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ORIGINAL ARTICLE

Complex Abdominal Aortic Pathologies: Operative and Midterm Results after Pararenal Aortic Aneurysm and Type IV Thoracoabdominal Aneurysm Repair

Stefan Ockert, Marcel Riemensperger†, Hendrik von Tengg-Kobligk‡, Hardy Schumacher†, Hans-Henning Eckstein*, and Dittmar Böckler†*

The aim of the study was to describe the clinical outcome of pararenal aortic aneurysm (PAAA) and type IV thoracoabdominal aneurysm (TAAA) repair, with special consideration placed on disease-related complications and midterm follow-up. Data were collected retrospectively between 1997 and 2004 for patients with PAAA or type IV TAAA repair. Comorbidities, operative details, and early and late outcome were analyzed to predict disease-related complications. During the study period, 63 patients (33 PAAAs, 30 type IV TAAAs) underwent aortic repair. The 30-day mortality rate of 7.9% was acceptable for complex aortic entities compared with other series. The morbidity for cardiac events was 3.2%, for pulmonary complications 17.5%, and the need for reoperation was 14.3%. With regard to disease-related complications, two patients (3.2%) required dialysis and one patient (1.6%) developed paraplegia (spinal cord ischemia) after type IV TAAA repair. Complex aortic repair for PAAAs and type IV TAAAs showed acceptable perioperative mortality, morbidity, and midterm survival rates. Patients with type IV TAAAs suffered more major complications, such as postoperative dialysis or spinal cord ischemia.

Key words: *pararenal aneurysm, renal ischemia, spinal cord ischemia, type IV thoracoabdominal aneurysm*

Pararenal aortic aneurysms (PAAAs) and type IV thoracoabdominal aortic aneurysms (TAAAs) both present complex aortic morphologies and provide very challenging tasks for peripheral aortic surgery. PAAA represents a proportion of 3 to 20% of abdominal aortic aneurysms (AAAs).[1–3] Type IV TAAA constitutes a more uncommon disease, with an incidence of only 2 to 5% of all aortic pathologies that begin at the level of the diaphragm and require thoracoabdominal exploration with supracelical clamping position.[4] Prolonged renal, visceral, and spinal duration of ischemia is known to increase the morbidity and mortality of patients after aortic repair.[1]

**Department of Vascular Surgery, Klinikum rechts der Isar, Technische Universität München, Munich, Germany;* †*Department of Vascular and Endovascular Surgery, University Hospital Heidelberg, Heidelberg, Germany;* ‡*Department of Radiology, German Cancer Research Center, Heidelberg, Germany.*

Correspondence to: Stefan Ockert, MD, Department of Vascular Surgery, Klinikum rechts der Isar, Technische Universität München, Ismaningerstr. 22, D-81675 München, Germany; e-mail: stefan.ockert@lrz.tum.de.

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This study focused on the results of suprarenal and type IV TAAA repair with defined clinical end points: early and follow-up mortality, early complications under special consideration of renal dysfunction, and late survival.

Methods

All consecutive patients who underwent open aortic surgery with suprarenal cross-clamping for PAAA or type IV TAAA repair between June 1997 and November 2004 were included in this retrospective clinical study. Demographic and study data were obtained by a retrospective review of patient charts. An aneurysm was defined as pararenal if one or both renal arteries were included in the aneurysm or if the aneurysm had no suitable neck for infrarenal cross-clamping (classification of Ayari and colleagues[5]) (Figure 1). Type IV TAAAs were defined according to Crawford's classification (Figure 2),[6] beginning at the diaphragm and terminating at the aortic bifurcation. Patients with more extended TAAAs (type I–III) and patients with signs of aortic rupture were excluded from the study.

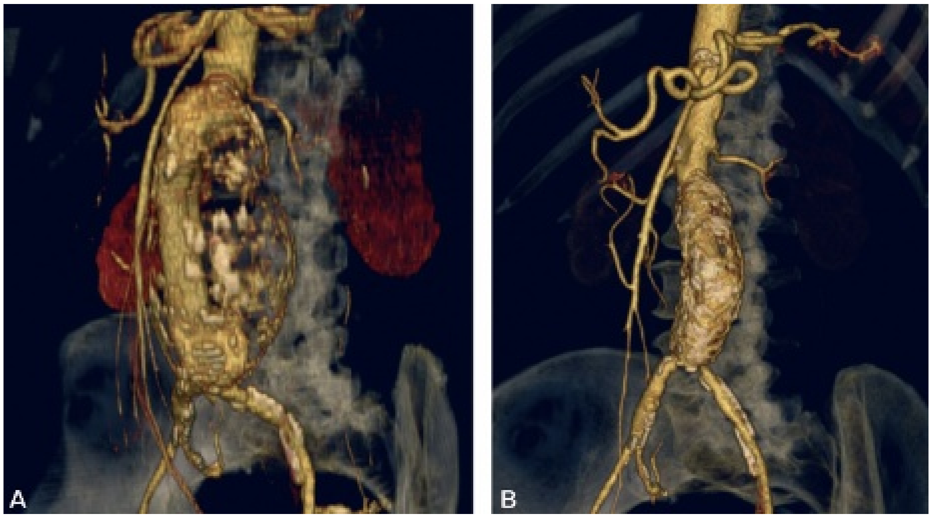

Figure 1. *A*, Preoperative volume rendering opacity (VRO) three-dimensional computed tomographic angiogram (CTA) showing pararenal aortic aneurysm. *B*, Postoperative VRO three-dimensional CTA demonstrating successful tube insertion at follow-up.

For each patient, several risk factors were considered, such as preoperative renal insufficiency, hypertension, coronary artery disease, American Society of Anesthesiologists (ASA) classification, and smoking. In addition, intraoperative details, such as clamping location, clamping time, concurrent renal artery reconstruction, and type of repair (tube graft, aortobifurcated graft), were analyzed.

During follow-up, patients from both groups underwent magnetic resonance angiography to exclude postoperative complications such as para-anastomotic aneurysms or visceral or renal artery occlusion.

Study Focus

Primary end points analyzed were in-hospital mortality, rate of postoperative renal insufficiency, dialysis dependence, rate of neurologic disorders (spinal cord ischemia), occurrence of myocardial infarction and pulmonary failure, length of hospital stay, and length of stay on the intensive care unit (ICU). The in-hospital morbidity and mortality and the follow-up outcome of both groups were also documented.

Definitions

Renal insufficiency was considered if any of the postoperative creatinine levels were greater than 1.3 mg/dL[7,8] or if a 50% increase occurred in the preoperative creatinine level. A compilation of total pulmonary complications included a prolonged postoperative intubation period ($>$ 24 hours), the need for reintubation, positive sputum, or radiographically confirmed pneumonia. Myocardial

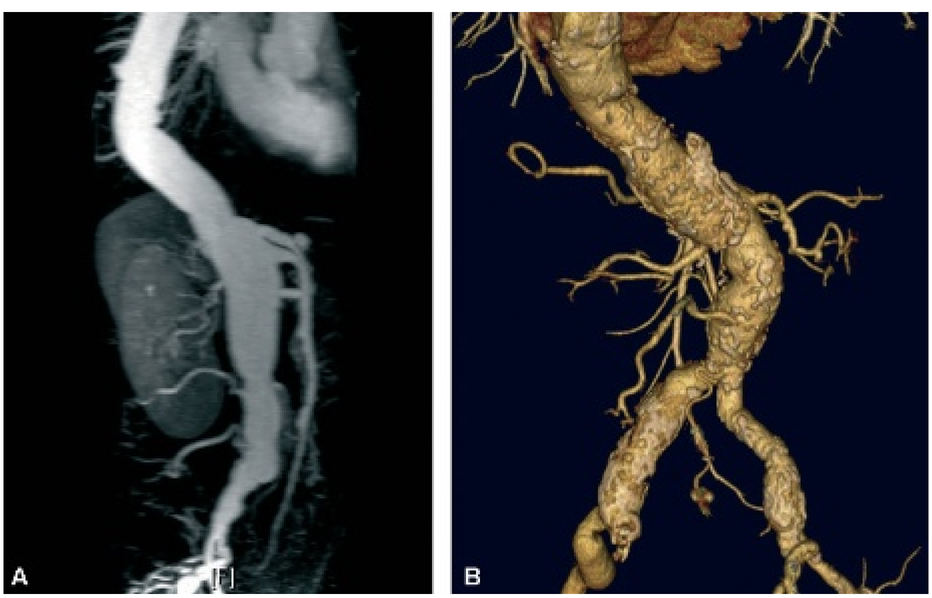

Figure 2. *A*, Preoperative maximum intensity projection reconstruction shows thoracoabdominal aortic aneurysm type IV from a lateral view. *B*, Seven years after operation follow-up, volume rendering opacity three-dimensional computed tomographic angiogram from a dorsal (posterior-anterior) view.

infarction was defined as elevated troponin T levels and/or electrocardiographic changes.[2]

Surgical Procedure

The standard surgical exposure performed for PAAA repair was the transabdominal approach via midline incision. Cold kidney perfusion is selectively indicated at our institution when a prolonged clamping time (> 40 minutes) is expected (complex morphology).

A retroperitoneal thoracoabdominal approach via an incision through the eighth, ninth, or tenth intercostal space was performed for type IV TAAA repair. Whenever possible, the celiac, superficial mesenteric, and renal artery orifices were included in the proximal anastomosis. According to the complexity of the cases, distal aortic perfusion was performed selectively. Protective techniques for prolonged renal ischemia time were performed using lactated Ringers fluid for the kidneys in selected cases. Visceral perfusion catheters were performed as an exception. We did not use standardized spinal cord monitoring or protection strategies such as cerebrospinal fluid drainage or epidural cooling in type IV TAAA. Furthermore, we did not use neuroprotective pharmacologic agents. Reimplantation of intercostal arteries was performed only in selected cases.

Follow-Up

Midterm results at follow-up were obtained through clinical investigation and magnetic resonance imaging of all patients.

Results

From June 1997 to November 2004, 853 operations for AAAs were performed in our department, including PAAAs and type IV TAAAs. Of those patients, 634 underwent open and 219 underwent endovascular aortic repair: 35 patients with PAAA (2 with rupture) and 32 patients with type IV TAAA (2 with rupture) were treated by conventional open treatment. The presented series includes 63 patients with complex AAAs (33 PAAAs, 30 type IV TAAAs). For the whole study population (PAAAs and TAAAs), demographic factors (age, sex); comorbidities such as hypertension, coronary artery disease, chronic obstructive pulmonary disease, and smoking; ASA classification; and renal function at the time of admission were documented. The patients' characteristics and risk factors are presented in Table 1.

Table 1. Demographics and Comorbidities

Patient Data	*PAAA (n = 33)*	*TAAA (n = 30)*
Gender (F/M)	5/28	9/21
Age (yr), mean	68.7	62.1
Aneurysm size (cm), mean	6.7	6.5
Symptomatic aneurysm	6	6
Hypertension	28	25
Coronary heart disease	21	16
COPD	12	7
Smoking	20	15
ASA classification mean	2.9	3.2

ASA = American Society of Anesthesiologists; COPD = chronic obstructive pulmonary disease; PAAA = pararenal aortic aneurysm; TAAA = thoracoabdominal aortic aneurysm.

Pararenal Aortic Aneurysms

Of 33 elective patients (28 males, 5 females) with pararenal aneurysm (PAAA) repair, 51.5% were treated with an aortic tube graft and 48.5% with a bifurcated graft. In both groups (PAAA and TAAA), an equal proportion of patients showed aneurysm-related symptoms.

A total of 43.3% of the PAAA group underwent simultaneous renal artery reconstruction: eight patients with renal bypasses and five patients with transaortic renal endarterectomies of one or both renal arteries; three patients underwent reimplantation of the renal artery in the aortic graft. Suprarenal cross-clamping was performed in 84.8% of pararenal cases, two patients (6.1%) were operated on using supraceliac clamping positions, and three patients (9.1%) were operated on with a supramesenterial clamping position owing to local morphologic reasons. Cold kidney perfusion was not performed in the PAAA group.

Thoracoabdominal Aortic Aneurysms

Seventy percent of patients with TAAA received tube interposition and 30% underwent implantation of a bifurcated graft. Beneath visceral revascularization via graft inclusion technique, the left renal artery had to be reimplanted separately in 20 patients (66.6%). Four patients (13.3%) received bypass implantation for the left renal artery. One patient showed occlusion of the left renal artery, another patient presented with relevant shrinking of the left kidney, and in both patients, no renal revascularization was performed. Two patients presented with previous nephrectomy of the left kidney, and one patient who had final renal function received ligation of the left renal artery at the time of the operation. In two patients, the orifice of the left renal artery was distal to the reconstruction level. Cold kidney perfusion (4°C lactated Ringers fluid) was performed in 12 patients (40%); a prolonged clamping time was expected. Six patients with TAAA underwent temporary distal perfusion via extra-anatomic bypasses during the operation (20%; four aortoiliac, one aortoaortic, one aortofemoral). Four patients (13.3%) with TAAA underwent additional intercostal artery reimplantation as a protection against spinal cord ischemia.

Results

Clinical Outcome

The overall in-hospital mortality for both diseases was 7.9% (two patients for PAAA and three patients for TAAA) (Table 2). The causes of death for the PAAA group included one myocardial infarction after postoperative bleeding and one patient with septic multisystem organ failure. The causes of death of the TAAA group were hypovolemic shock after postoperative bleeding (one patient) and septic multisystem organ failure (two patients).

The only cardiac complication was presented by one patient per group, who suffered a perioperative myocardial infarction. The distribution of pulmonary complications is listed in Table 2.

Reoperation was required in four patients with PAAA and in five patients with TAAA. From the PAAA group, two patients suffered a bleeding complication; one patient required reoperation for mesenteric ischemia and the other patient for lower extremity embolic event. The reoperations for the TAAA group included four patients with bleeding complications and one with acute occlusion of the visceral arteries. Two patients presented with postoperative indications of spinal cord ischemia. One patient suffered a mild paraparesis with regressive symptoms during the hospital stay; another patient showed a complete paraplegic situation. None of these patients received distal perfusion or reimplantation of intercostal arteries during the operation. The mean visceral clamping time of the patient with paraplegia was 38 minutes. The PAAA group had no patients with neurologic complications. The overall morbidity, including cardiac, pulmonary, and neurologic complications and the need for reoperation, was equal in both groups.

Patients with TAAA repair required a significantly extended length of stay in the ICU (9.8 days vs 5.9 days for PAAA; $p = .007$). The total time for mechanical ventilation (4.6 days for TAAA vs 0.8 days for PAAAs; $p < .001$) was also prolonged for the TAAA group. The general length of stay in the hospital was longer in the TAAA group compared with the PAAA group (26.5 days vs 24.6 days; $p = .036$) (see Table 2).

Renal Outcome

With regard to the renal outcome, one patient from each group required dialysis preoperatively for final renal function. The mean suprarenal clamping time for the

Table 2. In-Hospital Outcome

Results	*Overall,* n *(%)*	*PAAA* (n = *33)*	*TAAA* (n = *30)*
In-hospital mortality	5 (7.9%)	2	3
Operation time (min), mean		221	285
Renal ischemia time (min), mean (range)		28.6 (14–70)	40.5 (0–74)
Visceral ischemia time (min), mean (range)		36.6 (23–45)	37.3 (5–60)
Reoperation	9 (14.3)	4	5
Myocardial infarction	2 (3.2)	1	1
Pulmonary complication	11 (17.5)	6	5
Spinal cord ischemia (persistent)	1 (1.6)	0	1
ICU length of stay (d), mean		5.9	9.8
Length of stay (d), mean		24.6	26.5

ICU = intensive care unit; PAAA = pararenal aortic aneurysm; TAAA = thoracoabdominal aortic aneurysm.

PAAA group was 28.6 minutes (range 14–70 minutes), the total aortic clamping time was 40 minutes (28–90 minutes), and the mean duration of operation was 220.5 minutes. Five patients with PAAA required dialysis in the ICU (four with renal reconstruction). At the time of discharge, none of the patients required new-onset dialysis.

The mean clamping time of the TAAA group was 37 minutes for the visceral arteries (range 5–60 minutes), 35 minutes for the right renal artery (range 0–60 minutes), and 36 minutes for the left renal artery (range 0–74 minutes). In one case, a patient received visceral perfusion catheters prior to aortic clamping; the mean total operation time was 285 minutes. After the operation, two patients needed dialysis for new-onset final renal function; no additional patient needed temporary dialysis. At the time of discharge, two patients (6.6%) needed continuous renal support.

The data for renal function are listed in Table 3.

Follow-Up Outcome

The mean follow-up time was 22.3 months for the patients with PAAA and 32.3 months for the TAAA group (range 3–91 months). At the period of follow-up, there were no further deaths among the PAAA group (93.9% alive); however, 5 deaths occurred in the TAAA group (73.3% alive).

Eighteen patients (58.1%) from the PAAA group and 16 patients with TAAA repair (72.7%) consented to follow-up investigation by magnetic resonance angiography (Figure 3). Thirteen patients from the PAAA group refused further investigation owing to advanced age, immobility, or malignant disease. Six patients from the TAAA group refused follow-up. Follow-up imaging identified two PAAA patients with stenosis of the renal arteries (one patient after renal thromboendarterectomy, one patient after tube interposition without renal reconstruction). Both patients underwent successful percutaneous transluminal angioplasty and renal interventional stenting. With regard to the aortic reconstruction, no para-anastomotic aneurysms were detected at the proximal anastomosis in the PAAA group. One patient presented with a para-anastomotic dilatation of a distal reconstruction after implantation of a bifurcated graft. All renal reconstructions were patent at the time of follow-up.

No patients with TAAA required reoperation at the time of follow-up. Imaging detected one patient with occlusion of one renal artery without elevated creatinine levels. One additional patient showed asymptomatic occlusion of the celiac trunk with good collateralization and without clinical symptoms. One female patient with Marfan syndrome presented with visceral aortic expansion of 4.5 cm of the carrel patch reconstruction (see Figure 3). This patient is currently being monitored by the clinic, and

Table 3. Renal Function Data

	PAAA (n = *33)*		*TAAA* (n = *30)*	
	n	%	n	%
Renal function at admission				
Abnormal (> 1.3 mg/dL)	11	33.3	11	36.6
Dialysis	1	3	1	3
Postoperative				
Transient creatinine rise (> 50%)	19	57.6	17	56.6
Sustained creatinine rise (> 50%)	5	15.2	4	13.3
New-onset dialysis	5	15.2	2	6.6
Discharge				
Worse creatinine	6	18.2	5	16.7
Improved/unchanged	25	75.6	22	73.3
Dialysis at discharge	0	—	2	6.6
Creatinine level, mean (mg/dL)				
Preoperative	1.36		1.37	
At discharge	1.61		1.79	

PAAA = pararenal aortic aneurysm; TAAA = thoracoabdominal aortic aneurysm.

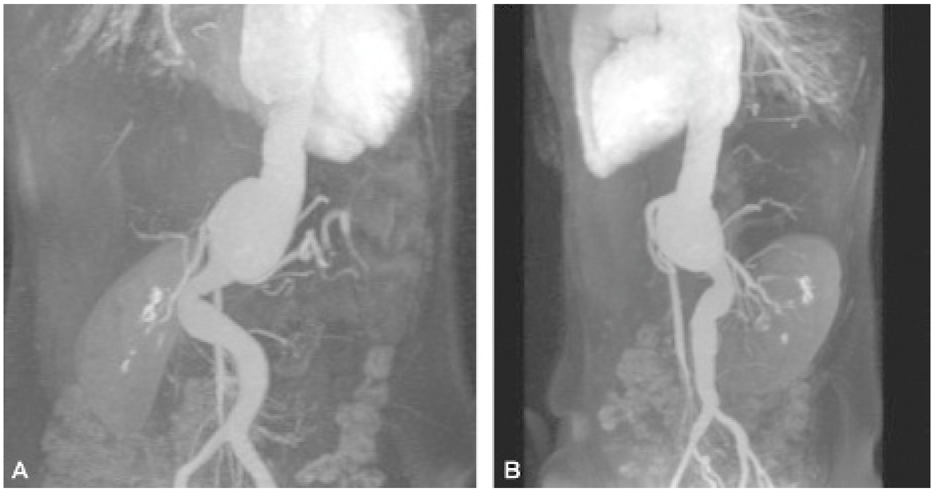

Figure 3. Maximum intensity projection reconstruction of a magnetic resonance angiogram demonstrating patch expansion 2 years after type IV thoracoabdominal aortic aneurysm repair in a patient with Marfan syndrome.

there is no need for intervention at the present time. No patient developed loss of renal function with the need for dialysis during the follow-up period in both groups.

Discussion

The present series of PAAA and type IV TAAA showed acceptable 30-day mortality and 30-day morbidity rates. With regard to the renal and neurologic outcome, patients with TAAA have an elevated risk of developing postoperative dialysis and spinal cord ischemia.

The natural history of untreated PAAA and TAAA is poor, with an estimated 5-year survival rate ranging from 13 to 46%.[9] Early attempts to repair these complex aneurysms were associated with a substantial mortality risk, often as high as 50%.[10,11] With the development of the inclusion technique by Svenson and Crawford,[12] the perioperative mortality, morbidity, rate of paraplegia, and renal failure declined substantially.

The challenge of complex aortic surgery for PAAA and type IV TAAA compared with infrarenal aneurysms can be traced back to hemodynamic derangement after more proximal aortic clamping.[13,14] Suprarenal or supraceliacal cross-clamping can induce ischemic injury of the kidneys, visceral organs, and spinal cord during operative management. Comparisons of PAAA and type IV TAAA repair are rather rare in the literature, with mortality rates varying between 1.3 to 12% (PAAA) and 5 to 17% (type IV TAAA).[1,15–17]

Bicknell and colleagues recently demonstrated significantly higher 30-day mortality rates of 17% for type IV TAAA compared with 2.3% for pararenal repair in a comparative analysis.[1] The higher mortality for TAAA can be explained by differences in operative factors, including longer duration of anesthesia, along with visceral and renal ischemia time.

We observed a higher mortality rate for patients with PAAA (6.1%) compared with those studies but a lower early mortality rate for patients with TAAA (10%). Nevertheless, for both diseases, we are able to demonstrate outcomes comparable to those seen in the literature, and differences might be due to sample size.

Midterm follow-up demonstrated elevated mortality for patients with TAAA (5 deaths: survival rate 73%) compared with PAAA (no death: survival rate 94%), but these rates are consistent with rates reported in other series,[1,13] justifying the repair of these aneurysms.

As reported by others, the leading cause for postoperative morbidity and death was hemorrhage after coagulopathy.[14,17–19] Both patients who died in the PAAA group suffered bleeding complications with the need for revision. Of the patients with TAAA who died, two deaths occurred after reoperation for postoperative bleeding. Therefore, it is mandatory to reduce coagulopathy by preemptive transfusion of fresh frozen plasma and platelets in the early operation, introducing warming facilities (fluids, ventilator gases), and minimizing clamping and operation time.

In-hospital morbidity is also associated with postoperative cardiac and pulmonary complications. Critical cardiac evaluation and adequate preoperative assessment have been proven to reduce the risk of perioperative myocardial infarction.[3] Every patient at our institution who is being prepared for open surgery for an AAA receives a cardiologic consultation and selective preoperative stress testing or coronary angiography, if necessary. Both the infarction rate and the pulmonary complication rate of our series were acceptable for both diseases.

Visceral ischemia time (> 40 minutes) has been associated with increased mortality rates for TAAA.[1,4] Methods of reducing such have been proposed, including selective visceral artery perfusion using extracorporeal circulation and shunting. In most uncomplicated type IV TAAA repairs with a single proximal anastomosis, it is possible to minimize the visceral ischemia to < 40 minutes. Only if separate proximal end-to-end anastomosis is anticipated is mesenteric shunting probably beneficial. In our series, 20% underwent distal perfusion and only one patient underwent selective visceral (and renal) perfusion during aortic clamping.

Spinal cord ischemia represents a serious complication, but it is seldom documented after PAAA repair[1,2,5,13] and reduced for type IV TAAA (0–4%) compared with more extended aneurysms (type I–III TAAA), with rates of up to 16%.[20] Among our group of patients, none had indications of spinal cord ischemia in the PAAA group. Paraplegia after type IV TAAA repair is mostly prominent after emergency repair of ruptured aneurysms.[4,19,21] There are also reports that the risk for spinal cord ischemia in type IV TAAA repair increases with aneurysm size and prolonged clamping time (> 45 minutes).[1,4] Several strategies have been proposed to limit neurologic complications for type IV repair, but none have proven to be effective. Treatment procedures performed were cerebrospinal fluid drainage, reimplantation of intercostal arteries, epidural cooling, aortic shunting via bypass, and administration of neuroprotective pharmacologic agents.[4,22] A recent review found limited data to support cerebrospinal fluid drainage in TAAA types I and II to prevent neurologic complications but none to reduce neurologic injury for TAAA type IV.[23]

There is a limited risk of spinal cord ischemia during uncomplicated repair of type IV TAAA, and there is actually no evidence to support the routinely used adjunctive treatment procedures.[4] Two patients from our TAAA group suffered early neurologic complications. One female with postoperative paraparesis recovered during her hospital stay and had no indications of spinal cord ischemia at the time of follow-up. One patient suffered early postoperative paraplegia, which persisted at the time of follow-up, demonstrating a spinal cord ischemia rate of 3% in our series. Selectively, we performed distal perfusion or arterial reimplantation for type IV repair, but both patients mentioned did not undergo distal perfusion, and intercostal arteries were not reimplanted in either of these patients. With regard to procedural duration, the patient with persistent paraplegia had a normal visceral clamping time < 40 minutes (38 minutes), but the total operation time was prolonged (555 minutes vs mean 285 minutes). Furthermore, aortic repair on this patient was complicated by an aneurysm that was 9 cm in size, which also influences neurologic outcome.[13]

Renal failure remains a common complication after complex aortic surgery, which greatly increases the risk of mortality after PAAA and TAAA surgery.[1,4]

With regard to the risk of renal morbidity, we documented high rates of transient renal insufficiency of up to 60% for both groups. Especially for PAAA repair, this is higher than that reported in other large studies (20–41%).[1–3,5,15,16] We saw 33% of patients from the PAAA group and 37% from the TAAA group with elevated creatinine levels before the operation. Our data show that 15% of patients from the PAAA group needed transient renal support. At the time of discharge, 18% of the PAAA group and 17% of the TAAA group had only slightly elevated creatinine levels compared with admission status. Whereas other studies reported dialysis rates between 9 and 15%, only two patients (6.6%) from the TAAA group required new-onset dialysis for final renal function in our series. Within the PAAA group, none of the patients developed permanent dependence on dialysis. The value of adjunct treatment to reduce renal ischemia is unclear. Renal hypothermia might be beneficial in renal surgery. Svenson and colleagues showed that cold perfusion of the kidneys with lactated Ringers solution or atriofemoral bypass did not significantly reduce the need for dialysis following TAAA repair.[18] The same authors later observed that patients with visceral occlusive disease undergoing TAAA repair seemed to benefit from cold perfusion of the renal arteries. On the other hand, it is mentioned that the risk to the renal arteries has been suggested to outweigh any potential benefit of perfusion. In our series, we did not use cold perfusion for PAAA but did use it in 40% of cases for TAAA repair, with low permanent dialysis rates. Careful preoperative evaluation is important to reduce the risk of postoperative renal failure, and selective intraoperative therapies such as cold renal perfusion appear to be beneficial for TAAA in our study. Cold perfusion might be favorable when renal artery occlusive disease and complex morphology occur and results in clamping times of > 45 minutes.[4] No other patient in our series required dialysis during the follow-up period. Regular follow-up imaging seems to be useful in detecting postprocedural complications or progression of the disease that requires further treatment.[24]

The presented series only included open repair for complex AAAs. We began using endovascular aortic repair for PAAA in March 2006 at our institution, but the caseload of these patients was far too low for comparison.

However, times have changed, and fenestrated and branched grafts are documented to be feasible and more common in several institutions.[25] In the future, it will be interesting to see whether the midterm and long-term results after endovascular aortic repair of PAAA or type IV TAAA are comparable to or even better than those from conventional aortic repair.

Conclusion

Complex AAAs involving the renal, visceral, or lower thoracoabdominal aorta show acceptable perioperative mortality and midterm survival rates. With regard to major complications such as postoperative dialysis or spinal cord ischemia, a better outcome has been documented for PAAA repair. The role of adjunct treatment procedures for renal and spinal cord protection is controversial, and no final recommendation can be given in this respect.

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