Chapter 4
The Hybrid Operating Room

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Advancements in neuroendovascular surgery have created a new era in the treatment of neurovascular diseases. The meteoric increase in technology coupled with device improvement has continued to propel our ability to treat a variety of cerebrovascular pathology via endovascular routes. At the same time, many complex cases are often managed best with the utilization of both open and endovascular techniques rather than as distinct therapeutic interventions [1, 2]. This has benefited patients by providing surgeons more avenues to safely intervene in neurovascular disease. Importantly, each individual can receive a tailored treatment plan that combines both open and endovascular tools. This marriage of open and endovascular surgery allows the surgeon the opportunity to combine the full array of capabilities in both specialties and unite them into a hybrid operating room [3]. This can result in specific challenges of patient selection, room layout, table adaptability, and anesthesia coordination which can be controlled in a single environment. Overall, as the discipline advances toward a combined effort in treating neurovascular disease, the evolution of the space in which we operate should also likely adapt. This will allow us a more efficient coordination and concentrated focus on the patient. This chapter will explore the challenges, layout, and patient selection of merging both worlds into one space: establishing a hybrid neurointerventional operating suite.

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Background

Cerebrovascular pathology can present with a wide variety of acuity of illness. Patients may present with an incidental finding or with life-threatening emergencies. The optimal care of these patients requires the need for various hospital resources such as intensive care units (ICU), operating rooms (OR), and radiology and endovascular suites. The current neurointerventional suite of today has evolved from traditional imaging suites. In the past, the major focus of these spaces was on diagnostic cerebral angiograms. Now these spaces serve as complex neuroendovascular operating rooms in which diseases such as complex intracranial aneurysms and large vessel occlusions can be methodically and comprehensively treated [3–5]. Treating and utilizing these rooms as similar to operating rooms require a change in mindset and culture. This poses many challenges for institutions. Traditionally, at most US hospitals, the operating room and endovascular suite are isolated and may geographically be distant. This can be fraught with medical issues when dealing with fragile and critically ill patients, particularly when resources such as anesthesia and/or ICU services are in a separate portion of the hospital. These logistical issues can place critical patients in situations that require multiple dangerous road trips. Not infrequently, many neurovascular patients require specialized airway equipment, emergency ventriculostomy kits, and surgical support that are not immediately available.

The current healthcare environment is also plagued with rising costs and limited resources. The continuation of this trend will force hospital administrators to operate with increased scrutiny on how resources are utilized as well as the associated cost. This will force us to be creative and smart in how we better utilize the resources and infrastructure we have. Into these challenges comes the hybrid operating room with combined full open and endovascular capabilities.

Obstacles to Establishment: Cost, Room Layout, and Specialized Equipment

Cost is usually the greatest limiting step in the procurement of a hybrid neurointerventional operating room. As the number of open microsurgical cases diminishes throughout the country, health economist and hospital administrators are hesitant to invest in a room that may not pay for itself. The increased cost for this room combined with the increased size creates a double challenge for the administration. The hospital administrators will be looking at what added revenues and incentives that embarking on such an endeavor would have. Recent clinical trials using endovascular thrombectomy have revolutionized the treatment of stroke from large vessel occlusion [6–10]. The development of comprehensive stroke centers will hopefully allow more patients to be funneled to high-volume centers which will bring in more revenue for the hospital to help offset costs elsewhere.

Operating room space has always been a premium. Combined space and personnel limit the number of ORs a hospital can staff. The hybrid rooms are typically larger than most operating rooms. In addition, many hospitals are limited by an established infrastructure with limited ability to expand. Strategies to overcome this include shared space with vascular and cardiothoracic surgery services, ability to use the space for diagnostic purposes, and room planning to allow the movement of imaging arms to allow versatility of room usage [4]. A significant investment and startup costs for renovations will be needed in order to bring about the change to have a more comprehensive, efficient system of the future. As hospitals struggle to stay economically balanced, this becomes a challenge.

The blueprint for a hybrid suite must consider both the inner room design as well as its position within the functional hospital system. Figures 4.1a, b are taken from within our hybrid operating room and shows several features important to its design. The unique space requires considerations for placing imaging equipment that is least intrusive and most adaptable. Ceiling-mounted equipment can be moved with more versatility and may best serve patients in such a constrained space as opposed to floor mounted that may be difficult to adapt to a variety of patient positions and pathologies. The mobility, in and out, of imaging equipment is a critical component in room design is shown nicely in Fig. 4.2. The surgical table must be dynamic in that it can be fixed during open cases and floating for endovascular procedures. Figure 4.3 demonstrates the radiolucent headholder, a necessary component, which allows 3D rotational angiograms to be performed after open microsurgical procedures. Dual rooms that are connected will achieve a better conservation of space in an ergonomic manner in addition to adapting to the unpredictable nature of emergent cases. The ability to have the table centered and avoid movement is typically preferred rather than rotating it into imaging mode. This is because of the access lines, anesthesia, and the endotracheal tube remaining free of manipulation by a centered fixed position. This allows for efficient flow during the case. Specifically, there is less risk to the patient and easier utilization of the 3D rotational angiography function. The control room is usually placed outside of the operating space to allow for image reconstructions and clinical decision-making away from the surgical space. These rooms should be placed in proximity to imaging and the ICU to further optimize care and provide a more efficient synchrony while limiting complications.

Patient Selection

The use of the hybrid room is ideal for the complex neurovascular patients, many of which require the application of combined endovascular and microsurgical procedures. The versatility of these rooms allows them to be expanded to other areas such as spine and skull base surgery. Neurovascular surgery technology has dramatically increased over the years, yet open microsurgery still maintains advantages in certain clinical circumstances. Many lesions are often best treated with a combined approach.

Fig. 4.1 (**a**, **b**) Intraoperative pictures demonstrating a typical setup for a hybrid OR for the bed, equipment, and anesthesia

Fig. 4.2 The dynamic nature of the hybrid OR must allow efficient transfer of equipment between open and endovascular cases

Fig. 4.3 The optimal radiolucent headholder fixated to a patient that will allow for a 3D rotational intraoperative angiogram

Several case examples of patients that would be optimally treated in a hybrid operating room are described. An evolving indication includes the treatment of an intracranial hemorrhage as depicted in Fig. 4.4. This patient was treated in the operating room with image-guided, endoscopic, minimally invasive removal of the hematoma as compared to traditional open craniotomy. Utilization of a hybrid room for this condition is both safe and can be more effective [5, 11]. Another common condition, ruptured intracranial aneurysms, will optimally be treated in hybrid OR's due to increased endovascular techniques in conjunction with open microsurgery if needed. Figure 4.5 demonstrates a patient that presented with a subarachnoid hemorrhage from a ruptured anterior communicating artery aneurysm. During endovascular coil embolization, there was intraprocedural rupture leading to

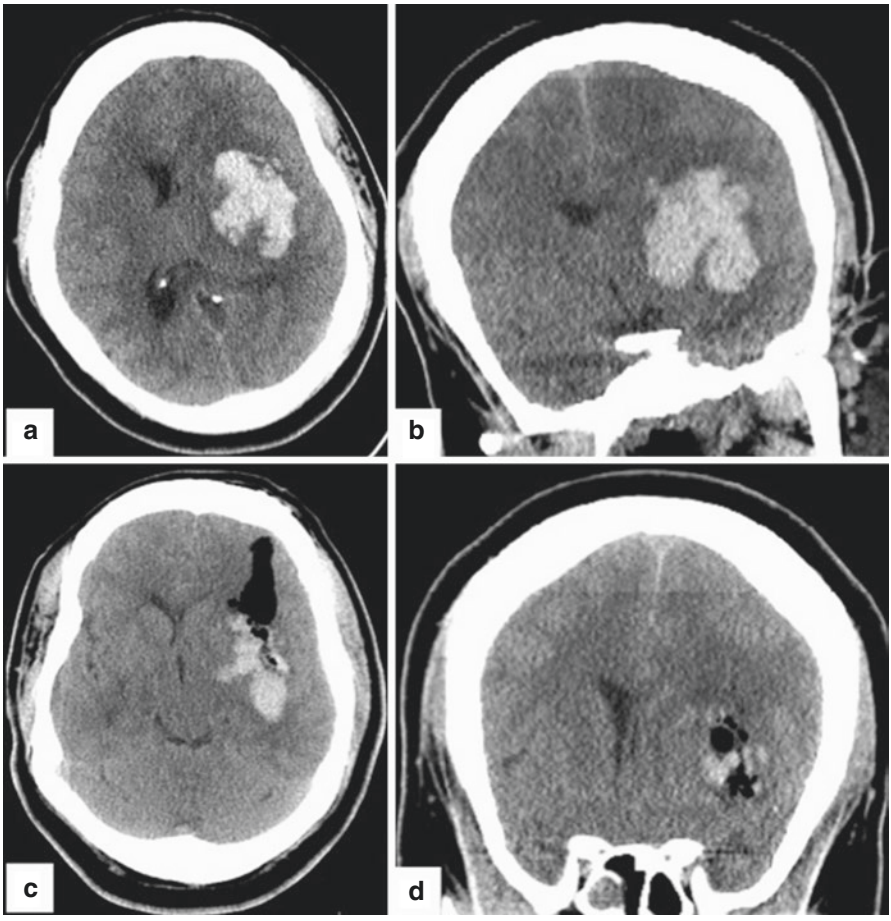

Fig. 4.4 A 45-year-old African American female presented with sudden onset aphasia and right hemiparesis. (**a**, **b**) Axial and coronal CT scans demonstrating a large basal ganglia hemorrhage. (**c**, **d**) Vascular lesion was ruled out, and patient was taken to the OR for image-guided minimally invasive endoscopic evacuation of hematoma

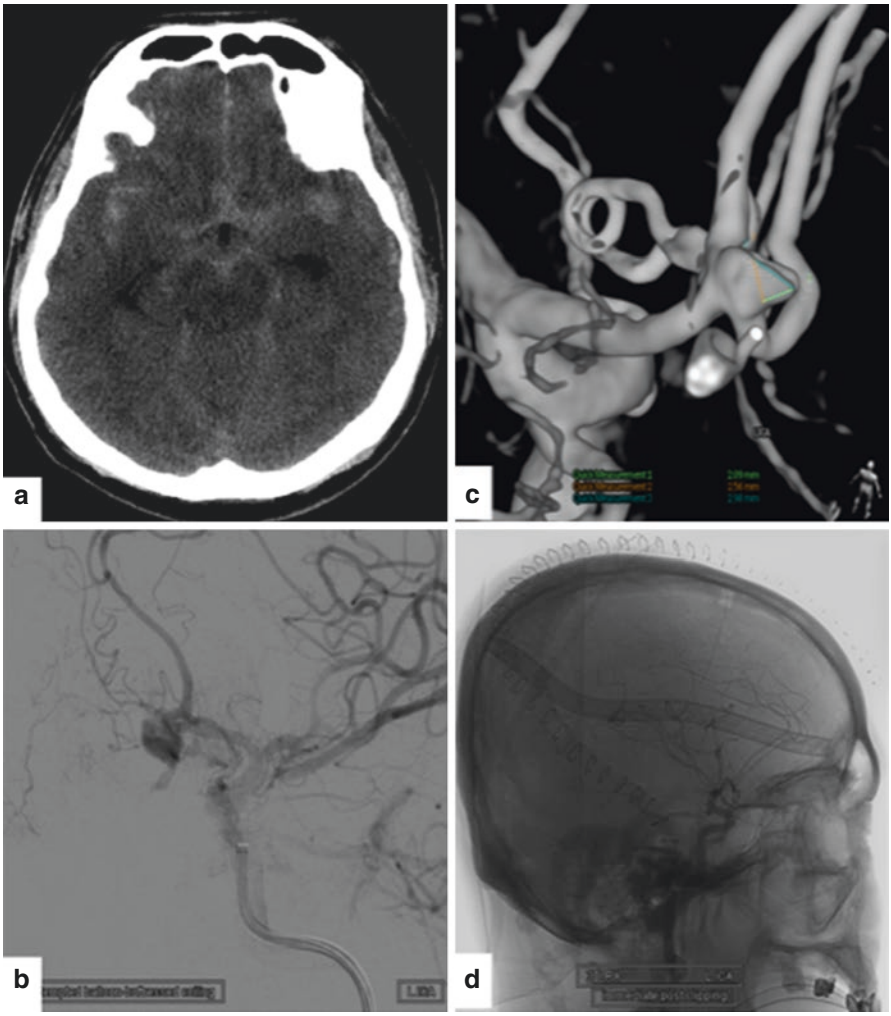

Fig. 4.5 A 55-year-old Korean gentleman presented with sudden onset headache and diffuse subarachnoid hemorrhage from a ruptured anterior communicating artery aneurysm. (**a**) Initial head CT showing diffuse subarachnoid hemorrhage. (**b**) Cerebral angiogram demonstrated ruptured anterior communicating artery aneurysm. Intraprocedural rupture occurred during attempted coil embolization requiring emergent transfer to the OR for microsurgical clipping. (**c**) 12-month follow-up angiogram showing enlarged triangular remnant requiring (**d**) repeat microsurgical clipping resulting in aneurysm obliteration

emergent open microsurgical clipping. A remnant remained that was present on follow-up angiogram that required subsequent clipping. Ruptured aneurysms that are associated with large hematomas are ideal for endovascular treatment as well as open decompression [12]. These types of cases are ideally suited for a hybrid operating room.

Other applications include the use of the 3D rotational angiogram post-microsurgical clipping to insure the aneurysm is ideally occluded and parent arteries are preserved. Figure 4.6 shows a patient with a ruptured anterior communicating artery aneurysm that underwent microsurgical clipping. Postoperative angiogram demonstrated residual filling of the aneurysm not appreciated on indocyanine green (ICG) angiography necessitating a return to the operating room. Hybrid OR's help to prevent a delay in detection, correction, or treatment of underlying vascular conditions.

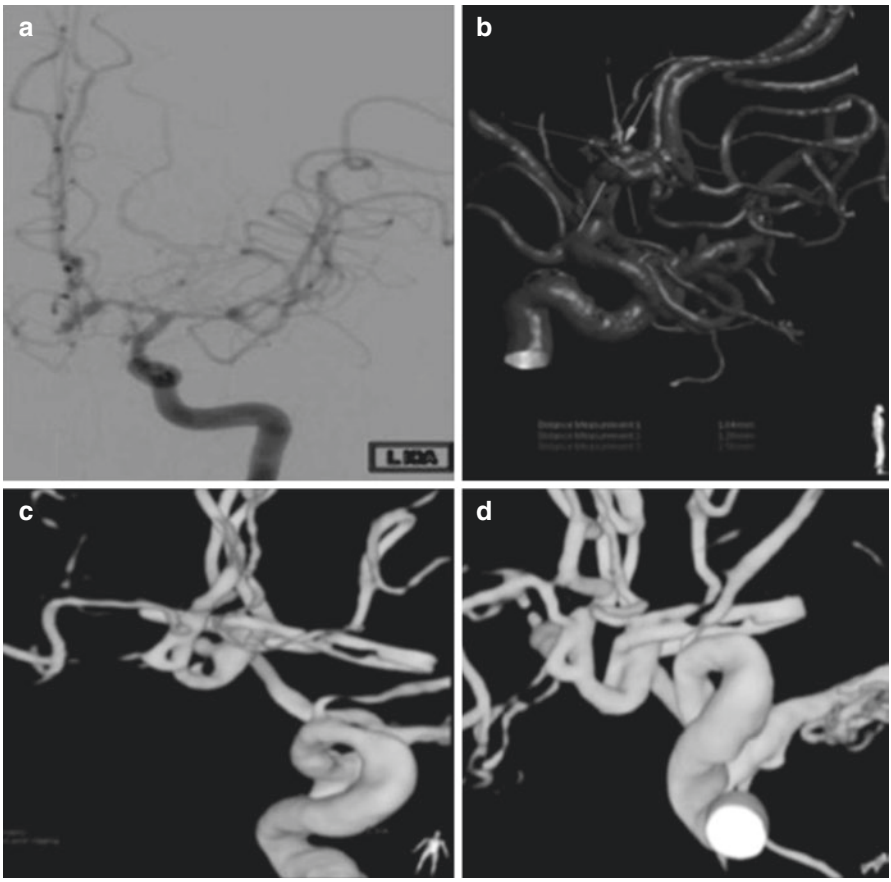

Fig. 4.6 (**a**, **b**, **c**) A 51-year-old Hispanic female presented with a Hunt and Hess 4, Fisher grade 3 subarachnoid hemorrhage from a wide-based anterior communicating artery aneurysm that underwent microsurgical clipping. Of note, the patient also had a chronic left supraclinoid ICA occlusion with collateral filling from the posterior circulation. (**d**) Postoperative angiogram demonstrated residual filling of the aneurysm necessitating return to the OR for repeat clipping

Other applications include the combined use of embolization and hematoma removal in a ruptured AVM or tumor embolization followed by microsurgical resection. Additional complex approaches to dural AVMs, bypass/trapping giant aneurysms, and in cases of penetrating trauma to insure underlying neurovascular injuries are not present as a decompressive craniectomy is emergently needed [13].

In the area of spine and skull base surgery, the use of combined percutaneous embolization, vertebroplasty, and open surgical decompression can be performed in one space [9]. Such combinations may limit blood loss, time of surgery, and physiologic stress to compromised patients [14]. This reflects the versatility that these rooms can have with applications to treat multiple types of pathology.

Conclusion

The future management of complex neurovascular disease should utilize a hybrid operating room. Figure 4.7 summaries the overall benefit of a hybrid operating room, specifically showing the ability to minimize patient transports and maximize therapeutic interventions. With increasing technology and improved techniques, employing both endovascular and open microsurgery to treat complex cerebrovascular disease will help improve patient outcomes. Many logistical obstacles including cost, infrastructure, and resources all will need to be evaluated before undertaking such a task. Solutions to these challenges must be overcome to better treat complex cerebrovascular disease and improve outcomes for our patients.

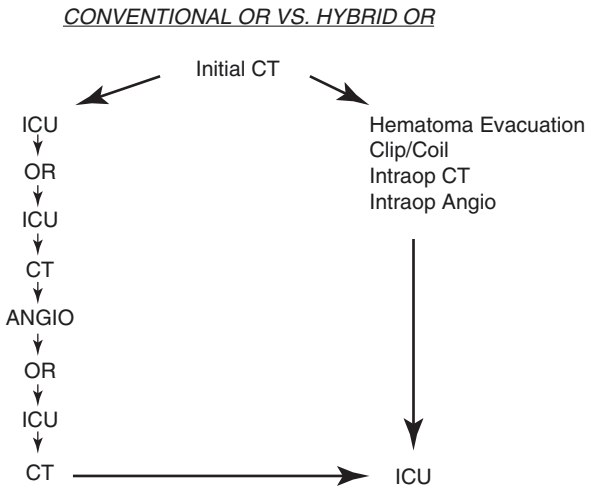

Fig. 4.7 A flowchart that details the advantages of a hybrid operating room by limiting patient transfers and increasing possible interventions

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