara, K., Satow, T., Matsushige, T., Kataoka, H., Nakajima, N., and Fukuda, K., "Hybrid operating room for the treatment of complex neurovascular and brachiocephalic lesions," J. Stroke Cerebrovasc. Dis., **65**, 178-183 (2012).
9. Fandino, J., Taussky, P., Marbacher, S., Muroi, C., Diepers, M., and Fathi, A., "The concept of a hybrid operating room: Applications in cerebrovascular surgery," Acta Neurochir. Suppl., **115**, 113-117 (2013).
10. Yamakawa, K., Kiyama, S., Murayama, Y., and Uezono, S., "Incidence and neurological outcomes of aneurysm rupture during interventional neuroradiology procedures in a hybrid operating suite," J. Anesth., **26**, 592-594 (2012).
11. Murayama, Y., Arakawa, H., Ishibashi, T., Kawamura, D., Ebara, M., Irie, K., and Takao, H., "Combined surgical and endovascular treatment of complex cerebrovascular diseases in the hybrid operating room," J. Neurointerv. Surg., **5**, 489-493 (2013).