Predictors of early and late mortality following open extent IV thoracoabdominal aortic aneurysm repair in a large contemporary single-center experience

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Objective: **The primary purpose of this study was to examine outcomes following open repair of extent IV thoracoabdominal aortic aneurysms (TAAAs) at a single university hospital. As a secondary aim, comparison was made to patients who underwent open abdominal aortic aneurysm (AAA) repair with supraceliac clamping but without left renal artery bypass to assess the effect of left renal artery bypass on outcomes.**

Methods: **Patients undergoing open extent IV TAAA repair from 1998 to 2008 were identified (n = 108). Primary outcomes were 30-day and long-term survival. Secondary outcomes were major complication, renal failure, and postoperative change in renal function. A second analysis was performed, comparing patients undergoing extent IV TAAA repair with patients undergoing AAA repair with supraceliac clamping but without left renal artery bypass (n = 50).**

Results: **Eighty-three men (76.9%) and 25 women (23.1%), with a mean age of 72.9 years, underwent open extent IV TAAA repair. Nine patients (8.3%) were ruptured. Mean aneurysm maximal diameter was 6.5 ± 1.3 cm. Supraceliac and left renal ischemic times were 22.9 ± 9.3 and 40.6 ± 16.2 minutes, respectively. Six patients (5.6%) died at 30 days. The only predictor of 30-day mortality was decreased preoperative estimated glomerular filtration rate (eGFR) ($P = .044$ by multivariate analysis; and $P = .011$ by univariate analysis). One-year and 5-year survival rates were 87% and 50%, respectively. Patients with a history of cerebrovascular disease ($P = .001$) and postoperative renal insufficiency ($P = .034$) had increased long-term mortality by log-rank test. Twenty-five (25.3%) patients sustained a postoperative decrease in renal function, while 19 (19.2%) patients had an improvement in renal function. There was no difference in 30-day mortality (5.6% vs 6.0%; $P = 1.000$), 5-year survival (50% vs 48%; $P = .886$), major complications (37.0% vs 38.0%; $P = 1.000$), renal failure (6.1% vs 0%; $P = .215$), or postoperative change in renal function, in patients undergoing extent IV TAAA repair vs AAA repair with supraceliac clamping but without left renal artery bypass.**

Conclusions: **Open extent IV TAAA repair can be performed with low morbidity and mortality rates. The performance of left renal artery bypass does not appear to contribute to the morbidity and mortality of extent IV TAAA repair. While decreased preoperative eGFR appears to increase the risk of 30-day mortality, a history of cerebrovascular disease and postoperative renal insufficiency appear to increase the risk of long-term mortality. Finally, open extent IV TAAA repair not uncommonly improves renal function. (J Vasc Surg 2011;53:299-306.)**

Open surgery remains the mainstay of therapy for extent IV thoracoabdominal aortic aneurysms (TAAAs).[1-12] Renal failure requiring institution of hemodialysis has been reported in 6% to 15% of patients following open extent IV TAAA repair, while postoperative renal dysfunction occurs in as many as 50% of patients. Thirty-day mortality for open extent IV TAAA repair ranges from 3% to 17% at single centers.[1-13] Open repair of extent IV TAAA is clearly useful: one of the largest single-center experiences with open extent IV TAAA repair reported a 1-year survival rate of 90%.[3]

Several studies have identified predictors, such as preoperative renal insufficiency and visceral ischemia, of 30-day mortality after open TAAA repair.[1,14-16] Moreover, recent studies in a wide range of surgical patients have identified postoperative kidney dysfunction as an independent predictor of long-term mortality.[17,18] The current study presents a single-center experience with open extent IV TAAA repair to update the morbidity and mortality of this procedure and to identify predictors of early and late outcome. Furthermore, to assess the contribution of true extent IV TAAA morphology and necessity for left renal artery bypass (LRAB) on patient outcome, comparison was made to patients who underwent abdominal aortic aneu-

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Competition of interest: none.

Presented at the 2010 Vascular Annual Meeting of the Society for Vascular Surgery, Boston, Mass, June 10-13, 2010.

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The editors and reviewers of this article have no relevant financial relationships to disclose per the JVS policy that requires reviewers to decline review of any manuscript for which they may have a competition of interest.

0741-5214/$36.00

doi:10.1016/j.jvs.2010.08.085

rysm (AAA) repair requiring supraceliac clamping but not LRAB.

METHODS

Patients. A prospectively maintained vascular database was used to retrospectively analyze data on patients who underwent open extent IV TAAA repair between January 1998 and December 2008 at the Hospital of the University of Pennsylvania. This study was conducted with the approval of the center's Human Research Ethic Committee.

All patients underwent computed tomography of the thoracic and abdominal aorta. Preoperative cardiopulmonary assessment was performed in all elective cases and in nonelective cases as time allowed. In addition, it became our practice toward the end of the study period to perform carotid duplex in patients undergoing repair. Patients were classified as undergoing elective, urgent, or emergent repair. Patients with ruptured aneurysms who were operated on within 6 hours of nonelective admission were classified as undergoing emergent repair. Patients with symptomatic aneurysms who were operated on within 24 hours of nonelective admission were classified as undergoing urgent repair. Urgently and emergently repaired aneurysms were classified together as nonelectively repaired aneurysms.

Extent IV TAAA repair was defined according to Crawford's classification.[15,16] Extent IV TAAA involved the upper abdominal aorta and required supraceliac clamping. Repair involved construction of a beveled anastomosis up to, or above, the celiac artery, and required reimplantation of the left renal artery. Patients undergoing open extent IV TAAA repair will be referred to as group one.

Patients in the comparison group (group 2) had pararenal or juxtarenal abdominal aortic aneurysms that required supraceliac clamping but not LRAB. Supraceliac clamping was required due to insufficient space between the superior mesenteric artery and renal vessels or heavy calcification of the suprarenal aorta prohibiting clamping at this location. None of these patients underwent LRAB or any other visceral or renal artery bypass.

Surgical technique. All extent IV TAAA repairs (n = 108) were carried out through a left retroperitoneal incision. Repair was performed with supraceliac cross-clamping only; neither renal cooling nor cardiopulmonary bypass was performed in any of the procedures. At the discretion of the surgeon, 61 patients had mannitol administered intraoperatively. Dacron graft was used in 107 patients and allograft was used in one patient with a mycotic aneurysm. A beveled proximal anastomosis incorporating the ostia of the celiac artery, superior mesenteric artery, and right renal artery, with separate reimplantation of the left renal artery was performed in 100 of 108 cases. Eight patients did not undergo LRAB due to end-stage renal disease (ESRD) (n = 4), atrophic left kidney (n = 2), and concomitant nephrectomy for renal cell cancer (n = 2). Of the 100 LRAB procedures, 94 were performed via anastomosis of a 6-mm Dacron graft from the main body of the aortic tube graft to the left renal artery, which had been previously taken off the aorta as a Carrell patch (Fig 1). Six patients underwent LRAB prior to the construction of the proximal anastomosis using the distal thoracic aorta (n = 5) or the left common iliac artery (n = 1) as the inflow. Of the 94 LRABs performed by anastomosis of a 6-mm Dacron graft off the main body of the aortic tube graft to the left renal artery, 53 were performed immediately prior to the distal aortic anastomosis, and 41 were performed after the distal aortic anastomosis. The timing of the LRAB was at the discretion of the surgeon. In the majority of cases, the LRAB was performed after the proximal aortic anastomosis; however, in situations where re-establishing distal aortic and pelvic perfusion rapidly (eg, prior colectomy, prior thoracic aortic repair, or prior lower extremity bypass) was considered essential, the LRAB was performed after the distal anastomosis. Twenty-two renal artery endarterectomies were performed in 21 patients. The indication for endarterectomy was significant renal artery stenosis in all cases. The distal anastomosis was to the aortic bifurcation in 95 patients and to the iliac vessels in 13 patients. Supraceliac ischemia, left renal artery, and lower extremity ischemia times were available in 98, 67, and 57 patients, respectively. Neither lumbar drainage nor monitoring of somatosensory or motor evoked potentials was routinely performed.

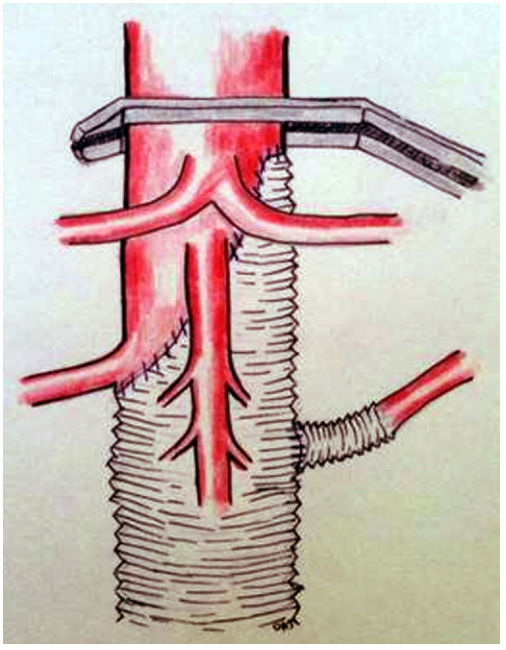

Fig 1. Open extent IV thoracoabdominal aortic aneurysm (TAAA) repair performed with a beveled proximal anastomosis incorporating the ostia of the celiac, superior mesenteric, and right renal arteries and separate reimplantation of the left renal artery.

In group 2 (n = 50), repair was carried out through a left retroperitoneal approach in 49 patients and through a transperitoneal approach in one patient. Supraceliac clamping was employed in all cases. No LRAB, nor other visceral or renal artery bypass, was performed in this group. Dacron

graft was used in all patients. Renal artery endarterectomy was performed in three patients. Distal anastomosis was to the aortic bifurcation in 44 patients, to the iliac vessels in five patients, and to the femoral vessels in one patient. Supraceliac ischemia times and lower extremity ischemia times were available in 48 and 21 patients, respectively.

Statistical analysis. Primary outcome variables were 30-day mortality and long-term survival. Secondary outcome variables included major complications, renal failure, and postoperative change in renal function. Renal failure was defined as postoperative kidney failure requiring long-term renal support in patients not on dialysis preoperatively.

Postoperative change in renal function was defined as an increase or decrease in estimated glomerular filtration rate (eGFR) stage. For example, a patient with preoperative stage III kidney disease who had stage II kidney disease postoperatively was classified as having an improvement in renal function. Creatinine levels measured 1 month postoperatively were used for calculation of postoperative renal function. Estimated GFR was determined by the Modification of Diet in Renal Disease formula.[19] Preoperative and postoperative renal insufficiency were defined as eGFR < 60 mL/min/1.73 m.[19-21]

Patient-related (age, age less than or greater than 80 years, gender, race, eGFR, renal insufficiency, coronary artery disease, cerebrovascular disease [history of transient ischemic attack or stroke], chronic obstructive pulmonary disease, and history of infrarenal abdominal aortic aneurysm repair), disease-related (aneurysm size, elective vs nonelective repair), and treatment-related (mannitol administration, duration of supraceliac ischemia, duration of left renal artery ischemia, duration of lower extremity ischemia, renal artery endarterectomy, and estimated blood loss) variables were assessed for their influence on primary and secondary outcomes using Pearson χ^2 test, Student *t* test, Mann-Whitney *U,* or logistic regression, as appropriate.

To determine the effect of the timing of the LRAB on postoperative renal outcomes, patients were divided into three groups depending on whether the LRAB was performed before the proximal anastomosis, after the proximal anastomosis, or after the proximal and distal anastomosis. With respect to supraceliac ischemia, patients were classified as having <20 minutes, 20 to 30 minutes, or >30 minutes of ischemic time. With respect to left renal artery ischemia, patients were classified as having less than or greater than 40 minutes of ischemic time.

Patient follow-up information was collected through the interrogation of medical records, the Social Security Database Index, and telephone interviews. Long-term survival was determined with the Kaplan-Meier life-table methods. Log-rank tests were used to compare life-table curves for categorical variables. Cox proportional hazards were also used to evaluate the effects of continuous patient-related and treatment-related variables on long-term mortality. Comparison between patients undergoing open extent IV TAAA repair (group 1) and open AAA repair requiring supraceliac clamping without LRAB (group 2) was performed by χ^2 and *t* test for categorical and continuous variables, respectively, and by log-rank test for Kaplan-Meier survival. Statistical analyses were performed with SPSS software (SPSS Inc, Chicago, Ill).

Table I. Preoperative clinical details in patients undergoing extent IV TAAA repair and AAA repair requiring supraceliac clamping without LRAB

	Group 1 (n = 108)	*Group 2 (n = 50)*	P *value*
Sex ratio (M:F)	83:25	35:15	.469
Age (mean ± SD)	72.9 ± 7.6 y	73.3 ± 8.1 y	.769
Octogenarian	20 (18.5%)	12 (24.0%)	.560
Coronary artery disease	62 (57.4%)	28 (56.0%)	1.000
CABG/PCI or previous MI	47 (43.3%)	21 (42.0%)	.995
COPD	39 (36.1%)	23 (46.0%)	.313
Cerebrovascular disease	20 (18.5%)	6 (12.0%)	.425
Estimated GFR (mean ± SD)	54.9 ± 23.7	76.7 ± 32.7	<.001
Renal insufficiency (GFR <60)	69 (63.9%)	16 (32.0%)	<.001
Previous infrarenal abdominal aortic aneurysm repair	26 (24.1%)	11 (22.0%)	.933
Aneurysm diameter (mean ± SD)	6.5 ± 1.3 cm	6.8 ± 1.5 cm	.214
Ruptured	9 (8.4%)	6 (12.0%)	.660
Nonelective	24 (22.2%)	14 (28.0%)	.555

AAA, Abdominal aortic aneurysm; *CABG*, coronary artery bypass grafting; *COPD*, chronic obstructive pulmonary disease; *GFR*, glomerular filtration rate; *LRAB,* left renal artery bypass; *MI,* myocardial infarction; *PCI,* percutaneous coronary intervention; *TAAA,* thoracoabdominal aortic aneurysm.

RESULTS

Preoperative characteristics. Salient preoperative characteristics of the 108 patients who underwent open extent IV TAAA repair (group 1) and the 50 patients undergoing AAA repair requiring supraceliac clamping without LRAB (group 2) are summarized in Table I: the two groups were similar except for preoperative renal function, which was worse in the extent IV TAAA repair group.

Operative details. Mean supraceliac, left renal artery, and lower extremity ischemic times for patients undergoing open extent IV TAAA repair were 22.9 ± 9.3, 40.3 ± 16.2, and 52.8 ± 13.0 minutes, respectively. Mean blood loss was 2.6 ± 1.9 liters. Table II presents operative details, including clamp times, in both groups.

Thirty-day mortality. Thirty-day and in-hospital mortality in patients who underwent open extent IV TAAA repair was 5.6% (n = 6). Causes of death were intestinal ischemia (n = 2), bleeding due to anastomotic disruption (n = 2), and multisystem organ failure (n = 2). One (11.1%) of nine patients with a ruptured aneurysm and one (25%) of four patients with preoperative ESRD sustained 30-day mortality. Excluding patients with ruptured aneurysms and ESRD, the 30-day mortality rate was 4.2% (4/95). There was no statistically significant difference

Table II. Operative details in patients undergoing extent IV TAAA repair and AAA repair requiring supraceliac clamping without LRAB

	Group 1 (n = 108)	*Group 2 (n = 50)*	P *value*
Retroperitoneal incision	108 (100.0)	49 (98.0)	.692
Supraceliac ischemia (mean ± SD)	22.9 ± 9.3 min	21.3 ± 7.9 min	.334
Left renal artery ischemia (mean ± SD)	40.3 ± 16.2 min	21.3 ± 7.9 min	<.001
Lower extremity ischemia (mean ± SD)	52.8 ± 13.0 min	43.7 ± 11.0 min	.006
Blood loss (mean ± SD)	2.6 ± 1.9 L	2.0 ± 1.3 L	.080

AAA, Abdominal aortic aneurysm; *LRAB,* left renal artery bypass; *TAAA,* thoracoabdominal aortic aneurysm.

Table III. Preoperative GFR by outcome following open extent IV TAAA repair

Outcome	*N*	*Estimated GFR (mean ± SD)*	*Univariate* P *value*	*Multivariate* P *value*
30-day mortality				
Yes	6	31.1 ± 13.6	.011	.044
No	102	56.3 ± 23.5		
Renal failure[a]				
Yes	6	33.2 ± 12.2	.004	.081
No	92	59.7 ± 21.6		
Major complication				
Yes	40	47.4 ± 22.8	.011	.667
No	68	59.3 ± 23.3		

GFR, Glomerular filtration rate; *TAAA,* thoracoabdominal aortic aneurysm.
[a]Excludes six patients who died and five patients with preoperative stage V kidney disease. One patient with preoperative stage V kidney disease died.

detected in 30-day mortality between elective and nonelective repairs (4.8% vs 8.3%; $P = .866$). Patients who sustained 30-day mortality had lower preoperative eGFR by univariate ($P = .011$) and multivariate ($P = .044$) analysis (Table III). All of the patients who sustained 30-day mortality had preoperative renal insufficiency.

Long-term survival. Mean follow-up for patients surviving extent IV TAAA repair was 38.2 ± 27.7 months (range, 1-123). Mean survival in all patients undergoing extent IV TAAA repair was 66.4 ± 5.6 months. One-year, 3-year, and 5-year Kaplan-Meier survival in all patients was 87% ± 3.4%, 71% ± 4.8%, and 50% ± 6.4%, respectively (Fig 2, *A*). Patients with a history of cerebrovascular disease (24% ± 12% vs 56 ± 7.2% at 5 years, $P = .001$; Fig 2, *B*) and postoperative renal insufficiency (43% ± 8% vs 74% ± 9.7% at 5 years, $P = .034$; Fig 2, *C*) had decreased long-term survival. Patients with preoperative renal insufficiency did not have a statistically different 5 year survival than others (43% ± 7.7% vs 54% ± 11.6%; $P = .110$).

Major complications. Major complications occurred in 40 (37.0%) patients in the extent IV TAAA repair group (Table IV). Patients who sustained major complications had a lower preoperative eGFR by univariate analysis ($P = .011$; Table III). No variable predicted major complication by multivariate analysis. The average length of stay following open extent IV TAAA repair was 13.5 ± 19.5 days (range, 5-180).

Renal failure and postoperative change in renal function. New renal failure requiring long-term dialysis occurred in six (6.1%) patients following open extent IV TAAA repair. Univariate analysis showed that patients who developed postoperative renal failure had lower preoperative eGFR ($P = .004$; Table III). While no variable predicted postoperative renal failure by multivariate analysis, there was a nonsignificant trend observed with decreased preoperative eGFR ($P = .081$). All of the patients who developed postoperative renal failure had preoperative renal insufficiency.

Nineteen (19.2%) patients had a postoperative improvement in renal function. Renal artery endarterectomy predicted postoperative improvement in renal function by univariate analysis ($P = .031$). Twenty-five (25.3%) patients had a postoperative decrease in renal function. No variable predicted a postoperative change in renal function by multivariate analysis. Neither elective vs nonelective repair status nor mannitol administration predicted either postoperative renal failure or postoperative change in renal function. No association between supraceliac or left renal artery ischemic time and either postoperative renal failure or change in renal function was found. Similarly, the performance of the LRAB before the proximal anastomosis, after the proximal anastomosis, or after the proximal and distal anastomosis, did not affect the incidence of either postoperative renal failure or change in renal function.

Comparative analysis. Comparisons between group 1 and group 2 are shown in Table V. There was no difference in 30-day mortality between the two repair groups. Although no patient in group 2 developed renal failure, this difference was not statistically significant ($P = .215$). There was no difference in change in renal function, postoperative major complications, or length of stay between the two groups. Long-term survival did not differ (50% ± 6.3% in group 1 vs 48% ± 9.1% in group 2; Fig 2, *A*).

DISCUSSION

A contemporary large, single-center experience with open extent IV TAAA repair has been presented. The renal failure and 30-day mortality rates in this series compare well with those from other singe-center reports. In addition, almost 20% of patients had improved renal function following open extent IV TAAA repair. Consistent with previous reports on open TAAA repair, decreased preoperative eGFR predicted 30-day mortality, the development of renal failure requiring dialysis, and major complications. Furthermore, we found that patients with cerebrovascular disease and postoperative renal insufficiency were at increased

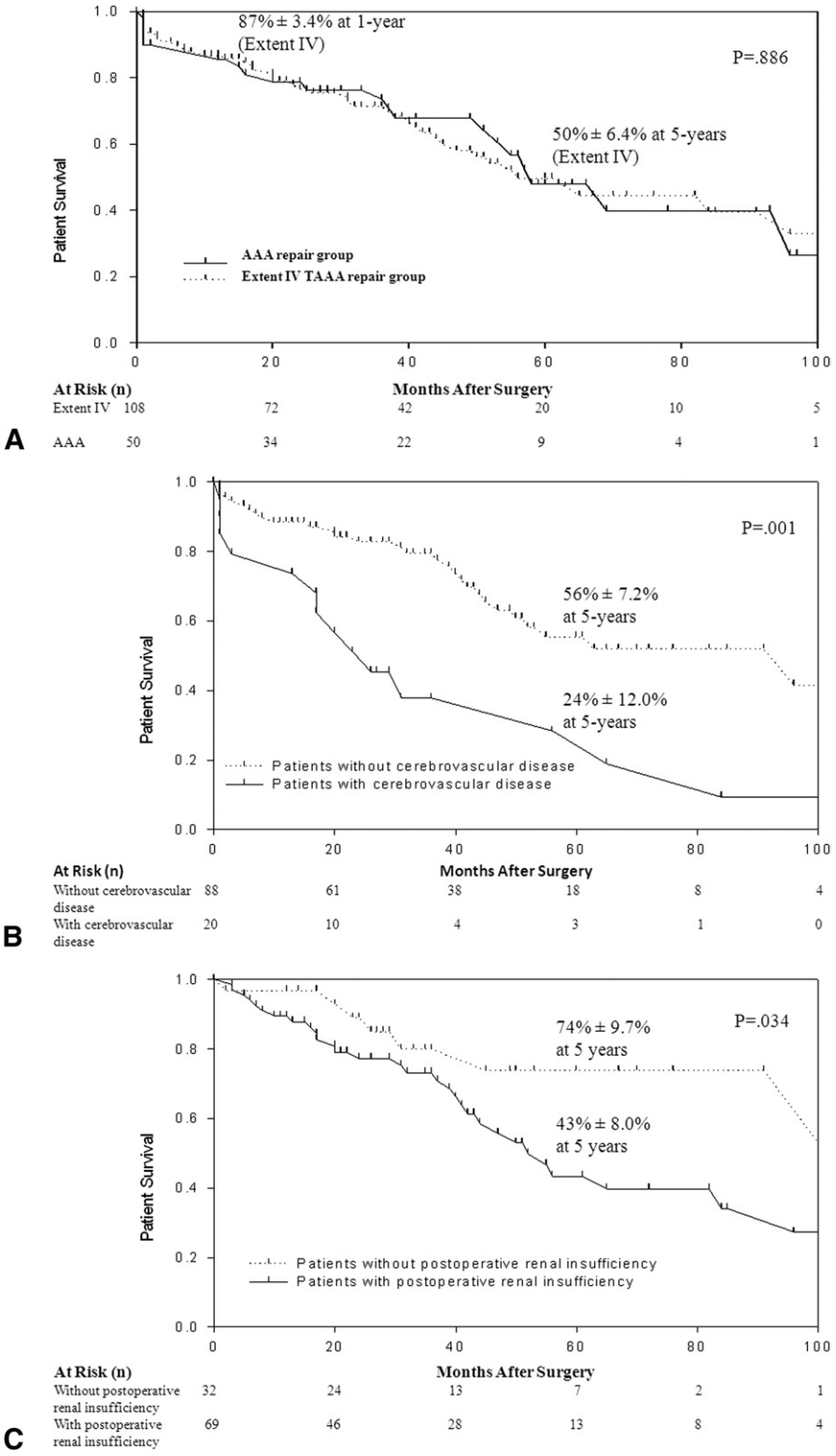

Fig 2. A, Kaplan-Meier survival curve for patients undergoing extent IV thoracoabdominal aortic aneurysm (*TAAA*) repair and abdominal aortic aneurys (*AAA*) repair with supraceliac clamping but without left renal artery bypass (LRAB). **B,** Kaplan-Meier survival curve for patients undergoing open extent IV TAAA repair by history of cerebrovascular disease. **C,** Kaplan-Meier survival curve for patients undergoing open extent IV TAAA repair by postoperative renal function.

Table IV. Major complications in patients undergoing extent IV TAAA repair and AAA repair requiring supraceliac clamping without LRAB

	Type IV TAAA (n = 108)	*AAA (n = 50)*
Total	40 (37.0%)	19 (38.0%)
Pulmonary (pneumonia, ventilator-dependent respiratory failure, tracheostomy, pleural effusion requiring drainage)	15 (13.9%)	9 (18%)
Cardiac (evidence of myocardial ischemia or infraction by EKG or laboratory markers, arrhythmia, CHF exacerbation)	7 (6.5%)	4 (8.0%)
Bleeding requiring re-exploration	8 (7.4%)	1 (2.0%)
Lower extremity ischemia requiring intervention	7 (6.5%)	2 (4.0%)
Mesenteric ischemia requiring laparotomy	2 (1.9%)	2 (4.0%)
Spinal cord ischemia	1 (0.9%)	1 (2.0%)

AAA, Abdominal aortic aneurysm; *CHF,* congestive heart failure; *EKG,* electrocardiogram; *LRAB,* left renal artery bypass; *TAAA,* thoracoabdominal aortic aneurysm.

Table V. Outcomes of patients undergoing extent IV TAAA repair and AAA repair requiring supraceliac clamping without LRAB

	Group 1 (n = 108)	*Group 2 (n = 50)*	P *value*
Mortality	6 (5.6%)	3 (6.0%)	1.000
Renal failure[a]	6 (6.1%)	0 (0.0%)	.215
Major complications	40 (37.0%)	19 (38.0%)	1.000
Postoperative decrease in renal function[a]	25 (25.3%)	16 (35.6%)	.284
Postoperative improvement in renal function[a]	19 (19.2%)	5 (11.1%)	.335
Average length of stay (mean ± SD)	13.5 ± 19.5 d (range, 5-180)	12.1 ± 8.3 d (range, 6-48)	.626

AAA, Abdominal aortic aneurysm; *LRAB,* left renal artery bypass; *TAAA,* thoracoabdominal aortic aneurysm.

[a]Excludes patients with preoperative stage V chronic kidney disease and patients who died within 30 days.

risk of long-term mortality. Finally, the morbidity and mortality of extent IV TAAA repair does not appear to be increased by left renal artery ischemia from LRAB.

The renal failure rate of 6.1%, compares well with the rates of 5.4% in the study by Coselli et al and the rate of 15.4% in the study by Bicknell et al, although the latter study only reported on short-term renal failure.[1,4] Moreover, the low renal failure rate achieved in this study was in a cohort of patients in whom almost two-thirds of the patients had preoperative renal insufficiency. Almost 20% of patients in our study had an improvement in renal function. Renal artery endarterectomy predicted an improvement in renal function by univariate analysis.

The demonstrated 30-day mortality rate of 5.6% also compares well with other single-center experiences, which have reported rates ranging from 3% to 17%.[1-12] It is important to note that the 30-day mortality rate of patients without ESRD or ruptured aneurysms undergoing open extent IV repair was 4.2%. The only other study that has reported long-term survival in patients undergoing extent IV TAAA repair was published by Coselli et al and reported a 5-year survival rate of 65.3%.[3] While it is difficult to compare the long-term survival between two studies, it is possible that advanced age (mean of 65.5 years in the Coselli et al study vs 72.9 years in the current study) and significant comorbidities in the current patient population, account, in part, for the higher 5-year mortality rate.

This study confirms previous findings, which suggest that preoperative renal dysfunction is a predictor of outcomes in patients undergoing open TAAA repair.[1,14-16] Univariate analysis showed that preoperative eGFR was significantly lower in patients who sustained 30-day mortality, developed postoperative renal failure, and had major complications. In addition, only patients with preoperative renal insufficiency sustained 30-day mortality or developed postoperative renal failure. Logistic regression revealed that lower preoperative eGFR predicted 30-day mortality. The use of eGFR in this study makes the results easier to apply to future patients undergoing preoperative risk-stratification for open extent IV TAAA repair. Specifically, patients with preoperative renal insufficiency (eGFR less than 60) might be viewed at high risk for 30-day mortality and the development of new renal failure following open surgical repair.

Patients with postoperative renal insufficiency had a significantly lower 5-year survival than those who did not. Our finding that there is an association between renal function and survival is consistent with findings from the general population in which reduced eGFR has been shown to be associated with increased risk of death, cardiovascular events, and hospitalization independent of other risk factors.[22] Our results are also supported by recent studies in the surgical literature, which have shown that surgical patients who sustain acute kidney injury in the perioperative period have an increased risk of long-term mortality.[17,18,22] The proposed mechanism of this decreased survival is the induction of a systemic inflammatory response that persists postoperatively.[22] Statins and beta-blockers, which mitigate this inflammatory response, have been shown to decrease mortality after vascular surgery.[23-25] It is possible that operative techniques, such as renal artery endarterectomy, balloon-expandable stenting of the right renal artery,[26] and renal cooling,[16] that preserve, or improve, renal function may also play a role in improving survival outcomes. A recent review by Hersey and Poullis supports our finding that the administration of mannitol does not reduce the incidence of postoperative renal dysfunction.[27] While the exact mechanism between renal function and survival remains unclear, implementing strategies to protect, or improve, renal function may play an important role in improving patient outcomes following open extent IV TAAA repair.

To assess the contribution of LRAB on clinical outcomes, we compared patients undergoing extent IV TAAA

repair with patients undergoing aneurysm repair with supraceliac clamping but without LRAB. Bicknell and colleagues performed a similar analysis, comparing patients who underwent open extent IV TAAA repair with 44 patients who underwent repair of juxtarenal aneurysms with either supraceliac (n = 18) or suprarenal (n = 26) clamping. They found significantly higher rates of mortality (16.9% vs 4.5%) and short-term renal failure (15.4% vs 0.0%) in the extent IV TAAA group.[1] Our comparison showed no difference in mortality and morbidity rates. This may be due to the lower morbidity and mortality for extent IV TAAA repair in the current study.

Lastly, in light of the high morbidity and mortality associated with the open extent IV TAAA repair, a variety of hybrid and endovascular techniques have been applied to this complicated disease process in an attempt to improve outcomes.[28-31] In a recent study, Kuratani and colleagues reported on 86 patients undergoing TAAA repair with a novel hybrid procedure.[28] Both 30-day mortality and postoperative renal failure were 2.3%. Donas et al evaluated the effectiveness of the Viabahn Open Revascularization Technique (VORTEC) in TAAA and pararenal aortic aneurysm repair (PAAA) in 58 high-risk patients.[29] The 30-day mortality rate was 8.6%, and no patient required permanent dialysis.[29] Greenberg et al assessed the use of branched endovascular grafts to treat complex aortic aneurysms in 50 patients at prohibitive risk for open surgical repair; early mortality was 2%, and the need for new dialysis was 2%.[30]

With respect to fenestrated aortic endografts, a recent study by Haulon et al reported on 80 high-risk patients who underwent elective fenestrated aortic endograft placement for juxtarenal, suprarenal, and extent IV TAAA aortic aneurysms. Early mortality was 2.5%, with one patient requiring long-term hemodialysis.[31] While these studies highlight the early safety of endovascular repair, long-term follow-up of aneurysm sac behavior, visceral artery patency, and long-term mortality remains lacking. Moreover, it is worth noting that there appears to be little difference in the "high-risk" patients undergoing elective endovascular repair and the patients referred to high-volume centers for open extent IV TAAA repair. In the study by Haulon et al, "high-risk criteria" included 15% of patients >80 years of age, 54% of patients with coronary artery bypass grafting/percutaneous coronary intervention or previous myocardial infarction, 20% of patients with left ventricular ejection fraction <40%, 40% of patients with chronic obstructive pulmonary disease, and 44% of patients with preoperative renal insufficiency with no patient on preoperative dialysis.[31] In the current study, 19% of patients were over 80 years of age, 43% of patients had a history of coronary artery bypass grafting, percutaneous coronary intervention, or myocardial infarction, 17% had left ventricular ejection fraction <45%, 36% of patients had chronic obstructive pulmonary disease, and 64% of patients had preoperative renal insufficiency with four patients on preoperative dialysis. Furthermore, 22% of the repairs in this study were nonelective.

There are several limitations of the current study. First, it is a retrospective study from a single center. Although a large number of patients underwent extent IV TAAA repair at the Hospital of the University of Pennsylvania during the 10-year time period, the results could be confirmed in a larger prospective multicenter study. Second, there were missing data on supraceliac, left renal artery, and lower extremity ischemia times, which might reflect bias if available times were more likely to be present for shorter ischemic times. However, it seems reasonable that our low mortality and morbidity rates following open extent IV repair reflect short ischemic times.

In summary, this study indicates that open extent IV TAAA repair can be performed with relatively low morbidity and mortality in high-risk patients at a high-volume center. Left renal artery bypass does not appear to contribute significantly to morbidity and mortality. We have confirmed the results of other studies, showing that preoperative renal insufficiency predicts 30-day mortality, renal failure, and major complications in patients undergoing open extent IV TAAA repair. In addition, we found that patients with a history of cerebrovascular disease and postoperative renal insufficiency have an increased risk of long-term mortality.

AUTHOR CONTRIBUTIONS

Conception and design: DN, RF, BJ
Analysis and interpretation: DN, EW, JC, RF, BJ
Data collection: DN, CB
Writing the article: DN, CB, BJ
Critical revision of the article: DN, EW, JC, RF, BJ
Final approval of the article: DN, CB, EW, JC, RF, BJ
Statistical analysis: DN, BJ
Obtained funding: Not applicable
Overall responsibility: BJ

REFERENCES

1. Bicknell CD, Cowan AR, Kerle MI, Mansfield AO, Cheshire NJ, Wolfe JH. Renal dysfunction and prolonged visceral ischaemia increase mortality rate after suprarenal aneurysm repair. Br J Surg 2003;90:1142-6.
2. Cina CS, Lagana A, Bruin G, Ricci C, Doobay B, Tittley J, et al. Thoracoabdominal aortic aneurysm repair: a prospective cohort study of 121 cases. Ann Vasc Surg 2002;16:631-8.
3. Coselli JS, Conklin LD, LeMaire SA. Thoracoabdominal aortic aneurysm repair: review and update of current strategies. Ann Thorac Surg 2002;74:1881-4.
4. Coselli JS, Bozinovski J, LeMaire SA. Open surgical repair of 2286 thoracoabdominal aortic aneurysms. Ann Thorac Surg 2007;83: S862-4.
5. Gilling-Smith GL, Worswick L, Knight PF, Wolfe JH, Mansfield AO. Surgical repair of thoracoabdominal aortic aneurysm: 10-years experience. Br J Surg 1995;82:624-9.
6. 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 results and late outcome. J Vasc Surg 2000;31:851-62.
7. Schepens M, Dossche K, Morshuis W, Heijmen R, van Dongen E, Ter Beek H, et al. Introduction of adjuncts and their influence on changing results in 402 consecutive thoracoabdominal aortic aneurysm repairs. Eur J Cardiothorac Surg 2004;25:701-7.

8. Schwartz LB, Belkin M, Donaldson MC, Mannick JA, Whittemore AD. Improvement in results of repair of extent IV thoracoabdominal aortic aneurysms. J Vasc Surg 1996;24:74-81.
9. Rigberg DA, McGory ML, Zingmond DS, Maggard MA, Agustin M, Lawrence PF. Thirty-day mortality statistics underestimate the risk of repair of thoracoabdominal aortic aneurysms: a state-wide experience. J Vasc Surg 2006;43:217-22.
10. Kieffer E, Chiche L, Godet G, Koskas F, Bahnini A, Bertrand M, et al. Extent IV thoracoabdominal aneurysm repair: predictors of postoperative mortality, spinal cord ischemia, and acute intestinal ischemia. Ann Vasc Surg 2008;22:822-8.
11. Richards JM, Nimmo AF, Moores CR, Hansen PA, Murie JA, Chalmers RT. Contemporary results for open repair of suprarenal and extent IV thoracoabdominal aortic aneurysms. Br J Surg 2010;97:45-9.
12. Ockert S, Riemensperger M, von Tengg-Kobligk H, Schumacher H, Eckstein HH, Böckler D. Complex abdominal aortic pathologies: operative and midterm results after pararenal aortic aneurysm and extent IV thoracoabdominal aneurysm repair. Vascular 2009;17:121-8.
13. Derrow AE, Seeger JM, Dame DA, Carter RL, Ozaki CK, Flynn TC, et al. The outcome in the United States after thoracoabdominal aortic aneurysm repair, renal artery bypass, and mesenteric revascularization. J Vasc Surg 2001;34:54-61.
14. Miller CC III, Grimm JC, Estrera AL, Azizzadeh A, Coogan SM, Walkes JC, et al. Postoperative renal function preservation with non-ischemic femoral arterial cannulation for thoracoabdominal aortic repair. J Vasc Surg 2010;51:38-42.
15. Crawford ES, Crawford JL, Safi HJ, Coselli JS, Hess KR, Brooks B, et al. Thoracoabdominal aortic aneurysms: preoperative and intraoperative factors determining immediate and long-term results of operations in 605 patients. J Vasc Surg 1986;3:389-404.
16. Svensson LG, Crawford ES, Hess KR, Coselli JS, Safi HJ. Experience with 1509 patients undergoing thoracoabdominal aortic operations. J Vasc Surg 1993;17:357-70.
17. Bihorac A, Yavas S, Subbiah S, Hobson CE, Schold JD, Gabrielli A, et al. Long-term risks of mortality and acute kidney injury during hospitalization after major surgery. Ann Surg 2009;249:851-8.
18. Hobson CE, Yavas S, Segal MS, Schold JD, Tribble CG, Layon AJ, et al. Acute kidney injury with increased long-term mortality after cardiothoracic surgery. Circulation 2009;119:2444-53.
19. National Kidney Foundation. K/DOQI clinical practice guidelines for chronic kidney disease: evaluation, classification, and stratification. Am J Kidney Dis 2002;39:S1-S266.
20. Go AS, Chertow GM, Fan D, McCulloch CE, Hsu CY. Chronic kidney disease and the risks of death, cardiovascular events, and hospitalization. NEJM 2004;351:1296-305.
21. Poggio ED, Wang X, Greene T, Greene T, Van Lente F, Dennis VW, et al. Performance of the modification of diet in renal disease and Cockcroft-gault equations in the estimation of GFR in health and in chronic kidney disease. J Am Soc Nephrol 2005;16:459-66.
22. Khuri SF, Henderson WG, DePalma RG, Mosca C, Healey NA, Kumbhani DJ. Participants in the VA National Surgical Quality Improvement Program. Determinants of long-term survival after major surgery and the adverse effect of postoperative complications. Ann Surg 2005; 242:326-43.
23. Welten GM, Chonchol M, Schouten O, Hoeks S, Bax JJ, van Domburg RT, et al. Statin use is associated with early recovery of kidney injury after vascular surgery and improved long-term outcome. Nephrol Dial Transplant 2008;23:3867-73.
24. Kertai MD, Boersma E, Westerhout CM, van Domburg R, Klein J, Bax JJ, et al. Association between long-term statin use and mortality after successful aneurysm surgery. Am J Med 2004;116:96-103.
25. Kertai MD, Boersma E, Westerhout CM, Klein J, Van Urk H, Bax JJ, et al. A combination of statins and beta blockers is independently associated with a reduction in the incidence of postoperative and nonfatal myocardial infarction in patients undergoing abdominal aortic aneurysm surgery. Eur J Vasc Endovasc Surg 2004;28:343-52.
26. Patel R, Conrad MF, Paruchuri V, Kwolek CJ, Cambria RP. Balloon expandable stents facilitate right renal artery reconstruction during complex open aortic aneurysm repair. J Vasc Surg 2010;51:310-5.
27. Hersey P, Poullis M. Does the administration of mannitol prevent renal failure in open abdominal aortic aneurysm surgery? Interact Cardiovasc Thorac Surg 2008;7:906-9.
28. Kuratani T, Kato M, Shirakawa Y, Shimamura K, Sawa Y. Long-term results of hybrid endovascular repair for thoraco-abdominal aortic aneurysms. Eur J Cardiothorac Surg 2010;38:299-304.
29. Donas KP, Lachat M, Rancic Z, Oberkofler C, Pfammatter T, Guber I, et al. Early and midterm outcome of a novel technique to simplify the hybrid procedures in the treatment of thoracoabdominal and pararenal aortic aneurysms. J Vasc Surg 2009;50:1280-84.
30. Greenberg RK, West K, Pfaff K, Foster J, Skender D, Haulon S, et al. Beyond the aortic bifurcation: branched endovascular grafts for thoracoabdominal and aortoiliac grafts. J Vasc Surg 2006;43:879-86.
31. Haulon S, Amio S, Magnan PE, Becquemin JP, Lermusiaux P, Koussa M, et al. An analysis of the French multicentre experience of fenestrated aortic endografts. Ann Surg 2010;251:357-62.

Submitted Jun 30, 2010; accepted Aug 27, 2010.