Surgical repair of thoracoabdominal aneurysms: patient selection, techniques and results

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**Background:** Repair of thoracoabdominal aortic aneurysms (TAAAs) continues to be a challenging task. Hemorrhagic shock, cardiac arrest and multisystem organ failures are the most frequent causes of death, and paraplegia and renal failure are the most devastating complications.

**Methods:** Flawless surgical technique and the use of adjuncts to protect key organs including the brain, heart, spinal cord, liver and kidneys affect outcome. Perfection in exposure and suturing technique decreases bleeding complications, shortens cross-clamp time and assures optimal, visceral, renal and lower extremity perfusion. Technical details include retroperitoneal abdominal aortic exposure, double thoracotomy for Type I and Type II aneurysms, and preservation of the diaphragm. The kidneys are protected by perfusion of iced lactated Ringers; visceral ischemia in Type I and Type II, aneurysms is diminished by using pulmonary vein-femoral artery pump with sequential clamping. Spinal cord protection is attempted by spinal fluid pressure monitoring and drainage, moderate general hypothermia, selective left heart bypass, reimplantation of critical intercostal arteries, monitoring somatosensory and somatomotor evoked potentials and epidural cooling of the spinal cord.

**Results:** Outcome in 203 patients (Group I) who underwent repair of TAAAs without epidural cooling was compared with outcome in 97 patients, 27 with thoracic aortic aneurysms and 70 with TAAA (Group II) who underwent repair using epidural cooling. In Group II paraplegia/paraparesis occurred in 11.6%, not different from the 8.9% in Group I. Thirty day mortality for elective cases decreased from 14.6% (Group I) to 7.2% (Group II, P<0.05).

**Conclusions:** Open surgical repair of TAAA carries elevated mortality and complication rates. The etiology of ischemic and reperfusion injury to the spinal cord is multifactorial and its prevention remains a formidable and as yet unresolved task. To select patients for surgical repair, the risk of TAAA rupture should be balanced against risks of perioperative mortality, paraplegia and renal failure. © 2002 Published by Elsevier Science Ltd on behalf of The International Society for Cardiovascular Surgery

**Keywords:** thoracoabdominal aortic aneurysm, surgery, outcome
the supra-aortic vessels, or the thoracic outlet. I include technical element currently used at UCSF. I also consider Dr Stoney my teacher because of his devotion to education of young surgeons and his pivotal role in the establishment of a premier fellowship of the Society for Vascular Surgery, with Drs Bergan and Yao. As the first recipient of the E.J. Wylie Traveling Fellowship Award in 1987, I am proud to represent a group of academic surgeons who started their careers with tremendous help as a result of this fellowship. Dr Oliver Beahrs, one of the best known surgeons at the Mayo Clinic once said that ‘a surgeon’s approach to surgery is not his alone but is a composite of the best of what he has seen and learned in the course of his educational experience’ [1]. Recipients of this award have exceptional opportunities to see and learn new treatments and surgical techniques at international centers of excellence early in the course of their academic careers. This has contributed to our growth as academic surgeons and influenced our subsequent laboratory and clinical research enormously. None of us will forget the spirit of the fellowship year, when we all traveled on the shoulders of a giant [2]. We owe a great deal to Dr Stoney for his visionary contribution to this fellowship and our education.

Surgical repair of thoracoabdominal aortic aneurysms (TAAAs) continues to be a challenging task. Most patients are high surgical risk due to advanced age and multiple co-morbidities. Many have generalized atherosclerosis with associated coronary, cerebrovascular, visceral and lower extremity occlusive arterial disease. Perioperative mortality remains elevated, morbidity can be devastating, hospital stay and recovery is usually prolonged and postoperative quality of life is frequently worse than before the operation. Ischemic injury to the spinal cord with resultant paraplegia remains the most severe complication of reconstructions on the thoracoabdominal aorta.

Protection of spinal cord from ischemic and reperfusion injury and surgical repair of TAAAs have long been in the center of interest at the Mayo Clinic and it has been topic of many experimental research projects [3–8] and clinical study [9–21] of our group, headed in the past two decades by Drs Hollier, Pair-olero and Cherry. While most aortic aneurysms are infrarenal, 7% of all aortic aneurysms repaired at the Mayo Clinic by our division in the past two decades required thoracoabdominal reconstruction (Figure 1).

**Indications for surgical treatment**

Risk of non-operative management should be balanced with expected surgical mortality and the risk of spinal cord injury in all patients before proceeding with surgical repair of thoracoabdominal aneurysms. Since rupture is the most important and lethal complication of TAAAs, the rupture rate of TAAAs, managed non-operatively, has to be assessed to establish correct indication for surgical treatment. Unfortunately, data on the natural history of TAAAs are scarce and the risk of rupture of TAAAs of different sizes are much less known than the risk of rupture of abdominal aortic aneurysms (AAAs), or of thoracic aneurysms. Cambria et al. from our institution reported on follow-up of 57 patients with degenerative, non-dissecting TAAAs, managed non-operatively [15]. Thirty-four of the 57 (60%) patients died during a mean follow-up mean of 37 months (range 1–82). Eight (14%) aneurysms ruptured, accounting for 24% (8/34) of the deaths. Two- and 4-year risks of rupture were 12 and 32%, respectively. No aneurysm ≥ 5 cm ruptured, while rupture rate of aneurysms > 5 cm of initial diameter had a 2 year cumulative rupture rate of 18% (Figure 2a and b). Patients who did not undergo repair during follow-up had 2- and 5-year survival rates of 52 and 17%, respectively. The median expansion rate of 0.2 cm/year was significantly greater in patients with chronic obstructive pulmonary disease (p<0.05).

In a group of 94 patients with TAAAs Crawford and DeNatale [22] noted a 2-year survival rate of only 24% without surgical treatment, one-half of the deaths (38% of the entire group) were due to aneurysmal rupture. The authors contrasted these numbers with their results with a 70% 2-year survival rate after repair of a TAAA. In a population-based study of thoracic aneurysms published from our institution in 1982, the actuarial 5-year survival rate was 13%, and rupture occurred in 74% of the patients [23]. In a more recent study survival rate has improved considerably and the 5-year risk of rupture as a function of aneurysm size at recognition was 0% for aneurysms <4 cm in diameter, 16% (95% CI, 4–28%) for those 4 to 5.9 cm, and 31% (95% CI, 5–56%) for aneurysms 6 cm or more [24].
Figure 2  
(a) Rupture-free survival of patients with TAAA. Cumulative 2- 
year risk of rupture was 12%. (b) Rupture-free survival of patients with-
out eventual repair, stratified by aneurysm size. Patients with aneurysms 
less or equal to 5 cm in diameter (■) had a significantly higher rupture-
free survival (p<0.05, log rank statistic) than those with aneurysms >5 
cm (●) (from [15], with permission)

The risk of rupture of a TAAA can also be assessed based on the age of the patient, the presence of pain and chronic obstructive pulmonary disease and the maximum diameters of the descending thoracic and abdominal aorta, using a formula recommended by Juvonen et al. [25]. Coselli et al. suggested, that the risk of death and paraplegia is based on the patient’s age, the presence of diabetes, the extent of aortic reconstruction, the presence of symptoms before operation and preoperative renal insufficiency. It is evident that in patients with TAAAs the risk of rupture should be considerably greater than the risk of both death and paraplegia, before surgical repair can be justified [26]. As suggested by Griepp [27], one should attempt to predict the risk of paraplegia (and renal failure) among those who survive the operation, since mortality, paraplegia and renal failure frequently overlap. Patients are interested and entitled to know the chance they have to leave the hospital in good health and the estimated chance to survive with a reasonably good quality of life.

Surgical techniques

Pioneering work of Dr Stoney’s group at the UCSF by Chuter is just one example that endovascular repair of a thoracoabdominal aneurysms is possible. However, these operations at present are performed using open surgical technique. Careful patient selection, flawless surgical technique and sophisticated general anesthesia, expeditious surgical repair and the use of adjuncts to protect key organs including the brain, heart, spinal cord, liver and kidneys will determine outcome. Perfection in exposure and suturing technique will decrease bleeding complications, shorten cross-clamp time and assure optimal visceral, renal and lower extremity perfusion after declamping. The techniques of thoracoabdominal repair have continuously evolved in the past two decades. Major surgical centers have developed their own technique of exposure, monitoring and use different adjuncts for cardiac, visceral and spinal cord protection.

At the Mayo Clinic in recent years technical details have included retroperitoneal abdominal aortic exposure and the use of left pulmonary vein–femoral artery partial bypass (Biomedicus Pump) for Type I and Type II aneurysms. Most surgeons preserve the diaphragm to decrease postoperative respiratory complications and double thoracotomy is performed frequently in Type I and II TAAAs to have a better exposure of the proximal thoracic aorta (Figure 3 a and b). Continuous hemodynamic monitoring with radial and femoral arterial lines and Swan–Ganz pulmonary artery catheter is used routinely. Systemic heparinization is used (5000 units, intravenous bolus) in patients with pulmonary vein–femoral artery bypass. We use zero porosity gelatin or collagen coated knitted polyester grafts to decrease graft and suture line bleeding and usually reimplant the celiac, superior mesenteric and right renal arteries into the graft as a separate Carrel patch. Revascularization of the left kidney is frequently done with a separate polyester bypass graft (Figure 3 a and b). Since the artery of Adamkiewitz originates at T9–L1 level in 85% of the patients [17] (Figure 4) intercostal arteries at these levels are reim-
planted as a Carrel patch or using a short polyester interposition graft (Figure 3 b).

Maintaining hemodynamic stability is the key to avoid perioperative complications, including spinal cord injury. Correction of coagulopathies and electrolyte imbalance, rapid retransfusion of autologous blood, timely delivery of blood components (packed red blood cells, fresh plasma, platelets, cryoprecipitates) will decrease hemodynamic instability, help oxygen delivery at cellular level and corrects coagulation abnormalities resulting from mesenteric and hepatic ischemia. The kidneys are protected by perfusion of iced lactated Ringers and visceral ischemia in Type I and Type II aneurysms is diminished by using Biomedicus pump with sequential clamping for retrograde perfusion. More recently we have adopted the technique popularized by Safi and use visceral perfusion with blood using Pruitt catheters attached to the atrio-femoral bypass [28,29].

**Spinal cord protection**

Currently available methods of spinal cord protection can be largely divided into two main approaches: maintenance of spinal cord blood flow during aortic occlusion and neuroprotection during the time of ischemia and reperfusion. Lack of revascularization of the cord at the end of the procedure will result in cord injury even if the most effective adjunct is used for neuroprotection during aortic occlusion. Blood flow to the cord can be maintained with left heart bypass, intercostal artery reimplantation and it can be improved by spinal fluid drainage, with or without pharmacological agents like intrathecal papaverin. Neuroprotection is achieved by systemic or regional hypothermia and by various neuroprotective pharmacological agents.

Experimental data from our laboratory and others have confirmed the benefit of multiple adjuncts to prevent the deleterious effects of temporary aortic clamping (Figure 5). These include the use of shunts, hypothermia, cerebrospinal fluid drainage, and the...
use of various pharmacological agents like calcium channel blockers, barbiturates, 21-amino steroids, free radical scavengers and antioxidants [3–8,16,17]. Prostaglandins, opiate antagonists and intrathecal papaverin have also been demonstrated to decrease the risk of paraplegia. Therapy with monoclonal antibodies and with N-methyl-D-aspartate receptor antagonist, particularly with MK-801 has also been promising. We have demonstrated the benefit of epidural cooling in both a dog and a rabbit model of spinal cord ischemia [6,3] In rabbits we also confirmed that moderate hypothermia (24°C) was as effective as profound hypothermia (17°C), therefore infusion of large quantities of cooling solution, potentially increasing spinal and intracerebral fluid pressure, is not required to achieve maximal benefit [8].

In patients we protect the cord using a multimodality approach. This includes spinal fluid pressure monitoring and drainage, moderate general hypothermia, left pulmonary vein–femoral artery bypass with sequential clamping for extensive repairs, reimplantation of critical intercostal arteries, and monitoring somatosensory and somatomotor evoked potentials. In a group of patients we have studied the effect of epidural cooling of the spinal cord.

Results of surgical treatment

Repair of thoracoabdominal aneurysms continues to be a formidable task. Mortality after elective repair in the last decade has decreased to 15% or less in most series [10,19,22,26,28–42]. Factors associated with mortality following TAAA include age, acute presentation, preoperative renal insufficiency, hemorrhagic shock, cardiac arrest, multisystem organ failure, and paraplegia. Effective protection of the spinal cord following extensive thoracoabdominal aneurysms remains the key to success and careful analysis of the published data reveals, that in most centers with large experience patients with Type II TAAA have some form of spinal cord injury, early or delayed, severe or partial, in at least in 8% of the cases. (Tables 1 and 2). Spinal cord injury in determined by multiple factors, Type II aneurysms being the most significant. In addition, age of the patients, the presence of diabetes, dissection and acute presentation determine outcome.

To assess improvement in morbidity and spinal cord complications and to investigate the benefit of epidural cooling, DeRuyter and Murray in 1999 analyzed our results of epidural cooling in 97 patients, who underwent surgical repair of descending thoracic (n = 27) or thoracoabdominal (n = 70) aneurysms at the Mayo Clinic, between 1993 and 1998. The 97 patients included 50 males and 47 females with a mean age of 66 years, ranging from 38 to 84 years. Ninety-six patients underwent successful cooling of the cord using an average of 1095±547 ml of 4°C epidural infusate of normal saline. Mean lowest cerebrospinal fluid temperature was 26.7±3.2°C, where the average lowest core temperature of the patients’ was 34.4±2.6°C. The cerebrospinal fluid volume that was drained averaged 176 ml, ranging from 2 to 202 ml. Paraplegia rate was 0 in the 27 patients who had descending thoracic aneurysms. It was also 0 in patients with Type I and 0 in Type IV thoracoabdominal aneurysms. However, there were six spinal cord injuries among the 26 patients (24%) who had Type II thoracoabdominal aneurysm; five had paraplegia (20%), and one had paraparesis (4%). Of the 19 patients with Type III thoracoabdominal aneurysms, one had paraplegia and four had paraparesis. This converts to a 5.3% paraplegia rate and a 26.4% paraplegia/paraparesis rate in this group. The overall paraplegia rate for the whole group was 6.3%, and paraparesis was 5.3% with a combined paraplegia/paraparesis of 11.6%. This was not significantly different, than the 8.9% (18/203) paraplegia/paraparesis rate, found in our historic control group of 203 patients with TAAA, operated on between 1980 and 1993, with a multimodality approach but without epidural cooling [43]. Mortality of elective TAAA operations decreased from 14.6% in the earlier series to 7.2% the recent series (p<0.05). Late survival of patients dismissed after thoracoabdominal aneurysm repair was 66% at 5 years in the Mayo experience (Figure 6).

The Mayo Clinic results have not confirmed the benefit of epidural cooling, although as in most series of TAAAs, Type II error must be considered because of the small sample size. For this reason, we have continued selective epidural cooling and our extended experience in a larger group of patients is currently analyzed. When used in conjunction with a clamp-and-sew technique and a strategy of selective intercostal reanastomosis, Cambria and associates reported on a paraplegia rate of 7% of 170 patients.
Table 1  Mortality, paraplegia and paraparesis after 97 descending thoracic and thoracoabdominal aortic operations using epidural cooling

<table>
<thead>
<tr>
<th>Type</th>
<th>No.</th>
<th>No.</th>
<th>%</th>
<th>No.</th>
<th>%</th>
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<td>20</td>
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<td>4</td>
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<td>0</td>
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<tr>
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<td>6.3</td>
<td>5</td>
<td>5.3</td>
<td>7</td>
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Table 2  Mortality and spinal cord deficit after descending thoracic and TAAA repairs

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<th>Spinal Cord Deficit</th>
<th>No. of Type II TAAA</th>
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<td>150</td>
<td>15</td>
<td>10</td>
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<td>Jacobs et al. [46]</td>
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<td>Coselli et al. [26]</td>
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<td>404</td>
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Figure 6  Late survival of 155 patients discharged after repair of TAAA

who underwent thoracic or TAAA repairs, when using epidural cooling for spinal cord protection [36]. Mean cerebrospinal fluid temperature at cross-clamp was 26.4±3°C. Spinal cord deficit rate was 12% in 83 Type I and II patients and 2.3 on the other 87 patients. The operative mortality rate was 9.5%. The authors concluded that epidural cooling was effective in reducing immediate, devastating, total paraplegia after TAAA repair. The effectiveness of profound deep hypothermia has been demonstrated in an impressive series published by Rokkas and Kouchakos [38].

Spinal fluid drainage and pressure monitoring and selective use of left heart bypass has shown excellent results in Coselli’s experience [26]. Coselli recently reported on a 4.8% mortality rate (58 of 1220 patients with TAAAs), and a 4.6% overall paraplegia rate (56 of 1206). Paraplegia rate of Type II aneurysms was 8.2%. Intercostal reimplantation has been used frequently by Coselli, while Griepp achieved a similar, 10% paraplegia rate without intercostals reimplantation [27]. Acher’s experience questions the benefit of intercostals artery reimplantation. The University of Wisconsin group compared results from patients who received cerebrospinal fluid drainage (150 patients) and low-dose naloxone (1.0 mcg/kg/h) to 67 patients who underwent thoracoabdominal or thoracic aneurysm repair but did not have naloxone or spinal fluid drainage [31]. The spinal cord deficit in the study group was 3.4% while in the non-treated group it was 21%.

Large experience has been accumulated by Safi et al. [34,35]. An overall paraplegia/paraparesis rate of 5% was observed in a group of 654 patients, operated for thoracic or TAAA [35]. Using distal aortic perfusion and spinal fluid drainage, deficit rate could
be decreased to 3.3%. In Type II patients paraplegia rate was reduced from 30.6% without adjuncts to 7.8% with adjuncts. Mortality in this series was 14%, but 6.9% of the patients required emergency operation.

The impact of motor evoked potential measurements was demonstrated by Jacobs and his colleagues in a recent series of 52 patients who underwent spinal cord protection using a multimodality approach [32]. Spinal cord cooling, distal aortic perfusion, cerebrospinal fluid drainage, and revascularization guided by motor evoked potential measurements was performed during repair of Type I and Type II aneurysms. The authors reported an 8% mortality rate, a 0% paraplegia rate, and a 2% paraparesis rate. These data suggest that measurements of motor evoked potential is useful to assess successful reimplantation of intercostal arteries.

Repair of TAAAs continues to be a challenge for patients and surgeons alike. Elective open surgical repair is offered to patients with 6 cm or larger TAAA who are of acceptable surgical risk. Depending on age, co-morbidities, symptoms and the extent of aneurysm repair, 80–95% of the patients can expect to leave the hospital and have a long term survival similar to those who had AAA repair. The etiology of ischemic and reperfusion injury to the spinal cord is multifactorial and multiple adjuncts are needed to decrease the risk of spinal cord injury. Progress has been made but complete prevention of paraplegia remains a formidable and as yet unresolved task. Because of the high risk of morbidity in some subgroups, the responsibility lies with the surgeon to help the patient understand potential complications of surgical repair and their impact upon the postoperative quality of life.

References