Surgical treatment of thoracoabdominal aortic aneurysms by simple crossclamping

Risk factors and late results

Between 1981 and 1987, 88 consecutive patients were operated on for a thoracoabdominal aortic aneurysm by simple crossclamping and a graft inclusion technique (without shunts or heparin). This article presents an analysis of the operative outcome and long-term follow-up. Patient- and operation-related variables are age (mean 64.3 years, range 28 to 82 years), sex (82 % men), rupture (20.5 %), diabetes (2.3 %), renal insufficiency (34.1 %), chronic obstructive pulmonary disease (27.3 %), previous aortic operation (31.8 %), arterial hypertension (66 %), postdissection (18.2 %) versus degenerative (80.7 %) origin, preoperative shock (11.4 %), ischemic cerebrovascular (12.5 %) or ischemic heart (17 %) disease, peripheral vascular disease (14.8 %), renal (mean 48 minutes, range 0 to 83 minutes) and lower spinal cord (mean 21 minutes, range 0 to 68 minutes) ischemic time, number of reattached intercostals, blood loss, and extent of the aneurysm (Crawford classification: type I, 16 patients [18.2 %]; type II, 21 patients [23.8 %]; type III, 29 patients [33 %]; and type IV, 22 patients [25 %]). Intraoperative mortality is 1.1 % ($n = 1$). Thirty-day mortality is 5.9 % ($n = 5$). Hospital mortality is 11.4 % ($n = 10$): 7 % for elective cases and 28 % for ruptured aneurysms ($p = 0.014$). The survival at 2 years is $78 \% \pm (4.4 \%)$ and at 5 years $54 \% \pm (5.3 \%)$. Postoperative spinal cord injury occurred in 12 patients (13.8 %) (5 had paraplegia and 7 had paraparesis) and postoperative renal dysfunction necessitating dialysis in 12 patients (14.1 %). Risk stratification for hospital death, late death, renal failure, and spinal cord dysfunction was performed by means of multivariate logistic regression and Cox proportional hazard regression as appropriate. The best fitting model to predict hospital death includes preoperative shock ($p = 0.02$), female sex ($p = 0.06$), preoperative elevated serum creatinine level ($p = 0.06$), and preoperative myocardial infarction ($p = 0.08$). Variables predictive for late death are postoperative dialysis ($p = 0.002$), age ($p = 0.008$), and rupture ($p = 0.04$). The risk factors of postoperative dialysis are age ($p = 0.003$) and preoperative serum creatinine level ($p = 0.04$). The risk of postoperative spinal cord dysfunction increases with longer lower spinal cord ischemic time ($p = 0.02$) and with the presence of preoperative shock ($p = 0.06$). (J THORAC CARDIOVASC SURG 1994;107:134-42)

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The study of the natural history of thoracoabdominal aortic aneurysms has shown that only 24% of patients

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treated conservatively are still alive 2 years after diagnosis; 50% of the deaths are due to aneurysm rupture.¹ Surgical treatment has favorably altered this outcome. In 1955, Etheredge and associates² reported the first successful repair with the use of a homograft. Later, DeBakey, McCollum, and Graham³ developed the technique of prosthetic bypass parallel to the aneurysm. The largest surgical experience with thoracoabdominal aortic aneurysm, however, was accrued by Crawford⁴ with the introduction of the graft inclusion technique. Despite major progress in treatment during recent years, surgical repair is still associated with a significant mortality and morbidity. Repair poses a continuing challenge to the

Fig. 1. Distribution of patients by aneurysm type, with associated postoperative paraplegia/paraparesis rate.

surgeon because of the extensive nature of the disease and its complications. The risk factors determining early and late death, postoperative renal failure, and spinal cord dysfunction of our initial 6-year experience with the simple crossclamping technique are analyzed.

Patients and methods

Between February 1981 and July 1987, 88 consecutive patients (72 men and 16 women) were operated on for thoracoabdominal aortic aneurysms at the St. Antonius Hospital, Nieuwegein, The Netherlands. The mean age was 64.3 years and the range 28 to 82 years. On the basis of the extent of aortic involvement, patients were divided into four groups according to the classification of Crawford and associates.⁵ A type I thoracoabdominal aortic aneurysms involving the aorta distal to the subclavian artery and extending down to the proximal abdominal aorta was replaced in 16 patients, a type II aneurysm involving most of the descending thoracic and abdominal aorta in 21 patients, a type III aneurysm involving the distal descending thoracic aorta and varying segments of the abdominal aorta in 29 patients, and a type IV aneurysm involving the entire abdominal aorta in 22 patients. The distribution of patients by aneurysm type is summarized in Fig. 1. Associated preoperative and intraoperative risk factors are displayed in Table I. In 71 patients (80.7%) the thoracoabdominal aortic aneurysms were degenerative; in 1 patient (1.1%), mycotic; and in 16 patients (18.2%), it was a postdissection aneurysm. Twenty-eight patients (31.8%) had had prior surgical aortic reconstructions in a total of 31 operations: these involved the ascending aorta (3

patients), the aortic arch (2 patients), the combined ascending aorta and arch (2 patients), the descending aorta (3 patients), and the infrarenal aorta (20 patients). Thirty-nine patients (44.3%) were asymptomatic at the time of the operation. Forty-eight of the remaining 49 patients (55.7%) had severe back pain. Dyspnea was present as well in 5 patients and hoarseness in 1. Ten of the 18 patients (20.5%) in whom rupture of the thoracoabdominal aortic aneurysms was proved at operation were in severe hypovolemic shock. The cardiac and pulmonary status of all patients was evaluated before the operation. Arterial hypertension, defined as a systolic blood pressure of 150 mm Hg or more and a diastolic blood pressure of 90 mm Hg or more, was present in 58 patients (66%). Chronic obstructive pulmonary disease was present in 24 patients (27.3%). A previous transient ischemic attack had occurred in 4 patients (4.5%) and previous stroke in 7 patients (8%). Two patients had insulin-dependent diabetes (2.3%). Fifteen patients (17%) had ischemic heart disease as evidenced by a documented myocardial infarction (12 patients), medical treatment for angina pectoris (11 patients), coronary artery bypass (2 patients), or percutaneous transluminal coronary angioplasty (2 patients). Thirteen patients (14.8%) had peripheral vascular disease. Stable elevated creatinine levels ($\geq 125 \mu\text{mol/L}$) were present in 30 patients (34.1%); of these, 3 had been undergoing dialysis for more than 2 years.

Operative technique. All patients were intubated with a double-lumen endotracheal tube that permitted deflation of the left lung, which facilitated surgical exposure and reduced injury to the lung. The electrocardiogram, intraarterial blood pressure, central venous pressure, and pulmonary artery pressure

Table I. Preoperative and intraoperative variables

	Patients (n = 88)	
	No.	%
Preoperative variables		
Prior aortic operation	28	31.8
Postdissection aneurysm	16	18.2
Arterial hypertension	58	66
Chronic obstructive pulmonary disease	24	27.3
Cerebrovascular accident	11	12.5
Ischemic heart disease	15	17
Peripheral vascular disease	13	14.8
Renal insufficiency	30	34.1
Shock	10	11.4
Sex		
Male	72	82
Female	16	18
Age		
<50	7	8
50-60	10	11.4
60-70	45	51.1
>70	26	29.6
Type of thoracoabdominal aortic aneurysm		
I	16	18.2
II	21	23.8
III	29	33
IV	22	25
Intraoperative variables		
Rupture		
Yes	18	20.5
No	70	79.5
Number of reattached intercostals		
0	37	42.0
1-5	37	42.0
>5	15	16.0
Renal ischemic time (min)		
<30 min	10	11.4
30-50 min	39	44.3
>50 min	39	44.3
Spinal ischemic time (min)		
<30 min	50	56.8
30-50 min	28	31.8
>50 min	10	11.4
Blood loss		
<3 l.	61	69.3
>3 l.	27	30.7

were continuously monitored. Four large-bore intravenous catheters were inserted to allow rapid fluid administration whenever necessary. An autotransfusion system was used to save red cells (Autotrans BT 795, Dideco SPA, Mirandola, Italy). Fluids given to the patient were administered through blood warmers. Urine output and central temperature were recorded continuously. Blood gases, electrolytes, and hemoglobin values were measured intermittently. Intrathecal pressure monitoring and cerebrospinal fluid withdrawal were not used routinely. No heparin or shunt was used, but some heparin could be retained after blood recovered by the cell saving system was washed.

Table II. Causes of hospital death

Cause	No.	%
Intraoperative exsanguination	1	1.1
Cardiac	2	2.3
Multiple organ failure	5	5.7
Massive stroke	2	2.3
Total	10	11.4

Hypothermia was not applied. All patients were operated on by way of thoracoabdominal exposure with a diaphragm-splitting thoracoabdominal incision in the left fifth or sixth intercostal space after division of the costal arch. A separate left thoracotomy was not used. A transperitoneal dissection was carried out lateral and posterior to the left colon, left kidney, spleen, and pancreas to expose the posterolateral aspect of the aorta. Left ventricular afterload reduction was obtained by infusion of sodium nitroprusside and urine production was stimulated before clamping by the administration of extra fluid or mannitol, or both. The clamps were always applied slowly to avoid proximal hypertension. After the clamps were applied, the thoracoabdominal aortic aneurysm was incised longitudinally and the walls were retracted by heavy stay sutures. Major back-bleeding from low intercostal arteries between T-8 and T-12 or visceral arteries was controlled by occlusive balloon catheters after the endoluminal thrombus was removed. We used selective catheter perfusion cooling of the kidneys with a 4° C Ringier's acetate solution (without heparin) in the 77 patients (88.5%) in whom the origin of the renal arteries was included in the aneurysm. We did not monitor the temperature of the kidneys. Small intercostal or lumbar arteries were ligated; major ones, showing intense back-bleeding, especially in the region from T-8 to L-2, were selected for reimplantation into the prosthesis. To reduce ischemia, we always used the step-by-step reattachment technique. Crawford's standardized graft inclusion technique and vessel reattachment were used. Sometimes an open distal anastomosis was performed. After the distal clamp was released, 20 mg of furosemide was given intravenously to reestablish diuresis. In most instances it was necessary to remove the clamp progressively to avoid hypotension and circulatory collapse. Initially, we used a woven Dacron prosthesis and later a collagen-coated knitted prosthesis (Hemashield; Meadox Medicals Inc., Oakland, Calif.) or gelatin-coated knitted vascular prosthesis (Gelseal Triaxial; Vascutek Ltd., Inchinnan, Scotland).

Often the orifice of the right renal, celiac, and superior mesenteric artery could be anastomosed in one oval opening in the graft, whereas the left renal artery usually required a separate anastomosis. Sometimes it was necessary to perform an eversion endarterectomy of one or more vessels having ostial plaque or stenosis.

Postoperative follow-up. All patients were followed up at regular intervals at the outpatient clinic of our department or the referring center. In September 1992 information was obtained on all of them. Late follow-up deaths were analyzed for cause. The follow-up was 100% complete.

Statistical methods. Twelve preoperative and five intraoperative variables, thought to be clinically important, were used to detect early morbidity and mortality (Table I). The preoperative variables were age, sex, etiology (postdissection aneurysm

Table III. Stepwise logistic regression analysis of hospital mortality

Risk factor	Log regression coefficient	Standard error	p Value
Preoperative shock	2.151	0.870	0.02
Female sex	1.567	0.897	0.06
Preoperative elevated serum creatinine	0.194	0.097	0.06
Preoperative myocardial infarction	1.614	0.884	0.08
Constant	-4.255	0.853	<0.01

versus nondissection), type of thoracoabdominal aortic aneurysms, arterial hypertension, chronic obstructive pulmonary disease, stroke, ischemic heart disease, peripheral vascular disease, previous aortic surgery, renal insufficiency, and shock. The five intraoperative variables used were renal and lower spinal cord ischemic time (defined as the time in minutes during which the intercostal/lumbar vessels between T-8 and L-2 or the renal arteries were excluded from the circulation), presence of rupture, the number of reattached intercostal/lumbar vessels, and the blood loss. Standard univariate methods (Yates corrected χ^2 or Student's *t* test) were used. Cumulative survival curves were made by the Kaplan-Meier product-limit method.⁶ The independent predictors of hospital mortality and postoperative renal and neurologic dysfunction were identified by stepwise logistic regression analysis.⁷ The Cox proportional hazard model was used to predict the independent determinants of long-term survival.⁸ All computations were performed with the aid of the BMDP statistical software package (BMDP release 1990; BMDP Software, Los Angeles, Calif.).

Results

Intraoperative and early mortality. The intraoperative mortality is 1.1% (1/88). One patient died on the operating table of intractable hypovolemic shock and exsanguination caused by preoperative rupture of the aneurysm. Thirty-day mortality is 5.9% (5/88), 2.8% for elective cases (2/70) and 16.7% for ruptured thoracoabdominal aortic aneurysms (3/18) ($p = 0.024$). Hospital mortality is 11.4% (10/88), 7% for elective cases (5/70) and 28% for ruptured aneurysms (5/18) ($p = 0.014$). The causes of hospital death are summarized in Table II. The hospital mortality in the patient group that had postoperative renal dysfunction necessitating dialysis is high: 41.7% (5/12) versus 6.6% (5/76) in the group without postoperative dialysis ($p = 0.0004$).

Of the twelve preoperative and five intraoperative variables entered in a stepwise logistic regression model (Table I), preoperative shock, female sex, preoperative elevated serum creatinine level, and preoperative myocardial infarction showed a significant association with hospital death. Preoperative shock increased the risk of dying in the hospital 8.6 times ($p = 0.02$). Although less significant, female sex increased the risk of early death 5.8 times ($p = 0.06$), preoperative elevated serum creatinine

level 1.2 times ($p = 0.06$), and preoperative myocardial infarction 5 times ($p = 0.08$) (Table III).

Late mortality. Forty-one patients died in the follow-up period between 30 days and 8.1 years after operation. Ten of these deaths were due to cardiac causes, 2 to pulmonary causes, 7 to multiple organ failure, 5 to major strokes, 4 to carcinoma, and 10 were due to unknown causes (no autopsy; nearly all sudden deaths). In 3 patients the cause of death was related to the aorta itself: an aortoenteric fistula, a rupture at the proximal anastomosis, and a rupture of an aneurysmal distal arch (Table IV). No significant difference in late mortality was identified between the group with renal dysfunction and the group without renal dysfunction: 50% (6/12) versus 46.6% (35/75) ($p = 0.83$).

The cumulative survival $\pm$ standard error at 2 years is 78% $\pm$ 4.4% and at 5 years 54% $\pm$ 5.3%. The survival curve is displayed in Fig. 2. As shown in Table V, postoperative dialysis ($p = 0.0022$), age ($p = 0.00782$), and rupture ($p = 0.0388$) were significant risk factors for late death as determined by multivariate analysis (the stepwise Cox regression model). The estimated effects of postoperative dialysis, age, and rupture on long-term survival are shown in Figs. 3 through 5.

Morbidity

Reintervention for persistent postoperative hemorrhage was necessary in 7 patients (8%). Low cardiac output necessitating low-dose catecholamines developed in 20 patients (23%). Five patients had a postoperative cerebrovascular accident (5.7%). Respiratory insufficiency necessitating ventilation for more than 7 days occurred in 23 patients (26.4%); 9 of them had chronic obstructive pulmonary disease as a preoperative risk factor. The group with aortic rupture included 6 patients who needed ventilation for more than 7 days (35.3%) compared with 17 in the group without aortic rupture (24.3%) ($p = 0.5375$). In 18 patients a tracheotomy was performed (20.7%). Pulmonary infection occurred in 20 patients (23%).

Three patients had been undergoing dialysis for several years and were excluded from analysis of postoperative

Fig. 2. Overall survival curve (time zero being the operation).

Table IV. Causes of late death

Cause	No.	%
Cardiac	10	12.5
Pulmonary	2	2.3
Multiple organ failure	7	7.9
Major stroke	5	5.7
Carcinoma	4	4.5
Unknown	10	11.3
Related to aorta	3	3.4
Total	41	46.6

renal complications. Of the 85 remaining patients, 30 had an elevated preoperative serum creatinine level of more than 125 $\mu\text{mol/L}$; in 8 this level was above 200 $\mu\text{mol/L}$.

Twelve patients (12/85 = 14.1%) required dialysis after the operation. Only 1 of the patients requiring postoperative dialysis had a normal preoperative serum creatinine level (<100 $\mu\text{mol/L}$). Five of them died in the hospital (41.7%); the 7 others recovered, and all maintained a stable elevated creatinine level without the need for long-term dialysis. In the group with aneurysmal rupture, dialysis was necessary for 4 of 18 patients (22.2%); in those without aneurysmal rupture, 8 of 67 (11.9%) needed dialysis ($p = 0.6838$). Perfusion of the renal arteries with iced Ringer's acetate was used in 77 patients. There are no indications that it had a protective effect

Table V. Multivariate prediction of late death (proportional hazard model)

Risk factor	Regression coefficient	Standard error	p Value
Postoperative dialysis	1.1834	0.3547	0.0022
Age	0.0523	0.0215	0.0078
Rupture	0.7650	0.3499	0.0388

Global χ^2 of the final model = 30.26 ($p < 0.0001$).

against renal function disturbances: 11 patients required postoperative dialysis in this group versus 1 of 10 in the group in which local cooling was not used ($p = 0.806$). The mean renal ischemic time for the whole group was 48.2 minutes (range 0 to 83 minutes). No difference was found between the mean renal ischemic time of the postoperative dialysis group and the nondialysis group (48 minutes versus 49 minutes).

To obtain a risk profile for postoperative renal failure, we entered patient- and operation-related variables in a stepwise logistic regression model. The incremental risk factors for postoperative dialysis are age ($p = 0.003$), which increases the risk by a factor of 1.2 per year, and the preoperative serum creatinine level ($p = 0.04$), which increases the risk by a factor of 1.01055 per 1 $\mu\text{mol/L}$ (Table VI). This means, for example, that a patient aged 70 years with a preoperative serum creatinine value of 300

Fig. 3. Effect of postoperative dialysis on long-term survival.

Fig. 4. Effect of age on long-term survival.

$\mu\text{mol/L}$ has a relative risk of postoperative dialysis which is 94 times higher than that of a patient aged 50 years with a preoperative serum creatinine level of $100 \mu\text{mol/L}$.

Ischemic spinal cord damage (paraplegia and para-

paresis) occurred in 12 patients of the 87 who survived the operation (13.8%). Five of them (5.7%) had permanent paraplegia and 7 patients (8%) had paraparesis. Six patients with spinal cord deficit were in the group having

Fig. 5. Effect of rupture on long-term survival.

Table VI. Stepwise logistic regression analysis of renal failure

Risk factor	Log regression coefficient	Standard error	p Value
Age	0.1723	0.0649	0.003
Preoperative serum creatinine level	0.0055	0.0029	0.04
Constant	-14.42	4.71	0.0008

Table VII. Stepwise logistic regression analysis of spinal cord deficit

Risk factor	Log regression coefficient	Standard error	p Value
Lower spinal cord ischemic time	0.04862	0.0207	0.022
Preoperative shock	1.765	0.910	0.0579
Constant	-3.264	0.753	0.067

a ruptured aneurysm ($n = 18$) and the other 6 patients were in the group without a ruptured aneurysm ($n = 70$) ($p = 0.0134$). The prevalence of postoperative spinal cord lesions is 18.7% (3/16) in those with a postdissection thoracoabdominal aortic aneurysm and 12.7% (9/71) in patients with a thoracoabdominal aortic aneurysm of degenerative origin ($p = 0.439$)—25% (4/16) in type I aneurysms, 28.5% in type II (6/21), 3.5% in type III (1/28), and 4.5% in type IV aneurysms (1/22) ($p = 0.0224$).

The mean spinal cord ischemic time was 18.8 minutes (range 0 to 68 minutes) in the group without postoperative neurologic problems; in the group with spinal cord damage it was 32.5 minutes (range 0 to 51 minutes) ($p = 0.1530$). We never infused iced saline solutions into the thoracoabdominal aortic aneurysm before opening the aneurysm to reduce the spinal cord metabolic demands. The late mortality in the paraplegia group is

extremely high: 80% versus 40% in the group without spinal cord problems ($p = 0.2006$). The prognosis is significantly better for those having paraparesis, with the late mortality being 28.5%. Most of these patients showed rapid improvement to total neurologic recovery. Delayed-onset paraplegia occurred in 1 patient and was probably caused by a prolonged period of hypotension on the second postoperative day.

Reattachment of open intercostal or lumbar arteries was performed in 51 patients (58.6%): 12 patients belonged to the postdissection group and 39 patients to the nondissection group. The mean number of reattached vessels in the nondissection group was 2.2 (range 0 to 12) versus 5.2 (range 0 to 11) ($p = 0.2179$) in the postdissection group. The paraplegia rate in the group of 51 patients in which intercostal or lumbar arteries were reimplanted into the prosthesis is 7.8% (4/51) and 2.7% (1/37) in the group without intercostal or lumbar vessel reattachment

Table VIII. Comparison of the results of different series of patients operated on for thoracoabdominal aortic aneurysm (mostly by crossclamping) from the literature

First author (year)	No. of patients	Thirty-day mortality (%)	Hospital mortality (%)	Five-year survival (%)	Paraplegia and paraparesis rate (%)	Overall prevalence of spinal cord injury (%)	Rupture (%)	Postop. dialysis (%)
Crawford ⁵ (1986)	605	8.9	—	60 ± 3	6/5	11.2	4	6.5
Sandmann ⁹ (1988)	99	21*	—	—	7/13	25	16	18
Hollier ¹⁰ (1988)	101	—	15	—	3/2	5.2	17.8†	3.9
Cambria ¹¹ (1989)	55	34.5*	—	—	—/—	7.2	11	3.6
Schmidt ¹² (1990)	40	—	12.5	—	10/—	10	30	5
Golden ¹³ (1991)	57	18	—	—	10/7	17.5	8.7	40‡
Cox ¹⁴ (1992)	129	35	—	37	16/25	21	18.6	27
Present series	88	5.9	11.4	54 ± 5	5.7/8	13.8	20.5	14.1

*Perioperative mortality.

†Emergency repair; rupture not specified.

‡Postoperative renal failure without further specification.

($p = 0.57$). Because of limitations of postoperative digital vascular imaging with venous contrast injection, the patency of the reimplanted small vessels could not be substantiated.

After multivariate analysis (stepwise logistic regression) (Table VII), the lower spinal cord ischemic time ($p = 0.02$) and, although less significant, the presence of preoperative shock ($p = 0.06$) showed an association with postoperative neurologic deficit. The risk increases 5.8 times when preoperative shock is present and 1.05 times per minute of longer spinal cord ischemic time.

Discussion

The natural history of thoracoabdominal aortic aneurysms is well established and surgery has significantly improved long-term survival. After surgical repair in 605 patients, Crawford and associates⁵ showed a 30-day mortality of 8.9% and a 5-year survival of 60% ± 3%. In our experience the 30-day mortality is 5.9% and the hospital mortality 11.4%. In elective cases our hospital mortality is 7% whereas in the case of rupture it rises to 28% ($p = 0.014$); if the high percentage (20.5%) of patients with rupture of the aneurysm is taken into account, the hospital mortality of 11.4% is low compared with other series. Recently others have reported early death rates from 8.9% to even 35%^{5, 9-14} (Table VIII). In our series, hospital mortality was related to preoperative shock, female sex, preoperative elevated serum creatinine level, and preoperative myocardial infarction. Aortic cross-clamp time and chronic obstructive pulmonary disease did not emerge as predictors of early death, as they did in the series of Crawford and coworkers.⁵

Late death has been shown to be related to age, rupture, renal dysfunction, type of aneurysm, and dissection.⁵

In our series postoperative dialysis, age, and rupture are variables predictive of late death; extent of disease and postdissection aneurysms do not seem to play any role. The long-term survival at 5 years is 54% ± 5% in our series.

Respiratory insufficiency is the most common complication after repair of thoracoabdominal aortic aneurysms, as reflected by the prevalence of prolonged ventilation (26.4%), tracheotomy (20.7%), and pneumonia (23%). It is obvious that in the case of ruptured aneurysms it was not possible to provide an adequate preoperative pulmonary preparation. Respiratory insufficiency has caused prolonged stay in the intensive care unit and certainly will have contributed to other major complications. We have always used a circumferential diaphragmatic division, but we cannot conclude that this technique is better or worse than using a radial incision. Thoracic epidural pain control was not routinely used.

The strongest predictor of postoperative dialysis is preoperative renal function.⁵ This observation is confirmed by our series; however, multivariate analysis showed that the risk for postoperative dialysis is also increased with age. Early reperfusion of the renal arteries, protection of the ischemic kidneys by reducing the metabolic needs, and institution of a diuretic status before clamping¹⁰ all may play a major role.

Paraplegia, probably caused by a temporary reduction of the perfusion pressure to the spinal cord during or after the operation, is still the most feared and catastrophic complication. It remains an unresolved source of severe morbidity. The reported rates of paraplegia and paraparesis vary in several series from 2% to 25% (Table VIII). It certainly is inappropriate to draw major conclusions from these numbers because preoperative and

intraoperative risk variables are considerably different. In our experience, the overall prevalence of spinal cord injury (paraplegia and paraparesis) is 13.8%, and there has been no change in the risk over time. The risk of postoperative neurologic complications varies with the type of thoracoabdominal aortic aneurysms and the presence or absence of rupture and dissection (all signs of the nature and extent of the disease).⁵ The reattachment of important intercostal and lumbar arteries and the aortic cross-clamp time could play a major role. It is as yet unclear whether critical vessels can be accurately identified during the operation. Multivariate analysis of our patients showed that only longer lower spinal cord ischemic time and preoperative shock were determinant risk factors for the development of postoperative spinal deficit.

For many years, numerous adjuncts have been used to reduce the prevalence of postoperative renal or spinal function disturbances, but none has consistently prevented these complications. Because it was shown that operating time and blood loss were reduced¹⁵ by the graft inclusion technique with reimplantation of the intercostal and visceral arteries popularized by Crawford, we have adapted this method in all the operations in this study. No heparin or shunts were used.

Since 1987 we have used, in 51 elective cases, a left heart bypass with a centrifugal pump without heparin because we think this adjunct maintains an adequate distal perfusion during the clamping phase and reduces the ischemic time of the spinal cord and abdominal organs including the kidneys. The paraplegia rate in the group with the centrifugal pump is 13.7% ($n = 7$, including 1 case of delayed-onset paraplegia) versus 5.7% ($n = 5$) in the crossclamp group ($p = 0.1888$). Four patients (7.8%) had renal failure necessitating dialysis in the left heart bypass group versus 12 (14.1%) in the crossclamp group ($p = 0.4096$). Although temporary left heart bypass is an adjunctive method, now widespread in descending thoracic and thoracoabdominal aortic aneurysm surgery, it has had no beneficial effect in lowering our paraplegia and renal failure rates.

Our experience shows that patients with thoracoabdominal aortic aneurysms can be treated with an acceptably low mortality and good long-term survival. Nevertheless, the postoperative complications, especially paraplegia and renal failure, remain vexing problems and further research will be necessary. Of the patient- and operation-related variables examined in this study, age and preoperative serum creatinine level increase the likelihood of postoperative dialysis; perfusion of the renal arteries with iced Ringer's acetate does not have a protective effect. The lower spinal cord ischemic time and, to a lesser extent, preoperative shock increase the likeli-

hood of spinal cord dysfunction; intercostal and lumbar vessel reattachment does not lessen the prevalence of paraplegia.

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