SURGICAL, ANESTHESICAL AND PERFUSION STRATEGY FOR OPEN THORACOABDOMINAL ANEURYSM REPAIR

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INTRODUCTION

Open repair of thoracoabdominal aortic aneurysms (TAAA) represents a formidable procedure for the patients and one of the most complex technical challenges for the team.

Since the pioneering works of Etheredge[1] and Rob[2] and the crucial improvements introduced by the experience of Michael DeBakey[3] and Stanley Crawford[4], that established the technical basis of contemporary open repair, some evolution on the surgical, anesthetic and perfusion techniques has occurred.

Most current experiences emerge from high volume centers, where the standardization of procedures from multidisciplinary teams is essential to success and for the reduction of mortality and morbidity rates. These teams include surgeons, anesthesiologists, nurses, perfusionists, intensive care specialists, neuromonitoring technicians, pneumologists, cardiologists and blood hematologists.

In our Heart and Vessels Department we treat a low annual volume of cases and we adopted most of the Maastricht strategy[5] and techniques, after a close cooperation with Prof. Michael Jacobs that helped in the organizational aspects and operated some patients during the initial learning curve.

The patients are operated by mixed surgical teams of vascular and cardiac surgeons and a close cooperation between all the members of the team is promoted.

Presently, one of the paramount aspects of the surgical strategy is the maintenance of organ perfusion during aortic clamping in the different phases of the procedure in order to prevent brain, spinal cord and visceral ischemia as well as minimizing blood loss.

The aim of this paper is to report the technical aspects of surgical management and organ protection used in our center for open repair of TAAA.

Overall criteria and patient selection

Our center has experience in both open and endovascular treatments of TAAA. Most cases are now repaired endovascularly and open surgery is usually reserved for fit young patients, patients with connective tissue disorders (CTD), infections and complications of endovascular procedures not amenable to endoluminal repair.

Patient preparation

All cases are discussed in a multidisciplinary meeting a week before the scheduled procedure. The CT angio is reviewed, the surgical strategy is defined, any special anesthetic care is anticipated and the required materials for surgery and perfusion are noted by the nurse and perfusion teams.

All patients are extensively evaluated regarding cardiac, pulmonary, and renal status and a coronary angiogram is routinely performed.

Anesthesia and monitoring

The patient is admitted on the day before in an intermediate care unit in order to introduce a spinal fluid catheter that will be used for cerebro-spinal fluid (CFS) pressure monitoring and drainage. This catheter is placed by the anesthesiology team the day before because if found to be bloody, the procedure is aborted due to the risk of spinal hematoma when heparin is administered when the catheter is placed the same day of the surgery.

Continuous electrocardiographic monitoring as well as invasive arterial pressure in the right upper arm and the right femoral artery to compare pressures above and below the clamping level. The upper right arterial pressure reflects cardiac output and cerebral perfusion and the line on the right femoral artery monitors arterial pressure on the lower body (inferior limbs and abdominal viscera).

General anesthesia is induced with fentanyl, propofol and rocuronium, and a propofol and remifentanyl perfusion is used to maintain anesthesia.

Selective endotracheal intubation with a double lumen tube is achieved with mandatory guidance by bronchoscopy, since a perfect left lung exclusion is essential to achieve a good exposure of the thoracic aorta.

A 4 lumen right jugular central venous catheter is also introduced in the right internal jugular vein and a large bore catheter in the right external jugular or left external jugular vein (we normally use a Swan-Ganz Catheter sheath) for rapid fluid infusion in case of unexpected hemorrhage. A bladder catheter for urine output is placed and central temperature is measured through a laryngeal probe.

Neuromonitoring is achieved using Near Infrared Spectroscopy (NIRS), which measures both frontal lobes oxygenation. Additionally, limb electrodes are placed for evoked somatosensitive evoked potentials monitoring (a task undertaken by a dedicated neurophysiologist) to assess spinal cord function after aortic clamping and intercostal and spinal arterial exclusion. If the evoked motor potential are dampened, we revert rocuronium with sugamadex. Electroencephalographic monitoring is performed using BiSpectral Index (BIS).

Cardiac function and pre-load are monitored through continuous transesophageal echocardiography (TEE). We do not usually place a Swan-Ganz catheter and monitor volemic status using the TEE.

Surgical preparation and exposure

The patient is placed in semi right lateral decubitus and then a half-way rotation of the left hip is obtained to allow exposure of the left femoral artery and vein for peripheral cannulation.

A 4-centimeter vertical left groin incision is performed, and the femoral artery and vein are exposed, and a 4/0 polypropylene purse string suture is placed in both vessels.

The thoraco-laparotomy is then performed (the intercostal space is selected according to the designed upper clamping level) with exposure of the thoracic and abdominal aorta with a special care for identifying the left renal artery. The frenotomy is limited to the muscular part to avoid injuring the phrenic nerve

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Perfusion

Our recent practice changed in relation to the Maastricht setup where the assistance of full femoro-femoral cardiopulmonary bypass (CPB) is suggested. In fact, we are now using a miniaturized Extra-Corporeal Circulation (MiECC) system, which has the advantage of requiring significantly less doses of heparin. So, instead of full heparinization with 300UI/Kg heparin, our protocol includes an initial heparinization with 100UI/Kg, in order to mantain ACT in 200''-250'' range.

The femoral artery and vein are cannulated with heparinized cannulas similar to the ones we use for longer-term ECMO runs. We normally use a 21 Fr multi perforated venous cannula that usually allows up to 5 L/min venous drainage (BE-PVL 21/55 Maquet, Rastatt, Germany) and a 15F arterial cannula that allows enough output without prohibitive trans-cannula gradients (BE-PAS 15/15 Maquet (Rastatt, Germany)).

These cannulas are connected to the MiECC system, which includes an oxygenating diffusion membrane, a centrifuge pump, and a heparin-coated tube set (similar to ECMO circuits). The heparin polymer that coats all the tube has a high biocompatibility and needs lower heparin administration, crucial for less hemorrhage in these patients with prolonged pump runs and extensive exposures. Heparin dosage is calculated using the Heparin Management System Plus (HMS) from Medtronic (Minneapolis, Mn, USA) and using a blood sample from the patient, in order to achieve an Activated Clotting Time (ACT) between 200 and 250 seconds. If the HMS is not available, we administer a heparin dosage of 100 UI/kg. A cell saver system - Livanova XTRA (LivaNova PLC, London, UK), is also utilized, in which 30000 UI/L of heparin are administered.

This same circuit also includes 5 surgical field suction input lines and 3 output lines. There is a malleable reservoir interposed between the venous and the arterial line offering some degree of control over the patient's volemia.

We also use a four-limb output visceral perfusion system (Octopus Set BE-H34361 (Maquet - Rastatt, Germany) to allow abdominal organ perfusion during the performance of renal, celiac and mesenteric anastomosis.

As we previously mentioned, we use a cell saver to lower the transfusion needs. This cell-saver system is connected to the MiECC circuit. Quick administration of volume to the patient is achieved using two different venous accesses: one is a peripheral venous access where we perfused centrifuged and washed red blood cells during the surgery; the other is a rapid large venous access where we quickly infuse aspirated but non washed/centrifugated blood in case of sudden blood loss from the surgical field.

After careful lung and visceral organ dissection, we normally initiate CPB and the patient reaches a new hemodynamic equilibrium: the superior right arm and supra-aortic branches are mainly perfused from oxygenated blood originating from the left ventricle (LV) and the lower body is perfused with oxygenated blood form the CPB circuit, similarly to ECMO patients. The venous drainage and output of the MiECC circuit will allow control of how much blood is left circulating in the patient and being ejected from the LV to the aorta. The perfusion team will then be able to balance these two outputs, which will vary during the different surgical stages. The right arterial radial line and the right arterial femoral line allow an accurate measure of the arterial pressure in these two territories.

The thoracic aorta exposure is sometimes demanding. The left lung is deflated through the double lumen endotracheal tube and posterior rib disinsertion is performed if needed. Lung and visceral organ adhesions to the aneurysm and to chest wall are very frequent, due to the continuous expansion and inflammation that always accompany TAA evolution, so careful thoracic and abdominal entry and exposure are paramount to achieve a good surgical result.

The surgical team then clamps the proximal thoracic aorta, distally to the left subclavian artery, and the distal thoracic aorta at a previously defined level. At this stage, as previously mentioned, the upper body and supra-aortic trunks are perfused with the blood originating from the LV, and the lower body and abdominal viscera are perfused by the MiECC circuit through the arterial femoral cannula. Careful and constant vigilance of both arterial lines, NIRS monitoring and evoked potentials allows the anesthetic and perfusion teams to maintain a satisfactory balance that prevents neurological damage. To avoid spinal cord damage, we usually monitor intra-thecal pressure, keeping it lower than 10mmHg, as well as maintaining the arterial pressure average arterial pressure higher than 60 mmHg to allow good spinal perfusion. When MiECC is started, lowering volemia leads to a decrease in the upper body perfusion, which can compensated by increasing the circulating volume with crystalloid solutions or packed red blood cells (RBC) units. We aim for an upper body average arterial pressure higher than 60 mmHg using the LV pulsatile output, while in the lower body non-pulsatile output (coming from the ECC circuit) a medium arterial pressure ranging from 50-80 mmHg is satisfactory.

The dynamic balance of these two parallel circulations creates an increase in lower body volemia and arterial pressure (opposite to the upper body situation), and this same balance is more susceptible to volume manipulation (increasing or decreasing venous drainage to the circuit decrease or increase LV output, respectively). In this setting, vasoactive drugs are less effective than volume manipulation.

This perfusion technique has the disadvantage of not including a blood reservoir connected directly to the circuit, so the patient acts as a real blood reservoir. Major hemorrhage or aortic clamping and unclamping are related to the larger arterial pressure variations and quick and large volume infusions in upper or lower body circulations are the fastest and most effective way to restore acceptable perfusion and preventing end-organ damage.

The surgical team then starts to sequentially replace the aorta from proximal to distal. When the anatomy suggests that visceral perfusion from the femoral cannula during clamping of the thoracic aorta may be insufficient, the reconstruction can be inverted (distal to proximal).

The aneurysmal sac is opened and partially excised, leaving the posterior wall (where intercostal arteries arise). We normally anastomose a long vascular prosthesis using 4/0 polypropylene supported by a teflon felt strip in an end-to-end fashion.

When maintaining a clamp proximal to the celiac trunk, a patch of aortic wall containing the ostia of the distal intercostal arteries is usually implanted in the graft to maintain spinal cord perfusion. This is mandatory when a decrease in the evoked potentials is observed. The smaller intercostal and lumbar arteries are ligated with 3/0 polypropylene sutures to diminish bleeding.

The clamping levels advances now to the distal abdominal aorta. At this stage, the upper body above the diaphragm including the intercostal patch is perfused with blood coming from the LV (so the output of the MiECC circuit is lowered). (Figure 1)

After opening the visceral aorta, a perfusion system of 4 cannula originated in the MiECC circuit (Octopus system) is used to perfuse the celiac trunk, both renal arteries and the superior mesenteric artery (Figure 2). Since we are not able to independently measure each visceral branch perfusion output, we calculate an overall output of 150-200 cc/min for each Octopus branch, and we keep the arterial outflow pressure inferior to 150 mmHg.

In patients without CTD, the revascularization of the celiac, SMA and right renal artery is achieved through a visceral patch and the left renal artery is usually re-implanted directly in the aortic graft. If necessary, a direct stent deployment is performed to enlarge the ostium of the visceral side branches.

In patients with CTD, a tetrafurcated vascular graft is used to separately revascularize the side branches aiming to minimize the aortic tissue left behind.

We use blood for renal perfusion. However, in many centers, custodiol is used with better outcomes of renal function. Custodiol is presently not available in our center[6].

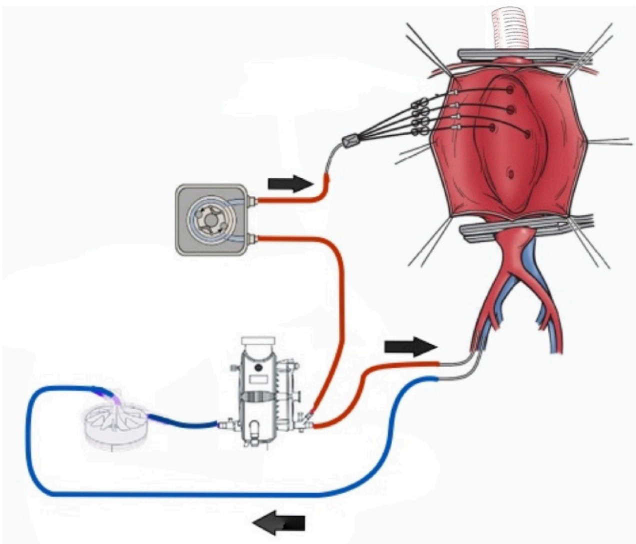

Figure 1 *Lower body visceral perfusion with the miniaturized ECC. The heart perfuses upper limbs, head and thorax, and balance of these two parallel circulations is crucial to achieve a good surgical result.*

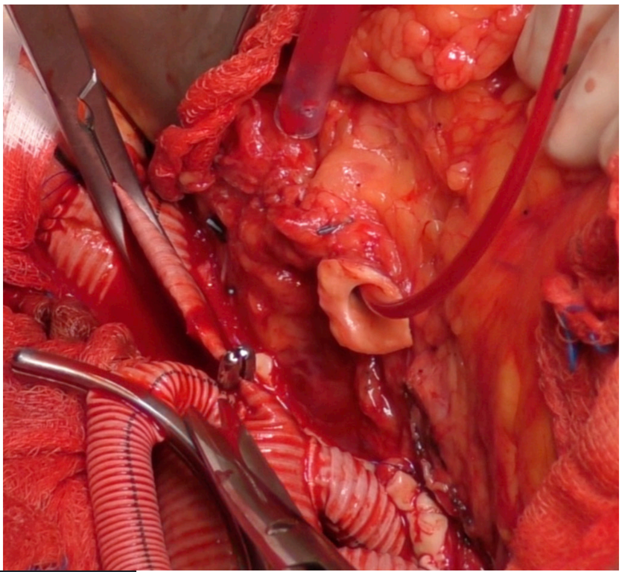

Figure 2 *Left renal artery perfusion during construction of the anastomosis to the abdominal aortic graft.*

Finally, the distal anastomosis is performed to the distal aorta or the iliac arteries and the clamps are removed. (Figure 3)

After checking for good pulsatility of all arteries, we stop MiECC output and revert heparin with a protamine dose calculated by the HMS, or using the direct method of 1 mg protamine for each 100 U of heparin.

After achieving a good hemostasis, two silicon drains

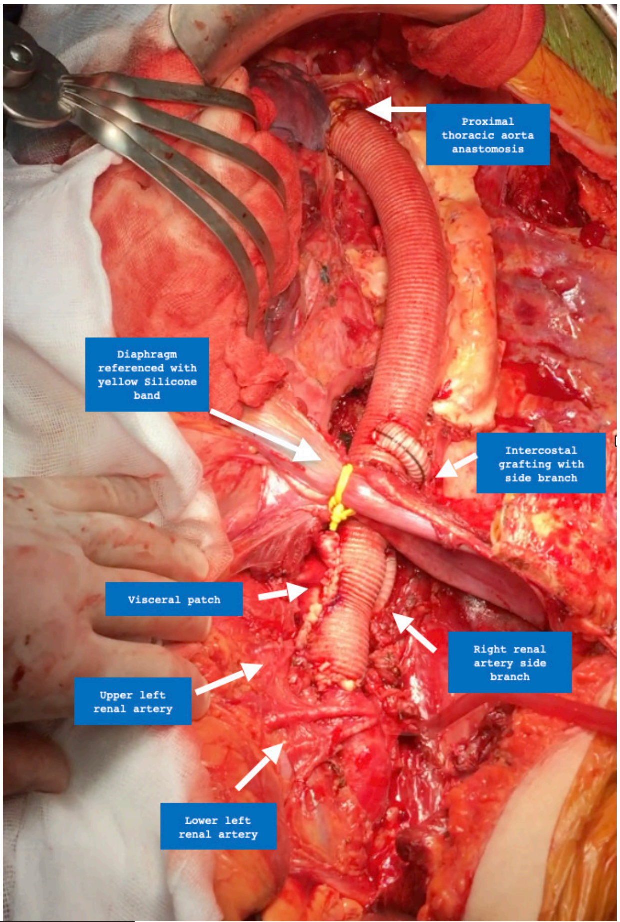

Figure 3 *Final aspect of the correction in a patient with double left renal arteries.*

Table 1 **Multidisciplinary involvement in CHULN for the treatment of TAAA.**

PATIENT	HOSPITAL–ORGANIZATION	HOSPITAL–TECHNICAL RESOURCES
• CARDIO-PULMONARY REHABILITATION PROGRAM (**Cardiology Department**). • Complete blood testing (renal function-creatinine and GFR). • ECG • Echocardiogram (M,2D,Doppler). • Coronariogram. • Respiratory function testing. • Carotid and lower limb ultrasound. • Multidisciplinary protocols for SCI prevention (**Vascular Surgery Department**). • Imagiology-Angio CT (**Imagiology Department**).	• Dedicated Surgeons (**Heart and Vessels Integrated Unit**). • Dedicated Anesthesiologists (**Anesthesiology Department**). • Dedicated Nurses and Perfusionists (**Cardiothoracic Surgery Department**). • Dedicated Intensive Care Units (**Cardiothoracic Surgery Department**). • Blood products management (**Imunohemotherapy Department**). • Evoked potentials monitorization (**Neurology Department**). • Bronchoscopy for double-lumen tracheal tube positioning (**Pneumology Department**).	• CSF drainage and pressure monitorization. • Evoked potentials monitorization. • TEE monitorization. • Double-lumen tracheal tube for left lung exclusion. • Arterial lines: right radial + right femoral. • Rapid infusion systems. • Thromboelastogram. • MECC system and Cell-Saver. • Thompson Retractor.

are placed, one in the chest and one in the abdomen and all the incisions are closed.

All the blood aspirated from the surgical field after the MiECC is discontinued is processed in the cell saver and reinfused by the anesthetic team to keep hemoglobin levels above 10g/dl. Due to the large quantities of blood that are processed, it is washed to keep residual supernatant lower than 10%, to lower thromboembolism risks.

After the surgery is terminated and the wounds dressed, the patient is placed in a supine position and the double lumen endotracheal tube is switched for a single lumen tube.

The patient is then transferred to the Intensive Care Unit and keep sedated and ventilated for at least 12 hours, to maintain stability and surveillance of complications. The cerebrospinal fluid catheter is not left more than 72 hours in place.

We believe this technique to be the most appropriated to perform in these complex patients, and firmly believe that a full collaboration between all teams of health professionals is essential to achieve the good results we have obtained. (Table 1)

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