

Hybrid Operating Room Design Basics

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Mary Fearon, MSN, RN, CNOR



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www.fgiguideines.org
info@fgiguideines.org

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Hybrid Operating Room Design Basics

A hybrid operating room (OR) combines the capabilities of an operating room with the technologies of interventional imaging. With the combination of surgical facilities and imaging systems in one room, hybrid ORs can be used for traditional open surgeries, image-guided surgeries, or a combination of procedure types, offering greater flexibility and utility of the space.

Hybrid ORs offer many benefits to patients, clinicians, and health care organizations. In particular, state-of-the-art hybrid ORs facilitate provision of a broad range of procedures that are less invasive than traditional surgery and offer faster recovery times for patients. For example, complex cardiovascular and endovascular conditions that formerly required open heart surgery are now being diagnosed and treated with less invasive surgery in hybrid ORs. See Figure 1 for a representative list of procedures, by surgical specialty, typically performed in a hybrid OR.

Figure 1: Procedures that May Be Performed in a Hybrid Operating Room*

Surgical Specialty			
Cardiovascular	Cardiothoracic	Neurovascular	Other
Abdominal aortic aneurysm repair	Transcatheter valve replacement (TAVR)	Coil embolization or microsurgical clipping of cerebral aneurysms	Hemorrhage control in trauma patients
Aortic stent grafting	Percutaneous removal of cardiac device leads	Intracranial stenting of cerebral arteries	High-risk obstetrics
Carotid stent grafting	Minimally invasive endoscopic bypass surgery	Cerebral balloon angioplasty	Orthopedic trauma
Endovascular aortic repair (EVAR)	Minimally invasive direct coronary artery bypass grafting	Microneurosurgical resection of brain tumors	
Thoracic endovascular aortic repair (TEVAR)	Robotically enhanced minimally invasive direct coronary artery bypass	Combined carotid surgical cutdown followed by endovascular coiling for bypass of tortuous anatomy	
	Pediatric aortic and pulmonary stenosis	Combined arteriovenous malformation embolization followed by microneurosurgical resection	
	Hypoplastic left heart syndrome treatment	Cerebral vascular tumors	
	Off-pump coronary artery bypass	Spinal vascular tumors	
	Atrial fibrillation/flutter ablation		
Hybrid maze			

*These procedures are referenced in the asterisked citations in the Resources section.

Planning and Design Tools

The inherent flexibility required of a hybrid OR environment challenges the design team to go beyond the design requirements for such spaces to create an efficient work environment that can support the planned uses of the room and the operational complexity that comes from combining surgical and imaging services in the

Types of Hybrid ORs

Hybrid ORs are typically characterized by the type of imaging equipment installed in the room and the clinical services offered. They can be found in cardiac catheterization suites, interventional imaging suites, and surgical suites. Regardless of where the room is located, the hybrid OR design must combine the requirements of an operating room and an imaging room to allow the flexible use expected of a hybrid OR.

Imaging equipment commonly installed in a hybrid OR includes single-plane or biplane angiography equipment, computed tomography (CT) scanners, and magnetic resonance imaging (MRI) scanners. The single-plane system is the most commonly installed and is used for an array of cardiac and vascular procedures.

The multi-axial robotic angiography system is a single-plane system with eight rotational axes that provides more images at different angles without using biplane technology. It provides images similar to a CT scan but offers more flexibility. These systems may be mounted on the floor or ceiling.

Biplane systems, which can acquire images from two reference points at the same time, have two C-arms—one mounted on the floor and one on tracks in the ceiling. These systems are used most often for small-vessel angiography in pediatric patients and neuro-angiography and are required for neurosurgical cerebral endovascular procedures. Using two C-arms reduces the amount of radiation exposure and the need for contrast media.

CT and MRI system design specifications each have personnel and patient safety requirements to protect against excessive radiation exposure. For example, if a hybrid OR will have an MRI system, the American College of Radiologists (ACR) requires the design team to define four zones that recognize screening requirements and safety checks to prevent the magnetic force from pulling objects into the imaging system. It is important for the design team to consult with a radiation physicist to assure all relevant safety measures are considered during design of a hybrid OR.

same space. To achieve the hoped-for clinical and cost benefits from building a hybrid OR, careful planning is vital at the outset of a project. To help design teams deliver a facility that supports a health care organization's goals, this white paper defines the purposes and types of hybrid ORs, discusses facility planning and design considerations, and looks ahead to future trends that will change the use of this type of facility.

The Functional Program

If designers are to deliver a functional, effective hybrid OR design, the project must begin with development of a functional program that communicates the owner's intent. The owner is responsible for this effort, but the functional program is often created by a multidisciplinary team composed of representatives of the health care organization and the design team, including clinicians, architects, engineers, acoustic/vibration consultants, and facility representatives. A well-written functional program provides a solid foundation for the schematic design and design development phases of the project and should reflect both the current needs and future plans of the organization.

Primary considerations in developing a functional program are identification of the characteristics of the patient population to be served (e.g., pediatric patients, patients of size, etc.), the procedures that will be performed, and the imaging equipment needed. The imaging equipment is the most expensive component of a hybrid OR, so it must be chosen carefully to support the clinical services identified in the functional program. As well, the imaging equipment specified for a hybrid OR will drive design decisions about shielding, structural support, and equipment placement.

Hybrid OR design is influenced and regulated by several federal, state, and local codes. Tools to assist the multidisciplinary design team include the Facility Guidelines Institute (FGI) *Guidelines for Design and Construction* documents and the Association of periOperative Registered Nurses (AORN) *Guidelines for Perioperative Practice*.

FGI Guidelines for Design and Construction

FGI provides baseline requirements for design of hybrid ORs in the 2018 FGI *Guidelines for Design and Construction of Hospitals*.¹ Section 2.2-3.3.4.1 (Hybrid Operating Room: Application) states a hybrid OR “shall be designed to comply with the requirements [for operating rooms] and the requirements [for imaging services] that

¹Facility Guidelines Institute, *Guidelines for Design and Construction of Hospitals*, 2018 ed. (St. Louis: Facility Guidelines Institute, 2018).

apply to the imaging modality used in the hybrid operating room.” Section 2.2-3.3.3.2 (2) (Operating room for image-guided surgery . . .) provides the relevant OR requirements, while Section 2.2-3.4.2.1 (Imaging Rooms: General) provides general imaging room requirements, which are modified by specific requirements for the imaging modality used.

Also in the 2018 Hospital *Guidelines*, an imaging classification system was introduced to help in the design of imaging facilities. An operating room in this classification system is a Class 3 imaging room, traditionally termed a “hybrid OR.” Figure 2 demonstrates that the *Guidelines* requirements for operating rooms, both standard and hybrid, and for Class 3 imaging rooms are the same.

Application of the FGI *Guidelines* requirements provides a foundation for the physical design of a hybrid OR. Consideration of additional information provided in several *Guidelines* appendix sections can help designers determine when the baseline requirements are not sufficient for the procedures a health care organization plans for a particular facility. Highlights of the *Guidelines* requirements for a hybrid OR are included in this paper, but an in-depth review of them is crucial to the design effort.

Figure 2: Summary of 2018 FGI *Guidelines* Operating Room and Class 3 Imaging Room Design Requirements

Use	Design Requirements		
	Room Type	Location	Surfaces
<p>Invasive procedures [as defined in the <i>Guidelines</i> glossary]</p> <p>Any procedure [or Class 2 procedure for imaging] during which the patient will require physiological monitoring and is anticipated to require active life support</p>	Restricted area	Accessed from a semi-restricted area	<p><i>Flooring:</i> cleanable and wear-resistant for the location; stable, firm, and slip-resistant</p> <p><i>Floor and wall base assemblies:</i> monolithic floor with integral coved wall base carried up the wall a minimum of 6 inches</p> <p><i>Wall finishes:</i> washable; free of fissures, open joints, or crevices</p> <p><i>Ceiling:</i> monolithic, scrubbable, capable of withstanding cleaning and/or disinfecting chemicals, gasketed access openings</p>

Excerpted from Tables 2.2-1 and 2.2-2 in the 2018 FGI Hospital *Guidelines* and Tables 2.1-4 and 2.1-5 in the 2018 FGI Outpatient *Guidelines*

AORN Guidelines for Perioperative Practice

²Association for periOperative Registered Nurses (AORN), “Guideline for Minimally Invasive Surgery” in *Guidelines for Perioperative Practice* (AORN, Inc., 2017).

³AORN, “Guideline for Design and Maintenance of the Surgical Suite” in *Guidelines for Perioperative Practice* (AORN, Inc., 2017).

The AORN “Guideline for Minimally Invasive Surgery”² (MIS) and “Guideline for Design and Maintenance of the Surgical Suite”³ documents are published as part of AORN’s *Guidelines for Perioperative Practice*. The recommendations in these guidelines are evidence-based, intended to be achievable, and represent what is believed to be an optimal level of practice. Variations in practice settings and/or clinical situations determine the degree to which each guideline can be implemented. The AORN guidelines provide recommendations for establishing safe practices and decreasing the risk of injury and complications associated with procedures performed in operating rooms, including hybrid ORs.

The MIS guideline recommends that “the multidisciplinary team... select the imaging system and adjunct technologies that meet the identified requirements associated with the scope of services.” The multidisciplinary team may be composed of the following members:

- Architect
- Engineer
- Equipment manufacturer
- Infection preventionist
- Circulating RN
- Radiology circulating nurse
- Surgeon
- Anesthesia care provider
- Radiology technician
- Interventional radiologist
- Interventional cardiologist
- Perfusionist

AORN also recommends considering provision of space for additional equipment, such as new adjunct technologies for digital manipulation of images acquired by the system. Such technologies used in the hybrid OR may include 3D imaging reconstruction, echocardiography, intravascular ultrasound, digital subtraction angiography, video integration systems with picture archiving, and audiovisual recording systems. Planning for the footprint required by these technologies will assure adequate space is provided.

To create a safe environment for the patient and personnel working in the hybrid OR, consideration should be given to the flow

of patients, personnel, and supplies that will be needed for the procedures to be performed. The use of evidence-based concepts in design of the surgical suite, as recommended in the AORN “Guideline for Design and Maintenance of the Surgical Suite,” will facilitate this effort. This AORN guideline also defines the surgical suite zones (unrestricted, semi-restricted, and restricted), and these definitions are also included in the FGI *Guidelines*. The zones are determined by the activities performed in them; required access pathways; required staff surgical attire; and heating, ventilation, and air-conditioning (HVAC) system and surface requirements.

In determining the size and floor plan of an OR, AORN recommends dividing the room into four zones: sterile field, circulation pathway, movable equipment zone, and anesthesia zone. In a hybrid OR, it is particularly important to designate these zones during the planning process to ensure the OR is large enough to accommodate the added fixed equipment and adjunct technologies needed in a room with built-in imaging equipment.

VA Design Guide

Another respected source for hybrid OR design is the *Surgical and Endovascular Services Design Guide* distributed by the U.S. Department of Veterans Affairs. Developed to provide their multidisciplinary design teams with a better understanding of the design process and to enhance collaboration, the document has design templates for hybrid ORs that illustrate space, equipment, and related engineered system needs.⁴

⁴U.S. Department of Veterans Affairs, *Surgical and Endovascular Services Design Guide* (April 2016, rev. 5/18).

Design Considerations

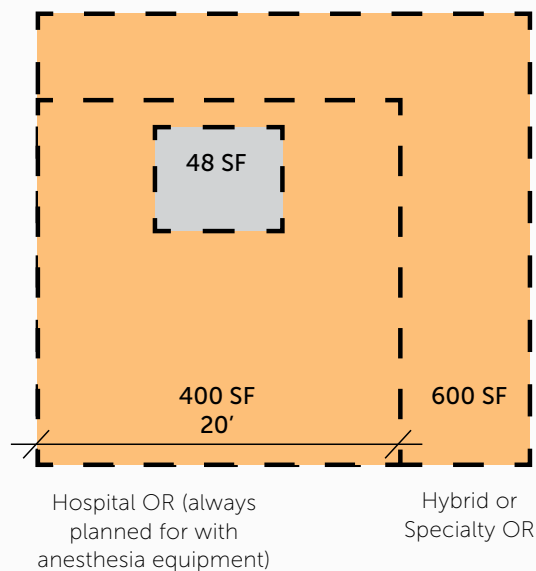
The functional program, discussed in greater detail above, provides the foundation on which the design team can base space planning decisions and health care administrators can base equipment purchase decisions during project delivery. Considerations essential for design of a hybrid OR include the following:

- Space requirements
- Imaging equipment
- Radiation protection
- Efficient workflow
- Acoustic considerations
- Environmental restrictions

Space Requirements

Because it must accommodate the space needed for both surgery and operation of the imaging equipment, a hybrid OR is larger than a standard operating room (see Figure 3). The 2018 FGI Hospital *Guidelines* requires a hybrid OR to “meet the clear floor area, clearance, and storage requirements for the imaging equipment contained in the room.” In addition, it must provide at least the minimum clear floor area of 600 square feet the *Guidelines* requires for a hybrid OR or a specialty operating room “for image-guided surgery using portable imaging equipment or surgical procedures that require additional personnel and/or large equipment” in Section 2.2-3.3.3.2 (2).

Figure 3: FGI *Guidelines* Minimum Clear Floor Area for Operating Rooms



However, ultimately, the size of a particular hybrid OR is determined by two components: the four zones required for all operating rooms (sterile field, circulation pathway, movable equipment zone, and anesthesia zone) and the clearances required by the imaging equipment to be installed. How much these zones and clearances may, or may not, overlap should be determined early in the design process.

The AORN “Guideline for Minimally Invasive Surgery” states, “The team should account for the specifications of the imaging system since it will drive the placement of the HVAC system center diffuser array, ceiling-mounted equipment (i.e., equipment booms, video monitors, and surgical lights), and other equipment.” In their 2013 *AORN Journal* article “Hybrid OR 101,”⁵ Jennifer Schaadt and Bruce Landau recommend hybrid ORs of 1,000 to 1,200 square feet for optimal functionality, although this may not be realistic in institutions with limited space.

⁵Jennifer Schaadt and Bruce Landau, “Hybrid OR 101: A Primer for the OR Nurse,” *AORN Journal* 97, no. 1 (2013): 81-100.

As recommended in appendix section A2.2-3.3.4.2 (Determining hybrid operating room size) in the 2018 *Hospital Guidelines* (see sidebar), it is important to consider how the imaging equipment, surgical field, ancillary fixed equipment, and clear floor area will interact when determining the size for a hybrid OR. As well, to assure adequate space for provision of anesthesia, the *Guidelines* establishes a minimum area of 48 square feet (6'x 8') for an anesthesia setup zone. Of this space, 32 square feet (4'x 8') is the anesthesia work zone. Once anesthesia setup is complete, the anesthesia equipment may be positioned closer to the head of the table, giving staff access to the remaining two feet from the setup zone to circulate during the procedure.

Two other design elements can also add to the footprint of a hybrid OR—a system component room and a control room. The system component room is a space for electronic components that need to be located in a room separate from the OR for heat load, infection control, noise, or serviceability reasons. The control room is the space from which staff operate the imaging equipment during a procedure. The large-format imaging modalities (i.e., CT, MRI, fluoroscopy)

Hybrid OR Space Requirements Excerpted from the 2018 FGI Hospital *Guidelines*

2.2-3.3.4.1 Application. Hybrid operating rooms (Class 3 imaging rooms) shall be designed to comply with the requirements in Section 2.2-3.3.3 (Operating Rooms) and the requirements in Section 2.2-3.4 (Imaging Services) that apply to the imaging modality used in the hybrid operating room.

***2.2-3.3.4.2 Space requirements**

- (1) Each hybrid operating room shall meet the clear floor area, clearance, and storage requirements for the imaging equipment contained in the room.
- (2) Where mobile storage units are used in lieu of fixed cabinets, placement of the storage units shall not encroach on the clear floor area and clearances needed for the equipment used.

A2.2-3.3.4.2 Determining hybrid operating room size. The size of a hybrid operating room is highly dependent on the functional requirements of the room as an operating environment as well as the requirements of the imaging equipment it contains, which generally increase the room area requirements. For example, in some hybrid operating rooms, imaging equipment is capable of sliding into and out of the surgical field to optimize clear floor area when it is not needed. In other examples, the hybrid operating room contains dual surgical fields—one adjacent to fixed imaging equipment and another outside of this sector.

The interaction of the imaging equipment, surgical field, ancillary fixed equipment (e.g., lights, service columns, etc.), and clear floor area for staff, floor equipment, and circulation should all be considered when determining the actual room size. The project team is strongly encouraged to perform a full-scale mockup of the room during design to ensure it will function properly as designed.

used in a hybrid OR each generally requires both a control room and a system component room.

The 2018 Hospital *Guidelines* requires provision of a system component room sized and configured “in compliance with manufacturer recommendations for installation, service, and maintenance” for a hybrid OR. A system component room may be

shared by more than one hybrid OR as long as the equipment manufacturer's recommendations are followed. Note that access to a system component room is permitted only from outside the OR to support infection prevention practices in the OR; in other words, no door from the system component room is permitted to open into the OR. This required arrangement may have an effect on OR layout.

The 2018 *Guidelines* does not require a control room for a hybrid OR, but the imaging equipment used in one is likely to require it. The control room generally must be separated from the hybrid OR with walls and a door; however, for hybrid ORs, the *Guidelines* permits omission of the door if the control room serves only one OR and meets the same requirements, including ventilation, as the OR itself. The orientation of the operating room table to the control room's shielded view window (designed for radiation protection) can also influence the size of an OR. It is preferable for the orientation to be determined by the interventionalist team and considered during the design phase to assure functionality in the completed space. In most hybrid ORs, the view from the control room is a "toe-view," although a "lateral or side view" is sometimes used. Room size, configuration, and geometry also affect the optimal view from the control room.⁶

Imaging Equipment

Determining equipment placement for a hybrid OR demands careful consideration as the imaging system dictates placement of some equipment based on the procedures to be performed and on the need to avoid interference with imaging equipment operation. Some systems have a fixed base mounted to the floor, while others have tracks in the ceiling that allow movement of the imaging equipment to different areas of a patient's body. These fixed points may affect placement of anesthesia equipment and access to the patient if the

Definitions for Support Spaces

System component room: A room that contains the electrical components for various imaging modalities (e.g., CT, MRI, fluoroscopy). **Note:** This room is not the same as the control room required for some imaging modalities.

Control alcove or room: A fixed shielded alcove or room intended to minimize radiation exposure of technologists and others in imaging rooms that contain non-portable radiation-emitting imaging equipment or imaging equipment requiring shielding from external sources of interference.

⁶U.S. Department of Veterans Affairs, *Surgical and Endovascular Services Design Guide*.

imaging equipment must, for example, be located at the head of the operating table.



Imaging equipment is a safety concern when it is moving due to the potential for collision with staff or other equipment. Designating a collision-free or “no-fly” zone in which personnel, monitors, and other ceiling-mounted equipment cannot be present while the C-arm is in motion limits opportunities for damage or injury. The multidisciplinary team should determine locations for the fixed imaging equipment, the operating table, and overhead lights and booms. Two ways to help with this task include use of a safety checklist of potential collision points (e.g., OR lights, video monitor, endotracheal tube, IVS, and catheters, etc.) and creation of standardized room setups that define optimal locations for anesthesia

machines, equipment booms, and monitors based on procedures to be performed, OR table position, and the particular imaging equipment's no-fly zone.

Radiation Protection

If the imaging equipment installed in a hybrid OR is a type that emits ionizing radiation, radiation protection must be planned during design of the room. Imaging modalities such as MRI or CT have different shielding requirements, which should be based on the manufacturer's requirements and the American College of Radiologists guidelines. As stated in the *FGI Guidelines*, a certified radiation physicist or expert representing the owner or relevant state agency specifies the type, location, and amount of radiation protection needed for the final approved imaging services layout and selected equipment.

Radiation protection requirements are typically included in the design specifications and project drawings. The design team will need to work closely with the radiation consultant to finalize these shielding requirements.

Creating an Efficient Workflow

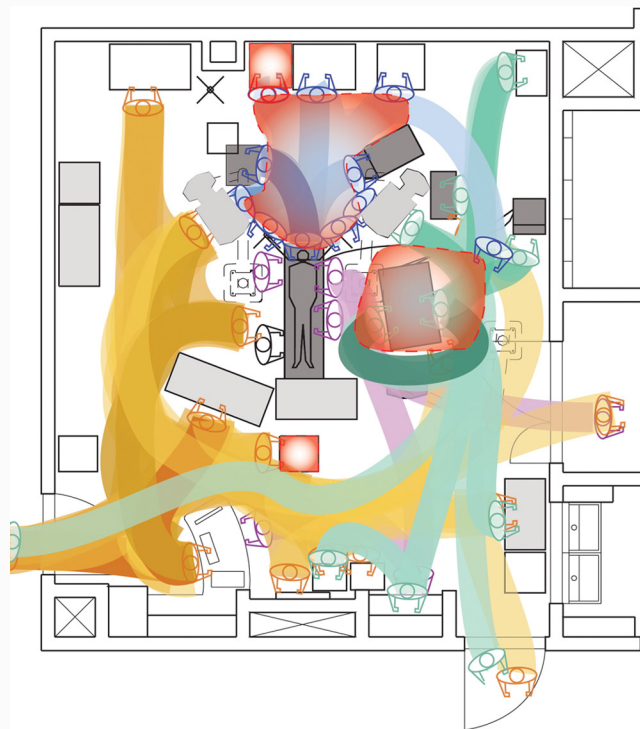
The unique challenges presented in designing a hybrid OR give the multidisciplinary project team an opportunity to improve workflow for all who will use the space. The interventional team traditionally has worked in a dimly lit room with the imaging equipment driving the design of the space and little to no flexibility in the location of the operating table. Development of a creative workflow model will support creation of an environment that accommodates imaging equipment and space for mobile equipment while still allowing flexibility for locating the operating table.

The traffic map shown in Figure 3, excerpted from a 2013 *Anesthesiology* article by G. Palmer et al.,⁷ demonstrates the interruptions and traffic flow of a typical surgical team. In this study, the researchers observed 10 cardiothoracic operations to capture

⁷G. Palmer et al., "Realizing improved patient care through human-centered operating room design: A human factors methodology for observing flow disruptions in the cardiothoracic operating room," *Anesthesiology* 119, no. 5 (2013): 1066-77.

flow disruptions as they occurred. Observers watched the traffic flow of personnel in the room through each phase of the procedure: preoperative, intraoperative, and postoperative. The color-coded diagram shows movement of nurses (goldenrod), anesthesiologists (blue), surgeons (purple), and perfusionists (green). The red zones show areas of concern (e.g., the space required for administering anesthesia and the clearance surrounding the sterile field).

Figure 4: Observed Operating Room Traffic Flow Patterns



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Mapping the flow of standard care tasks during the procedures performed in an OR will help designers plan a space that can accommodate an efficient workflow and support safe patient care. Studying the dynamics of the OR workflow, such as patient transfer to the operating table, the space required for anesthesia equipment, surgeon and other health care personnel ergonomics, and the nurses' ability to find equipment can have a profound influence on the design of the space. At minimum, creating a mock room setup—with movable temporary materials such as foam-core board or cardboard

boxes to simulate the fixed imaging equipment, equipment boom, and monitor locations—will allow the design team to assess the space required for the red zones (i.e., clearances around the sterile field or potential collision points of boom arms).

Finding design solutions that can decrease disruptions in the workflow in a hybrid OR will improve patient and staff safety. A multidisciplinary team that includes both imaging and perioperative personnel provides excellent perspectives for creating a successful workflow design and a safe patient care environment, according to the AORN “Guideline for Minimally Invasive Surgery.” The design team can guide the multidisciplinary team through a simulation merging two workflows—imaging and surgical—to test assumptions, identify areas of conflict, and find opportunities that may:

- Save money by reducing modifications during design and after construction begins.
- Encourage better staff communication during procedures.
- Make the OR environment safer for patients and staff.
- Reduce complexity by placing equipment, supplies, and controls in easily accessible locations.
- Support better teaching by providing sufficient space.
- Reduce disruptions during procedures.
- Improve patient outcomes.

Acoustic Considerations

Vibrations and acoustic disturbances can degrade the quality of images created in a hybrid OR; thus, experts in acoustic engineering should be included on the multidisciplinary project team to make sure the design avoids issues caused by excessive noise and vibration. The FGI *Guidelines* requires protection of the hybrid OR from “disruptive environmental vibrations and other disturbances in accordance with the imaging equipment manufacturer’s technical specifications.” Site readiness testing may be required prior to equipment installation.

Restricted Environment

Both the FGI and AORN documents state that an OR is a restricted area that can be accessed only through a semi-restricted space. This requirement means the hybrid OR must be located in a suite with semi-restricted corridors connecting the rooms.

Designation as a restricted area brings certain surface and ventilation requirements to support infection prevention practices. The FGI surface requirements for operating rooms and Class 3 imaging rooms (including hybrid ORs) are summarized in Figure 2. Monolithic ceilings are required to prevent contaminants such as dust from falling onto the surgical field.⁸ HVAC systems must meet the parameters for an operating room in ANSI/ASHRAE/ASHE 170: *Ventilation of Health Care Facilities*, which is included as Part 3 of the 2018 FGI *Hospital Guidelines*. A minimum of 20 air changes per hour (ACH) is required in a hybrid OR, and the room must have a positive pressure relationship to any adjacent space, including the control room and other semi-restricted areas such as corridors and storage rooms.

⁸AORN, "Guideline for Design and Maintenance of the Surgical Suite."

Challenges to Improve Design

Research to improve hybrid OR design is focused on human factor methodology, which takes a systematic approach to the evaluation of errors or disruptions in workflow that can lead to errors. Academic centers such as the Illinois Institute of Design and University of Chicago Medicine—Center for Care and Discovery are researching improved OR design. At University of Chicago Medicine, health care personnel and designers have worked together in teams to conceptualize an OR environment with improved ergonomics, equipment placement mapped to a specific surgeon, and improved cleanliness achieved with colored chemical tiles and bacteria-sensing mops.⁹

Looking to the future of hybrid OR technology will facilitate design of hybrid ORs that are flexible enough to change as imaging technology evolves. For example, a 2016 *World Neurosurgery* article

⁹Theresa Criscitelli, "Applying Human-Centered Design Thinking to Enhance Safety in the OR," AORN Journal 105, no. 4 (2017): 408-12.

by R. Ashour et al.¹⁰ describes a change in the typical design of a hybrid OR using biplane equipment for neuroendovascular procedures to improve efficiency when a combined open procedure using angiographic images is performed. The floor-mounted C-arm was moved to allow surgical access to the head of the operating table while keeping the biplane angiographic system in place over the lower body of the patient. This human factor design change improved workflow efficiency and decreased procedure time by reducing the transition between surgical and angiographic positions. The footprint required for imaging systems, design of the system component and control rooms, and location of the hybrid OR in the facility may change as more research is conducted on hybrid OR design and outcomes.

Further improvements in hybrid OR design can stem from studies of user-centered outcomes such as patient comfort on bed transfer, nurse ability to find important equipment, surgeon and anesthetist ergonomics during long procedures, and ability to communicate during patient hand-offs.^{11, 12}

¹⁰R. Ashour et al., "Refinement of the hybrid neuroendovascular operating suite: Current and future applications," *World Neurosurgery* 91 (2016): 6-11.

¹¹Adrien Hertault et al., "What should we expect from the hybrid room?" *Journal of Cardiovascular Surgery* 58, no. 2 (2017): 264-69.

¹²Andrew M. Ibrahim; Justin B. Dimick; and Anjali Joseph, "Building a better operating room: Views from surgery and architecture," *Annals of Surgery* 265, no. 1 (2017): 34-36.

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ABOUT THE AUTHOR



Mary Fearon is service line director for neuroscience at the Eastside Health Alliance in Kirkland, Wash. She was the lead author for the AORN “Guideline for Minimally Invasive Surgery” and “Guideline on Team Communications” in the *AORN Guidelines for Perioperative Practice*. Mary has been an operating room (OR) nurse for more than 30 years, working as a staff nurse, charge nurse, clinical nurse specialist, manager, and director. She has worked with multidisciplinary teams to complete several OR construction projects incorporating video and data integration, imaging technology, and improved efficiency in the environment.

Mary has participated in construction and design of hybrid ORs with single-plane, biplane, and multiaxial angiography and MRI technology. She speaks internationally on “The Power and Influence of the Perioperative Nurse” and the AORN “Guideline for Minimally Invasive Surgery and Emerging Technologies.”