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7 Hybrid room: Role in modern adult cardiac surgery

7.1 Introduction

A hybrid approach was initially proposed in the 1990s, as a combination of means available only in the catheterization laboratory with those typical for the operating room. The aim was to decrease the procedure invasiveness, while expanding the spectrum of cardiovascular lesions that could be tackled [1]. Angelini and colleagues [2] presented the first case series comprising six individuals submitted to an integrated surgical and percutaneous approach (minimally invasive direct coronary artery bypass [MIDCAB] with left internal mammary artery [LIMA] graft to the left anterior descending [LAD] artery with multivessel percutaneous coronary intervention [PCI] to non-LAD vessels), followed by a report of 18 cases in 1999 [3]. Today, hybrid procedures are performed routinely by dedicated teams, consisting of cardiac and/or vascular surgeons, along with invasive and noninvasive cardiologists or radiologists, supported by anesthesiologists and perfusionists, nurses, and technicians. The workplace for such a broad group of specialists and a manifestation of multidisciplinary approach toward patient care is a hybrid room.

The growing application of endovascular procedures and the complex minimally invasive cardiac and vascular surgeries lead to increasing imaging requirements in the operating room. Mobile image intensifier systems (C-arms) are often limited in terms of their image quality, radiation safety, and overheating. On the other hand, catheterization laboratories are not suitable for performing complex procedures involving cardiopulmonary bypass (CPB). Not only do they fail to meet the space requirements, but also there is difficulty managing asepsis. Hybrid rooms are modern (usually large) operating theaters, which provide comfort and safety to the surgical team, optimal radiation management, and best compromise between imaging quality and asepsis.

7.2 Components of the hybrid room

7.2.1 Surgical requirements

As all operating theaters, hybrid rooms should comply with asepsis requirements, typical for procedures with open approaches and implantation of medical devices. Beside an operating table offering a wide range of spatial settings (operating table must be radiolucent and is often made of nonmetallic carbon fiber [4]) and proper shadeless overhead surgical light, a hybrid room is required to have atmosphere

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control to prevent infections [5]. Proper laminar airflow and positive room pressure should be considered at the time of hybrid room planning, and used materials should be chosen as to minimize the release of any airborne particles. The presence and availability of all crucial elements of a traditional operating room, including cautery knife, suction, surgical sutures, and instruments, is necessary for easy conversion from a minimally invasive or percutaneous procedure to a fully open approach. The latter requires a possibility to back off the imaging system quickly, which should be easily and intuitively maneuverable. For cardiac hybrid rooms, it is also necessary to have an operational CPB machine on standby, and a clinical perfusionist should be a constant member of the team.

7.2.2 Room requirements

A large team of physicians, technicians, and nurses works with a single patient. Spatial requirements are substantial, as the team can count up to 20 members; a hybrid room should have a large area (≥70 m^2) to accommodate the personnel along with the equipment, including the fixed C-arm. Ceiling-mounted monitors should be abundantly present to allow all team members to visualize the images simultaneously (including, for example, angiographic and echocardiographic images together with hemodynamic monitoring [6]).

7.2.3 Fixed C-arm and imaging techniques

Hybrid rooms should offer good imaging quality resulting from the use of fixed high-quality radiological equipment. A basic imaging modality in the hybrid room is fluoroscopy, offering a live 2D x-ray view of progressing medical devices within the body. In cardiac interventions, quality requirements are high, and the fixed C-arm should be able to deliver a fluoroscopy with a high frame rate. Fixed C-arms are usually mounted to the ceiling or the floor, most of them having the ability to be moved away when not in use. Image quality improves, as image intensifiers are replaced by flat panel detectors. These offer a higher signal-to-noise ratio, have a wider dynamic signal range, and reduce the geometric distortion [5]. Other modalities (like integrated ultrasound, electromagnetic navigation systems, etc.) can be incorporated into the system. Moreover, advanced digital image processing methods are implemented to meet the needs of specific clinical situations, such as valve deployment planning during TAVI. A 3D C-arm CT can be obtained quickly to assist valve replacement or aortic stent graft placement. Workstations that allow image postprocessing are crucial for any hybrid room, as they not only allow planning and guidance but also support immediate intraoperative assessment of complex cases, e.g., intraoperative vessel analysis using automated vessel analyzing software to accurately size the implantable device.

All imaging devices within the hybrid room should be integrated into the institutional network to easily exchange information with other imaging modalities, and a connection with Picture Archiving and Communication Systems is mandatory. In addition, the control area for radiological technicians should have a direct view of the surgical field.

7.2.4 Image fusion

Live fluoroscopy imaging can be enriched by a superimposition of a 3D model of the vasculature, obtained preoperatively (CT or MRI) or periprocedurally (contrast-enhanced cone-beam CT). Original idea of simple approximate superimposition of 3D volume rendering on the vasculature evolves into more complex models, integrating case-specific information chosen by the operators, such as vessels ostia, best gantry angulation to support catheterization of those vessels, etc. This has been used in complex endovascular aneurysm repair with branched grafts [6]. The future of hybrid rooms will likely be influenced by the emergence of augmented reality technologies. Possible solutions that could find application include projection of data extracted from preoperative imaging studies on live fluoroscopy, or directly on patient skin, and virtual representations of x-ray exposure within the room. The new generation of image fusion will not only make the operator feel safer and more comfortable but also improve safety and efficiency of the hybrid room.

7.2.5 Radiation safety

Hybrid rooms with fixed imaging systems generally deliver less radiation than mobile C-arms; however, any personnel operating within this environment should use personal protection and radiation dosimeters, following the “as low as reasonably achievable” principles. Also, the room design itself is different from traditional operating rooms, including lead-lined walls and doors to reduce radiation outside the room, clear shields mounted to the ceiling (to be placed between the patient and the operator), lead aprons, etc. The building design needs to consider these requirements when planning a hybrid room.

7.2.6 Training

A growing number of hybrid procedures are performed worldwide, and this has implications for both interventionalists and surgeons. Vascular surgeons adopted percutaneous approach early, whereas cardiac surgeons were rarely trained in endovascular skills. The need for cross training is essential for multidisciplinary approach, and surgeons should be trained in the catheterization laboratory before moving to the hybrid room. Conversely, cardiologists and interventional radiologists should gain exposure to proper surgical technique and knowledge on anatomy. Although "hybrid specialists" are emerging, the role of the Heart Team is not to be underestimated and still vital.

7.3 Clinical application of the hybrid room

7.3.1 TAVI

TAVI has been performed since 2002, when Alain Cribier performed the first implantation in human [7]. Since that transfemoral implantation of a pericardial valvular prosthesis under fluoroscopic guidance, tremendous progress has been done. Currently, TAVI is the procedure of choice in patients deemed to have to high a surgical risk and plays an important role in valvular disease treatment. In some countries, TAVI represents almost half of interventions on the aortic valve [8], and the number of implantations has long exceeded 100000 [9]. Valve bioprostheses undergo crimping to minimize their size and represent grossly three main types:

– Balloon-expandable devices; e.g., Sapien valve (Edwards Lifesciences, Irvine, CA)
– Self-expanding devices; e.g., Evolut valve (Medtronic, Minneapolis, MN)
– Mechanically expandable devices; e.g., Lotus valve (Boston Scientific, Marlborough, MA)

The approaches used in TAVI include percutaneous transfemoral implantation, transapical implantation through small left lateral thoracotomy, or transaortic implantation, the latter usually requiring sternotomy. A dedicated Heart Team, always including a cardiac surgeon, should perform any such procedure. Although percutaneous transfemoral TAVI can be performed in either an interventional cardiology suite or a hybrid room (size of implantation systems is decreasing), the remaining types of procedures are best suited for hybrid rooms because of a larger surgical component. Procedural invasiveness gradually decreases, with straightforward transfemoral cases being performed under local anesthesia. A recent study of 12121 TAVI procedures performed in 48 French centers showed similar midterm mortality after TAVI performed in catheterization laboratory and in a hybrid room [10]. Notwithstanding, a cardiac hybrid room is best suited for the treatment of complications (such as vascular injury, myocardial perforation, or valve migration), where emergency conversion to a fully open approach with CPB use is possible immediately. Other possible approaches, such as transiliac, transaxillary, or transcarotid, are used less frequently.

New devices are vigorously developed, and the market is expanding because of excellent TAVI results. The PARTNER trials showed that TAVI was superior to medical therapy in inoperable patients (cohort B [11]) and had similar results to surgery in high-risk patients (cohort A [12]). Recent PARTNER 3 trial showed TAVI noninferiority compared with surgery in low-risk subjects for balloon-expandable devices [13], whereas Evolut low-risk trial presented similar results for self-expandable prostheses [14]. The trial data should be interpreted cautiously and still need to be verified by registries and real-life data; however, TAVI has already gained a great popularity. Despite that, the number of classic surgeries did not drop dramatically [8]. The undebatable advantage of TAVI is that it can be practiced on computerized phantoms, a feature unavailable for surgeons. Also, a growing body of evidence supports the notion that TAVI might be helpful in patients with previous surgeries (e.g., patient with a history of coronary artery bypass grafting [CABG] who developed aortic stenosis) or those who suffer from prosthetic dysfunction (valve-in-valve procedures) [6]. One should bear in mind, however, that infectious complications of prosthetic valve implantations (infectious endocarditis) are always managed surgically, irrespectively of the initial implantation technique. Hybrid interventions on other valves are currently under development, with mitral valve implantation being the most advanced.

7.3.2 Hybrid coronary artery revascularization

Hybrid coronary artery revascularization combines surgical technique with percutaneous interventions for multivessel coronary artery disease in a structured fashion. Usually, off-pump MIDCAB of the LAD is done through a small left lateral thoracotomy, whereas PCI-remaining non-LAD lesions are addressed with PCI. This approach is suitable for individuals who present with a high-grade multivessel coronary disease, whose LAD lesion is proximal whereas the peripheral vessel is surgically available, and the remaining lesions are suitable for PCI [1], especially in the setting of lacking graft material or LAD anatomy unfavorable for PCI. Hybrid coronary revascularization bases on the concept that LIMA to LAD graft is the main source of benefit from CABG, as LIMA-LAD grafts are known to have excellent long term patency (>95% after 20 years [15]). Hence, the arguable benefit of CABG is sustained by performing minimally invasive LIMA-LAD grafting, whereas other vessels are treated percutaneously [6]. Typically, MIDCAB is done first to provide protection of LAD territory during PCI and to prevent exposure to dual antiplatelet therapy during surgery [6]. It can be a one- or two-stage procedure, yet the perfect procedural timing is still to be established. In case of one-stage procedures performed in a hybrid room, the revascularization is complete with minimal patient discomfort [1]. Furthermore, the performance of the LIMA-LAD anastomosis can be immediately verified angiographically. CABG may also be combined with concomitant carotid artery stenting, whereas PCI can be a part of a hybrid procedure involving valve replacement, which can be done minimally invasive with less risk in such setting.

7.3.3 Endovascular aortic repair

Endovascular aortic repair is one of the most common procedures performed in hybrid rooms, especially if the indication is aortic aneurysm. Open repair of thoracoabdominal aortic aneurysms carries a high morbidity and mortality and was essentially replaced by endovascular techniques in cases with suitable anatomy. Hybrid room also finds increasing application in the treatment of Stanford type A acute aortic dissections, enabling exact diagnosis of coronary status and downstream organ malperfusion [16]. The perioperative diagnostic possibilities the hybrid room has to offer can alter the plan of surgical attack and influence the design of surgical and endovascular treatment, remaining safe for the patients [16]. In hybrid rooms equipped with CT capabilities, the verification of stent graft placement and early detection and correction of endoleaks (which might remain undetected with classic fluoroscopy [17]) are possible, also facilitating placement of branched or fenestrated grafts.

7.3.4 Hybrid antiarrhythmic procedures

Atrial fibrillation (AF) affects a growing number of patients, and the treatment of choice in case of paroxysmal AF is catheter ablation, if pharmacotherapy fails. Despite the high success rate (approx. 80%), the recurrences are common, and multiple procedures are frequently required [18]. The surgical treatment of AF, based on the procedure proposed by Cox and colleagues (Cox-Maze procedure), where the pathological conduction pathways are transected [19], has excellent efficacy, at the cost of invasiveness. With the development of surgical ablation tools, Maze procedure can be performed thoracoscopically, in a minimally invasive fashion; nevertheless, the less invasive approaches often lack transmurality and are less efficacious than the actual atrial wall transection. Hybrid approach combines both transvenous endocardial and thoracoscopic epicardial ablation to maximize the effect. Furthermore, left atrial appendage (where thrombi in case of AF are frequently generated) can be occluded minimally invasive in the hybrid room).

7.4 Conclusions

Hybrid rooms have become a necessary part of any cardiovascular hospital, enabling a whole spectrum of procedures that would otherwise be unavailable. This evolutionary concept integrating advanced imaging modalities with safety of an operating theater offers new possibilities, also by bringing together diverse and multidisciplinary teams. In the near future, augmented reality is likely to enter the daily routine of many hybrid rooms.

7.5 References

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