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Management of thoracoabdominal aortic aneurysms

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ABSTRACT

Conventional treatment of thoracoabdominal aortic aneurysms (TAAAs) consists of graft replacement with reattachment of the main aortic branches. Over the past 20 years a multimodal approach has gradually evolved to reduce the trauma of surgery by maximizing organ protection, allowing experienced surgical Centers to have better outcomes than previously reported. However, mortality and morbidity associated to TAAA open repair remain significant. Hybrid repair, consisting of open aortic debranching and revascularization followed by endovascular exclusion of the aneurysm, may extend the indications of TAAA repair to high-risk patients that cannot benefit from surgery, however results are still under evaluation. Aim of this paper is to illustrate the management and results of thoracoabdominal aortic aneurysms surgery with open techniques of organ protection and hybrid approach in our Center.

Keywords: *Thoracoabdominal aortic aneurysms, Vascular surgery, Surgery, Anesthesia.*

INTRODUCTION

A thoracoabdominal aortic aneurysm (TAAA) is characterized by enlargement of the aortic segment at the diaphragmatic crura and extends for variable distance proximally and/or distally from this point (1).
Historically, open surgical repair of TAAAs has involved greater operative risk than repairs of aneurysms in other aortic segments. The main sources of morbidity during operative repair of TAAAs are multiorgan failure, paraplegia and respiratory, cardiac or renal complications. Experienced surgical Centers now report lower mortality and morbidity rates for TAAA repair than they once did, largely because of the use of adjuncts to prevent end-organ ischemia (2).
The recent introduction of endovascular techniques may extend the indications of TAAA repair to high-risk patients, whose only alternative is now represented by the best medical therapy.

OPEN REPAIR

Conventional treatment of TAAAs consists of graft replacement with reattachment of the main aortic branches. A multimodal approach is currently used to reduce the trauma of surgery by maximizing organ protection. The surgical technique used, as the extension of the aneurysm, has a significant impact on the outcome of the procedure.

Thoracoabdominal incision and aortic exposure

The patient is positioned with a beanbag in right lateral decubitus (shoulders 60°,

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pelvis 30°). The upper portion of the thoracoabdominal incision is made through the 6th intercostal space; anterolaterally, the incision curves gently as it crosses the costal margin, reducing the risk of tissue necrosis. The pleural space is entered after single right-lung ventilation is initiated (*Figure 1*).

Paralysis of the left hemidiaphragm by its radial division to the aortic hiatus would contribute significantly to postoperative respiratory failure (3), hence after thoracoabdominal incision, a circumferential section of the diaphragm is routinely carried out, sparing the phrenic center. Under favorable anatomic conditions, a limited phrenotomy is carried out to preserve the tendinous center of the diaphragm; this has been shown to reduce respiratory weaning time (4).

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 can be retracted anteriorly and to the right. Transperitoneal approach allows direct view of the abdominal organs to evaluate the efficacy of revascularization at the end of aortic repair.

Left Heart Bypass (LHB)

Cross-clamping of the descending thoracic aorta leads to several hemodynamic disturbances, including severe afterload increase and organ ischemia. The rationale of LHB is providing flow to the spinal cord, viscera and kidneys during the aortic cross-clamp period together with the reduction of proximal hypertension and afterload to the heart (5). In preparation for LHB and aortic clamping, intravenous heparin (1 mg/kg) is administered with a target ACT (Activated Clotting Time) of 220-270 seconds.

Proximal descending thoracic aorta, left atrium or pulmonary vein are usually cannulated for arterial blood drain that is reinfused through a centrifugal pump (Biomedicus) into the subdiafragmatic aorta or the common left femoral artery. Flow is initially low (500 mL/min) to avoid retrograde embolization and then increased after aortic clamping to a mean distal aortic pressure of about 70 mmHg, a value that is usually achieved using a flow between 1500 and 2500 mL/min. A “Y” bifurcation is connected to the circuit and is provided with two occlusion/perfusion catheters for selective perfusion of visceral vessels (*Figure 2*).

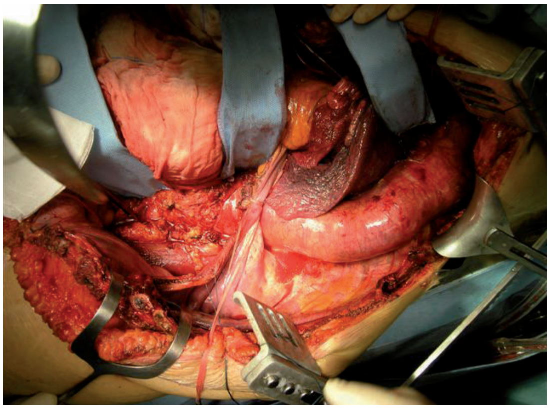

Figure 1 - *Type II thoracoabdominal aortic aneurysm exposure through thoraco-phreno-laparotomy.*

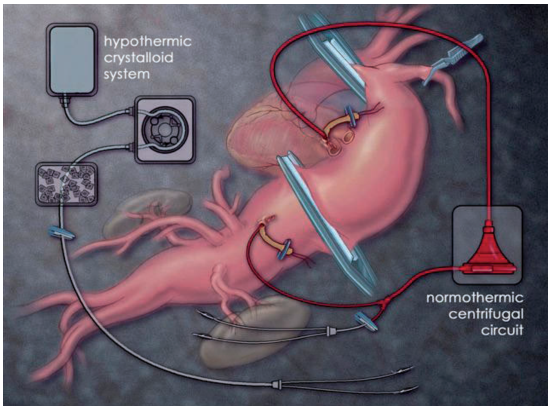

Figure 2 - *Left heart bypass and renal perfusion catheters.*

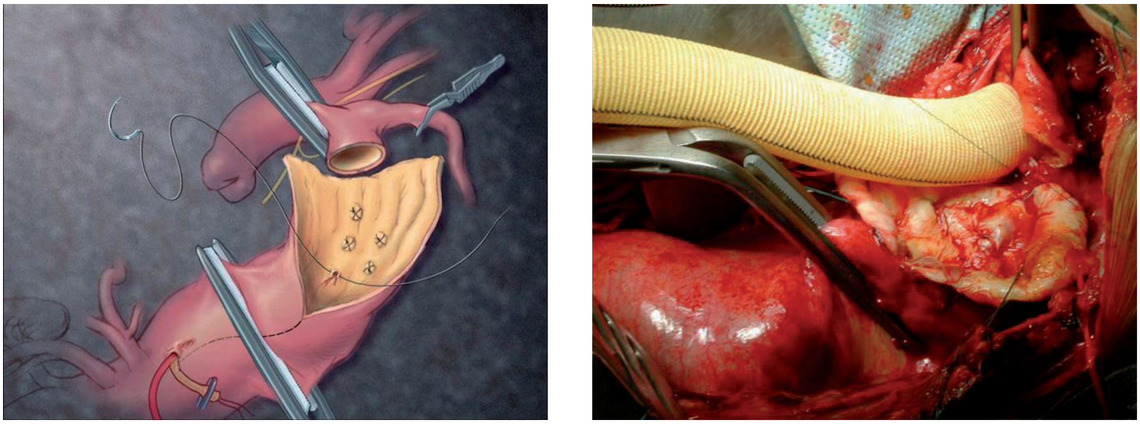

Figure 3 - *Transection of the thoracic aorta and end-to-end anastomosis. Ligature of segmental arteries is also shown.*

Aortic repair

Once the proximal aspect of the TAAA is isolated between clamps the descending thoracic aorta is transected and separated from the esophagus (*Figure 3*). The proximal end of the graft is sutured to the descending thoracic aorta using a 2/0 monofilament polypropylene suture in a running fashion. The anastomosis is reinforced with felt pledgets. The clamp is then removed and reapplied onto the abdominal aorta above the celiac axis (sequential cross-clamping).

Reimplantation of intercostal arteries to the aortic graft plays a critical role in spinal cord protection (6). Critical patent segmental arteries from T7 to L2 are selectively reattached to the graft by means of aortic patch or graft interposition. These arteries can be temporarily occluded with Pruitt catheters to avoid blood steal phenomenon.

The distal clamp is moved onto the distal abdominal aorta below the renal arteries and the upper abdominal aortic aneurysm is opened. Visceral hematic perfusion is then maintained by the pump with occlusion/perfusion catheters (9 Fr) inserted selectively into the celiac trunk and the superior mesenteric artery (400 mL/min). Selective perfusion of renal arteries is performed with a cold crystalloid solution (Ringer 4°C + mannitol 18% 70 mL, 6-methylprednisolone 500 mg in 500 mL) (7).

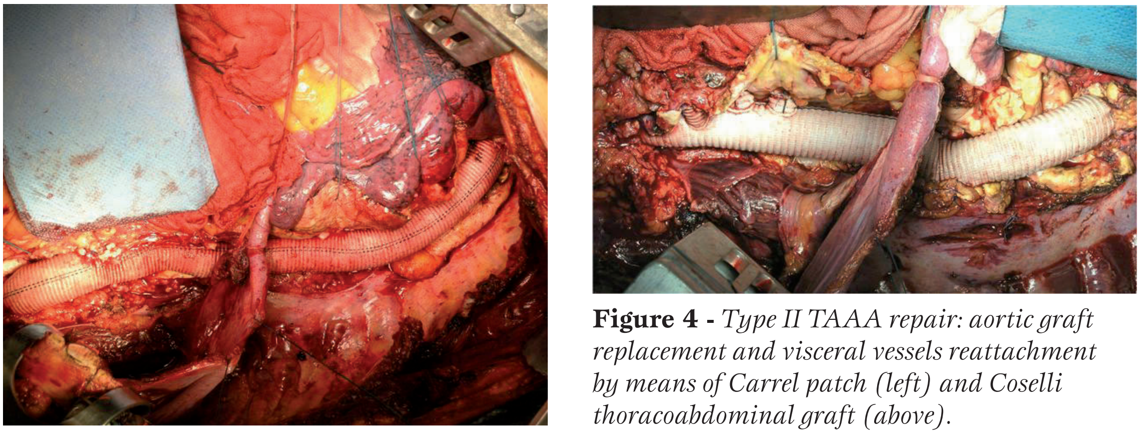

Figure 4 - *Type II TAAA repair: aortic graft replacement and visceral vessels reattachment by means of Carrel patch (left) and Coselli thoracoabdominal graft (above).*

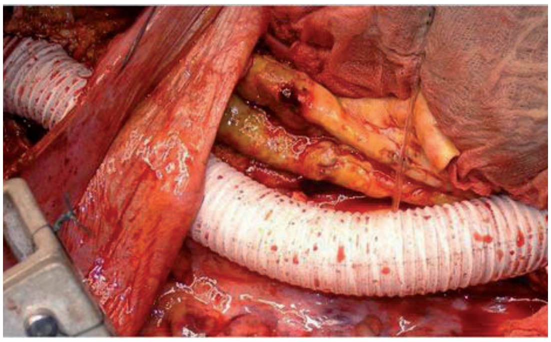

Figure 5 - *The Vascutek Triplex™ graft consists of three layers: an inner polyester graft, an outer ePTFE layer and a central layer of elastomeric membrane.*

For visceral arteries 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. This technique has been performed in 82.3 % of the patients in our series.
In 33.1 % of the cases treated by Carrel patch the left renal artery has been separately reattached to the graft in a direct fashion or by graft interposition. When the relative distance of the visceral arteries would have required a large Carrel patch, a branched graft can be successfully used (Vascutek gelweave – Coselli thoracoabdominal graft™) (*Figure 4*). This prosthesis allows single vessel reattachment, reducing the risk of recurrent aortic patch aneurysm. In our series the Coselli branched graft has been used in 10.5 % of cases.
The Vascutek Triplex™ graft is a new vascular prosthesis and consists of three layers: an inner polyester graft, an outer ePTFE layer and a central layer of elastomeric membrane (*Figure 5*). In our preliminary experience with this graft we found good handling and tailoring performances and actually a reduced bleeding from the suture lines.
Finally, an end-to-end anastomosis with the distal aorta is performed. In some cases (TAAA type I) the visceral arteries can be incorporated in a beveled distal anastomosis.

HYBRID REPAIR

Endovascular procedures may be an appealing less invasive approach to the thoracoabdominal aorta, however, the involvement of the visceral segment of the aorta represents a major challenge for TAAA stent-graft repair.
Although total endovascular treatment with branched stent-graft (8) has made it technically feasible to preserve visceral perfusion, the cost-efficacy and durability of these pioneering techniques are yet to be fully assessed.
Hybrid TAAA repair was first introduced by Quiñones-Baldrich in 1999 (9) and mainly consists of open aortic debranching and revascularization followed by endovascular exclusion of the aneurysm.
The inflow site for visceral grafts is a healthy artery, usually the infrarenal aorta, the iliac arteries or an infrarenal graft. Visceral and renal arteries are then ligated at the origin to avoid back-flow in the aneurysm and consequent type II endoleak. The open

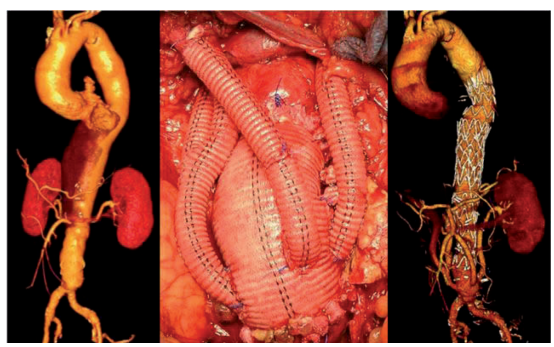

Figure 6 - *Preoperative CT of a patient with type III TAAA (left). The hybrid procedure consisted of infrarenal aortic grafting with single visceral vessels revascularization (center). Control angioCT demonstrated TAAA excusion and visceral bypasses patency (right).*

surgical stage requires a laparotomy and a transperitoneal or extraperitoneal access to the visceral vessels; however, proximal aortic cross-clamping, thoracotomy, aneurysm exposure and monopulmonary ventilation are avoided (*Figure 6*). The surgical and endovascular procedures can be simultaneous or staged.
Hybrid TAAA repair may be indicated in case of previous descending thoracic aortic repair in which a redo left-sided thoracotomy may be associated with major bleeding, increased rate of postoperative respiratory and organ failure and longer total aortic clamping time.
A further advantage of the hybrid treatment is the possibility to reduce organ ischemic time and perform visceral protection techniques by selective cooling.
Hybrid repair is appealing in case of visceral aortic patch (VAP) aneurysm after TAAA conventional repair (10).
Moreover, VAP aneurysms have ideal straight and long "in-graft" proximal and distal necks where the stent-graft can be safely delivered (11). With this technique, the aortic branches are anastomosed separately and virtually no native aortic remnants are left in situ, thus avoiding the risk of recurrences.

RESULTS

From literature, mortality and morbidity rates after TAAA conventional repair remain significant even in high-volume Centers (12-15) (*Table 1 and 2*).
These data could be not totally representative of the actual outcomes of TAAA surgical repair. Cowan et al. (23) analized data from the Nationwide Inpatient Sample (NIS), dividing Centers where TAAA surgical repair has been performed (1988-1998) in low volume (1-3 cases/year), medium volume (2-9 cases/year) and high volume (5-31 cases/year). Annual surgeon volume has been defined as low (1-2 cases) or high (3-18 cases). Conclusions were that the results of low-volume Centers and surgeons were significantly different from those of high-volume Centers and surgeons. (*Figure 7*).
In particular, in a specific subset of high-risk patients, the outcomes are associated to higher morbidity and mortality rates. As a result, these outcomes have encouraged some Centers to consider the hybrid repair as the treatment of choice (24).
The data reported in literature regarding classification and extension of pathology, patient's overall clinical conditions, surgi-

Table 1 - *Morbidity and mortality after TAAA conventional repair in high-volume Centers.*

Author	Patients (n)	30-day mortality (%)	Paraplegia/ Paraparesis (%)	Dialysis (%)	1-year mortality (%)
Coselli (16)	2755	4.7	3.6	5.1	no data
Svensson (17)	1509	10	16	9	no data
Rigberg (18)	1010	19	no data	no data	31
Sandmann (19)	673	12.5	7.5/6.6	10	no data
Crawford (20)	605	8.9	6	17	21
Schepens (21)	500	11.4	no data	no data	17
Conrad (22)	445	6.8	9.5/3.7	4.6	20

Table 2 - *Results after TAAA conventional repair - Università Vita-Salute, Scientific Institute San Raffaele, Milan, Italy.*

	Total n (%)	Elective n (%)	Emergency n (%)
Total	345	286	59
Mortality	45 (13.3)	24 (8.6)	21 (35.6)
Paraplegia	34 (9.8)	23 (8.0)	11 (18.6)
Renal failure	23 (6.6)	15 (5.2)	8 (13.5)
Respiratory failure	67 (19.9)	43 (15.4)	24 (40.7)

cal technique and results of TAAA hybrid repair are still very heterogeneous (*Table 3*). Further studies are needed to assess the safety, efficacy and long-term survival associated to the hybrid treatment of thoraco-abdominal aortic aneurysms.

Spinal cord ischemia

The etiology of spinal cord ischemia during thoracic aortic procedures is multifactorial, and the risk of paraplegia is a debated concern. Conrad et al. demonstrated the impact of paraplegia/paraparesis on survival of patients who underwent surgical or endovascular TAAA repair: 5-year survival rate was 25 % in paraplegic/paraparetic patients versus 51 % in patients with no spinal complications. Five-year survival rate was 41 % in paraparetic patients, while no paraplegic patients survived for more than 5 years (28) (*Figure 8*).

Extensive coverage of the thoraco-abdom-

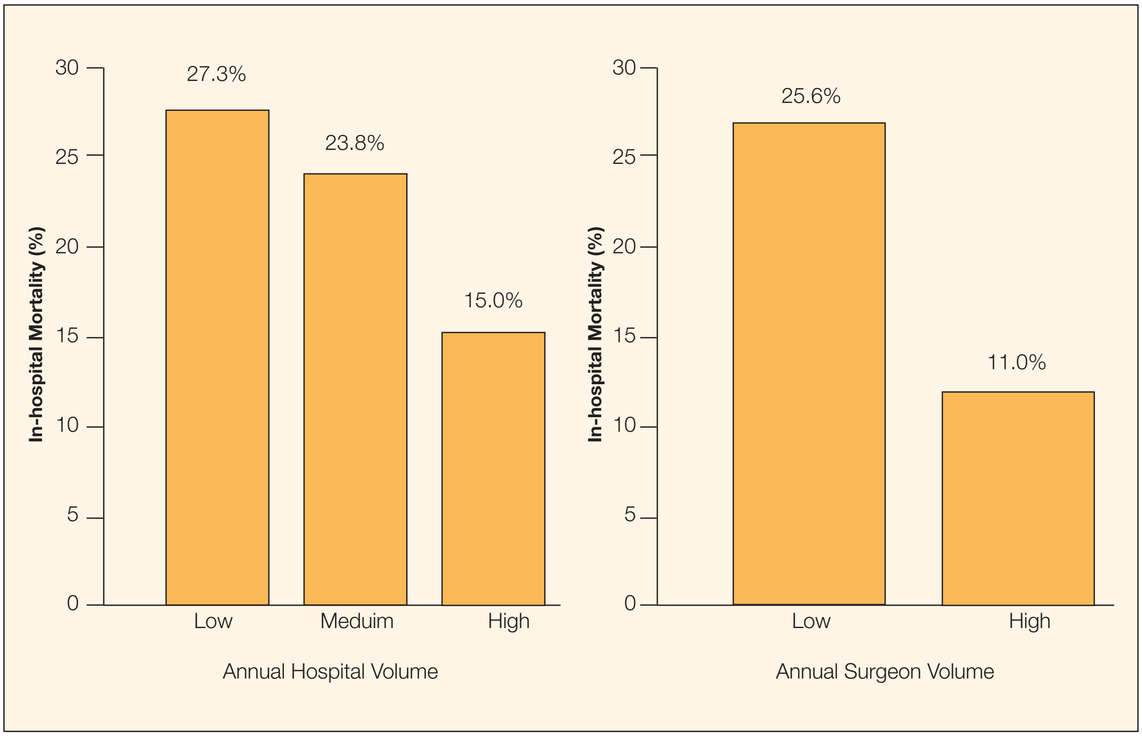

Figure 7 - *Graphs show in-hospital mortality rates in function of annual hospital volume (left) and annual surgeon volume (right).*

inal aorta could be identified as the cause of a higher rate of spinal complications. Greenberg et al. compared total stent-graft length in patients that did and did not develope neurological deficit, demonstrating a significant association with the lenght of aortic coverage (29). These findings were confirmed by Carroccio et al. (30).
Böckler et al. demonstrated that in the animal model endovascular repair is associated to lower spinal cord ischemia and paraplegia rates than aortic cross-clamping (31).
During hybrid TAAA repair, the avoidance of supraceliac clamping and the shortened duration of visceral ischemia should lead to greater perioperative hemodynamic stability compared with that during conventional open repair of TAAA, and the risk of spinal cord ischemia could be hypothesized to be reduced (32).

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.
Patient selection has to be based on a careful preoperative assessment and risk evalu-

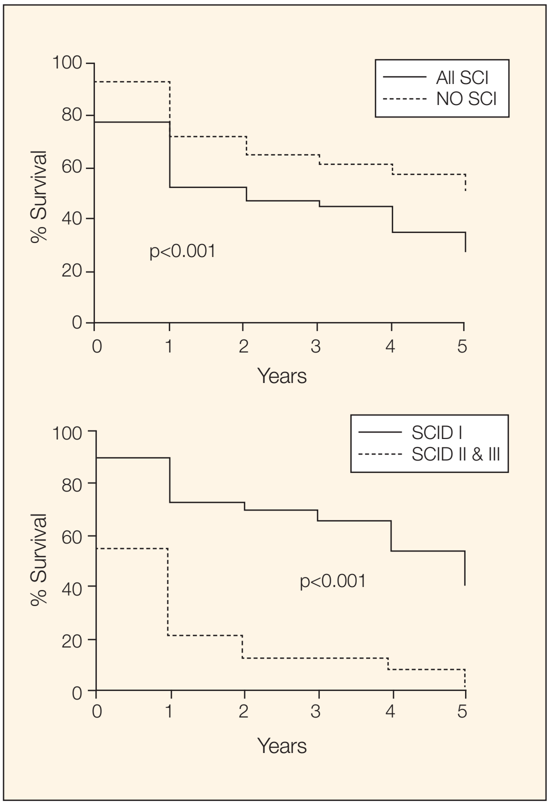

Figure 8 - *Graphs show the impact of paraplegia/paraparesis on survival of patients who underwent surgical or endovascular TAAA repair (SCI: spinal cord ischemia; SCID: spinal cord ischemia deficit; SCID I: flaccid paralysis; SCID II: muscle function < 50 %; SCID III: muscle function > 50 %)*

Table 3 - *Morbidity and mortality after TAAA hybrid repair in the main series in literature.*

Author	Patients (n)	Complications (%)	Paraplegia/ paraparesis (%)	RF (%)	30-day mortality (%)	Overall mortality (%)
Black (24)	29	61	0	15.4	13	23
Böckler (31)	28	59	11	11	14.3	30
Wolf (25)	20	55	10	15	10	25
Resch (26)	13	53	15	2	23	38.5
Lee (27)	17	25	0	6	18	24
Chiesa	31	35.5	9.6	9.6	19.4	35.5
Jenkins*	89	19	8	3	13	No data

*Collaborative group

ation. Surgical TAAA repair is to be performed in high-volume Centers by experienced surgeons. Conventional treatment is the gold standard for patients fit for open surgery.
The hybrid treatment is currently indicated in a subset of patients, however morbidity and mortality are significant. Further studies are needed to assess the safety, efficacy and long-term benefits of this technique.

No conflict of interest acknowledged by the authors

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