Descending thoracic and thoracoabdominal aortic aneurysms

James I. Fann

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Department of Cardiothoracic Surgery, Falk Cardiovascular Research Center, Stanford University Medical School, Stanford, California, USA.

Correspondence and requests for reprints to James I. Fann, MD, Department of Cardiothoracic Surgery, Falk Cardiovascular Research Center, Stanford University Medical School, Stanford, California 94305-5247, USA.
Tel: +1 650 858 3917; fax: +1 650 723 7110; e-mail: jfann@stanford.edu

Introduction

Since the incidence of thoracic aortic aneurysms are over five cases per 100 000 person-years, patients with this entity are not infrequently evaluated by the physician in the outpatient or hospital setting [1]. A descending thoracic aortic aneurysm is defined as involving any portion of the thoracic aorta distal to the left subclavian artery and extending to above the diaphragm; thoracoabdominal aortic aneurysms are more extensive with the distal portion involving all or part of the abdominal aorta. The main goal of the diagnosis and treatment is to prevent aneurysm rupture, which is the most feared and devastating complication. Historically, techniques to treat patients with aneurysms of the aorta or peripheral arteries included ligation proximal to the aneurysm, excision and over-sewing of the neck of the aneurysm, placement of wire into the sac to effect thrombosis, aneurysm wrapping with an external support, and endoaneurysmorrhaphy.

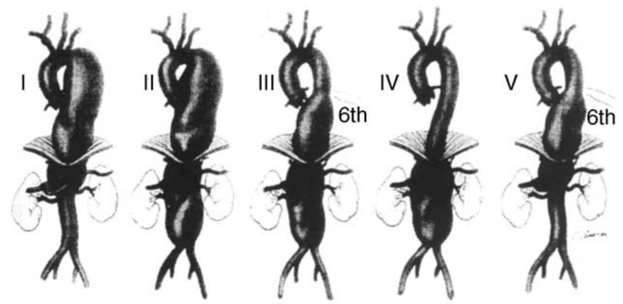
Approximately 40 years ago, the modern era of thoracic aortic surgery was heralded by Lam and Aram, who used an aortic homograft to replace the descending thoracic aorta for aneurysmal disease [2]. In 1953, DeBakey and Cooley reported the first successful replacement of a descending thoracic aortic aneurysm using a synthetic vascular graft [3] and the surgical approach to thoracoabdominal aortic aneurysms has been carefully evaluated by Crawford and his colleagues [4–7]. Since the early therapeutic approaches, the diagnosis and treatment of thoracic and thoracoabdominal aortic aneurysms have become better defined with advances in technology resulting in improved surgical outcomes.

This following review focuses on current diagnostic and surgical modalities for treating patients with descending thoracic and thoracoabdominal aortic aneurysms, excluding the entity of aortic dissection. An alternative technique in treating descending thoracic aortic aneurysms (but not thoracoabdominal aortic aneurysms) employed at Stanford University since 1992 is endovascular stent-grafting, which is less invasive and may be associated with lower morbidity than open surgical repair [8,9]. This therapeutic alternative is comprehensively discussed in another section of this review.

Pathogenesis and natural history

The majority of descending thoracic and thoracoabdominal aortic aneurysms are degenerative in etiology and

Fig. 1



The classification of thoracoabdominal aortic aneurysms as proposed by Crawford and modified by Safi. Type V (formerly a subset of type I) involves the descending thoracic aorta at the level of the sixth interspace extending to just above the renal arteries. (Reprinted with permission from the Society of Thoracic Surgeons (**The Annals of Thoracic Surgery** 1998; **66**:1204–1209) [10]).

associated with atherosclerosis. Other causes of descending thoracic aortic aneurysms include traumatic aneurysms, mycotic (or infectious) aneurysms and post-operative pseudoaneurysms. Most aneurysms due to degeneration and atherosclerosis are fusiform; less frequently, saccular aneurysms, which represent a localized weakening of the aortic wall, are found. Of the aortic aneurysms limited to the thorax, the ascending aorta is affected most often (approximately 50% of cases), the aortic arch in 10%, and the descending aorta in 40% [1]. The majority of thoracic aortic and thoracoabdominal aortic aneurysms are chronic; however, some aneurysms, particularly those due to infection, can present acutely.

Classification of thoracoabdominal aortic aneurysms has important diagnostic and therapeutic implications (Fig. 1) [5,6,10]. Type I, accounting for one-quarter of thoracoabdominal aortic aneurysms, involves most of the thoracic aorta with the distal portion extending to the upper abdominal aorta; type II (in nearly 30%) are those involving most of the descending thoracic aorta and most or all of the abdominal aorta; type III (less than one-quarter) involves the distal descending thoracic aorta extending to most of the abdominal aorta; and type IV (less than one-quarter) is limited to most or all of the abdominal aorta (including the visceral arteries).

Since the majority of patients with thoracic or thoracoabdominal aortic aneurysm are asymptomatic, treatment is directed at the most devastating event—rupture. McNamara and Pressler found that in patients with descending thoracic aortic aneurysms who did not undergo surgery, approximately 40% died from aneurysm rupture, and 32% died from other cardiovascular disease [11,12]. In this group, mean survival was less than 3 years. Over 90% of patients sustained aneurysm rupture during the period of observation, with 68% of ruptures occurring more than 1 month after the time of diagnosis [11]. In a group of 72 patients with thoracic aortic aneurysms evaluated at the Mayo Clinic, aneurysm rupture occurred in 74% (with a rupture rate of 95% for those with an aortic dissection and 51% for those with aneurysms); rupture was associated with fatality in nearly all patients [1]. The diagnosis was not known prior to rupture in 70%; in the remaining 30% of patients, the time interval between diagnosis and rupture was 2 years. The actuarial survival estimates for patients with thoracic aortic aneurysms not surgically treated was 60 and 20% at 1 and 5 years, respectively [1,11]. Recently, Griepp and his colleagues followed 165 patients with degenerative and dissecting thoracic and thoracoabdominal aortic aneurysms and found a rupture rate of 20% in those treated non-operatively [13]. Increased risk factors for rupture included older age, chronic obstructive pulmonary disease, and uncharacteristic continued pain. Maximal abdominal aortic diameter was also a predictor of rupture in patients with degenerative aneurysms involving the thoracic and abdominal aorta.

The age at time of diagnosis for those with thoracic or thoracoabdominal aortic aneurysms due to atherosclerosis or medial degeneration is generally between 50 and 70 years of age, and men are affected more commonly than women [4–7,11,14–17]. Frequently, patients with aortic aneurysms have significant co-existing medical illnesses, including hypertension, coronary artery disease, chronic obstructive pulmonary disease, congestive heart failure, and cerebrovascular or peripheral vascular disease [11–14,18]. These comorbidities are important considerations in assessing the patient's operative risk and prognosis.

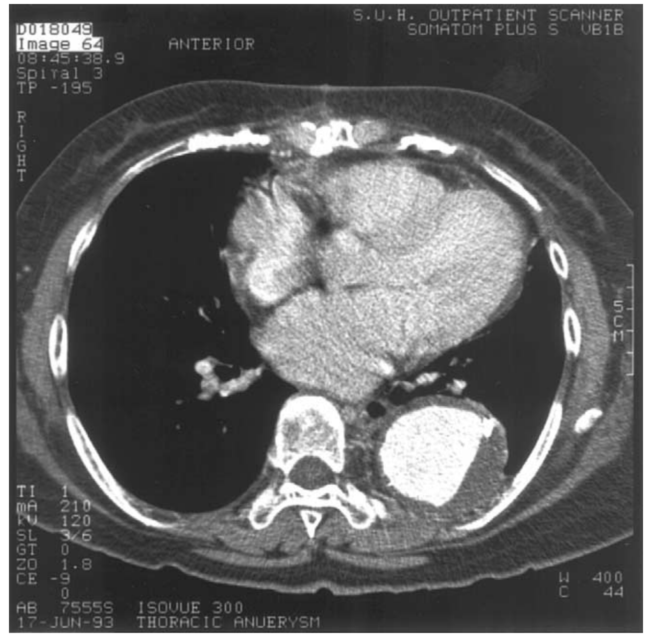
Diagnosis

Most patients with descending thoracic or thoracoabdominal aortic aneurysms have no symptoms attributable to the aneurysm when first diagnosed [11,14]. The only common presenting symptom is vague chest, back, flank, or abdominal pain. The pain may increase in severity as the aneurysm enlarges, or it may be sudden due to rapid expansion and impending rupture. Symptoms in patients with thoracic aortic aneurysms can result from compression of or erosion into adjacent intra-thoracic structures or bony thorax [12,15,19]. Hoarseness from stretching or compression of the left recurrent laryngeal nerve, tracheal deviation, persistent cough, or other respiratory symptoms is sometimes seen. Particularly worrisome are hemoptysis from bronchial or pulmonary parenchymal erosion and dysphagia and hematemesis from esophageal compression and erosion. Neurologic deficits due to spinal cord ischemia and erosion into the spine or chest wall sometimes occur. Patients with an abdominal component to the aneurysm can present with gastrointestinal hemorrhage from duodenal erosion or compression of the porta hepatis leading to jaundice. On examination, patients with

Fig. 2

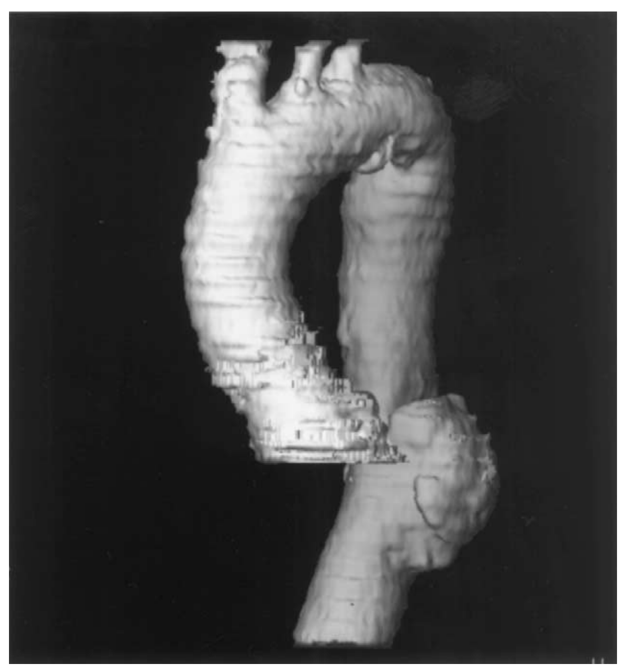
Aortography (oblique view) of a patient with a proximal descending thoracic aortic aneurysm.

Fig. 3



Computer tomography cross-sectional view of a patient with descending thoracic aortic aneurysm.

Fig. 4



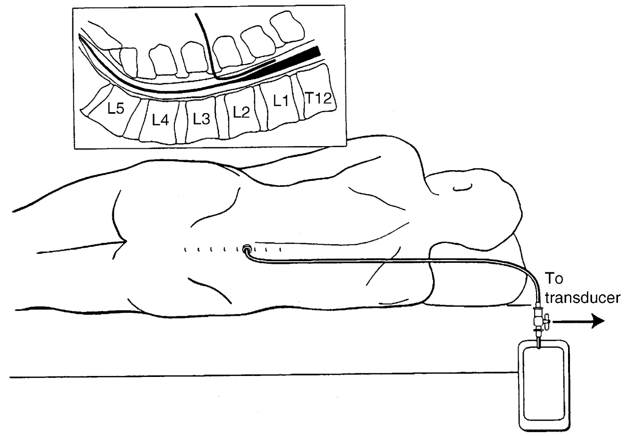
Spiral computer tomography (three-dimensional reconstruction) of a patient with a mid-descending thoracic aortic saccular aneurysm.

descending thoracic aortic aneurysms generally have no obvious findings unless there is tracheal or recurrent laryngeal nerve impingement. Patients with a thoracoabdominal aortic aneurysm may have a palpable pulsatile mass in the upper abdomen.

In these patients with thoracic or thoracoabdominal aortic aneurysms, chest radiography often shows ascending aortic, arch or descending thoracic aortic enlargement. The aortic wall may be calcified and the cardiac silhouette enlarged. Abdominal radiographs similarly may demonstrate a rim of calcium outlining the abdominal component of the aneurysm. Left ventricular hypertrophy from chronic hypertension is commonly evident on the electrocardiogram; occasionally, there is evidence of ischemic heart disease.

In the past, aortography was obtained routinely in the preoperative evaluation of patients with thoracic aortic aneurysms in order to define the location and extent of the aneurysm (Fig. 2). As less invasive cross-sectional studies have become increasingly available, aortography has been used less frequently but can nonetheless provide additional information regarding important aortic tributary anatomy, including the arch branches and the intercostal arteries [12,14,15,20]. In patients with thoracoabdominal aortic aneurysms, aortography is important in operative planning to define the status of the intercostal and renal and visceral arteries. In patients with co-existent occlusive peripheral vascular disease, angiography of the distal iliac and femoral arteries is often necessary. In addition to the ability to generate high quality images, current less invasive imaging modalites avoids the complications (e.g., stroke) associated with angiography. Axial or spiral computed tomography (CT), magnetic resonance imaging (MRI), and magnetic resonance angiography (MRA) have become valuable in the evaluation and operative planning of patients with thoracic or thoracoabdominal aortic aneurysms (Fig. 3) [20]. Spiral three-dimensional CT techniques can document the full extent of the pathoanatomy and provide an accurate aneurysm measurement (Fig. 4). Additionally, spiral CT technology permits assessment of the patency of intercostal, visceral, and renal arteries. Current MRI and MRA technology is limited in that thrombus and calcified plaques are not prominently displayed. Echocardiography may be useful preoperatively to demonstrate left ventricular function and concomitant cardiac valvular abnormalities. Coronary cineangiography is performed in patients who are over the age of 40 years or those clinically suspected of having ischemic heart disease by history or non-invasive functional study. Other co-existing medical conditions, including pulmonary and renal disease, are identified and treated preoperatively.

Fig. 5



Placement and positioning of the cerebrospinal fluid drain. (Reproduced with permission. Copyright © 2000 by W.B. Saunders Company. This material may not be reproduced, stored in a retrieval system, or transmitted in any form or by any means without the prior written permission of the publishers) [35].

Indications for surgery

Because of the risk of rupture, all patients with thoracic or thoracoabdominal aortic aneurysms are considered for surgical repair, taking into careful account the patient's overall health [11,13,15,18]. Asymptomatic patients with an aneurysm diameter that is twice the size of a normal, contiguous segment of aorta or greater than 6 cm should be evaluated for surgery. Patients with symptomatic aneurysms should undergo urgent surgical repair, even if smaller in size. Patients with evidence of progressive aneurysm enlargement should be offered an operation unless they have a prohibitively high operative risk or some other major medical problem limiting their life expectancy. Those with smaller asymptomatic thoracic or thoracoabdominal aortic aneurysms are followed with serial CT or MRI scans. Currently, surveillance-imaging studies are performed at 6-month intervals, unless the aneurysm is approaching 6 cm in size, at which point these studies are done more frequently prior to surgical intervention.

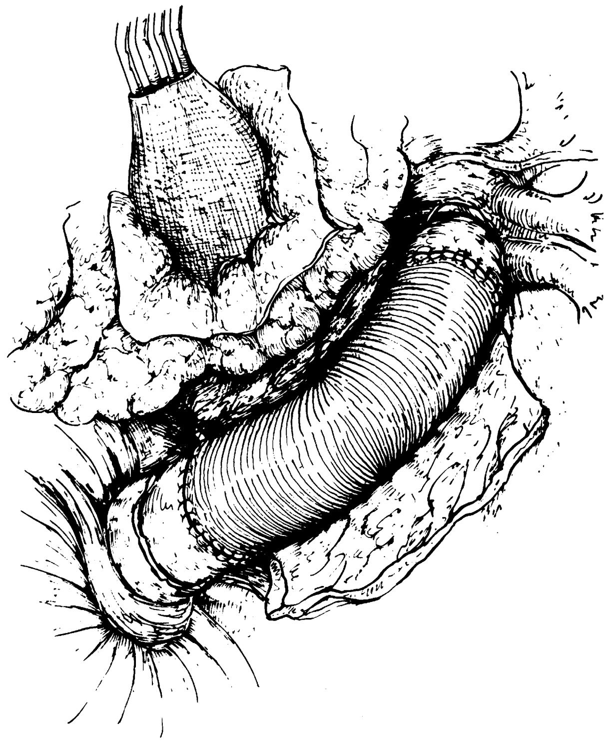
Surgical techniques

Descending thoracic aortic aneurysm

Advances in intra-operative monitoring and anesthetic techniques and the ability to replace volume and blood rapidly have improved the outcome of patients requiring thoracic and thoracoabdominal aortic surgery. Monitoring and vascular access lines include radial arterial pressure line, a pulmonary artery (or Swan-Ganz) catheter, and large bore intravenous lines (in addition to the side port of the Swan-Ganz introducer sheath). Selective double-lumen endobronchial intubation permits left lung deflation thereby facilitating the procedure. A lumbar drain (for cerebrospinal fluid drainage) is placed prior to patient positioning (Fig. 5) and because any portion of the thoracic aorta may be involved, the surgical approach for a given patient is individualized. In general, the patient undergoing descending thoracic aortic repair is placed in the right lateral decubitus position for a left posterolateral thoracotomy, which is planned to provide optimal exposure of the proximal and distal necks of the aneurysm. For more extensive descending thoracic aortic aneurysms, rib resection and/or access via an additional interspace may be necessary. In patients with thoracic aortic aneurysms with an adequate proximal neck, partial cardiopulmonary bypass (femoral artery and femoral vein cannulation) with full systemic heparinization and an oxygenator is used. Alternatively, left atrial-femoral artery cardiopulmonary bypass can be employed for distal perfusion. In patients in whom the aneurysm involves the origin of the left subclavian artery, the optimal approach is to avoid aortic clamping and the risk of cerebral embolization by utilizing femoral-femoral cardiopulmonary bypass and profound hypothermic circulatory arrest. This method provides for an open graft to proximal aortic anastomosis. Using this technique, the patient is gradually re-warmed while performing the distal anastomosis.

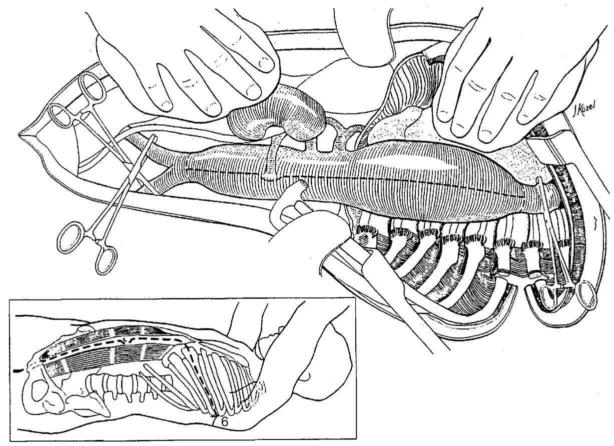
In patients undergoing conventional repair, once partial cardiopulmonary bypass is instituted and the aorta clamped, adjustments in the rate of venous return and infusion of vasodilating agents minimize left ventricular strain and hemodynamic fluctuations. A longitudinal aortotomy is made over the aneurysm and the thrombus evacuated. The intercostal branches in the proximal aorta are controlled with suture ligatures. When patent intercostal arteries in the region of T_8–L_1 are encountered, re-implantation of these arteries into the graft is performed. One option is to anastomose a smaller caliber Dacron graft to the island of lower intercostal vessels and perfuse selectively via a side limb of the cardiopulmonary bypass circuit (this graft is later anastomosed to the main graft

Fig. 6



Through a left lateral thoracotomy, thoracic aortic aneurysm repair with graft placement from the proximal descending thoracic aorta (just distal to the left subclavian artery) to the thoracic aorta at the level of the diaphragm. (Reproduced from Miller DC. Surgical treatment of thoracic aortic aneurysms. In: Jamieson SW, Shumway NE, eds. *Rob and Smith's Operative Surgery*. London: Butterworths; 1986:509–525).

Fig. 7



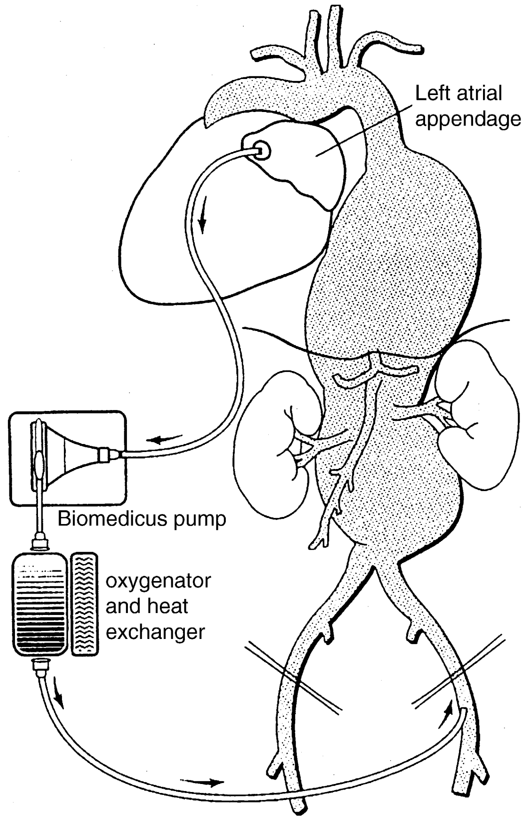
Thoracic and abdominal exposure for an extensive thoracoabdominal aortic aneurysm. (Reproduced with permission. Copyright © 2000 by W.B. Saunders Company. This material may not be reproduced, stored in a retrieval system, or transmitted in any form or by any means without the prior written permission of the publishers) [35].

after completion of the proximal and distal graft to aortic anastomoses). Proximal and distal aortic full-thickness cuffs are defined, and a woven Dacron graft is anastomosed to the cuffs (Fig. 6). Prior to securing the distal anastomosis, the native aorta and graft are flushed both antegrade and retrograde thereby removing air and debris. Cardiopulmonary bypass is gradually weaned and the heparin neutralized with protamine. After decannulation, the femoral artery and femoral vein are repaired. After assuring hemostasis, the residual aneurysm sac is closed over the graft and the chest incision closed.

Thoracoabdominal aortic aneurysm

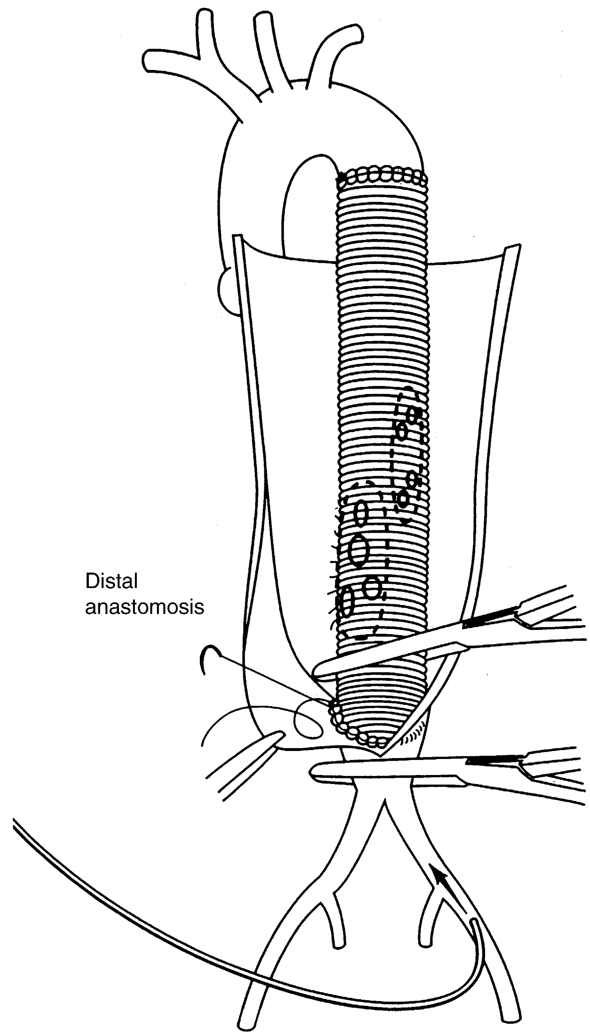
Surgical treatments of thoracoabdominal aortic aneurysms require extensive thoracic and abdominal exposure with particular attention directed at re-implantation of the renal and visceral arteries. Currently, most surgeons have adopted the graft inclusion method with direct visceral artery re-implantation as described by Crawford and the Houston group [4–7,10,17]. A double-lumen endotracheal tube is employed to permit deflation of the left lung during the procedure. As with the repair of descending thoracic aortic aneurysm, monitoring and vascular access lines and a lumbar drain for cerebrospinal fluid drainage are placed. The patient's abdomen and pelvis are placed supine with a slight rotation, and the thorax is rotated to a right lateral decubitus position. A left thoracoabdominal incision is made dividing the costal margin and extending down the abdominal midline (Fig. 7). The exposure of the thoracic aorta is achieved in the pleural cavity, while the exposure of the abdominal aorta is via the retroperitoneal plane after division of the diaphragm circumferentially. The proximal neck of thoracic aortic aneurysm is exposed; the abdominal portion of the aorta, the left renal artery, and the origin of the celiac and superior mesenteric arteries are identified. After systemic heparinization and cannulation of femoral artery and vein (or left atrium and femoral artery), cardiopulmonary bypass is instituted (Fig. 8). Normothermia is maintained during the procedure to permit continued cardiac contraction. The proximal thoracic aorta and abdominal aorta are clamped and the aortic pressure, proximal to the clamp, is maintained by increasing or decreasing the venous drainage into the cardiopulmonary bypass circuit. The thoracic aortic aneurysm is incised and the proximal neck of the aneurysm defined (Fig. 9). A woven Dacron graft is sewn to the proximal neck. Intercostal arteries are selectively re-implanted into the graft. The proximal clamp is then replaced distal to the site of re-implanted intercostal arteries. The distal aorta (i.e., abdominal aorta) is prepared depending on the extent of the abdominal involvement. If the aneurysm extends to the celiac artery and visceral arteries but not beyond (as in type I), the abdominal aorta can be partially divided tangentially and the distal anastomosis performed without separate re-implantation of the visceral vessels. If the abdominal component of the aneurysm is more extensive (as in types

Fig. 8



Left atrial-femoral partial cardiopulmonary bypass with blood return from the left atrium and pumped back (using a Biomedicus centrifugal pump and through a heat exchanger) into the femoral artery. (Reprinted with permission from the Society of Tharacic Surgeons (**The Annals of Thoracic Surgery** 1998; **66**:1204–1209) [10]).

Fig. 9



After completing the proximal and distal anastomoses and re-implantation of the intercostal and visceral vessels, the aneurysm sac is closed over the graft. The graft is sequentially clamped to permit proximal reperfusion of the intercostal and visceral arteries while the distal anastomosis is performed. (Reproduced with permission [17]).

II, III, and IV), the visceral and right renal arteries may be re-implanted using the graft inclusion method as one large 'island' with the left renal artery re-implanted as a separate button. The distal neck of the aneurysm is defined and the graft sewn to it in an end-to-end fashion. After sequential flushing of air and debris from the graft and aorta, the aortic clamps are released and the patient weaned from cardiopulmonary bypass. The divided diaphragm is re-approximated and the thoracic and abdominal incisions closed.

'Elephant trunk' technique for extensive thoracic aortic aneurysms

In patients with diffuse thoracic aortic aneurysmal disease involving the ascending and descending thoracic aorta, the elephant trunk technique has been used in sequential or serial aortic operations [22,23]. By leaving a dangling portion of the graft in the descending aorta at the time of the initial ascending aortic and arch repair (via a median sternotomy), this technique facilitates later replacement of the descending thoracic aorta (via a left thoracotomy). An effective method for the aortic arch repair (as the first surgery) is to invaginate the graft and place both layers down into the descending thoracic aorta followed by the anastomosis of the invaginated graft and the distal arch. A 'draw-string' suture attached to the inner graft allows this segment to be extracted once the graft to distal arch anastomosis is completed. The residual portion of the graft, which is less than 15 cm, is thus anchored at the distal arch and dangles in the descending aorta. The previous retrograde cardiopulmonary bypass (using femoral-femoral cannulation) is converted to an antegrade technique by inserting an arterial cannula into the arch graft after re-implantation of the arch vessels. Retrograde cardiopulmonary perfusion from femoral arterial access is not advisable since the dangling elephant trunk graft may not permit satisfactory flow to the arch branches. The graft to proximal aortic anastomosis is performed. Usually 2–3 months later, the second stage of the operation to replace the descending thoracic aortic component of the aneurysm is performed via a left thoracotomy. Because of the dangling elephant trunk, it is not necessary to obtain exposure of the proximal descending thoracic aorta and distal arch. With the patient on femoral-femoral cardiopulmonary bypass, the descending thoracic aortic aneurysm is opened, and the free end of the elephant trunk graft clamped. The distal aortic cuff is defined and anastomosed to a new graft. This graft is then sutured to the distal end of the elephant trunk graft and the patient gradually weaned from cardiopulmonary bypass (CPB).

Results

In patients undergoing surgery for descending thoracic aortic aneurysms, the operative mortality rate for all cases (emergency or elective) averaged 11% [14–16,24–26]. Risk factors for early mortality and morbidity included emergency operation, congestive heart failure, advanced age, and atherosclerotic etiology [14,16]. Operative risk appeared not to be influenced by hypertension, chronic lung disease, aneurysm location, or the method of adjunctive distal perfusion (simple aortic cross-clamping, temporary shunt, or partial CPB). The actuarial survival estimates were 70–79% at 5 years, 40–49% at 10 years, and 25% at 20 years depending on whether or not the aneurysm resection was performed electively [14,15,24,26]. Hypertension and preoperative congestive heart failure were independent predictors of late mortality [14]. Causes of late death included cardiovascular and cerebrovascular events in 41–59% of cases and rupture of another aortic aneurysm in an additional 20–25% of cases [14,15].

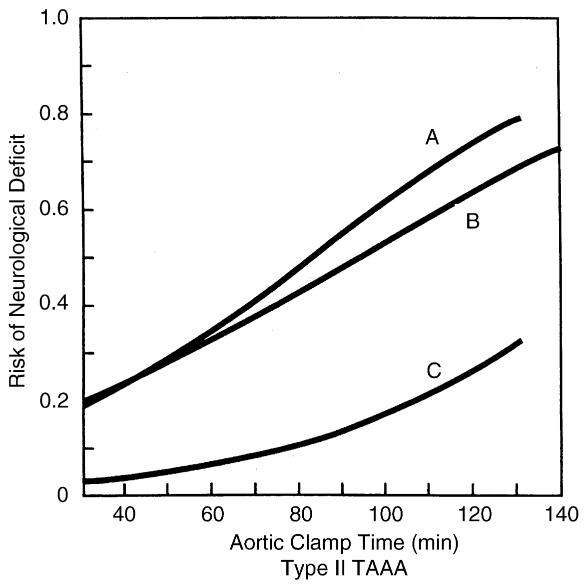
For patients undergoing repair of thoracoabdominal aortic aneurysm, the overall operative mortality rate was 5–12% [6,17,18,27,28]. Predictors of early death for patients undergoing elective surgery were advanced age, symptomatic aneurysms, type II aneurysms, long aortic cross-clamp time, and presence of renal or pulmonary disease [6,18]. The estimated long-term survival rates were 59 and 32% at 5 and 10 years, respectively. Predictors of late death included advanced age, rupture, renal dysfunction, extent of aneurysmal disease, and aortic dissection [6].

Because of the extent of operation and consequent physiologic disturbances, there are considerations unique to patients undergoing descending thoracic and thoracoabdominal aortic aneurysm repair. Intra-operatively and in the early post-operative period, the patient requires close monitoring, aggressive volume resuscitation, and correction of any electrolyte disturbances. The patient is transfused with packed red blood cells as necessary. The use of cardiopulmonary bypass and visceral organ ischemia during the abdominal component of the operation often leads to a coagulopathy that persists into the post-operative period. Thus, the patient's coagulation status is frequently evaluated and corrected with transfusions of blood components, such as platelets and fresh frozen plasma. For patients undergoing descending thoracic aortic aneurysm repair, the risk of renal insufficiency or failure is approximately 5% [14–16,24–26]. In patients undergoing extensive thoracoabdominal aneurysm repair, renal failure occurs in 13%. Additionally, because of the extent of surgery and often a history of cigarette smoking, pneumonia is a significant concern in these patients.

A particularly troubling complication of extensive replacement of the thoracic and abdominal aorta is paraplegia, which is related to intra-operative or post-operative spinal cord ischemia. For those undergoing descending thoracic aortic aneurysm repair, the paraplegia rate is approximately 4% [14–16,24–26]. For those requiring more extensive thoracoabdominal aneurysm repair, the incidence of paraplegia correlates with the extent of aorta repaired. Risk factors for post-operative paraplegia include more extensive repair (type II), duration of aortic cross-clamp, and presence of diabetes [10,18]. If the patient required replacement of the entire descending thoracic aorta and all of the abdominal aorta (type II), the paraplegia or paraparesis rate can range up to 30% [10,17,27,29,30]. Repair of the entire descending thoracic aorta and upper abdominal aorta (type I) is associated with a paraplegia or paraparesis rate of 15%. If the lower descending thoracic aorta and all of the abdominal aorta (type III) are replaced, the risk of paraplegia is estimated at 7–20%. Replacement of the entire abdominal aorta (type IV) has a paraplegia risk of 2–4%. Rupture of the thoracoabdominal aortic aneurysm is associated with a paraplegia risk of over 25%.

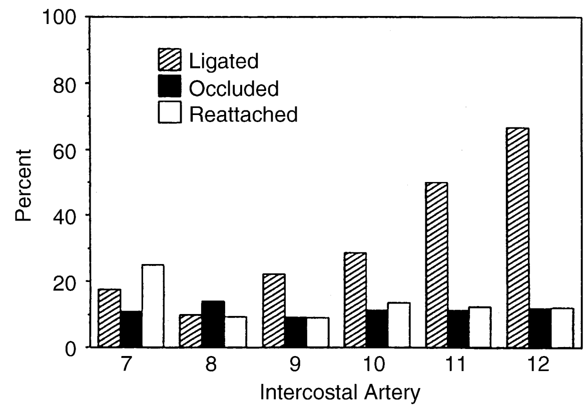
Current modalities intended to decrease the risk of paraplegia include re-implantation of lower thoracic and upper abdominal aortic intercostal branches (with or without intra-operative assessment of spinal cord ischemia), distal aortic perfusion (e.g., partial cardiopulmonary bypass), drainage of cerebrospinal fluid, and various pharmacologic interventions [10,17,18,27,29–34]. During the period of aortic cross clamping, spinal cord perfusion is dependent on a number of variables, including aortic cross-clamp time, extent of aneurysmal disease, available collateral channels, cerebral spinal fluid pressure in the lower cord region, and adequacy of distal cardiopulmonary bypass perfusion. The degree to which aortic cross-clamp time impacts on the risk of spinal cord injury remains controversial, but it does appear that the incidence of

Fig. 10



Relationship between aortic cross-clamp time and the use of adjuncts (distal aortic perfusion and cerebrospinal fluid drainage) on neurologic deficits in patients undergoing repair of type II thoracoabdominal aortic aneurysm (TAAA). (A and B) no adjuncts used at time of surgical repair (current and historical studies); (C) adjuncts used. (Reprinted with permission from the Society of Thoracic Surgeons (**The Annals of Thoracie Surgery** 1998; **66**:1204–1209) [10]).

Fig. 11



Percentage of patients with neurologic deficit by intercostal artery and artery status. The lower the position of the artery, the higher the risk of deficit if the artery is ligated. (Reproduced with permission [17]).

paraplegia is markedly increased when the cross-clamp time exceeds 30 min in the absence of distal circulatory support (Fig. 10) [10,16]. Drainage of cerebrospinal fluid intra-operatively and early post-operatively provides some protective effect against paraplegia, especially in patients with more extensive thoracoabdominal aortic aneurysms [10,17,32,34–37]. Multiple mechanisms, including decreasing the cerebrospinal fluid pressure thus increasing spinal cord perfusion pressure and removal of negative neurotrophic factors that accumulate during the aortic cross clamping, have been postulated [36,37]. Additional maneuvers, such as re-implantation of patent intercostal arteries, have not totally eliminated the risk of paraplegia; nonetheless, re-implantation of what are judged to be important intercostal arteries between T_8 and L_1 levels should be considered in patients undergoing thoracic and thoracoabdominal aortic surgery (Fig. 11) [17,28,33].

Various techniques have been proposed to assess spinal cord ischemia intra-operatively and to attempt to identify segmental vessels critical to spinal cord perfusion [33]. In this manner, intra-operative interventions to restore spinal cord perfusion, such as replacement of the distal aortic cross-clamp and selective perfusion and re-implantation of intercostal arteries, can be performed. Somatosensory evoked potentials, which monitor signal transmission through the dorsal columns, is based on repeated stimulation of the posterior tibial nerve and signal recording at the level of the high thoracic cord and above (e.g., scalp). Although somatosensory evoked potentials can provide indirect information regarding spinal cord perfusion, its response time is too slow to be of practical use, and it does not provide information regarding the motoneural system in the anterior horn (which is most subject to ischemic injury) [33]. Motor evoked potentials, based on stimulating the scalp and taking measurements at the right and left anterior tibialis and thenar muscles, has provided a specific means of intra-operative assessment of motor tract perfusion [33]. Measurements are obtained frequently during the period of aortic cross-clamp, and a reduction in the motor evoked potential amplitude to 25% of baseline is considered to be reflective of spinal cord dysfunction. Use of motor evoked potentials may prove to be a valuable adjunct in the intra-operative assessment of and in guiding surgical strategies for spinal cord ischemia. Commonly employed is distal circulatory support, such as femoral-femoral cardiopulmonary bypass or left atrial-femoral bypass, which provides cardiac decompression and reduces distal ischemic injury; however, this modality may decrease, but not eliminate, the risk of paraplegia or renal insufficiency [10,16,17,29,30].

Pharmacologic interventions have been directed at several pathogenetic mechanisms of neuronal cell death after spinal cord ischemia. Because of multiple mechanisms and processes involved in ischemic neuronal death, including excitotoxicity, intracellular calcium overload, nitric oxide, eicosanoids, apoptosis, inflammation, and reactive oxygen species, one single agent or drug is unlikely to impact on the clinical outcome [31]. It remains to be established whether current pharmacologic agents can significantly improve upon conventional techniques of partial cardiopulmonary bypass with mild-to-moderate hypothermia, drainage of cerebrospinal fluid, and re-implantation of lower intercostal arteries.

Conclusion

The diagnosis and treatment of patients with descending thoracic or thoracoabdominal aortic aneurysms have improved with advances in technology. Because the risk of rupture, surgical treatment should be considered in all patients with aneurysmal disease, taking into account their overall medical status. Descending thoracic aortic aneurysms are repaired through a left lateral thoracotomy and defining the proximal and distal aneurysm necks. Thoracoabdominal aortic aneurysms are more extensive and require a thoracotomy extending into the abdomen with circumferential division of the diaphragm and retroperitoneal exposure of the abdominal aorta. Partial cardiopulmonary bypass is generally utilized for distal circulatory support in order to decrease major complications, including paraplegia and renal failure. Other modalities proposed to decrease the risk of paraplegia include intra-operative and early post-operative drainage of cerebrospinal fluid and re-implantation of lower intercostal arteries (with or without intra-operative assessment of spinal cord ischemia). The overall success of the surgical repair is further dependent on intensive monitoring, aggressive volume replacement, and correction of various physiologic disturbances. In all patients with thoracic or thoracoabdominal aortic aneurysms, long-term follow-up with serial CT or MRI imaging is critical to assess the native aorta for progression of aneurysmal disease.

Annotated references

● of special interest
●● of outstanding interest

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6 ● Crawford ES, Crawford JL, Safi HJ, Coselli JS, Hess KR, Brooks B, *et al*. Thoracoabdominal aortic aneurysms: preoperative and intra-operative factors determining immediate and long-term results of operations in 605 patients. *J Vasc Surg* 1986; **3**: 389.

This classic article describes the early Houston experience of 605 patients undergoing thoracoabdominal aortic aneurysm repair. Predictors of operative and late mortality were assessed, along with variables that contributed to paraplegia and renal dysfunction. Although current research has contributed to the understanding of these complications and methods have been proposed to decrease their incidence, the outcomes reported by Dr. Crawford and his colleagues in this report remain a benchmark in aortic surgery.

7 ● Crawford ES, Coselli JS, Svensson LG, Safi HJ, Hess KR. Diffuse aneurysmal disease (chronic aortic dissection, Marfan, and mega aorta syndromes) and multiple aneurysm. *Ann Surg* 1990; **211**: 521–537.

A very large series (4170 patients) from one of the most revered and prolific aortic surgeons (E. Stanley Crawford). The surgical results for patients with diffuse aneurysmal disease, often involving the arch, was explored.

8 ● Dake MD, Miller DC, Semba CP, Mitchell RS, Walker PJ, Liddell RP. Transluminal placement of endovascular stent-grafts for the treatment of descending thoracic aortic aneurysms. *N Engl J Med* 1994; **331**: 1729–1734.

This landmark article describes the Stanford experience in the endovascular treatment of patients with descending thoracic aortic aneurysm using a homemade stent-graft. Thirteen patients were evaluated in this early study with acceptable results. Since this initial experience, over 150 patients have undergone this procedure.

9 Mitchell RS, Miller DC, Dake MD, Semba CP, Moore KA, Sakai T. Thoracic aortic aneurysm repair with an endovascular stent graft: the ‘first generation’. *Ann Thorac Surg* 1999; **67**: 1971–1974.

10 ● Safi HJ, Winnerkvist A, Miller CC III, Iliopoulos DC, Reardon MJ, Espada R, *et al*. Effect of extended cross-clamp time during thoracoabdominal aortic aneurysm repair. *Ann Thorac Surg* 1998;1204–1209.

The authors retrospectively evaluated their experience using cerebral spinal fluid drainage and distal aortic perfusion in a subset of patients undergoing thoracoabdominal aortic aneurysm repair and requiring extended (greater than 30 min) aortic cross-clamp time. This article provides further confirmation of the benefits of adjuncts for extensive thoracoabdominal aortic aneurysm operations.

11 Pressler V, McNamara JJ. Thoracic aortic aneurysm: natural history and treatment. *J Thorac Cardiovasc Surg* 1980; **79**: 489–498.

12 McNamara JJ, Pressler VM. Natural history of arteriosclerotic thoracic aortic aneurysms. *Ann Thorac Surg* 1978; **26**: 468–473.

13 ●● Griepp RB, Ergin MA, Galla JD, Lansman SL, McCullough JN, Nguyen KH, *et al*. Natural history of descending thoracic and thoracoabdominal aneurysms. *Ann Thorac Surg* 1999; **67**: 1927–1930.

The authors reviewed the outcome of 165 patients with descending thoracic and thoracoabdominal aortic aneurysms initially managed non-operatively. Risk factors for rupture, including older age, presence of chronic obstructive pulmonary disease, uncharacteristic continued pain, and aortic diameter, in patients with degenerative aneurysms were identified. This study provides a much-needed systematic and comprehensive update in risk assessment in this patient population.

14 Moreno-Cabral CE, Miller DC, Mitchell RS, Stinson EB, Oyer PE, Jamieson SW, *et al*. Degenerative and atherosclerotic aneurysms of the thoracic aorta. *J Thorac Cardiovasc Surg* 1984; **88**: 1020–1032.

15 DeBakey ME, McCollum CH, Graham JM. Surgical treatment of aneurysms of the descending thoracic aorta. *J Cardiovasc Surg* 1978; **19**: 571–576.

16 Livesay JJ, Cooley DA, Ventemiglia RA, Montero CG, Warian RK, Brown DM, *et al*. Surgical experience in descending thoracic aneurysmectomy with and without adjuncts to avoid ischemia. *Ann Thorac Surg* 1985; **39**: 37–46.

17 Safi HJ, Miller CC III, Carr C, Iliopoulos DC, Dorsay DA, Baldwin JC. Importance of intercostal artery reattachment during thoracoabdominal aortic aneurysm repair. *J Vasc Surg* 1998; **27**: 58–68.

18 ● Coselli JS, Lemaire SA, Miller CC, 3rd, Schmittling ZC, Koksoy C, Pagan J, *et al*. Mortality and paraplegia after thoracoabdominal aortic aneurysm repair: a risk factor analysis. *Ann Thorac Surg* 2000; **69**: 409–414.

This report provides an update of the Houston experience of 1220 patients undergoing thoracoabdominal aortic aneurysm between 1986 and 1998. The operative mortality rate was an impressive 4.8% and the overall paraplegic rate 4.6%. The risk factors for operative mortality included renal insufficiency, increasing age, symptomatic aneurysm, and type II aneurysms; risk factors for paraplegia included type II aneurysms and diabetes.

19 Cooke JC, Cambria RP. Simultaneous tracheobronchial and esophageal obstruction caused by a descending thoracic aneurysm. *J Vasc Surg* 1993; **18**: 90–94.

20 ● Fillinger MF. Imaging of the thoracic and thoracoabdominal aorta. *Sem Vasc Surg* 2000; **13**: 247–263.

Technical and clinical considerations of computed tomography, magnetic resonance imaging, magnetic resonance angiography, and spiral computed tomography angiography are discussed in a comprehensive manner. The illustrations are particularly impressive.

21 Miller DC. Surgical treatment of thoracic aortic aneurysms. In: Jamieson SW, Shumway NE, (editors): Rob and Smith's Operative Surgery. London: Butterworths; 1986; 509–525.

22 Borst HG, Frank G, Schaps D. Treatment of extensive aortic aneurysms by a new multiple-stage approach. *J Thorac Cardiovasc Surg* 1988; **95**: 11–13.

23 Borst HG, Laas J. Surgical treatment of thoracic aortic aneurysms. In:Karp RB, Laks H, Wechsler AS, (editors): Advances in Cardiac Surgery. **Volume 4**. St. Louis: Mosby Year Book; 1993. pp. 47–87.

24 Hamerlijnck RP, Rutsaert RR, DeGeest R, de la Riviere AB, Defauw JJ, Vermeulen FE. Surgical correction of descending thoracic aortic aneurysms under simple aortic cross clamping. *J Vasc Surg* 1989; **9**: 568–573.

25 Verdant A. Descending thoracic aortic aneurysms: surgical treatment with the Gott shunt. *Can J Surg* 1992; **35**: 493–496.

26 Hilgenberg AD, Rainer WG, Sadler TR. Aneurysm of the descending thoracic aorta. *J Thorac Cardiovasc Surg* 1981; **81**: 818–824.

27 Martin GH, O'Hara PJ, Hertzer NR, Mascha EJ, Krajewski LP, Beven EG, *et al*. Surgical repair of aneurysms involving the suprarenal, visceral, and lower thoracic aortic segments: early result and late outcome. *J Vasc Surg* 2000; **31**: 851–862.

28 Coselli JS, LeMaire SA. Surgical techniques. Thoracoabdominal aorta. *Cardiol Clin* 1999; **17**: 751–765.

29 Safi HJ, Miller CC III. Spinal cord protection in descending thoracic and thoracoabdominal aortic repair. *Ann Thorac Surg* 1999; **67**: 1937–1939.

30 Coselli JS, LeMaire SA. Left heart bypass reduces paraplegia rates after thoracoabdominal aortic aneurysm repair. *Ann Thorac Surg* 1999; **67**: 1931–1934.

31 ●● De Haan P. Pharmacologic adjuncts to protect the spinal cord during transient ischemia. *Sem Vasc Surg* 2000; **13**: 264–271.

This excellent review addresses the pharmacologic adjuncts previously evaluated and currently used in spinal cord protection during transient ischemia. Neuronal ischemia leading to neuronal death is diagrammed and discussed systematically paying particular attention to areas of potential intervention. This article is well balanced in that potential and real benefits of various drugs are presented, as are their toxic side effects. This brief review is an excellent primer for anyone interested in the underlying mechanisms of spinal cord ischemia and paraplegia associated with aortic surgery.

32 Coselli JS, LeMaire SA, Schmittling ZC, Koksoy C. Cerebrospinal fluid drainage in thoracoabdominal aortic surgery. *Sem Vasc Surg* 2000; **13**: 308–314.

33 ● Jacobs MJHM, Meylaerts SA, deHaan P, deMol BA, Kalkman CJ. Assessment of spinal cord ischemia by means of evoked potential monitoring during thoracoabdominal aortic surgery. *Sem Vasc Surg* 2000; **13**: 299–307.

The authors present a comprehensive review of their experience with a novel adjunct in the intra-operative assessment of spinal cord ischemia. Although used only in selected centers, the technique of measuring motor evoked potentials has gained considerable interest. The authors' results using this technique in thoracoabdominal aortic aneurysm repair are to be commended.

34 Safi HJ, Hess KR, Randel M, Iliopoulos DC, Baldwin JC, Mootha RK, *et al*. Cerebrospinal fluid drainage and distal aortic perfusion: reducing neurologic complications in repair of thoracoabdominal aortic aneurysms type I and II. *J Vasc Surg* 1996; **23**: 223–229.

35 Tefera G, Acher CW, Wynn MM. Clamp and sew techniques in thoracoabdominal aortic surgery using naloxone and CSF drainage. *Sem Vasc Surg* 2000; **13**: 325–330.

36 Saether OD, Juul R, Aadahl R, Stormholm T, Myhre HO. Cerebral haemodynamics during thoracic and thoracoabdominal aortic aneurysm repair. *Eur J Vasc Endovasc Sur* 1996; **12**: 81–85.

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