Endovascular operating suite: future directions for treating neurovascular disease

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Object. The purpose of this study was to evaluate initial experiences in a surgical operating room (OR) with a multi-purpose angiography unit, which offers integrated neurosurgical and radiological capabilities.

Methods. A specially designed biplane digital subtraction (DS) angiography system was installed in the neurosurgery OR. The new suite, which allows three-dimensional DS angiography with C-arm for computerized tomography and microsurgery capabilities, allows the neurosurgeon to perform a wide range of neurosurgical and endovascular procedures. Three hundred thirty-two procedures were performed in the endovascular OR between November 2003 and March 2005. Patients arriving in the emergency department were transferred to the endovascular OR without delay. The neurovascular team performed diagnostic angiography followed by endovascular interventional procedures or surgery.

Conclusions. The newly designed endovascular OR facilitates safe and systemic treatment of neurovascular disease.

KEY WORDS • endovascular therapy • digital subtraction angiography • cerebrovascular disease

Endovascular therapy was established during the last decade as an alternative treatment for neurovascular disease. In particular, development of the Guglielmi detachable coil system expanded the indications for endovascular treatment of cerebral aneurysms. This minimally invasive method plays an important role in the treatment of various neurovascular diseases. Historically, endovascular treatments have primarily been performed by radiologists, and procedures have been performed in the radiology angiography suite. However, neuroendovascular procedures involve both radiological examination and therapeutic neurosurgery. Although many endovascular procedures can be performed in conventional angiography suites, an environment with proper sterility and preparedness is needed to perform combined surgical exposure and endovascular procedures. If untoward technical complications occur, patients must be transferred immediately from the angiography suite to the operating suite. This delay of emergency procedures may result in the risk of poor clinical outcomes. To achieve a safe and effective endovascular and surgical environment, we established a new concept of the endovascular OR for the treatment of neurovascular disease.

A newly designed state-of-the-art biplane DS angiography unit was installed in a surgical OR offering integrated neurosurgical and radiological capabilities. This facility helps accommodate the expansion of neurosurgery from conventional surgery to the more widely used minimally invasive endovascular neurosurgery.

Clinical Material and Methods

One of two neurosurgery ORs at our institution was renovated for the endovascular OR, and a specially designed biplane DS angiography system (Axiom Artis BA; Siemens Medical Solutions, Erlangen, Germany) was installed in November 2003. The system was recently upgraded to an Axiom Artis dBA flat panel detector unit (Fig. 1). The new suite, which has 3D DS angiography and microsurgery capabilities, allows neurosurgeons to perform a wide array of neurosurgical and endovascular procedures.

Patient Population

Three hundred thirty-two procedures were performed in the endovascular OR between November 2003 and March 2005. The following procedures were performed: aneurysm embolization (100 patients), arteriovenous malformation and dural arteriovenous fistula embolization (32 patients), angioplasty or stent placement (13 patients), tumor embolization (nine patients) and presurgical cerebrospinal angiography with or without subsequent surgical procedures (aneurysm clipping, spine intervention, and so on; 164 patients).

Operating Room System and Equipment

The endovascular OR consists of a surgical procedure

Abbreviations used in this paper: CT = computerized tomography; DS = digital subtraction; MR = magnetic resonance; OR = operating room; 3D = three-dimensional.
room, a DS angiography control room for the technologist, and a computer room (Fig. 2). Ample operative space (12 × 10 m) is required for performance of endovascular procedures and microsurgery. Adequate lighting and ventilation were included as standard requirements for an operating suite.

The DS angiography system consists of a biplane C-arm and a newly designed multipurpose radiolucent surgical table with a special radiolucent head clamp system. The surgical table allows 120° rotation, with the capability for ± 15° head tilt and ± 15° lateral head movement. The radiolucent operating table can be controlled by neurosurgeons using foot pedals and control panels without the assistance of a technologist.

The biplane C-arm unit comprises a floor-mounted frontal plane and a ceiling-mounted lateral plane, allowing biplane fluoroscopy and digital acquisition.

For image viewing, seven flat display monitors were equipped for biplane angiographic imaging and 3D imaging. During surgery, the monitor is easily repositioned to assist in visualization. Images from 3D CT, MR imaging, or angiography can be displayed on the 3D monitor during endovascular and surgical procedures.

Biplane real-time fluoroscopic images and macro images (handling of the catheter, and so forth) are digitally recorded on the digital video system.

For microsurgery, a conventional macro light was mounted in the ceiling and an OME 8000 microscope (Olympus, Tokyo, Japan) was included.

Soft-Tissue Imaging (Dyna CT)

In addition to conventional two-dimensional and 3D angiography, a newly developed imaging system (Dyna CT: Siemens) for soft-tissue visualization was installed. This advanced application provides bone and soft-tissue images using the DS angiography C-arm system. Postprocedural 3D CT can thus be obtained using the DS angiography C-arm in the OR without moving the patient. During 3D image acquisition, the anteroposterior C-arm moves continuously around 220°. The high-resolution 3D image data set is reconstructed using the OR 3D workstation.

Three-Dimensional Workstation Office

In addition to the conventional 3D workstation in the operating angiography suite, another 3D workstation was installed in the endovascular neurosurgery office. This workstation is useful for neurosurgical planning and simulation before surgery or embolization. Images from MR imaging, MR angiography, angiography, and 3D CT can be automatically sent to this workstation. Surgeons can then carefully
evaluate vascular anatomy and relationships to the skull before the procedure.

**Endovascular Procedure Setup**

Patients arriving in the emergency department can be immediately transferred to the CT unit. Conventional CT and 3D CT angiography were performed using a 16-multislice CT scanner (Siemens Medical Solutions) for all aneurysm patients. The 3D data were immediately transferred to the OR 3D workstation. Subsequently, the patients were transferred to the endovascular OR. Diagnostic angiography followed by endovascular interventional procedures or surgery was performed by the neurovascular team.

By that time, patients were intubated for induction of general anesthesia. In general, all aneurysm embolizations were performed with the patient in a state of general anesthesia. Under sterile conditions, uni- or bilateral femoral arteries were punctured and a No. 5- or 6-French sheath was placed.

After diagnostic angiography, a 3D DS angiogram was usually obtained for embolization. Embolization was selected in most cases. If aneurysm morphology was not appropriate for embolization (extreme wide-neck or too small for embolization), then surgical intervention was performed.

**Surgical Setup**

After diagnostic angiography, the biplane C-arm unit was placed in the parking position. The OR table was then rotated 60° to the surgical position. The conventional head folder was removed and the newly designed, carbon head clamp adaptor was attached to the OR table. The radiolucent Mayfield head clamp was then attached to the patient (Fig. 3). The monitor system was positioned in front of the neurosurgeon for evaluation of images from 3D CT or 3D angiography.

After surgical clipping, conventional and 3D angiography were immediately performed to confirm the location of clips. Postoperative CT scan (Dyna CT) was performed in the endovascular OR without moving the patient.

**Results**

This new system was applied successfully in 332 procedures, including unruptured aneurysm embolization, ruptured aneurysm embolization, ruptured aneurysm clipping, arteriovenous malformation/artiervenous fistula embolization, carotid/vertebral percutaneous transluminal angioplasty or stent placement, tumor embolization, open surgery, and diagnostic angiography. Among the 112 intracranial aneurysms treated, endovascular embolization was performed in 100 patients. Surgical clip occlusion was performed in 12 patients due to aneurysm morphology and rupture during embolization in one.

To verify the accuracy and quality of Dyna CT, we compared original images obtained in the first 15 patients with postoperative conventional multislice CT scans. Although the original image quality of soft-tissue imaging obtained using the conventional image intensifier was not as good as that obtained using the multislice CT, the quality was remarkably improved using the flat panel detector system (Fig. 4).

**Illustrative Cases**

**Case 1**

This 45-year-old woman presented with a right unruptured carotid ophthalmic aneurysm; 3D DS angiography confirmed aneurysm size, volume, and relationship with the parent artery (Fig. 5). A microcatheter was advanced into the aneurysm, which was embolized using platinum coils. Postembolization angiography demonstrated occlusion of the aneurysm with a small remnant. The patient was discharged without deficit 3 days after embolization.

**Case 2**

This 70-year-old woman presented with acute severe headache. Conventional CT and CT angiography demonstrated acute subarachnoid hemorrhage and a small aneurysm of the left posterior communicating artery. She had a Hunt and Hess grade of III and a Fisher score of 3. The
The patient was immediately transferred to the endovascular OR. Cerebral angiography demonstrated a small (2-mm-diameter dome) aneurysm with a wide neck (Fig. 6). Severe stenosis of the internal carotid artery and atherosclerotic changes were noted. The neurovascular team decided on and planned to perform surgical clip placement. The radiolucent head clamp was fixed to the operative table, and microsurgical clipping was performed. After surgical clipping, intraoperative angiography was performed. Cerebral angiography demonstrated obliteration of the aneurysm. However, the internal carotid artery was stenotic due to clipping. The surgical clip was thus repositioned and postoperative angiography demonstrated normal appearance of the parent artery. The patient was discharged 1 month after her subarachnoid hemorrhage, with mild deficit.

**Discussion**

In the field of general vascular surgery such as triple-A aneurysm repair, endovascular intervention has been performed in the OR by using a portable C-arm system. Although portable C-arm fluoroscopy is acceptable for vascular surgery, the quality of images is insufficient for neurovascular interventions.

The dedicated endovascular operating suite offers several advantages over the conventional angiography suite. First, if coil embolization is unsuccessful (for example, due to a wide neck), the neurosurgeon can immediately convert the endovascular approach to conventional open surgery. Postoperative angiography can confirm the position of clips immediately after clipping. Second, much better support can be obtained from anesthesiologists. Due to the nature of the OR, anesthesiologists can work as normal without stress.

Third, although uncommon, immediate surgical intervention can be performed for unexpected complications, such as aneurysm rupture during embolization. Immediate ventriculostomy or hematoma evacuation can be performed with minimal delay compared with the delay involved in using a radiology angiography suite.

Fourth, combined surgical exposure can be performed through an endovascular procedure when this approach is
considered optimal or when a transarterial–venous approach proves unsuccessful, such as in isolated sinus with dural arteriovenous fistulas.

Fifth, using new soft-tissue imaging software Dyna CT, postoperative conventional CT can be replaced by C-arm 3D CT. This software enables imaging of soft tissue from digital angiography and DS angiography data. Transferring the patient from an OR to obtain CT scans is thus unnecessary. This software is also very useful for surgical interventions for the spine, such as instrumentation-placement procedures. Hott, et al., recently reported spinal intervention using C-arm CT on a portable system.

Sixth, because the equipment and operating suite belong to the neurosurgery department, there are no conflicts with the radiology department or other departments, such as therapeutic indications and room scheduling.

The system does have some limitations. Current operating tables cannot bend like the conventional surgical table. Only a head-up position, with or without lateral lean, is available (a V-shape is not available). New table designs are apparently under development. The cost of room modification is also higher than for conventional angiography suites, and OR air conditioning systems typically must be regulated by law.

A biplane DS angiography system with a 3D workstation is essential for modern endovascular procedures to avoid image-related complications. The system described herein requires a relatively large operative space for installation. Despite these limitations, we believe that this system facilitates the provision of safe and effective procedures for neurovascular patients.

Conclusions

Both endovascular and surgical capabilities are important to fully treat the spectrum of neurovascular disease in the optimal fashion. The neurovascular team must be familiar with both open surgery and endovascular technology for...
best treatment. The newly designed endovascular OR provides a resource for safe and systematic neurosurgical practice.

References


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