Video-atlas of open thoracoabdominal aortic aneurysm repair

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Open surgical repair of thoracoabdominal aortic aneurysms has evolved significantly over the last decades thanks to technical improvements, especially in the area of organ protection. However, despite adjunctive strategies, morbidity and mortality rates are still not negligible. Repair of the thoracoabdominal aorta represents a formidable challenge for surgeons, anesthesiologists and patients alike. While operative repair is generally carried out in specialized institutions, knowledge of the state-of-the-art diagnostic, anesthesiologic, surgical and endovascular aspects will certainly be of great value to all physicians involved in the care of these patients at any level. This "How to" video will explain all of these diagnostic, anesthesiologic and surgical aspects in our daily practice.

Key Words: Thoracoabdominal aortic aneurysm; diagnosis; open surgical rapair

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Introduction

Repair of the thoracoabdominal aorta represents a formidable challenge for surgeons, anesthesiologists and patients alike. As opposed to aortic disease confined to the chest, where the introduction of endografts has radically changed the therapeutic paradigm with significantly improved results, endovascular options for thoracoabdominal aortic disease are still investigational and limited by significant rates of mortality and morbidity.

In the near future thoracoabdominal aortic disease will be diagnosed with increasing frequency due to the aging of the population and the increasing sensitivity of non-invasive imaging modalities; in the current era, this is therefore a "hot topic".

While operative repair is generally carried out in specialized institutions, knowledge of the state-of-the-art diagnostic, anesthesiologic, surgical and endovascular aspects will certainly be of great help to all physicians involved in the care of these patients at any level.

Since 1993, we have treated over 500 cases of thoracoabdominal aneurysms with open repair and have become a major referral centre for this technically demanding condition (1).

Operative technique

Imaging

In order to plan the best possible treatment modality for every individual patient, accurate imaging must be obtained preoperatively (*Video 1*). Provided that there are no specific contra-indications, our preferred modality is state-of-the-art multi-detector computed tomography (CT) scanning, which produces excellent imaging with typically 1,000-2,000 scans for the thoracoabdominal aorta.

The acquisition of CT data in particular has benefited from spectacular progress, including multi-row detectors, higher rotation and translation speeds with reduced scan (single breath-hold), cardiac cycle synchronization, and better post-processing capabilities.

To obtain the most information from the CT dataset one must be able to navigate through the images and manipulate (or reformat) them in order to extract the most appropriate images. The traditional way to present a CT dataset is with axial (transverse) scans and their orthogonal projections, however the aorta has a tortuous path that curves in all directions of space. An oblique cut may therefore help us produce a scan whose angulation matches that of the aorta, or the vessel we need to study.

Until recently, dedicated imaging workstations were required to appropriately assess the CT dataset post-processing. These workstations are not only costly but may also create logistic inconvenience because of their fixed location and the fact that they are often shared by several specialists. In addition, a multidisciplinary approach can be critical for correct evaluation, representing another important limitation of stand-alone dedicated workstations.

OsiriX is an open-source editing software for navigating and visualizing multimodality and multidimensional Digital Imaging and Communications in Medicine (DICOM) images, including CT. It includes many useful measuring tools and all modern reproduction methods: multiplanar reconstruction (MPR), surface and volume rendering and maximum intensity projection (MIP) (2).

Interaction among specialists is important especially in complex cases. OsiriX, together with the connectivity options offered by the Mac platform, allows different doctors to view and discuss images from different locations. This increases communication and enhances the quality of the final clinical decision. Moreover, in our teaching institution, all fellows, residents and interns familiarize themselves with the system and gain important experience with the planning and sizing process for aortic disease.

Beyond diameters and extension of the pathology, analysis of vessel walls includes characteristics of calcification and thrombus. We found it particularly useful to evaluate the presence, extension and characteristics of thrombus, particularly at clamping sites and the infra-diaphragmatic aorta, if cannulation of the aneurysm is chosen for distal aortic perfusion. Additional general information is routinely obtained by visualizating 3D surface reconstructions of the entire aorto-iliac system to obtain an overall evaluation of the diseased vessels.

The exact location and geometry of aortic branches are obtained to demonstrate possible anatomic variations or anomalies, which are particularly common at the level of the renal arteries and arch vessels. Vessel patency is also routinely evaluated; in particular, obstruction of the superior and inferior mesenteric arteries and the hypogastric artery and dominance of vertebral artery.

The volume rendering (VR) function allows assignment of values for opacity, transparency, and color to each voxel included in the entire dataset depending on its intensity, position, and the prospective direction in which the image volume is observed.

Timely diagnosis and accurate planning and sizing allows one to offer an effective treatment to many patients. However, in spite of a flawlessly executed operation, several important complications may occur after thoracic aortic procedures. The most severe complication after these procedures is certainly spinal cord (SC) ischemia, which can in some cases cause paraplegia. Preoperative knowledge of the arterial supply to the SC could be extremely useful for procedure planning and risk stratification. Recent advances in medical imaging, especially non-invasive techniques, have increased the possibility that this knowledge will soon be available for individual patients (3).

Once validation and improved understanding of the information acquired from magnetic resonance (MR)-angiography and CT-based angiography of the SC vasculature are realized, preoperative stratification of the risk of SC ischemia and selective intercostal/lumbar artery re-implantation may be feasible.

Patient optimization

An adequate preoperative assessment of physiologic reserve of cardiac, pulmonary, and renal function and an accurate knowledge of cerebral and SC vascular anatomy are useful in evaluating operative risk, planning the best operative strategy and taking early additional perioperative precautions (*Video 1*). As the number of elderly people in the population has increased, so has the number of patients with thoracic aortic aneurysm associated with comorbidities such as ischemic heart disease [16% to 30% (4)], respiratory dysfunction and renal failure.

Preoperative trans-thoracic echocardiography is a satisfactory non-invasive screening method that evaluates both valvular and biventricular function. Exercise testing or dipyridamole-thallium myocardial scanning identifies regions of myocardium that are reversibly ischemic and, in patients with a significant history of angina or reduced ejection fraction, cardiac catheterization with coronary arteriography should be performed (5). Computed tomographic coronary angiography has recently emerged as a less-invasive method to visualize the coronary arterial anatomy. Multislice CT with up to 256 detector arrays, along with 3-dimensional rendering, has further improved the temporal and spatial resolution of non-invasive coronary imaging. New multi-detector scanners allow us to obtain images at certain specific phases of the cardiac cycle with the least coronary artery motion providing information also about the aorta and left ventricular ejection fraction.

In patients with an asymptomatic thoracic aneurysm, severe coronary artery occlusive disease is treated with percutaneous transluminal angioplasty prior to aneurysm repair, avoiding the use of a drug-eluting stent requiring prolonged double antiplatelet therapy that in turn increases the risk of perioperative bleeding. Surgical myocardial revascularization is limited to selected patients with severe high-risk coronary lesions that are inappropriate for percutaneous transluminal angioplasty.

Renal function is an established predictor of postoperative outcome that has been traditionally estimated with serum creatinine levels, serum electrolytes and blood urea nitrogen. These indices are considerably insensitive, especially in patients with mild to moderate degrees of renal dysfunction. The National Kidney Foundation currently recommends the use of estimated glomerular filtration rate (GFR) to assess renal function in order to avoid the misclassification of patients on the basis of serum creatinine levels alone (6). Based on the GFR assessment, chronic kidney disease has been shown to be a strong predictor of death after thoracic aneurysm repair for both open and endovascular procedures, even in patients without clinical evidence of preoperative renal disease (7). Renal size and renal artery anatomy are determined from angio-CT/angio-MR and by ultrasound. Occlusive disease of the renal arteries should be treated prior to, or during aneurysm repair, and patients are not rejected as surgical candidates based on impaired renal function alone.

Evaluation of pulmonary function with arterial blood gases and spirometry is performed for all patients undergoing open surgery of the descending aorta. In patients with a FEV_1 lower than 1.0 L and a PCO_2 higher than 45 mmHg, pulmonary function can be improved by stopping smoking, progressively treating bronchitis, losing weight and following a general exercise program for a period of 1 to 6 months before operation. However, in patients with symptomatic aortic aneurysms, despite having poor pulmonary function, the operation often may not be delayed.

A brain CT scan together with a neuropsychological evaluation by an independent neurologist is obtained for all elective patients.

Thoracoabdominal incision and aortic exposure

Single-lung ventilation by means of a double-lumen endobronchial tube is required in order to obtain adequate surgical exposure and to limit compression of the heart by retractors (*Video 2*). Fiberoptic bronchoscopy is recommended to check correct positioning of endotracheal tube especially in large aneurysms of the descending aorta that may lead to distortion of the trachea or the left main bronchus. A large nasogastric tube is routinely used and may be helpful in identifying the esophagus during the isolation and repair maneuvers of the proximal thoracic aorta.

The right femoral artery line is placed before draping, since the right side of the patient can be difficult to reach during surgery. The patient is then positioned in lumbar flexion for the spinal drain insertion using a strict aseptic technique. We prefer a lateral decubitus rather than sitting position to decrease the hydrostatic pressure of the column of cerebrospinal fluid (CSF), thereby minimizing the amount of CSF inadvertently drained from the relatively large bore needles used to puncture the dura. The lower limit of spinal cord extension should be considered when determining the level of insertion. Ideally, an intervertebral space approximately at the level of the iliac crest should be chosen. Once the dura has been punctured with the introducer needle, a drainage catheter is inserted 8 to 10 centimeters beyond the tip of the needle into the subarachnoid space. After the drain is secured to the patient, it can be connected to the pressure transducer and baseline measurements can then be made. The CSF is set to drain at a threshold of 10 cm of a preset column height.

The patient is positioned in a right lateral decubitus with the shoulders at 60° and the hips flexed back to 30°. A circulating water mattress is placed between the beanbag and the patient, in order to assist body temperature management. A shoulder roll is placed under the chest so that the right shoulder is free from pressure. The operating table is hyperextended to open the space between iliac crest and costal margin.

Patient position is maintained with the help of a moldable beanbag attached to a suction line for vacuum creation. A skin incision is planned from the midpoint between the spinal processes and the scapula, around the lower end of the scapula, down to the umbilicus, and then to the pubis if the infrarenal aorta requires repair. A gentle curve to reduce the risk of tissue necrosis at the apex of the lower portion of the musculoskeletal tissue flap is made as the incision crosses the costal margin. Prepping and draping allows for access to the left thorax, the abdomen and both inguinal areas. Usually an incision through the 5th, 6th or 7th intercostal space is employed according to the desired level of exposure. The latissimus dorsi, anterior serratus, and rectus muscles are divided by electrocautery. The pleural space in entered after single right-lung ventilation is initiated. Monopulmonary ventilation is maintained throughout thoracic aorta replacement. The subcostal margin is cut with either electrocautery or scissors at the bed of the lower intercostal space and the incision is linked downward with the abdominal incision. Resection of the posterior section of the rib, or when necessary, the whole rib, with gentle and progressive use of the retractor is useful to reduce thoracic wall trauma and fractures; anterolaterally, the incision curves gently as it crosses the costal margin, reducing the risk of tissue necrosis. Paralysis of the left hemidiaphragm produced by its radial division to the aortic hiatus may contribute significantly to postoperative respiratory failure. Hence after a thoracoabdominal incision, a limited incision of the diaphragm is routinely carried out. The diaphragm is circumferentially divided for several centimeters near its peripheral attachment to the anterior chest wall. Sparing the phrenic center, the diaphragmatic crus is divided and the aorta is dissected free. The thoracic retractor is gently and progressively opened to avoid rib fractures. The descending thoracic aorta is exposed, taking care to limit pulmonary manipulation.

Special care must be taken when isolating the proximal neck in the thoracic aorta, which can be supported using a vessel-loop. Care should be taken not to perforate the posterior distal arch while the aorta between the left carotid and left subclavian arteries is being mobilized. The insertion of a large-caliber esophageal probe makes it easier to identify and preserve the esophagus at the level of the proximal aortic neck.

The remnant of the atretic ductus arteriosus is divided. The vagus nerve and the origin of the recurrent nerve must also be identified, since they can be damaged during isolation and clamping maneuvers.

Identification and clipping of some "high" intercostal arteries can sometimes facilitate the preparation for the proximal anastomosis, thus reducing aortic bleeding. The aorta is encircled at a point where it narrows more distally, usually at the diaphragm, so that sequential clamping and repair can be performed.

The upper abdominal aortic segment is exposed via a transperitoneal approach; the retroperitoneum is entered lateral to the left colon, and medial visceral rotation is performed so that the left colon, the spleen and the left kidney are shielded with a large abdominal towel and then retracted anteriorly and to the right. The transperitoneal approach allows direct visualization of the abdominal organs to evaluate the efficacy of revascularization after completing the aortic repair.

If a retroaortic left renal vein is preoperatively detected, we prefer a modified access to the infradiaphragmatic aortic aneurysm that avoids bleeding from the venous drainage of the left kidney and the need to reattach the vein with a direct reanastomosis or interposition grafting at the end of aortic repair. Once the retroperitoneum has been entered lateral to the left colon in the routine fashion, the kidney is initially identified by palpation and left *in situ* while the left colon, spleen, and tail of the pancreas are retracted anteriorly and to the right. The Gerota's fascia is entered to expose the anterior surface of the kidney's upper pole and the dissection continues cephalad, exposing the anterior surface of the left adrenal gland behind the pancreas. The origin of the left renal artery is then isolated and an adequate amount of aneurysm wall anterior to the renal artery is dissected free to enter the aneurysm.

The aorta or iliac arteries are also encircled at the distal, infrarenal neck of the aneurysm, with care taken not to damage the inferior vena cava and iliac veins, posterior to the aorta.

Distal aortic perfusion

Cross-clamping of the descending thoracic aorta leads to several hemodynamic disturbances, including severe afterload increase and organ ischemia. The use of distal aortic perfusion with left heart bypass (LHB) has proven to be extremely useful during aortic repair (8) (*Video 3*). The rationale of LHB is providing flow to the SC, viscera and kidneys during the aortic cross-clamp period together with the reduction of proximal hypertension and afterload to the heart. In preparation for LHB and aortic clamping, to reduce bleeding from the extensive tissue exposure, low dose intravenous heparin is administered with a target activated clotting time (ACT) of no more than 200 seconds.

With a small groin cutdown, the left common femoral artery is punctured through a prolene purse-string and a 0.35 guidewire inserted. A 16 French percutaneous cannula is then introduced over the guidewire.

The left pulmonary vein is usually cannulated to provide drainage of oxygenated blood that is reinfused through a centrifugal pump (Biomedicus) into the subdiafragmatic aorta or the common left femoral artery. A "Y" bifurcation is connected to the circuit with two occlusion/perfusion catheters (9 Fr.) for selective perfusion of visceral vessels.

Aortic repair

After the LHB is started, the aorta is gently cross-clamped at the most convenient site, usually immediately after the left subclavian artery paying close attention to the proximal pressures (*Video 3*). When the aneurysm involves the proximal descending aorta, cross-clamping the aorta between the left carotid and subclavian arteries is required. Once the proximal aspect of the aorta is isolated between clamps, the descending thoracic aorta is transected and separated from the esophagus. Bleeding proximal intercostal arteries are oversewn with pledgeted suture. The proximal end of the graft is sutured to the descending thoracic aorta using a 2/0 monofilament polypropylene in a running fashion. The anastomosis is reinforced with felt pledgets.

The clamp is then removed and reapplied onto the distal thoracic aorta above the celiac axis (sequential cross-clamping) and the aneurysm is opened.

Reimplantation of intercostal arteries to the aortic graft plays a critical role in spinal cord protection. Critical patent segmental arteries from T7 to L2 are identified and temporarily occluded with Pruitt catheters to avoid the blood-steal phenomenon. The segmental arteries are then reattached to a tailored side-cut the in graft by means of an island technique. To reduce the amount of native aorta, some intercostals higher than T8 can be either sutured or selectively reattached with an 8 millimeter tube graft interposition.

The distal clamp is moved below the renal arteries and the aneurysm is opened. Visceral hematic perfusion is then maintained by the pump with 9 Fr irrigation-occlusion catheters (LeMaitre Vascular) inserted selectively into the celiac trunk and the superior mesenteric artery (400 mL/min). Selective cold perfusion of renal arteries is performed: initially a crystalloid solution with mannitol and steroids was used; however, following the evidence of improved organ preservation of kidney, liver, and pancreas by perfusion with Custodiol (9) (histidine-tryptophane-ketoglutarate), we recently introduced the use of this solution in our patients, the results of which are currently under investigation.

If a tight stenosis is encountered, before placing the irrigation occlusion catheter, orificial stenting may be accomplished by direct placement of an appropriate-sized balloon expandable stent within the artery. Neither guidewire nor fluoroscopic imaging is usually required (10). When severe atherosclerotic disease is present at the origin of the left renal artery, an endoarterectomy is performed before reattaching the artery. For visceral artery reimplantation, a side cut is tailored in the graft and the celiac trunk, superior mesenteric artery and renal arteries are reattached by means of a Carrel patch. Usually, the left renal artery is reattached separately by an 8 mm Dacron graft interposition.

Finally, an end-to-end anastomosis with the distal aorta is performed and the last clamp removed. In some cases (type I) the visceral arteries can be incorporated in a beveled distal anastomosis.

Graft selection

The reimplantation of a large amount of native aorta in the inclusion technique for TAAA repair carries the risk for subsequent recurrent aneurysm formation (11) (*Video 4*).

Techniques proposed to reduce the incidence of visceral aortic patch degeneration included the routine exclusion of the left renal artery from the aortic patch or single-vessel reattachments with commercially available multi-branched aortic grafts. These individual anastomoses can be safely and quickly accomplished when the visceral vessels are far away from each other, but can be technically difficult if the vessels originate close together. With the use of LHB and sequential aortic cross clamping, the aneurysm at the level of the visceral vessels is opened only after the completion of proximal anastomosis.

We developed an original, computerized technique based on preoperative measure of the relative distance among the visceral vessels on CT scan to obtain a virtual reproduction of the opened aneurysm before surgery. The computed aortic model (1:1 scale) is then printed to preview the actual relative position of the visceral ostia.

The surgeon can add this information to the selection criteria of the graft. When a large amount of native aorta is to be included in the repair, a multi-branched graft is usually preferred (Vascutek gelweave - Coselli thoracoabdominal graft™). This prosthesis allows single vessel reattachment, effectively reducing the risk of recurrent aortic patch aneurysm.

Comments

Open surgical repair of TAAA has evolved significantly over the last decades thanks to technical improvements, especially in the area of organ protection (12). However, despite adjunctive strategies, morbidity and mortality rates are still not insignificant. Patient selection has to be based on a careful preoperative assessment and risk evaluation. Surgical TAAA repair is best performed in high-volume centers by experienced surgeons. Conventional treatment is the gold standard for fit patients open surgery treatment. The hybrid approach is currently indicated only in a subset of patients, and morbidity and mortality are still significant. Further studies are needed to assess the safety, efficacy and long-term benefits of this technique.

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