Manual of Thoracic Endoaortic Surgery

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Foreword

In today's healthcare environment, the real driver is value. Maximizing outcomes and minimizing costs or providing similar outcomes with lower cost in terms of actual numbers or recovery time will dominate our healthcare delivery system. An excellent example of this evolution is in the field of cardiovascular intervention. Dr. Jacques Kpodonu's *Manual of Thoracic Endo-Aortic Surgery* is a most timely and descriptive work in this burgeoning field. It provides an excellent overview of current technology and techniques, plus the endovascular expert can drill down into the details of the devices and technologies described and significantly enhance their knowledge and perspective. Procedural detail, excellent graphics, pertinent imaging studies, and relevant instruction are the mainstays of this text.

The first chapter comprises the key overview and very comprehensively covers the platform – the hybrid OR, the tools, the accessories, and the medium – superb, state-of-the-art imaging modalities required to perform these advanced procedures. The text then moves into more technical details including options and instruction regarding access approaches and potential pitfalls of such. This is followed in ensuing chapters by dissemination of precise information, techniques, and indications for the most popular and utilized grafts including Boston Relay Stent Graft, Cook TX2 Zenith Stent Grafts, as well as the Gore and Medtronic Aortic Stent Grafts. Transitioning from the devices themselves, the ensuing chapters cover challenging clinical problems such as dissections, traumatic aorta injury, and hybrid debranching techniques as well as a chapter on fenestrated and branched graft technology for thoracoabdominal aortic pathology expertly written by an expert in the field Dr. Roselli. Points are well illustrated with case examples. A most essential final clinical chapter covers the identification, treatment, and avoidance of complications. The text is completed with a look into future technologies.

The *Manual of Thoracic Endo-Aortic Surgery* is well organized, flows efficiently, and is well written. It reflects the significant clinical experience of Dr. Kpodonu and embodies his commitment to teaching and education. It is important for any clinician in the field of cardiovascular care to be aware of the therapeutic options and imaging modalities covered in this text. Furthermore, the endo-aortic specialist will benefit most significantly by the technical details elucidated in this publication. This entire field is rapidly evolving and represents a major advance in medical therapy.

Knowledge of current therapeutic options and clinical expertise in delivering these options are essential. This text provides an important element in the foundation for that process.

Newport Beach, California Aidan A. Raney

Preface

The development of less invasive technologies over the past decade has resulted in a changing paradigm for the management of aortic diseases. Endovascular and hybrid surgical approaches are gradually being adopted by cardiovascular surgeons which has been proven to shorten hospitalization, reduce morbidity and mortality, speed recovery, and hasten return to normal life. Clinical investigations have shown these procedures to be favorable over open surgical techniques in most situations.

Our current training programs have not been designed to easily accommodate the rapid evolution in endovascular technology, 3D imaging modalities, intravascular ultrasound technology, and advanced navigational tools. In an effort to bridge the gap which exists between our training, educational programs, and the technology explosion, it is essential that the cardiovascular surgeon of today and the future will have the fundamental knowledge and skill sets required to adequately understand and incorporate all the latest technology into the practice of aortic surgery.

Although certain limitations currently exist regarding thoracic aortic endografting techniques and their application to thoracic aortic pathologies there is every indication that most thoracic aortic pathologies will be treated with these less invasive procedures in the future. There is no substitute for learning from experience; it is my hope that the Manual of Thoracic Endoaortic Surgery will provide a useful tool for practitioners as they plan and execute treatment of patients with these various thoracic aortic pathologies as well as serve as a useful reference as this segment of the field expands.

Newport Beach, California Jacques Kpodonu

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The author would like to acknowledge the following for his contribution to this work: Eric Roselli, MD, Department of Cardiothoracic Surgery, Cleveland Clinic, Cleveland, OH, USA.

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Chapter 1
The Cardiovascular Hybrid Room

The last few years have seen a paradigm shift in the treatment of cardiovascular-related diseases from once traditional open surgical modalities to the entire cardiovascular tree being amenable to percutaneous interventions. The tremendous advances in transcatheter endovascular procedures currently been applied to the heart and the peripheral vasculature have resulted in a treatment paradigm shift in the care of the cardiovascular patient. These changing winds in the treatment of cardiovascular disease require that a new type of cardiovascular specialist code named the cardiovascular hybrid surgeon be trained to perform to provide seamless care in providing both endovascular and open surgical procedures to this increasingly complex group of patients.[1]

Patient and market forces continue to push for minimally invasive approaches over more traditional open surgical approaches with proven efficacy and long-term treatment benefit. The cardiovascular surgeon of today must be required to adapt to this new technology-driven trend. These minimal invasive procedures or hybrid procedures have resulted in markedly decreased morbidity and mortality of elderly

J. Kpodonu, *Manual of Thoracic Endoaortic Surgery*,
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patients who would otherwise be exposed to major operative morbidity and mortality. Currently large areas of traditional cardiac surgery as it stands are rapidly disappearing and have been substituted with less invasive percutaneous techniques. Areas of cardiovascular surgery in which transcatheter techniques are firmly established and are rapidly adapted to treat the whole spectrum of the cardiovascular tree include treatment of coronary artery disease in which coronary revascularization is increasingly being replaced by percutaneous interventions and possibly by the emerging techniques of angiogenesis and related advances in molecular genetics. Thoracic aortic aneurysms are rapidly disappearing from the surgical repertoire and are being treated with endovascular procedures. Here, a true benefit is already being observed when applying this minimally invasive, percutaneous approach in aged, polymorbid patients. Percutaneous techniques are currently used to treat atrial septal defects, patent foramen ovale, patent ductus arteriosus, and coarctation of the aorta. In the developing world, mitral and pulmonary stenosis is not being seen by surgeons: Arrhythmia surgery (Wolff–Parkinson–White syndrome, ventricular ablation, and atrial flutter) is an established domain of electrophysiologically trained interventionists who have also completely taken over the pacemaker and defibrillator implantations, previously the work of cardiac surgeons. Aortic valve stenosis is currently being treated by transfemoral and transapical valve replacement, avoiding the inherent morbidity of cardiopulmonary bypass, aortic manipulation, and prolonged intensive care unit stay with in some cases patients leaving the hospital the next day.

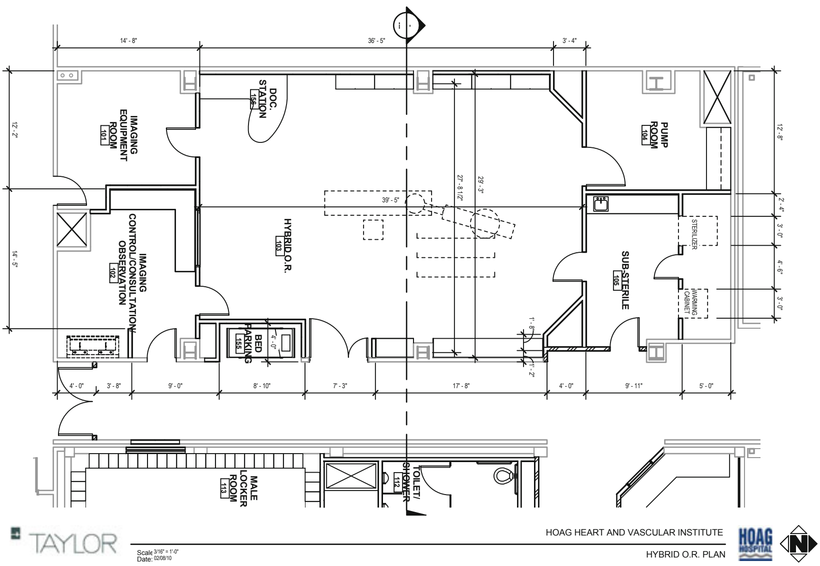

Fig. 1.1 Architectural drawing of a hybrid suite

The ability to provide such cutting-edge technology borders on the availability of a new operative environment known as the hybrid surgical suite (Fig. 1.1).

1.1 The New Operative Environment (The Hybrid Surgical Suite)

A fully integrated interventional suite combines surgical sterility[2–4] with flat-panel cardiovascular imaging, a linked workstation, post-processing, and storage facilities.[5–7] The size of the hybrid room should be of sufficient dimensions to allow anesthesiology facilities needed for full patient monitoring. Furthermore any type of supportive equipment available in the room including equipment for anesthesia, intravascular ultrasound, intra cardiac echochardiogram, transesphageal echochardiogram and rotational angiography as well as endovascular supplies must be able to fit in the room in a seamless fashion irrespective of wether the room is used for an open surgical, hybrid surgical or totally percutaneous procedure. Current peripheral suites are fitted with many interesting features to make certain procedures easier. An on-table duplex ultrasound makes puncturing easy and is a good guide during endovenous laser therapy. The possibility of storing several reference points to which the C-arm can be automatically relocated at any time during the procedure facilitates the management of even extremely complex procedures. It is obvious that routine endovascular and open surgical practice both clearly gain from performance in this dual-capability working environment. For example, classic open bypass creation is immediately controlled on-table. When improvement of inflow or outflow becomes necessary after bypass surgery, balloon dilation with or without additional stent placement can be rapidly performed without dramatically prolonging procedural time. The use of an integrated endovascular suite, however, stretches beyond hybrid procedures and opens doors to new diagnostic and treatment possibilities. Three-dimensional reconstructions generated by integrated CT or rotational angiography can make a real-time visualization of vessel morphology in any direction and improve the visibility of vessel structures. Application of 3D reconstruction during treatment of intracranial aneurysms, for instance, is a must to ensure optimal positioning of catheters, coils, balloons, and stents. An integrated setting means saving time and personnel because more procedures can be completed in the same room by the existing staff without increasing the strain on the team and without relocating equipment or personnel from another department. The hybrid suite should become the one stop shop where patients can get diagnosed and treated in one visit, for less downtime and a speedier recovery. Unique technology in the suite allows doctors across different specialties to work together on a case-by-case scenario, in the best interest of each patient. The most advanced imaging systems available provide quick and detailed information for shorter, more accurate treatment with substantially less X-ray exposure when compared to traditional devices. Complex cases are more easily treated, since the suite is designed to handle both minimally invasive percutaneous, hybrid operations and open surgical procedures.

1.2 Basic Equipment and Design of the Hybrid Endovascular Operating Room

The primary components of the hybrid suite center on intra-operative angiography and fluoroscopy as well as on carefully designed operating tables to accommodate and optimize the usefulness of the radiographic equipment. The hybrid suite imaging system provides superior image quality and higher tube heat capacity and has measurement capabilities capable of simple and complex procedures requiring high resolution. Prices range between (US $1.2 and US $5.0 million) depending on the brand, specifications, ability to provide rotational angiography, addition of a bi-planar system and with integration of various sophisticated imaging modalities like 3D echocardiography, intracardiac ultrasound, intravascular ultrasound, and electromagnetic navigation systems the cost of the room rises.

1.2.1 Size of the Hybrid Operating Room and Radiation

The operating room should ideally be between 550 and 900 square feet (Fig. 1.1), with a minimum clear area of 400–500 square feet. Floor to ceiling height should be at minimum 10 ft to accommodate floor- or ceiling-mounted C-arms capable of rotational angiography for volume rendering 3D CT-like images achieved with advanced biplanar imaging systems (Fig. 1.2). In existing operating rooms, the fixed ceiling-mounted C-arm requires some structural modifications to install the mounting plates and run electrical conduits under the floor to the components. Most states dictate that any operating room with a fixed imaging system must have lead-lined walls. Most

Fig. 1.2 Endovascular suite integrated in the operating room comprising a biplane digital substraction angiography unit with multipurpose surgical capabilities. The Allura Xper FD20 biplanar fixed system by Phillips

standard ORs have leaded covering 0.5 mm which is not sufficient for the radiation dose generated by a fixed unit. Lead-lined walls in the range of 2–3 mm for the fixed units may be needed and may vary from state to state (must see regulations for the state of California). The expense of these constructions/modifications can vary up to $100,000 depending on the original condition of the room, local contracting costs, architect's fees accompanies that market fixed fluoroscopic units usually provide consulting services for such alterations.

As endovascular/cardiovascular hybrid surgical procedures become more complex, the relationship of the C-arm, table, and patient's position becomes even more important. The fluoroscopic unit should be able to move in a horizontal plane from the groin along the course of the vessel with the ability to "snap images on the move." This parallel movement prevents the need for excessive contrast material and greatly expedites the procedure. When a catheter is placed in the brachial artery, the fluoroscopic unit must be capable of rapid movement over the catheter's path from the arm and through the thoracic aorta to the area of ultimate instrumentation. Obstructions from a table or a floor-mounted portable unit that hinder rapid panning over wide anatomic areas limit potential success of the procedure.

1.2.2 Carbon-Fiber Table

To optimize the usefulness of the radiographic equipment, a nonmetallic, carbon-fiber surgical table is available for the interventional techniques.[10] The preferred surgical operating table to accommodate such techniques should be preferably thin but highly stable table and should provide complete clearance beneath a panning X-ray system. The Diethrich IC 2020 Surgical Imaging Table (Fig. 1.3) is a thin carbon-fiber table supported at only one end to provide complete clearance beneath for a panning. The telescoping pedestal allows vertical travel from 28 to 48 in., 20°

Fig. 1.3 The Diethrich IC 2020 Surgical Imaging Table

side-to-side roll, and 20° Trendelenburg tilt (reverse and standard) which makes it ideal as a surgical operating room. Complete clearance is achieved beneath for unobstructed neck to toe imaging and rapid horizontal panning is achieved with multiple position, height, tilt, and roll adjustments.

1.2.3 Flat Screens and Monitors

The surgeons, the assistants, the anesthesiologists, and the nurses should all have views of all major imaging and monitoring sources. It is therefore suggested that display of all these sources should be available in all four quadrants of an integrated room. A total of four to six ceiling-mounted flat screens as imaging tools for the procedures are necessary. Extreme care should be taken to ensure that these ceiling-mounted flat screens do not collide with operating lights. Monitors for the vital signs of the patient with provision for systemic arterial monitoring, central venous monitoring, and continuous electrocardiographic surveillance is imperative. A large 40 in. flat panel should be available as well as cameras (wall/or in-light).

1.3 Patient Monitoring

The hybrid suite must be equipped for accurate patient monitoring during the procedure; for continuous electrocardiography, surveillance is imperative. Observation of urine output is also essential for cases involving renal arteries and higher abdominal or thoracic aortic segments. Intra-arterial monitoring that includes precise measurement of pressure differentials is also important during performance of these procedures. Space for storage for the special procedure-related equipment such as stents, wires, balloons, and stent grafts, should be available.

1.4 Fluoroscopy and CT Imaging Systems

The imaging quality is dominated by the quality of the fluoroscopy unit available. Available systems can be divided roughly into two categories: portable and fixed C-arm units. Fixed C-arm units could be flooring mounted (Fig. 1.4) or ceiling mounted. There are a number of fixed fluoroscopic units available with various modifications, depending on the manufacturer (e.g., Philips, GE, OEC, Siemens, Toshiba). The image quality of fixed systems is usually superior to portable systems which can be explained by the focal spot sizes of fixed systems being significantly smaller than those of portable units.[8,9] A smaller focal spot size means higher resolution through more line pairs per millimeter. Nevertheless, the latest portable C-arm systems (Fig. 1.5) are able to reach resolutions up to 2.5–3 line pairs per millimeter, values which only could be attained by fixed systems until recently. The monitor resolution of fixed systems differs from portable systems, with the

Fig. 1.4 Floor-mounted hybrid surgical system Artis zeego. Multi-axis system by Siemens

monitors of fixed systems usually having twice the lines of resolution as the monitors of portable systems. Portable systems have a smaller generator in order to keep the system "practical" while fixed systems have a large remote generator which provides more power, with better tissue penetration and improved imaging quality. Currently, portable C-arm systems are able to provide sufficient quality for the

Fig. 1.5 A General Electric OC 9900 mobile fluoroscopic unit

majority of the standard procedures in cardiovascular surgery. However, the more complex procedures are best performed with a fixed unit.

1.5 Image Acquisition and Display

Traditional fluoroscopy provides real-time, high-resolution, low-contrast images in two dimensions through the use of an image intensifier. The development of a flat-panel detector to replace the image intensifier has enabled fluoroscopy to transition into three dimensions, producing a CT-like image (Fig. 1.6). The contrast resolution of CT is approximately 1 Hounsfield unit (HU), whereas the contrast resolution of a CT-like image is around 10 HU. CT fluoroscopy is not meant to replace diagnostic CT but to be used as a tool that will supplement interventional procedures. The ability to acquire data in three dimensions during an intervention has led to the fusion of 3D datasets with the 2D images displayed on typical monitors. In CT rotational angiography which the latest hybrid imaging systems have, the C-arm is used to rapidly rotate, obtaining serial images of the area in question in a radial fashion. The 3D reconstruction can be registered with subsequent real-time fluoroscopic images and projected to offer the clinician the ability to work in three dimensions. The process by which the image is registered and displayed is the subject of considerable research efforts on the part of many imaging equipment manufacturers. Data can be rendered volumetrically and overlayed on the fluoroscopic image, making the anatomy much more identifiable, a fused 2D /3D dataset can be created, or the information can be placed side by side. Further requirements of the suite's imaging system are a processing unit, a workstation, and a central image storage unit. The

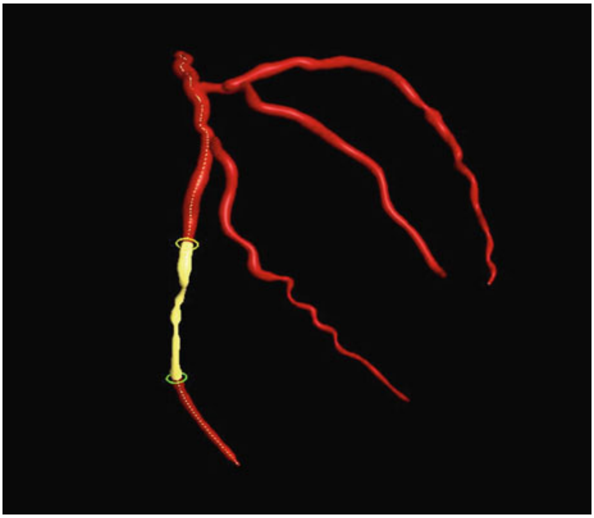

Fig. 1.6 Three-dimensional reconstruction of the left coronary artery in the projection with the least foreshortening performed with rotational angiography

potential of any C-arm equals the weakest link of each of these last three elements. While performing a procedure, smooth and fast graphic abilities are a must. Using large-size, superb-quality images from a C-arm implies that a powerful processing unit is needed. The higher the image quality, the more working memory the processing unit needs. Images from a C-arm are stored in DICOM format files, which can then be used for biometric post-processing, such as quantitative vessel analysis or 3D reconstruction. The higher the quality of the images obtained from the C-arm, the larger the size of the files that have to be processed by the workstation. Advanced imaging using Dynamic 3D Roadmap has significant clinical advantages for applications such as real-time catheter navigation and monitoring coil delivery. The image is dynamic, meaning the 3D roadmap remains displayed even if the C-arc projection, source-to-image distance, and field of view size are changed (Fig. 1.7). The 3D volume automatically follows the orientation of the C-arc in real time, so that users can choose the optimal projection view. This dynamic overlay ensures excellent positioning for catheter navigation during challenging interventions. The dynamic 3D image decreases the number of DSA acquisitions and fluoroscopy time for an examination. The user can also recall roadmap positions to reduce the need to re-mask. This reduces X-ray dose and contrast medium, which can reduce procedure costs. Dynamic 3D Roadmap provides live interventional catheter navigation.

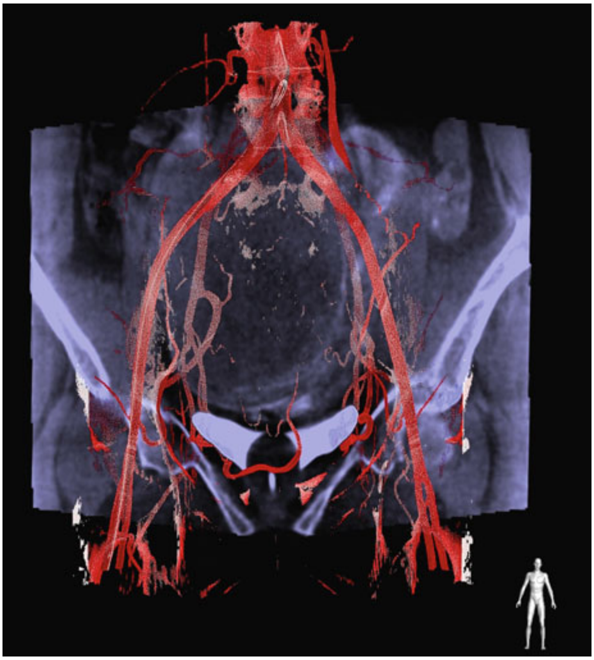

Fig. 1.7 Dynamic 3D Roadmap provides live 3D guidance through tortuous vasculature. It creates an overlay of real-time 2D fluoroscopy images and the 3D reconstruction of the vessel tree

1.6 Other Imaging Modalities

Integration of other imaging modalities like intravascular ultrasound (IVUS) (Fig. 1.8) permits more data acquisition.[11] The explosion of the endovascular revolution with particular application to the aorta has placed new demands on accurate pre-operative and intra-operative imaging to obtain accurate aortic measurements for endovascular stent grafting of the aorta.[12,13] IVUS technology requires that the user be adequately versed in the process of performing the acquisition and interpretation of the images. In patients undergoing cardiac surgery, transesophageal echocardiography and epi-aortic ultrasound have been used to characterize the severity of atherosclerosis within the ascending aorta.[14] Such information has been used to modify surgical technique, altering the location of cannula insertion, the position of aortic cross-clamps, and the placement of saphenous vein grafts, and reducing the risk of dislodging atheromatous debris.

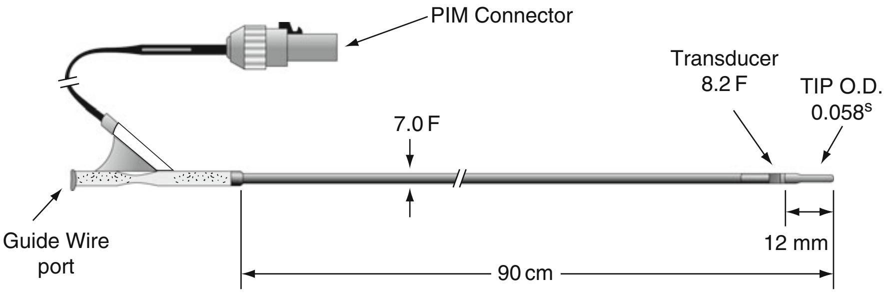

Fig. 1.8 Intravascular ultrasound 0.035 PV catheter system (PIM Connector, patient interface module connector; TIP O.D., tip outer diameter of probe)

1.7 Future Perspectives

Wireless devices would become reality in the near future and would overcome the direct limitations now present due to wire connection points. In a wireless setting, the operating table, C-arm, and other equipment can be rotated a full 360° (and beyond) at any location within the surgical/endovascular suite. Wireless equipment would also save time in case one piece of equipment needs to be repaired. A broken piece of equipment can be temporarily removed from the interventional suite and replaced by a spare. The cardiovascular surgeon or interventionist would not lose valuable operation time, and patients would not need to be put on hold. The technical team would not have to wait for spare parts or specialized tools for a certain repair because the broken piece could easily be shipped to a central repair point. Moreover, this approach would save time and costs related to the mobility of a highly specialized technical team. Integration of robotic and navigational techniques into clinical practice may lead to improved catheter accuracy, stability, and safety in comparison with conventional techniques, while minimizing radiation exposure. By maximizing the use of existing technologies while developing new approaches to treating these challenging cases, we hope that these would lead to improve overall clinical outcomes and further reduce the mortality and morbidity rates associated with managing the cardiovascular patient. It is hoped that as these new fields develop and with increasing experience with these new hybrid methods, we may well be able to maximize the applicability of minimally invasive endovascular and hybrid technology to treat a larger cohort of patients with cardiovascular disease.[15]

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Part I
Accessories Used in Thoracic Endografting