Surgical treatment of thoracic and thoracoabdominal aortic aneurysms: technical notes and the use of left heart bypass

Tratamento cirúrgico de aneurismas da aorta torácica e toracoabdominal: considerações técnicas e uso de derivação cardíaca esquerda

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Abstract

Objective: The aim of this study was to analyze perioperative morbidity and mortality in patients undergoing thoracic and thoracoabdominal aortic aneurysm surgery at the Department of Vascular Surgery of IRCCS San Raffaele, Milan.

Methods: The study included 332 patients (256 males and 76 females) with a mean age of 65 (range from 34 to 82 years) undergoing 333 operations for aneurysmectomy of thoracic and thoracoabdominal aortic aneurysm between January 1988 and October 2002. Cerebrospinal fluid drainage was used in 212 cases (75% of thoracoabdominal aortic aneurysms, 53% of thoracic aortic aneurysms); 215 patients (110 thoracoabdominal aortic aneurysms and 105 thoracic aortic aneurysms) were operated under left heart bypass using a Biomedicus pump.

Results: The overall mortality rate at 30 days was 40/332 (12%); a total of 32 deaths (10.5%) were recorded during elective surgery and eight (29.6%) in patients undergoing emergency repairs. The following perioperative complications were reported: paraplegia/paraparesis in 21 cases (6.3%), respiratory failure requiring prolonged intubation in 79 cases (24%), cardiac complications (major arrhythmia, myocardial infarction) in 29 cases (9%), renal failure in 23 cases (7%), postoperative bleeding requiring redo surgery in 17 cases (5%), graft infection in six cases (1.8%).

Conclusions: Morbidity and mortality consequent to thoracoabdominal aortic aneurysm and thoracic aortic aneurysms surgery are still high. However, based on our experience, the use of an active distal circulatory support, sequential cross-clamping and cerebrospinal fluid drainage enables acceptable results to be achieved and reduces complications secondary to spinal cord and visceral ischemia, without the need for expeditious clamping times.

Key words: aortic aneurysm, thoracic aneurysm, abdominal aneurysm, cardiac surgical procedures, heart-assist devices.

Resumo

Objetivos: O objetivo deste estudo foi o de analisar morbidade e mortalidade pós-cirúrgicas em pacientes submetidos à cirurgia de aneurisma da aorta torácica e aneurisma toracoabdominal no Departamento de Cirurgia Vascular do IRCCS San Raffaele, Milão.

Métodos: O estudo incluiu 332 pacientes (256 homens e 76 mulheres) com idade média de 65 anos (variação de 34 a 82 anos) que foram submetidos a 333 operações para aneurismectomia de aneurisma da aorta torácica e aneurisma toracoabdominal entre janeiro de 1988 e outubro de 2002. A drenagem do líquido cefalorraquidiano foi utilizada em 212 casos (75% dos aneurismas toracoabdominais, 53% dos aneurismas da aorta torácica); 215 pacientes (110 aneurismas toracoabdominais e 105 aneurismas da aorta torácica) foram submetidos à cirurgia de bypass coronário esquerdo através do uso de bomba Biomedicus.

Resultados: A taxa total de mortalidade aos 30 dias foi de 40/332 (12%); um total de 32 mortes (10,5%) foram registradas durante as cirurgias eletivas e oito (29,6%) em pacientes submetidos a reparos emergenciais. As seguintes complicações pós-cirúrgicas foram relatadas: paraplegia/paraparesia em 21 casos (6,3%), insuficiência respiratória com necessidade de entubação prolongada em 79 casos (24%), complicações cardíacas (arritmia grave, enfarte do miocárdio) em 29 casos (9%), insuficiência renal em 23 casos (7%), hemorragia pós-cirúrgica com necessidade de revisão cirúrgica em 17 casos (5%), infecção do enxerto em seis casos (1,8%).

Conclusões: As taxas de morbidade e mortalidade ocorridas após a cirurgia de aneurisma toracoabdominal e aneurisma da aorta torácica ainda são altas. Contudo, de acordo com nossa experiência, o uso de suporte circulatório distal ativo, clampeamento seqüencial e drenagem de líquido cerebrorraquidiano faz com que resultados aceitáveis sejam alcançados e reduz complicações secundárias à isquemia visceral e isquemia da medula espinhal, sem a necessidade de tempo de clampeamento rápido.

Palavras-chave: aneurisma aórtico, aneurisma torácico, aneurisma da aorta abdominal, procedimentos cirúrgicos cardíacos, coração auxiliar.

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Numerous problems are related to the surgical treatment of thoracic and thoracoabdominal aneurysms and their anatomical localization. These problems are secondary to massive blood losses, extensive surgical exposure, radical hemodynamic alterations and mainly to the limited tolerance of organs subject to a temporary ischemia during aortic clamping.

During clamping of the descending aorta, the arterial pressure proximal to the clamp increases rapidly, and this is accompanied by a sudden fall in the pressure distal to the clamped aorta. The high elevation of the cardiac postload results in increased ventricular tension and hence also in preload. This results in an increased right heart pressure and central venous pressure. Such cascade of events leads to a rise in venous pressure and cerebrospinal fluid pressure. As a direct consequence of interrupted aortic flow, the organ below the clamping point is deprived from the normal oxygen intake and energy substrates, and has a reduced removal of cellular catabolites.

The effects of the hypoperfusion affecting the spinal cord, kidneys, intestine and liver are of particular clinical interest (Table 1).[1]

Table 1 - Complications of thoracoabdominal aorta surgery reported in the literature

Complications	Range	Mean
Paraparesis/plegia	4-32%	14%
Respiratory failure	16-43%	32%
AMI	2-23%	11%
Renal failure	4-37%	18%
Multiple organ failure	2-13%	5%
Postoperative bleeding	3-29%	7%

AMI: acute myocardial infarction

There are currently several strategies to reduce the duration and extent of tissue ischemia:

– Mechanical devices: including extracorporeal circulation, shunt, sequential cross-clamping, retrograde perfusion and cerebrospinal fluid drainage (CSFD);
– Surgical strategies: including the selective reattachment of intercostal arteries critical for spinal cord perfusion, selected through somatosensory evoked potentials (SEP) or motor evoked potentials (MEP);
– Reduction of metabolic activity: using moderate or profound hypothermia;
– Pharmacological aids: such as the use of mannitol, steroids, scavengers and new agents to prevent spinal cord damage caused by ischemia or reperfusion.

Materials and methods

Patients

A total of 333 operations for descending thoracic aortic or thoracoabdominal aneurysms were carried out from January 1988 and October 2002 at the Vascular Surgery Department of IRCCS S. Raffaele in Milan on 332 patients (256 males and 76 females) with a mean age of 65 years (range 34-82). These included a patient suffering from chronic aortic dissection (Stanford type B) who initially underwent isthmus repair and, three years later, complete replacement of the descending thoracic aorta due to the subsequent dilatation of the distal tract.

Table 2 shows the anatomical distribution of the treated aneurysms.

Aortic repair was performed on thoracic or thoracoabdominal aneurysms with restricted indications until 1993 (symptomatic aneurysms, emergency surgery following rupture, voluminous aneurysms) and subsequently on all patients, extending the indications for surgery to the guidelines set out in the recent literature (Table 3).[2]

Data on the preoperative, intraoperative, and follow-up periods have been collected for all patients referred to our department with this pathology since January 1993.

Table 2 - Distribution of cases in this series according to aneurysm size

Extent of aneurysm	n. of cases	%
Thoracic (TAA)	168	51
Thoracoabdominal (TAAA)	164	49
Type I*	32	20§
Type II*	50	30§
Type III*	48	29§
Type IV*	34	21§

* Classification according to Crawford
§ Percentage referred to TAAA

Table 3 - Surgical indication

Medical treatment	Clinical status
Control of risk factors Close instrumental follow-up Magnetic resonance, annual CT	Maximum diameter < 5 cm
Relative indication Given the scant information available concerning the expansion rate and risk of rupture of aneurysms, the data reported in the literature delegate indications for surgery to the individual Centers depending on their results and surgical series. A clinical and instrumental evaluation of the risk-benefit ratio for each individual case must be made in relation to surgical risk factors and possibilities of rupture.	Maximum diameter between 5-8 cm
Absolute indication	Symptomatic aneurysm Diameter > 8 cm Fissured/ruptured Expansion rate > 1 cm/year
Surgical risk factors Patient's age and clinical status Diabetes mellitus Extent of pathology Heart, respiratory and renal function	Risk of rupture Symptomatology Presence of COBP Dissecting aneurysm Max diameter and expansion rate

According to the Società Italiana di Chirurgia Vascolare ed Endovascolare (SICVE) Guidelines

Aneurysm was of atherosclerotic origin in 278 patients (84%). Type B aortic dissection was observed in 46 cases (14%); two cases were treated for para-anastomotic pseudoaneurysm in a previous suprarenal abdominal aortic replacement, one case of mycotic aneurysm in a patient undergoing dialysis and five pseudoaneurysms of the isthmus and descending aorta in patients injured in previous car accidents.

On presentation, 73 patients (22%) were symptomatic (Table 4). Surgery was elective in 92% of cases (305 patients) and urgent in 8% (27 patients).

All patients undergoing elective surgery were submitted to multiplanar scans of the thoracic and abdominal aorta using magnetic resonance (MR) with weighted T1 and T2 SE sequences (Toshiba MRT 50, 0.5 Tesla) and, until December 1994, we used also subtraction digital angiography. From January 1995 onwards, the aorta was only studied using angio-MR + Gd DTPA bolus (GE Med. Syst. Horizon IST) (Figure 1).

Patients selected for surgery were also submitted to cardiological screening using ECG and to examination by a specialist, which was extended, if necessary, using thallium-dipyridamole scintigraphy or echo-stress test in cases of suspected coronary pathology. Those patients with positive results underwent also coronarography,

Table 4 - Symptoms on presentation (excluding emergency cases)

Symptoms	n. of cases
Chest pain	51
Microembolization	9
Dysphonia	5
Acute renal failure	4
Dyspnea	3
Hemoptysis	1
Total symptoms	73

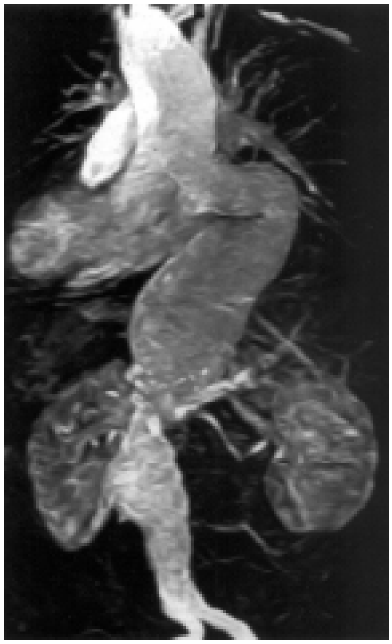

Figure 1 - Type 2 thoracoabdominal aortic aneurysm using angio-MR.

and possible myocardial revascularization prior to aortic repair.

The systematic preoperative use of TSA color Doppler ultrasonography enabled those patients with surgically relevant carotid stenosis to be identified. They were then submitted to carotid endarterectomy prior to major vascular repair, thus reducing the risk of neurological ischemic events correlated with the radical hemodynamic alterations during aortic surgery.

Routine preoperative screening was completed by assessment of peripheral arterial system using color Doppler ultrasonography of the lower limbs. Lung function was studied using chest X-ray, blood gas analysis and respiratory function tests (FVC, FEV1 and FEV 25-75%).

Technique

The preparation of patients for surgery starts in the ward approximately one hour before admission to the operating room, with the administration of antibiotic prophylaxis (IV cefazolin 2 g.) and premedication (IM scopolamine 0.25-0.5 mg.; oral diazepam 0.1 mg/Kg, IM morphine 0.1 mg/kg). Ten units of concentrated erythrocytes, 10 units of frozen fresh plasma and 10 units of platelet concentrate were available.

Anesthesia was induced using peripheral venous access with a 14G needle cannula in the right arm. In the operating room, an 18G peridural catheter was then positioned at level T6-T7 for perioperative analgesia.

General anesthesia was then induced and the double lumen endotracheal tube (Robertshaw) for monopulmonary ventilation was inserted and monitored using fibroscopy. If compression of the tracheal bifurcation by a voluminous aortic dilatation is present, there is a consequent risk of left main bronchial or aneurysm rupture. In these situations it would be preferable to use a single-lumen tube with a bronchial excluder (Univent).

Mean arterial pressure was monitored by cannulation of the radial and right femoral arteries to control proximal and distal pressure during aortic clamping. The venous accesses were then completed using 4-lumen central catheter in the right subclavian vein and a high capacity 3-lumen catheter in the right internal jugular vein.

The use of a vesical catheter with a thermometric sensor allows body temperature to be monitored in the phase of moderate hypothermia during aortic clamping.

After inserting the subarachnoid catheter for CSFD (14G Tuohy needle) in the intervertebral space between L2 and L3 or L3 and L4, the patient was positioned in the right lateral decubitus (shoulders 60°, pelvis 30°) propped up by a beanbag.

The patient was then sterilized to create an operating field extending from the left axillary cavity to mid thigh and from the spine to the right anterior axillary line.

After executing thoraco-phreno-laparotomy in the 6th intercostal space, with proximal section or resection of the 6th rib when necessary, the aneurysmatic aorta was then isolated (Figure 2). The isolation phase may be facilitated by excluding the left lung. Monopulmonary ventilation is maintained throughout thoracic aorta replacement. In favorable anatomic situations the tendinous center of the diaphragm may be preserved with a limited phrenotomy, which reduces the time required for respiratory weaning[3] (Figure 3).

Special care must be taken when isolating the proximal neck in the thoracic aorta, which can be supported using a vessel-loop. The insertion of a large esophageal probe makes it easier to identify and detach

Figure 2 - Preparation of aneurysm involving the entire thoraco-abdominal aorta (Type 2).

Figure 3 - Limited phrenotomy can reduce respiratory weaning times.

the esophagus from the proximal aortic neck. The vagus and the source of the recurrent nerve must also be identified at this stage 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 abdominal aorta as far as the bifurcation and the splanchnic vessels at source are identified and isolated using transperitoneal access, with medial visceral rotation after left parietocolic groove resection. This access allows preoperative exploration of the viscera and enables the correct revascularization following aortic reconstruction to be evaluated.

Systemic low-dose heparinization (70 UI/Kg) was used in all patients to prevent embolization and preserve the microcirculation during clamping.

When executing left circulatory assistance, the left atrium was cannulated (32 Fr angled cannula) after making a pericardial incision posterior to the course of the phrenic nerve. In the event of difficult cannulation owing to previous heart surgery or the presence of atrial thrombosis, the pulmonary veins or descending aorta can be cannulated. More recently the descending aorta is the site of choice to proximal cannulation.

Our preferred method for distal perfusion, given its relative simplicity, is the direct cannulation of the subdiaphragmatic aorta (20-24 Fr flexible cannula). A careful evaluation of preoperative CT or angio-MR makes it easier to recognize the ideal site for aortic cannulation, avoiding areas with intraluminal thrombus, which might cause peripheral embolization. This method avoids an inguinal incision and the need to reconstruct the femoral artery (Figure 4).

The circuit is then completed external to the operating field with the interposition of a centrifugal pump and reservoir. In addition to the basal circulation, a heat exchanger can be also associated, together with a supplementary arterial line onto which four 9 Fr occlusion/perfusion catheters (Pruitt-Inhara) are fixed to allow the selective perfusion of visceral arteries (octopus). The body temperature is maintained around 32 °C (moderate hypothermia).

Flow detectors on the circuit allow constant monitoring of bypass flow, enabling better control of distal aortic and visceral perfusion. It is initially kept low (500 ml/min) to avoid retrograde embolization and then increased after aortic clamping. Distal aortic pressure should be about 70 mmHg, a value that is achieved using a mean flow between 1,500 and 2,500 ml/min. These flow rates should correspond to 2/3 of the basal cardiac output measured at the start of surgery.

Sequential cross-clamping is used from the aneurysm proximal tract, and when necessary, has been done between the carotid and left subclavian arteries ensuring

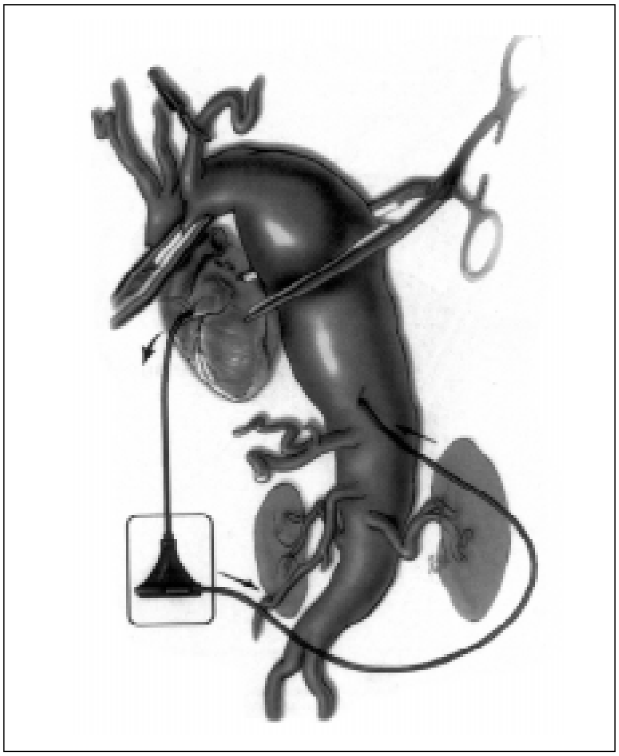

Figure 4 - Atriodistal cannulation for left bypass with centrifugal pump.

control of aneurysms extending proximally as far as the isthmus. The aorta is resected transversely and the proximal anastomosis is prepared using graft (Dacron woven double velour soaked in collagen) and 3-0 polypropylene thread for all aortic sutures, with reinforcement pledgets (teflon) at points of maximum tension. The complete section of proximal aortic neck allows the anastomosis to be made avoiding esophageal lesions when passing the suture thread (Figure 5).

The clamp is then moved caudally and the aorta is resected at the diaphragm; any "critical" intercostal arteries (T8-L2) are anastomosed at the prostheses by attaching the aortic segment including the source of the vessel (Carrel's patch). The last clamp is positioned on the infrarenal aorta or iliac arteries depending on the aneurysm distal extension. After resecting the abdominal aorta, visceral hematic perfusion is maintained by the pump using occlusion/perfusion catheters (9 Fr) inserted selectively into the splanchnic vessels. Currently we perform perfusion of renal arteries with a cold crystalloid solution and the celiac trunk and superior mesenteric artery receive normothermic blood perfusion.[4]

Figure 5 - Proximal clamping and complete resection of the aneurysm neck.

The position of visceral vessels generally enables them to be attached to the prosthesis using Carrel's patch. In some cases, the source of the visceral arteries, in particular the left renal artery, was set apart from the aneurysm and required individual anastomosis, either directly or using a graft. During this phase the presence of any lesions creating stenosis at the source of the visceral arteries can be corrected using endarterectomy or bypass. More recently, we have performed direct open stenting during operation in patients with ostial stenosis of visceral arteries (Figure 6).

Figure 6 - Open stenting of the celiac trunk before introducing the cold perfusion in a type 4 aneurysm.

Lastly, we proceeded to prepare the anastomosis with the distal aorta (Figure 7). When the aortic dilatation ended at the level of the renal arteries a distal beveled anastomosis was prepared, including the visceral and distal aorta together.

In type 3 and 4 aneurysms we used mainly a less invasive approach with limited phrenotomy, systemic low-dose heparinization (70 IU/Kg), simple aortic clamping and selective cold perfusion of the visceral arteries (superior mesentery and celiac trunk: Ringer lactate +4°C; renal arteries: Ringer 4°C + mannitol 18% 70 ml, 6-methylprednisolone 500 mg in 500 ml).

On completion of the procedure, after the removal of the perfusion cannulae and heparin antagonization using sulfate protamine, careful hemostasis was performed with closure of residual aortic wall covering the graft. The use of biological glue and absorbable knitted fabric of oxidized cellulose or fibrillar collagen may have an important role in obtaining blood-tight anastomosis. Before re-expanding the left lung, two suction thoracic drainage tubes (32 Fr) and one retroperitoneal periprosthetic drainage (Jackson-Pratt) were positioned.

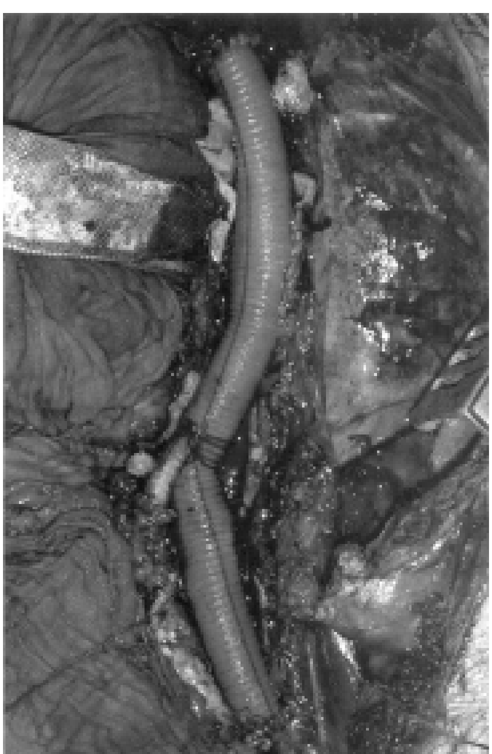

Figure 7 - Final result of a type 2 aneurysm repair, with an aortic left renal artery bypass.

Cerebrospinal fluid drainage (CSFD) and distal aortic perfusion (DAP) were not used in emergency surgery. CSFD was maintained throughout the intraoperative period and for the first three postoperative days, thus keeping cerebrospinal fluid pressure below 10 mm/Hg; this period was extended if neurological deficits appeared.

The instrumental follow-up included chest X-ray, abdominal color Duplex scan (in cases of TAAA) at one month after surgery, angio-MR after three months and a check-up at 6 months and thereafter annually using CT or angio-MR.

Results

Intraoperative data

Assisted circulation was used in 215 cases in the form of left heart bypass (110 TAAA and 105 TAA), associated with sequential cross-clamping in TAAA. Almost all type IV and some type III TAAA were perfused with cold Ringer solution (34 cases). Deep hypothermia was used in seven cases with circulatory arrest.

The mean aortic clamping time was 48 minutes (range 25-107 min).

The interoperative identification of "critical" intercostal arteries resulted in their reattachment to the body of the prosthesis using Carrel's patch in 62 cases.

In 13 cases the left renal artery was attached separately to the prosthesis (using 6-mm Dacron prostheses in nine cases). Endarterectomy of the visceral artery ostium was performed in 14 cases, four cases underwent preoperative PTA-stenting of the renal arteries; no patients required additional revascularization surgery (bypass). Four patients were treated with intraoperative stenting: two renal arteries, one celiac trunk and one superior mesenteric artery.

Cerebrospinal fluid drainage (CSFD) was used in 212 cases (75% of TAAA, 53% TAA). The mean quantity of fluid drained intraoperatively was 70 ml (range 12-180 ml) and 380 ml (range 5-635 ml) postoperatively. There were a total of 6 intraoperative deaths (four cases of uncontrollable hemorrhage, two cases of cardiac arrest).

Postoperative data

Overall mortality at 30 days was 40/332 cases (12%), with 32/305 deaths (10.5%) in patients undergoing elective surgery and 8/27 (29.6%) in emergency operations (Table 5).

Table 5 - 30-day mortality rates in our series

Extension	n. of cases	%
Thoracic (TAA)	10/168	6*
Thoracoabdominal (TAAA)	30/164	18§
Type 1	6/32	19
Type 2	13/50	26
Type 3	6/48	13
Type 4	3/34	9

* Referred to TAA, § referred to TAAA

The causes of death were: multiple organ failure in 12 cases, bleeding in 11 cases, cardiac complications in nine cases; systemic embolization in four cases, cerebral ictus, intraoperative aortic thrombosis, synchronous aneurysm rupture and visceral aortic patch rupture in one case, respectively.

The following major complications were reported: respiratory failure requiring prolonged intubation in 79 patients (24%); renal failure in 23 (7%), temporary hemodialysis in 14 cases, bleeding requiring redo surgery in 17 (5%); paraplegia/paraparesis in 21 patients (6.3%) (Table 6), associated in one case with complete thrombosis of basilar artery aneurysm that was not diagnosed prior to surgery, cardiac complications (major arrhythmia, myocardial infarction) in 29 patients (9%) and 6 cases of prosthetic infection (1.8%) related to chylothorax in one patient.

Table 6 - Neurological morbidity rate in our series

Extension	n. of cases	%
Thoracic (TAA)	5/168	3.0*
Thoracoabdominal (TAAA)	16/164	10.0§
Type 1	4/32	12.5
Type 2	8/50	16.0
Type 3	3/48	6.0
Type 4	1/34	3.0

*Referred to TAA; § referred to TAAA

Discussion

Indications

Since results of surgical repair of thoracic and thoracoabdominal aneurysms have gradually improved over the past few years, the indications for treatment based essentially on the size of the aneurysm are increasingly inadequate. Several authors have recently looked for a more personalized risk/benefit ratio of surgery based on objective data.[5,6] From these studies we conclude that, in addition to the real dimensions (based on 3D reconstructions), the risk of rupture is aggravated by old age, the co-presence of chronic obstructive bronchopulmonary disease and symptoms related to the aneurysm. This risk of rupture must however be compared with cofactors that aggravate the risk of surgery, in particular old age, the presence of symptoms correlated with aneurysm and preoperative renal insufficiency (Figure 8).[7]

Left heart bypass

Results of surgery on thoracic and thoracoabdominal aorta secondary to aneurysmatic pathology have markedly improved since 1965, when S.E. Crawford introduced the inclusion technique which, by significantly reducing surgical time, allowed repair to be done by simple clamping.[8-10]

After these pioneering results, a number of additional methods of organ protection were introduced, and as a result no other field of vascular surgery possesses such a wide variety of surgical techniques. This diversity is mainly based on the persistent risk of perioperative organ damage (in particular, the spinal cord and kidneys) and on the multifactorial nature of these severe events. Extremely divergent data continue to be reported in the literature concerning the incidence of paraparesis/paraplegia and postoperative renal failure (Table 1).

There are two diverse schools advocating antithetical methods of organ protection. The lack of a precise etiopathogenetic definition gives equal authority to both of them, which have developed over the past two decades, with comparable results (Table 7, Table 8).[11-19] Some authors state the need to maintain adequate

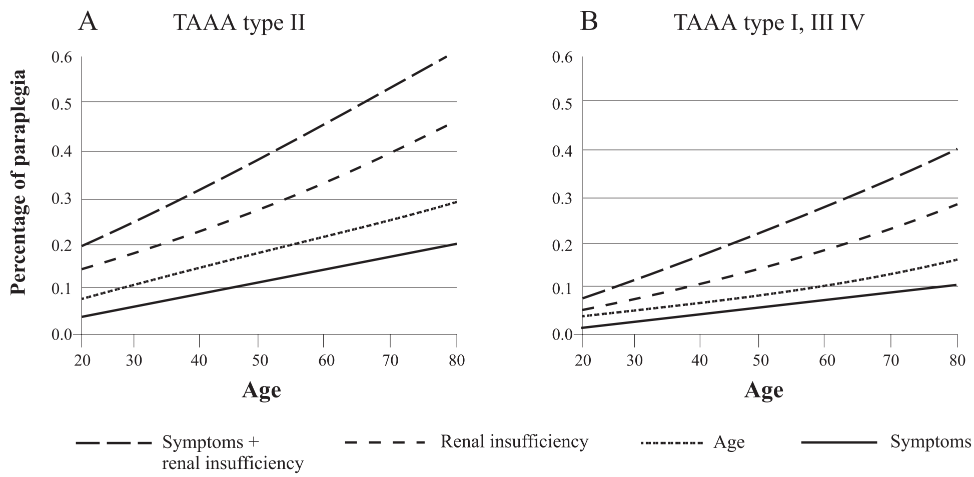

Figure 8 - A,B) Stratification risk curves for onset of postoperative complications following TAAA repair.

visceral and spinal cord perfusion during aortic clamping (passive shunts, extracorporeal circulation methods, fluid drainage, reattachment of critical intercostal arteries, intrathecal administration of vasodilators).[11,15,17,19-21] In contrast, others prefer to use simple aortic clamping (clamp and sew) convicted that more rapid surgery results in a lower percentage of complications.[11,12,14-16]

However, all the series reported agree on the close correlation between aortic clamping time and the risk of spinal cord injury, as was clearly demonstrated by Crawford in a series of 1,509 patients (Figure 9).

Likewise, prolonged aortic clamping (> 100 min) and the presence of preoperative renal dysfunction are predictive factors for the onset of acute postoperative renal failure. All authors agree that this severe complication drastically reduces ($P < 0.001$) the short-term and long-term[22] survival of operated patients.

The technique of assisted circulation was initially proposed by Cooley et al.[23] in 1957 using left heart bypass.

Utilization of left heart bypass allows a mean distal perfusion pressure to be obtained, which is higher than 60 mm/Hg during sequential aortic cross-clamping.

Table 7 - Results of TAAA surgery using simple clamping method reported in the literature

		Clamp and Sew		
Series	n. of cases	Paraplegia n (%)	Renal insufficiency n (%)	Mortality n (%)
Cambria[11]	170	12 (7.0)	16 (9.4)	16 (9.5)
Grabitz[12]	260	39 (15.0)	27 (10.4)	37 (14.2)
Coselli[13]	574	32 (5.6)	33 (5.7)	28 (4.9)
Acher[14]	110	12 (11.0)	3 (2.7)	8 (7.3)
Crawford[15]	1,251	178 (14.2)	235 (18.8)	100 (8)
Hollier[16]	150	6 (4.0)	4 (9.3)	11 (7.3)
Total	2,515	279 (11.0)	318 (12.6)	200 (7.9)

Table 8 - Results of TAAA surgery using distal aortic perfusion method reported in the literature

		Clamp and Sew		
Series	n. of cases	Paraplegia n (%)	Renal insufficiency n (%)	Mortality n (%)
Safi[17]	186	12 (7.0)	22 (15.1)	18 (9.6)
Coselli[18]	312	15 (4.8)	33 (10.6)	16 (5.1)
Schepens[19]	50	5 (10.0)	5 (10.0)	4 (8.0)
Svensson[15]	258	56 (21.7)	34 (13.2)	23 (8.9)
Total	806	88 (10.9)	94 (11.6)	61 (7.5)

The employment of selective additional perfusion of visceral arteries, using occlusion/perfusion catheters linked to the pump (Octopus), enables the entire replacement of thoracoabdominal aorta to be made with continuous visceral perfusion. By using these additional methods, the duration of "hot" visceral ischemia (in particular, renal ischemia) is reduced to few minutes (range 2-7 min in our series) required to explore and cannulate the arterial openings with perfusion catheters. By augmenting the duration of clamping tolerance, visceral perfusion contributes to a higher level of surgical accuracy and precision.

A reduction in left ventricular tension is also achieved with this method, which decreases preload and prevents hypertension of the proximal aorta. This hemodynamic control cannot be achieved with the same efficacy by extraluminal shunt systems,[24,25] unless vasodilators are used (sodium nitroprusside and/or anesthetic drugs).[26] Moreover, blood flow is not constant along the shunt but depends on various concomitant factors, such as the tube diameter, the presence of kinking and the "driving force" in the proximal aorta.[27]

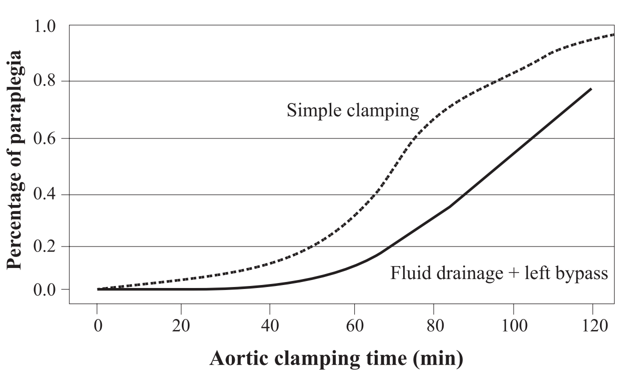

Figure 9 - Risk of paraplegia correlated with aortic clamping time.

An additional advantage of left heart bypass is the possibility of connecting a heat exchanger to the circuit, thus allowing homeothermia/moderate hypothermia to be achieved during surgery. On completion of aortic reconstruction, prior to decannulation, this exchanger also enables the patient's physiological temperature to be restored, thus diminishing the risk of coagulation disorders and cardiac arrhythmia.

Left circulatory assistance is generally supported by a centrifugal pump, unless the patient has undergone full heparinization. First described by Rafferty & Kletschka[28] in 1968 and introduced into clinical practice in 1975, this kinetic pump offers several advantages compared to traditional methods (Roller pump). The kinetic energy transmitted to the blood is generated by the high-speed rotation of a series of coaxial cones, producing a hematic vortex identical to a cyclone. The Bio Console motor interacts with a magnet fitted to the base of the cones which regulates the speed of revolution: increased velocity means an increased centrifugal force of blood and hence an increased output. The cones are designed to minimize the traumatic lyses of red blood cells. Owing to the dynamics generating the hematic vortex, any potentially thrombogenic element is trapped at the tip of the cones (the eye of the cyclone), thus preventing its emission into the circulation. Lastly, the circuit is fitted with a filter thus guaranteeing the complete safety of the system.

Although the preliminary results were often divergent in small series of patients,[29-33] it is now clear that, if executed using left heart bypass and sequential aortic cross-clamping, distal aortic perfusion (DAP) exerts a protective effect on the kidneys and spinal cord in the event of prolonged aortic clamping.[34-40]

Conclusions

Our personal experience confirms that the use of DAP in the form of left heart bypass with Biomedicus pump and sequential cross-clamping, associated with cerebrospinal fluid drainage, allowed us to achieve complication rates comparable to international experience.

In spite of the technical evolution in the past twenty years, aneurysmatic pathologies of thoracic and thoracoabdominal aorta continue to represent a challenge for vascular surgeons, owing to the complexity of their surgical repair and perioperative management.

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