

Hybrid operating room applications in the increasingly complex endovascular era: the trump card of modern vascular surgery

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Hybrid operating room represents nowadays an important tool in the management of a constantly increasing number of complex surgical procedures which necessitate appropriate settings in order to be performed safely. We herein present the peculiarities and applications of such a versatile operating environment which is capable of guaranteeing the best performances in terms of equipment and imaging tools respecting the standards of asepsis that a simple angiographic room could not offer. In particular, we focus on its relevance in the field of complex vascular pathology, and on the importance of setting an appropriate management process in order to make the most of its potentialities without sacrificing the not negligible costs connected to it.

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INTRODUCTION

The growing complexity of aortic pathology and the consistent improvements of imaging techniques we witnessed during the last years have given the hybrid operating room an increasingly central and strategic role in the management of high-risk procedures. In the modern era, patients are more and more oriented toward receiving treatments as less invasive as possible. It is, therefore, necessary to have clear in mind what are the roles that a hybrid operating room can play and what is the correct way of managing such an advantageous instrument. Aim of this paper is to review recent modifications in a high-volume Vascular Center in the last years thanks to the improvements a hybrid angio suite has been able of guaranteeing. It was not necessary to clear this work with an institutional review board for the

descriptive nature of this study.

MAIN BODY

During the last 20 years, we assisted a constant evolution in the field of vascular surgery, through increasingly widespread use of endovascular techniques. These techniques guarantee a significant reduction in the invasiveness of surgical interventions; this trend has allowed both to offer a possibility of treatment to patients deemed at high risk for open surgery, and to meet the desire for a low-invasive surgical approach.

Operative tools in the hybrid operating theatre setting

The fundamental resources which a hybrid operating room

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must be provided include an angiographic platform with advanced imaging systems (3-dimensional [3D] reconstruction systems, image fusion with vascular navigator tools), an operating table totally integrated with the movements of the fixed C-arm angiography, a multimedia monitor system, anesthesiological monitoring and supporting tools (ventilators, multiparametric monitors), complementary diagnostic tools (duplex scan, transesophageal echocardiography, and intravascular ultrasound) and the necessary equipment for carrying out surgical procedures (aspiration systems, blood ultrafiltration device, extracorporeal circulation, and generator for electrosurgical knife) (Fig. 1A).

New angiographic platforms provide the additional capability of 3D imaging by acquiring a series of 2-dimensional projections while the C-arm rotates around the patient for 200° and reconstructing them as 3D cone-beam CT (CBCT) images; these acquisitions can be performed with or without contrast medium. These systems make it possible to perform an extremely detailed intraoperative or completion control in order to accurately evaluate the success of the procedure without exposing the patient to the high dose of radiation and contrast medium deriving from a postoperative CT angiography examination.

Image fusion system represents the most important innovative imaging tool and it involves the use of the pre-operative imaging as template for intraoperative guidance. The registration of a noncontrast CBCT or 2 single fluoroscopic images are post-processed on the angiographic platform and matched on preoperative 3D reconstructions by allineation of bony structures; furthermore, automated image segmentation algorithms have the capacity of extracting relevant vascular landmarks such as aortic center-line, visceral, renal and hypogastric arteries ostium, and overlaying them on fluoroscopy images in order to guide vessel navigation, with an important sparing of iodine contrast medium and radiation dose (Fig. 1B) [1].

The proper design of the spaces inside a hybrid room plays an essential role in guaranteeing its maximal employability, allowing instruments repositioning and setting reconfiguration based on the type of surgical procedure to be performed. Furthermore, it is necessary to set up a dedicated warehouse in which all the material and the endovascular devices can be stored and be ready for use at any time if needed.

Applications in vascular surgery

Aortic pathology interventions

In an analysis of data collected in United States Medicare records in 2018, Suckow et al. [2] showed an evident tendency of preferring an endovascular approach in those contexts where the surgical alternative is highly invasive, such as the aortic disease. In the early 2000s, in fact, there was an overtaking of the number of both standard and advanced endovascular procedures compared to the traditional surgical open approach in the treatment of aortic aneurysms. Nowadays we managed to extend the indications for treatment to both clinically and anatomically extremely complex patients thanks to a considerable innovation of materials and techniques; however, many of these cases require interventions in which it is necessary to associate endovascular and open surgical procedures.

The increasing level of complexity of the surgical interventions makes it essential to have suitable settings and equipment, capable of providing the highest possible performance; in addition, vascular surgeons are now required to have an increased understanding of advanced imaging techniques. In the past, the vascular surgeon carried out diagnostic-therapeutic angiographic procedures using mobile angiography (C-arm devices) placed inside standard surgical rooms with low potency and poor cooling capabilities, reduced size detector panel, absence of radiation protection tools,

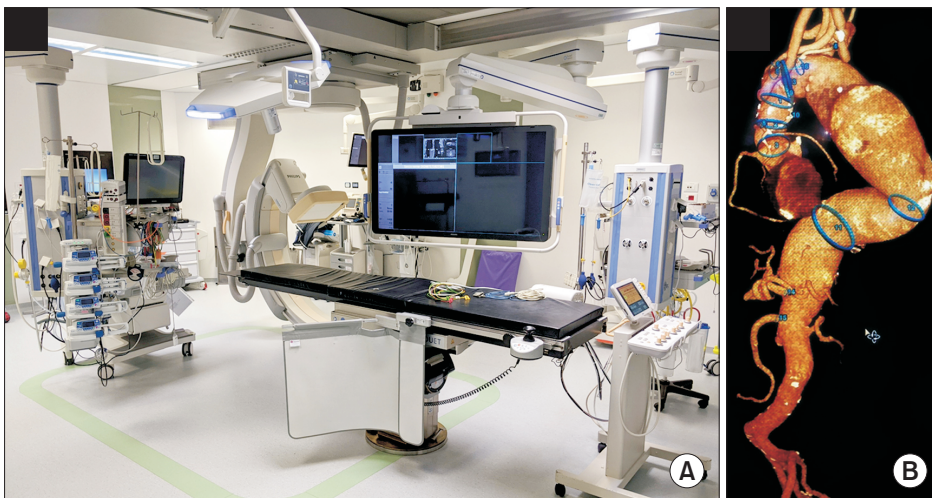


Fig. 1. (A) Hybrid operating room setting. (B) Three-dimensional image reconstruction of a thoracoabdominal aorta showing relevant vascular landmarks with fusion imaging system, essential for procedure planning and execution.

nonspecific operating tables, and without the possibility of using dedicated radiological and support instruments. Until recently, in the endovascular treatment of districts such as the thoracoabdominal aorta or the aortic arch, vascular surgeons had to deal with the limitations deriving from operating inside an angiographic room (limited space and asepsis compared with a surgery room) due to the need for high-performance angiographic platforms equipped with image processing systems, available only on a fixed workstation.

Today the hybrid room allows the combination of an optimal traditional surgical environment, guaranteeing safety and asepsis standards, with the most advanced angiographic imaging systems both in the case of complementary procedures and conversions. Moreover, it is able to provide the operator with the ideal context for the execution of highly complex interventions.

In one of the first papers on this subject, Kaneko and Davidson [3] stressed the importance of using the hybrid operating room in cardiovascular surgery and the potential that this setting can offer, allowing maximization of the benefits and a reduction of the risks related to various surgical procedures. An example is well represented by the treatment

of aortic arch diseases; the intervention could be carried out by the vascular surgeon alone through the surgical debranching of the supra-aortic trunks associated with the endovascular exclusion of the aneurysm (thoracic endovascular aneurysm repair [EVAR]), or in collaboration with a cardiac surgery team performing the complete debranching of the aortic arch thus allowing the vascular surgeon to subsequently position an endoprosthesis in the most proximal tracts of the aorta (Fig. 2).

Among advanced endovascular procedures that require highly performing angiographic equipment combined with the highest levels of sterility and safety, it is important to remind the interventions of exclusion of complex aneurysms with branched or fenestrated endografts (B/F-EVAR).

Peripheral artery occlusive disease interventions

Another clear example of application of hybrid operating rooms is represented by peripheral hybrid revascularizations performed in case of peripheral artery occlusive disease. In the presence of multilevel arterial lesions, involving both the common and the superficial femoral arteries or the iliac district, the hybrid open and endovascular intervention can be considered a successful option [4]. Such interventions consist

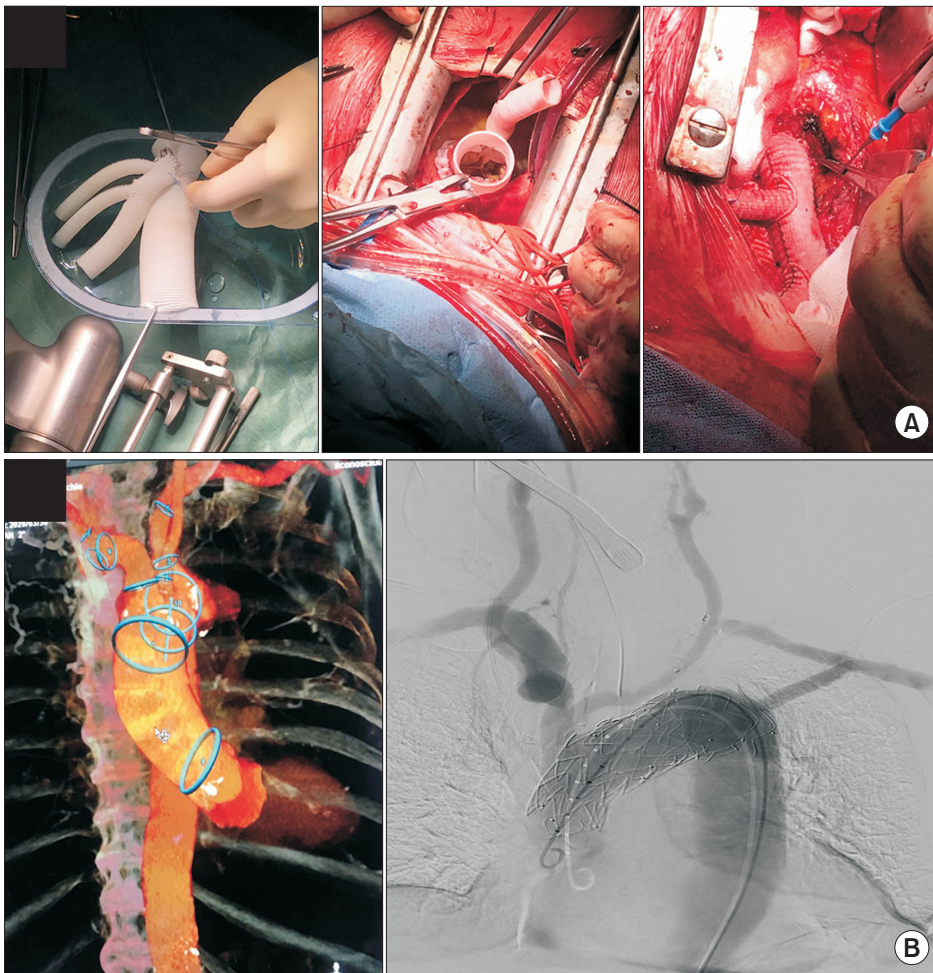


Fig. 2. Multidisciplinary procedure involving vascular and cardiac surgeons in the hybrid room setting. (A) First step consisting of “ascending aorta replacement with interposition of straight vascular prosthesis and supra-aortic trunks debranching with trifurcated surgical graft” was performed by the cardiac surgery team. (B) Second step of “aortic arch ulcerated plaque endovascular exclusion with thoracic endoprosthesis and subsequent left subclavian artery embolization” was carried out by the vascular surgery team.

of a surgical part of femoral bifurcation endarterectomy which allows a subsequent femoral or iliac district endovascular revascularization.

In the same manner, when it is rendered necessary to perform a surgical arterial access in conditions in which a percutaneous one could represent a high-risk procedure (small-lumen vessels, presence of calcific plaques), such operations are made easier and safer to carry out in hybrid operating environments.

Multidisciplinary teams

To fully exploit the potential offered by the hybrid room, however, the involvement of expert professionals capable of integrating their specific skills and characteristics is mandatory; it is also crucial to create multidisciplinary teams collectively taking care of the patient in the context of personalized programs dealing with the various cardiovascular diseases. The professional figures involved in these managements, clinical and therapeutic processes are represented by cardiac surgeons, vascular surgeons, interventional radiologists, anesthesiologists, cardiologists, nurses, radiology technicians, perfusion technicians, and health workers.

The importance of this new activity plan, together with the need of disposing of a hybrid operating room, is reaffirmed as a class I recommendation in the 2019 European Association for Cardio-Thoracic Surgery (EACTS) and European Society of Vascular Surgery (ESVS) Consensus Document for the treatment of thoracic aortic pathology involving the aortic arch [5].

The vascular surgeon finds its ideal setting in the hybrid room; not just as the one and only actor in patient's treatment, combining both surgical and endovascular techniques in a hybrid procedure, but also as the member of a team in the combined treatment of complex diseases requiring the collaboration of different specialties, such as the aortic district pathology.

Vascular surgeons indeed play a central role in all those cases where a surgical vascular access is required due to either the type of device to be used or the anatomical characteristics of the patient. In this way, the interventional specialists are helped to successfully accomplish the endovascular procedure lowering the risk of possible complications (transaortic valve replacement procedures, positioning of aortic counterpulsors, and arteriovenous cannulation for extracorporeal membrane oxygenation).

Radiological protection in hybrid settings

As described by Hertault et al. [6] in a series of 102 patients treated by standard and complex EVAR, focusing on the many advantages offered by the latest generation angiographic platforms, it is clear that image fusion systems allow a significant reduction in surgical procedure length, quantity of

iodine contrast medium used and total time of fluoroscopy; they made a comparison of cases of EVAR performed in the hybrid room vs. a previous prospective cohort treated with a mobile C-arm: the median dose-area product was significantly reduced during bifurcated endografts (30.0 Gy/cm² vs. 12.2 Gy/cm²), 2- or 3-fenestrated endografts (72.9 Gy/cm² vs. 43.7 Gy/cm²), and branched or 4-fenestrated endografts (159.0 Gy/cm² vs. 47.4 Gy/cm²) performed in the hybrid room (P < 0.01), as was the contrast medium volume during 2- or 3-fenestrated endografts (138 mL vs. 105 mL) and branched or 4-fenestrated endografts (226 mL vs. 120 mL) (P = 0.003 and P < 0.01, respectively) [7].

Sailer et al. [8] also reported a significant reduction in operating times and amount of contrast medium in the group of patients treated with B/F-EVAR procedures performed with the aid of an image fusion system, compared with the control group (5.2 hours [95% confidence interval, 4.5–5.9 hours] vs. 6.3 hours [5.4–7.2 hours], P = 0.022; and 159 mL [132–186 mL] vs. 199 mL [170–229 mL], P = 0.037).

All the authors agree that these benefits, both for patients and operators, are emphasized in case of endovascular procedures of greater complexity, such as the treatment of aortoiliac, pararenal, thoracoabdominal, and aortic arch aneurysms.

The extensive use of endovascular techniques today makes the concept of radiation protection highly relevant and discussed; the improvement of protection measures and awareness regarding radiation protection should be a long-term goal [9].

The operator has the role of supervisor of radiation exposure toward himself, the staff, and the patient; the latter, as already recommended by Ketteler and Brown [10], should be clearly aware of the radiological risk he undertakes at the moment of acquisition of the consent for intervention.

As Kirkwood et al. [11] showed in their study dealing with radio exposure during endovascular procedures, although the dose absorbed for a single complex intervention is acceptable for both operators and patients, it is recommended that the first operator performs a maximum number of endovascular procedures that allows the absorbed dose of 10 mSv/year not to be exceeded. Moreover, adherence to ALARA (as low as reasonably achievable) strategies should be a key part of training of vascular surgeons, although, as recently reported by an anonymous survey, 45% of a cohort of vascular surgery trainees have no formal training in radiation safety [12].

Costs considerations

Unavoidably, the costs deriving from building a hybrid operating room, which vary according to the need to build it from scratch or reconfigure a standard surgical theatre, and the management costs have an extremely important impact on the economic resources of a hospital facility.

The possibility of spreading the initial costs is linked to the amount of procedures for which the hybrid room is intended, making it clearly more advantageous for high-volume surgical procedures centers. It is essential to ensure the highest occupancy rate of the hybrid room at all times through an accurate scheduling based on its use by all the surgical specialties of the cardiovascular district.

CONCLUSION

Considering its versatility and having ascertained the extensive number of possible applications, the hybrid operating room becomes clearly an important added value for a large hospital facility, capable of satisfying the new health requests of the population without sacrificing the economic sustainability of the project.

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Conflict of Interest

No potential conflict of interest relevant to this article was

reported.

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