



Hybrid rooms for transcatheter valve interventions: rationale, vision and technical requirements

Transcatheter valve interventions are rapidly developing as an alternative to surgery for high-risk patients. Optimal management of patients before, during and after the procedure requires well-organized teamwork, gathering professionals with different skills and backgrounds. Hybrid operating rooms are becoming a requirement to increase safety and effectiveness. They will be multifunctional rooms with features derived from surgical rooms and angiographic suites. The design of the hybrid suite should be tailored to the planned procedures, and could be different in cases of aortic valve interventions compared with mitral valve interventions. Finally, building a hybrid operating suite goes beyond the mere design of a blueprint, but enters the crucial field of teambuilding and development of a multidisciplinary program. In the future, there will be a new generation of subspecialized interventionalists who will be specifically trained to perform transcatheter valve interventions and will operate in hybrid rooms.

KEYWORDS: aortic stenosis cardiac surgery hybrid suite mitral regurgitation transcatheter aortic valve implantation transcatheter valve intervention

The need for dedicated hybrid multifunctional rooms is increasing in several fields of medicine and surgery, including aortic disease and pediatric structural heart disease [1-4]. Hybrid rooms have usually been designed as upgraded surgical rooms, adding fluoroscopic capabilities to support special types of surgery requiring either intraoperative quality control or some form or radiologic guidance. Only rarely has a radiologic room or a cardiac catheterization laboratory been reconverted into a room with surgical capabilities.

The recent development of transcatheter valve interventions is introducing a new standard of technical and cultural requirements involving multiple imaging modalities and other supportive technologies to perform the procedures safely and effectively. This translates into the need for next-generation hybrid suites, the natural evolution of both cardiac surgical operating rooms and interventional catheter laboratories (cath-labs). By definition, a hybrid suite should fulfill the requirements of both a cath-lab and an operating room, without any compromise to sterility, imaging and patient workflow. Currently available cath-labs and operating rooms are highly inadequate for a safe performance of transcatheter valve interventions. While the cardiac cath-lab usually has good imaging capabilities but lacks in the necessary sterility, the opposite is true for the operating room. To overcome these limitations, the position statement of the European Society

of Cardiology (ESC)/European Association of Cardio-Thoracic Surgery (EACTS)/European Association of Percutaneous Cardiovascular Interventions (EAPCI) working group has acknowledged the need for an adequate environment for the performance of transcatheter valve interventions [5].

An evolving scenario of multidisciplinary collaboration

Transcatheter valve interventions are becoming a widely accepted alternative to valve surgery for high-risk and inoperable patients. A multidisciplinary approach has been and remains instrumental for the evolution of this field of cardiovascular medicine. The skills necessary to perform the procedures and to manage the patients are independent from the individual professional backgrounds and are a mixture of cardiac surgical and interventional skills.

The evolution of cardiac surgery has been characterized by a continuous trend towards less invasive interventions, not limited to reducing the size of the incisions, but also redesigning the overall management of the procedure, while increasing the role of image-guided decisionmaking. As an example, minimally invasive surgery is mainly guided by indirect visualization and is often planned with preoperative echocardiography guidance. Currently, interventional cardiology has progressively increased the degree of invasion, particularly in the field of structural heart interventions. As a result of Francesco Maisano^{†1}, Iassen Michev¹, Antonio Colombo¹ & Ottavio Alfieri¹

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this evolution, the next-generation operating room needs to become similar to a cath-lab and the next-generation cath-lab needs to become similar to an operating room.

Transcatheter valve technologies

Balloon dilatation of stenotic valves (aortic, pulmonic and mitral) is a standard procedure that has been performed for at least 25 years [6]. Its applicability has been relatively small and therefore the technology is not widely available and the experience is concentrated in only a few specialized centers.

Less than 10 years ago, the initial clinical experience of pulmonic and aortic valve implantation and of mitral valve repair took place surrounded by a general sense of incredulity, but soon they showed their potential and recently became viable alternatives to surgery for high-risk patients. The intrinsic value of these technologies may even suggest a potential evolution towards the treatment of all patients with valve disease, becoming an alternative to all surgical candidates.

The very first experience with implantation of transcatheter valves has been reported by Bonhoeffer et al., who first developed a balloon-expandable valve to treat pulmonary stenosis in the pediatric population [7]. At present, this technology is available with the commercial name of MelodyTM valve (Medtronic, Inc., MN, USA). The valve is a bovine jugular vein conduit used as a surgical conduit (ContregraTM; Medtronic Inc.) sutured into a balloon-expanding stent. The procedure is performed exclusively under fluoroscopic guidance and it involves a femoral vein puncture, the positioning of a guidewire across the lesion and the implant of the device at the level of the stenotic lesion, usually preceded by lesion predilatation and the positioning of a stent to decrease the stress on the Melody stent, and avoid the reported stent fractures. The procedure requires an extensive preimplant assessment in order to plan the procedure and to assess feasibility.

The next-generation Melody valve will allow its implantation in large anatomies (e.g., after patch enlargement of the right ventricular outflow tract) with the support of additional devices (spacers) to overcome the anatomical challenges. Potentially, individualized custombased devices could be helpful to treat a greater number of patients, similar to what happens in the field of aortic aneurysm repair. To achieve this task, a hybrid room with CT scan capabilities would potentially allow easier handling of the patients flow since a detailed anatomic reconstruction could be obtained at the time of the diagnostic catheterization.

Transcatheter aortic valve implantation (TAVI) is the most commonly performed transcatheter valve procedure to date. Two technologies are commercially available in the European market and under evaluation in the USA: the balloon expandable SAPIEN bovine pericardial valve (Edwards Lifesciences, CA, USA) (FIGURE 1) and the Medtronic, Inc./CoreValve[®] self-expandable porcine pericardial valve (Medtronic, Inc.) (FIGURE 2). In both cases, before the valve is implanted, predilatation with a undersized balloon is carried out to prepare for valve crossing and allow full expansion of the valve.

The Medtronic/CoreValve self-expanding valve is implanted using a 18-Fr-compatible delivery system [8]. The stent is made of shape memory nitinol alloy. The lower third is covered by pericardium. This portion should be placed at the level of the native annulus. The radial force is highest in this portion of the stent to allow safe and durable attachment of the device, as well as to provide enough force to compress the native valve. The middle portion is the most narrow, to reduce the impingement at the sinotubular junction and allow unrestricted flow to the coronary arteries once the valve is implanted. The commissures of the pericardial leaflets are sutured at this level. The upper portion of the valve is the largest diameter, with lower radial force, with the aim of stabilization of the implant. Once the lower two-thirds of the prosthesis are implanted, the upper portion lays on the ascending aorta, gaining a coaxial positioning of the stent. The valve is retrievable in case of malposition, but is repositionable only in one direction (towards the aorta) in case of low implant. Repositioning, and eventually retrieving, are obtained simply by dragging the device backward, using the delivery catheter, unless the valve has been fully deployed and detached from the catheter. In such cases, the CoreValve stent can still be repositioned using a loop catheter, but cannot be retrieved.

CoreValve devices have been implanted only retrogradely, using a variety of approaches, including percutaneous transfemoral, subclavian (axillary and FIGURE 3B) and transaortic (direct access to the ascending aorta). The two latter options require open surgical cutdown to access the artery, while general anesthesia is mandatory only in those patients undergoing sternotomy (ascending aorta access). Sternotomy access has the advantages of a very short root to the aortic valve, allowing very precise positioning and allowing short radiation exposure times as well as low contrast dose (similar to the transapical approach); however, owing to its invasiveness, it is reserved for patients with no other access options.

The SAPIEN valve is currently available in two sizes (23 and 26 mm) to treat patients with annular dimensions between 19 and 25 mm. The delivery system adopts a steerable balloon catheter (RetroFlex 3; Edwards LifeSciences, CA, USA) to allow easier navigation over the aortic arch and across the valve [9]. The delivery system has two sizes: 22-Fr and 24-Fr compatible at the groin, depending on the size of the SAPIEN valve. The future development of the SAPIEN valve will involve the modification of the metal alloy (from stainless steel to cobaltchromium) to reduce its profile and to reduce the delivery catheter size accordingly. The SAPIEN valve can be delivered with either the antegrade or the retrograde route. The antegrade route includes the trans-septal approach (now abandoned) and the transapical approach. The trans-septal approach has the advantage of overcoming any anatomical limitation of arterial access. However, the risk of lesions to the mitral valve and the hemodynamic instability related to the interaction with the mitral valve and the subvalvar apparatus make this procedure less reliable and at higher risk compared with the others. The transapical approach requires a surgical exposure of the apex via a limited anterior thoracotomy (FIGURE 3A). Although it is a challenging maneuver, it can be carried out relatively safely after appropriate training. Owing to the short route to the valve and the minimal aortic manipulation, this procedure is theoretically competitive with any retrograde approach. However, the need for general anesthesia and the more invasive nature of the procedure have limited its application to patients with contraindications to transfemoral implant in the majority of centers. The development of smaller delivery systems and dedicated closure devices could enable a wider application of the transapical approach in the near future, potentially towards a fully percutaneous approach. The retrograde approach is the most common method to implant the SAPIEN valve. The transfemoral implant can be carried out percutaneously (with access preclosure using the Prostar XL system; Abbott Vascular, IL, USA) in most cases. However, surgical cutdown is preferred in



Figure 1. SAPIEN transcatheter heart balloon-expandable valve. Root angiogram after the implantation of a SAPIEN transcatheter heart valve (inset). A guidewire is still left across the valve until proper positioning is confirmed by the angiogram.

some centers and may be preferable in selected cases due to the size of the delivery systems of the currently available SAPIEN valve. A few cases of subclavian retrograde implants have been reported with the SAPIEN valve as well.

The subclavian access has the advantages of a short delivery distance for better delivery control and a lesser manipulation over the aortic



Figure 2. Medtronic/CoreValve® self-expanding valve. Implant of a self-expanding Medtronic/CoreValve device (inset). The delivery system is still in place, with the guidewire across. The temporary pacemaker lead is left in place for 1 day after the procedure.



Figure 3. The alternative approaches to CoreValve® implantation. (A) Transapical approach: the valve is implanted in antegrade fashion; the delivery system is shown in the bottom right side of the picture. (B) Subclavian access: this is an alternative to transfemoral approach in patients with peripheral vascular disease; the delivery system is shown in the top of the picture.

arch, while avoiding any groin access with large bore sheaths. Since the procedure is performed under local anesthesia, and groin access is carried out only with the diagnostic catheters. The procedure has the potential to be performed on a day-hospital base in selected patients.

Besides the aforementioned devices, new-generation valves will probably enter into clinical practice in the next few years. Most devices will be repositionable and retrievable and will promise better final results with less risks of complications such as perivalvular leak, coronary ostia obstruction or valve embolization. As an example, the direct-flow valve is a stentless percutaneous valve mounted over an inflatable support, which can be inflated and deflated until valve position is considered optimal. The implant is then finalized by injecting a polymer into the inflatable structure, which stiffens the inflatable support over the long term. Another interesting valve is the Ventor (Netanya, Israel)/Medtronic EmbracerTM [10]. This device has been implanted from a transapical approach and has the unique feature of being self-seating once it is positioned across the native valve and correctly oriented to the leaflets.

Transcatheter treatment of mitral valve regurgitation is still in its infancy; however, it will expand in the near future due to the need of serving a larger undertreated population compared with aortic valve disease. Compared with the aortic valve, the mitral valve is characterized by a more complex 3D anatomy and functionality. TAVI, although being a more demanding procedure, can still be compared with stent dilatation of a stenotic lesion with a valved device. The mitral valve is not visible at conventional angiography, and there are no landmarks such as the aortic calcifications to support the angiographic identification of the leaflets. Therefore, mitral interventions rely on echocardiographic guidance as the main imaging modality. Fluoroscopy is also important to manipulate the catheters and activate the devices and therefore a combination of the two modalities is necessary. Although there are several technologies under evaluation, the majority of the mitral valve interventions (>80%) have to date been performed with the MitraClip® (Abbott, Inc.). The MitraClip is a device intended to reproduce the Alfieri technique of mitral repair with an interventional approach: the leaflets are joined at the site of regurgitation in order to restore adequate valve competence [11]. The MitraClip system includes a guide catheter, a clip delivery system and the clip itself. The procedure is performed under general anesthesia mainly owing to the mandatory use of transesophageal monitoring. The septum is punctured under echocardiogram guidance. Thereafter, the guide catheter is positioned in the left atrium and the clip delivery system is positioned above the mitral valve, aligned to the long axis of the heart. Multiple controllers are available to steer the system towards the target. The clip is opened above the site of the regurgitation and its arms are positioned perpendicular to the line of coaptation. Then the clip is first advanced past the valve in the left ventricle and subsequently retracted to capture the leaflets. During these steps, live 3D echocardiography is a very useful adjunct to conventional 2D imaging, offering intuitive pictures to guide the maneuvering of the device in free 3D space (FIGURE 4). Other technologies under evaluation include annuloplasty systems for either indirect (through the coronary sinus) or direct annuloplasty, chordal replacement systems and other nonconventional treatments. Transcatheter mitral valve replacement may also become available in the near future.

Imaging requirements for transcatheter interventions

Transcatheter aortic valve implantation is a sophisticated procedure that relies on accurate preprocedural screening, procedure planning and optimal procedural management. Imaging plays a major role in the safety and effectiveness of the procedure. Imaging requirements entail the highest possible standards compared with other interventional procedures. They involve angiography, echocardiography and hemodynamic monitoring. In addition, in most occasions, multiple image displaying is needed, and sometimes the operators are positioned on the two sides of the operating table. Therefore, the display requirements are quite demanding, with multiple screens on both sides of the table. Finally, image recording, archiving, postprocessing and rapid access capabilities are of utmost importance.

Preprocedural screening is based on a combination of radiologic and ultrasound imaging. Transthoracic echocardiography is a versatile imaging tool for the initial patient screening. It is used to assess the severity of aortic stenosis, to rule out associated valve or cardiac lesions, to evaluate left ventricular function and to analyze valve anatomy (bicuspid vs tricuspid, site and extension of calcifications and annular dimension).

For the choice of the access route, either quantitative angiography or CT scan is used to assess the ilio-femoral and subclavian anatomy. The size of the arteries, presence of calcifications, atherosclerotic lesions and tortuosity are evaluated in order to plan the procedure. Furthermore, the anatomy of the aortic root, the angulation between the ascending aorta and the plane of the aortic annulus are important factors involved in the choice of the prosthesis and in the prediction of the final result. Most of this information can be obtained from a single CT scan session, including coronary anatomy and size of the annulus, in patients in sinus rhythm undergoing multidetector CT scanning. Most patients are studied well before the intervention in order to preselect the prosthesis, plan the procedure and to reduce the contrast media load.

Most parts of the transcatheter aortic valve procedure are carried out under fluoroscopic and angiographic guidance. During the procedure, high-quality fluoroscopic imaging is fundamental to avoid malpositioning and to be able to treat the eventual complications (e.g., coronary lesions, access site rupture or dissection). As a consequence, mobile C-arms sometimes used in the conventional operating rooms are grossly inadequate to perform these procedures safely. Even a transapical implant, which requires minimal catheter manipulation, can require more advanced procedures to solve complications such as coronary ostia impingement. In addition, the use of low-definition imaging may increase the use of dye and prolong the operation time. Furthermore, in the operating room setting, some important cath-lab features are missing, such as hemodynamic recording and high-power injectors required for angiography of the aortic root.

One important step of the implant is to identify the plane of the annulus and to use it as a working plane. Misalignment to the annular plane may result in incorrect positioning and a number of complications involving embolization and occlusion of the coronary ostia. New software for assistance during implantation is undergoing evaluation such as rotational CT scanning, which is able to create a 3D image of the aorta and of the aortic annulus. The image can be overlaid on the live fluoroscopy image and used as a guide for the implantation. This feature could be particulary helpful in special situations, such as for implanting devices requiring alignment of some parts to the leaflets (e.g., Ventor and JenaValve[™] Technology [München, Germany]). Image tagging technologies are also developing that will allow a more automated procedure flow and will assist during the implant according to either preoperative imaging or to intraoperative 3D data.

Echocardiography is rarely used for guidance during the implant, while it is widely used as a monitoring method. Transesophageal



Figure 4. MitraClip™ mitral repair. The MitraClip device (inset) is implanted using a combination of fluoroscopic and echographic guidance. The picture shows a live 3D echocardiogram image of the clip open perpendicular to the line of coaptation prior to the implant.

echocardiography delivers excellent images of the aorta and of the valve, and could be used to assist the implant. However, since most of the procedures are performed under local anesthesia, its use is limited. However, echocardiography is fundamental in some steps of the procedure, such as the evaluation of residual aortic regurgitation. Discriminating between a central versus a perivalvular leakage can be important during use of a balloon-expandable valve, where a central leak can be exacerbated by postdilatation, while a perivalvular leak can be treated with an additional balloon dilatation. Intravascular ultrasound (IVUS) has also been used in a laboratory setting to guide the intervention; however, IVUS has been mostly utilized in selected patients for a more sophisticated evaluation of the ilio-femoral anatomy either in the screening process or during the procedures.

Mitral interventions require live 3D imaging of the mitral valve structures, including the leaflets and the subvalvar anatomy. Live 3D is usually obtained with transesophageal echocardiography under general anesthesia. Intracardiac echocardiography could be used to guide procedures under local anesthesia; however, the current quality of the images is insufficient and there is little experience of the use of this imaging to guide mitral repair (although most of the preclinical work has usually been carried out using this device). CT scanning can be helpful to plan the procedures and for patient selection, and its data could be incorporated in the fluoroscopic machine during the operation to support the procedural planning and some steps of the procedure adopting some overlays.

In addition to fluoroscopy and ultrasound, MRI-guided interventions have been proposed, although only based on preclinical studies. This imaging modality involves the use of a complete set of dedicated MRIcompatible catheters and guidewires, which could limit the possibility of the development of MRI-compatible devices.

Operating room features required in the hybrid room

The operating rooms meet the standards for a sterile environment. Sterility is ensured by the presence of laminar flow air conditioning, a well-defined clean pathway for the instrumentation and for the operators and by the availability of a sterilization facility. In addition, most appliances are ceiling-mounted to allow better cleaning of the floor. Cardiac surgery operating rooms have also been designed to be large enough to allow the presence of multiple operators and personnel, including anesthesiologists, surgeons, perfusionists and scrub and circulating nurses. All cardiac surgical rooms have a state-of-the-art heart and lung machine to allow complete management of cardiopulmonary bypass in the most complex cases, including a heat exchanger. Managing a complicated TAVI could lead to complex operations, which may involve long cardiopulmonary bypass times and even circulatory arrest (e.g., patients with porcelain aorta or aortic dissection complicating a valve implant).

Most cardiac surgeons have had the chance to experience the challenge of carrying out an emergency operation in the cardiac cath-lab. The main limitations of performing an openheart operation in the current design cathlabs, besides the lack of sterile environment, are related to the limited space, to the ergonomics of the operating table and to the inadequate lighting. Surgical operating rooms are equipped with sophisticated tables that allow multiple settings with 'breakable' portions, with multiple movements including elevation, tilting and cradling. These movements are fundamental for ergonomics, to reduce the fatigue on the surgeons and allow more precision during the operation.

The operating room has also been designed to treat high-risk and challenging clinical conditions; this is different to a cath-lab, which was originally designed mainly as a diagnostic room. Therefore, an operating room is usually positioned in a complex setting designed to optimize the perioperative pathway of the patients, including a preanesthesia room and a short track to the intensive care unit, both of which are features missing in most cath-labs.

The hybrid suite: the cath-lab & operating room of the future

The attempt of combining the features of a cardiac cath-lab with those of a surgical room is an enormous challenge. The ideal hybrid room should offer an environment for fruitful and expeditious collaboration among several professionals including surgeons, cardiologists, echocardiographers, anesthesiologists, nurses, radiology technicians, perfusionists and industry product specialists. This implies that the room has to be large enough (i.e., $\geq 80 \text{ m}^2$) in order to offer enough space to all the individuals and the instruments involved in the procedures. In addition to space availability, good room planning and versatility of the

table/C-arm/display are fundamental to improving the operational capability of the various actors. In addition, radiation protection has to be carefully studied in order to reduce the risk of inappropriate exposure (this applies particularly to the echocardiographers and to the anesthesiologists who are typically very close to the C-arm) (FIGURE 5). The place for the ventilator and the echocardiogram machine has to be planned in advance and according to the operator-dependent preferences, to the type of instruments and to the specific procedures. The supplies required to run any catheter intervention as well as any cardiac intervention related to the procedures that are undertaken should be rapidly available, potentially stored within the room or in an adjacent storing room. A control room is also important for image storage and management. A clean pathway and an unclean pathway for the used surgical instruments should be available, as it is a standard requirement for operating rooms. The same applies to the access to a sterilization facility. The floorplan should incorporate and predict the location for the multiple appliances required to run the procedures and for the potential bailouts, including the cardiopulmonary bypass machine, the power injector, the defibrillator, the intra-aortic balloon pump console, the electrocauthery system, the aspirators, the containers for the waste and so on. In addition, the ceiling plan is of utmost importance and represents one of the most challenging steps in the planning of the hybrid suites: in a limited space, surgical illumination, laminar flow ceiling, cameras, monitor booms and C-arm (if ceiling-mounted) should be positioned to be fully operational and avoid any conflicts. Multiple monitors should be placed at both sides of the table to allow operators from each side to effectively access the required information (images and hemodynamic monitoring).

The ideal solution for the C-arm is unclear, and the portable C-arm is insufficient to carry out these procedures safely and effectively. Fixed C-arms can be either floor- or ceiling-mounted. Ceiling-mounted systems have the potential advantages that they can be located far away from the table and easily repositioned without interfering with the anesthesiologist. They can also provide complete patient coverage with no or minimal table movement, which can be useful in cases of general anesthesia or in cases of cardiopulmonary bypass, when the patient position should not be modified. Ceiling-mounted



Figure 5. Radioprotection in the hybrid suites. The anesthesiologist and the echocardiographist are often close to the C-arm. The picture shows an ideal environment with appropriate shields for these operators at the head of the operating table.

C-arms can be located in one of two positions, either at the head or at the side of the patient; in the latter, they can be able to provide rotational angiography. The main limitation of ceilingmounted systems is that the ceiling is already very busy with multiple appliances, particularly with the lighting system. In addition, the ceiling construction involves special architectural requirements. Ceiling-mounted systems are also difficult to clean and may interfere with the laminar flow.

Floor-mounted systems allow more table positions compared with the ceiling-mounted systems, although full body coverage is possible only using a floating table. Rotational angiography (DynaCT, Siemens Medical Solutions, Germany) can be performed only from the head of the patient. However, owing to the easier combination with the surgical lights and the other ceiling-mounted appliances, and since floor-mounted systems are preferable for infection control, most hybrid suites are equipped with floor-mounted systems.

Recently, a new technology, specifically developed for the hybrid suites and adopting a robotic system C-arm, offers the combined advantages of both ceiling-mounted and floormounted systems: the Artis Zeego[®] system (Siemens Inc.). The robotic C-arm is not isocentric, allowing high versatility in positioning (FIGURE 6). The C-arm is very compact and



Figure 6. The Siemens Artis Zeego®. The Artis Zeego is an integrated robotic C-arm and table specifically designed for hybrid suites. The robotic C-arm allows different positions relative to the floating table, for various applications (transfemoral vs transapical vs axillary approach).

it minimizes when in parked position. It allows full body coverage and 3D reconstructions. In addition, the system is fully integrated with a surgical table, allowing a flexible isocenter relative to the table position (the table has all the surgical movements including tilting and cradling). This technology allows variable working heights to optimize ergonomics. Flexibility



Figure 7. The Leipzig hybrid suite. The Leipzig Heart Center has been one of the first institutions to set up a dedicated hybrid room for transcatheter aortic valve implantation. Note the large number of screens to accommodate multiple imaging modalities.

and versatility of the hybrid room set-up is a very valuable features as several procedures with different requirements can be performed requiring different teams, variable table positions and imaging modalities.

The table is the other fundamental component of the hybrid suite. The preferred tables for the hybrid suites are the floating tables, similar to those used in the cardiac cath-lab, to allow full coverage of the body in most situations. The table should be completely radiotransparent. Modern tables offer the possibility of controlling most operations of the cardiac cath-lab remotely. In addition, incorporated in the table, lead shields are present to reduce radiation exposure to the operators.

Human resources for the next generation of hybrid suites

The construction of a hybrid room raises a number of challenges, and few centers have succeeded in building a well-functioning hybrid room (e.g., the Leipzig Heart Center, FIGURE 7). In an increasingly demanding cost-containing scenario, rationalization of the resources is fundamental for the evolution of new technologies. At present, transcatheter interventions are performed by a team of professionals covering the different skill sets required to perform the procedure. However, the strict collaboration is enabling cross-training among the professions. Cross-training involves not only the operators, but also and equally important, the professionality of the nurses and the technicians. There is a strong need for creating a subspecialty team with hybrid skills deriving from surgery and interventions. This is particularly true for the nurses. Most nurses can acquire the knowledge required to assist a hybrid procedure; however, this is not yet the case in most institutions, and so hybrid procedures involve a team rotation across the various steps of the procedures. Similar considerations may apply to the operators. Few surgeons have acquired the necessary catheter skills to run the transcatheter valve interventions, and so pave the way for the development of a new subspecialty: the valve interventionalist, a hybrid figure between the surgeon and the interventionalist, with the skill set required to manage valve patients treated with transcatheter procedures. The ideal valve interventionalist should master several fields of cardiovascular intervention, including imaging, catheter skills, surgery and patient management. This professional figure is yet to be fully defined, but it is predicted that several operators, coming either from surgery

or from interventional cardiology, will convert and enrich their skill sets to get involved in transcatheter valve interventions.

Future perspective

The evolution of both operating rooms and cardiac cath-labs is directed towards the integration among specialties. The construction of a hybrid room in an hospital goes beyond the operational issues, it implies an evolution of how healthcare is delivered to our patients, with teamwork acting around the patient's needs, optimizing the resources and delivering an unbiased therapy tailored on the specific clinical conditions of the individual.

This evolution also involves a dramatic change at the administrative level. The transcatheter valve technologies have evoked a need for a collaboration never seen before, which requires full support from the hospital management and the healthcare system. After many years, professionals with different skills, yet with similar backgrounds and mindsets, are joining the effort in a collaborative attitude. The hybrid suite is the temple where this union will be celebrated and where new and better healthcare will be delivered to our patients.

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The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

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Executive summary

New-generation hybrid rooms

- The next-generation hybrid suites are the natural evolution of both cardiac surgical operating rooms and interventional catheter laboratories.
- The ideal hybrid suite should fulfill the requirements of both a catheter laboratories and an operating room, without any compromise to sterility, imaging and patient workflow.
- The the European Society of Cardiology (ESC)/European Association of Cardio-Thoracic Surgery (EACTS)/European Association of Percutaneous Cardiovascular Interventions (EAPCI) working group has acknowledged the need for an adequate environment for the performance of transcatheter valve interventions.

Transcatheter valve interventions & multidisciplinary collaboration

- The skills necessary to perform transcatheter valve interventions and to manage patients are independent from the individual professional background.
- As individual skills are often insufficient, teamwork is mandatory, and hybrid suites are designed to support teamwork and multidisciplinary collaboration.

Transcatheter valve interventions

- The first experience with transcatheter valves has been for the treatment of pulmonary stenosis in the pediatric population.
- Transcatheter aortic valve implantation is the most commonly performed transcatheter valve procedure to date. Two technologies are commercially available: the balloon-expandable SAPIEN bovine pericardial valve (Edwards Lifesciences, CA, USA) and the CoreValve[®] self-expandable porcine pericardial valve (Medtronic, Inc., MN, USA).
- Transcatheter treatment of mitral valve regurgitation will expand in the next future. MitraClip™ (Abbott, Inc.) is the most commonly performed mitral valve intervention besides mitral balloon valvuloplasty.

Imaging requirements for transcatheter interventions

- Transcatheter intervention imaging requirements are more demanding compared with other interventional procedures. They involve angiography, echocardiography and hemodynamic monitoring. Often multiple images are displayed, and sometimes the operators are on the two sides of the operating table, requiring multiple displays.
- Mitral interventions require live 3D imaging of the mitral valve structures, including the leaflets and the subvalvar anatomy. Live 3D is usually obtained with transesophageal echocardiography under general anesthesia.

Hybrid suite: the catheter laboratories & the operating room of the future

- The attempt to combine the features of a cardiac catheterization laboratory with those of a surgical room is an enormous challenge.
- The room has to be large enough (i.e., ≥80 m²) in order to offer enough space to all the individuals and the instruments involved in the procedures.
- The angiographic C-arm, table, lighting, ventilator and displays combinations are infinite and should be tailored to the purpose of the hybrid room.

Human resources for the next generation of hybrid suites

- The planning of the hybrid room should include the development of a dedicated multidisciplinary team.
- Strict collaboration is enabling cross-training among professionals and potentially serving to create a new profession.
- It is predicted that several operators, coming either from surgery or from interventional cardiology, will convert and enrich their skill sets to get involved in the transcatheter valve intervention.

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