Factors affecting outcomes of open surgical repair of pararenal aortic aneurysms: A 10-year experience

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Purpose: Few large series document surgical outcomes for patients with pararenal abdominal aortic aneurysms (PAAAs), defined as aneurysms including the juxtarenal aorta or renal artery origins that require suprarenal aortic clamping. No standard endovascular alternatives presently exist; however, future endovascular branch graft repairs ultimately must be compared with the gold standard of open repair. To this end, we present a 10-year experience.

Methods: Between 1993 and 2003, 3058 AAAs were repaired. Perioperative variables, morbidity, and mortality were retrospectively assessed. Renal insufficiency was defined as a rise in the concentration of serum creatinine by ≥0.5 mg/dL. Factors predicting complications were identified by multivariate analyses. Morbidity and 30-day mortality were evaluated by multiple logistic regression analysis.

Results: Of a total of 3058 AAA repairs performed, 247 were PAAAs (8%). Mean renal ischemia time was 23 minutes (range, 5 to 60 minutes). Cardiac complications occurred in 32 patients (13%), pulmonary complications in 38 (16%), and renal insufficiency in 54 (22%). Multivariate analysis associated myocardial infarction with advanced age (P = .01) and abnormal preoperative serum creatinine (>1.5 mg/dL) (P = .08). Pulmonary complications were associated with advanced age (P = .03), renal artery bypass (P = .02), increased mesenteric ischemic time (P = .01), suprarenal aneurysm repair (P < .0008), and left renal vein division (P = .01). Renal insufficiency was associated with increased mesenteric ischemic time (P = .001), supravisceral clamping (P = .04), left renal vein division (P = .04), and renal artery bypass (P = .0002), but not renal artery reimplantation or endarterectomy. New dialysis was required in 3.7% (9/242). Abnormal preoperative serum creatinine (≥1.5 mg/dL) was predictive of the need for postoperative dialysis (10% vs 2%; P = .04). Patients with normal preoperative renal function had improved recovery (93% vs 36%; P = .0002). The 30-day mortality was 2.5% (6/247) but was not predicted by any factors, and in-hospital mortality was 2.8% (7/247). Median intensive care and hospital stays were 3 and 9 days, respectively, and longer stays were associated with age at surgery (P = .007 and P = .0002, respectively) and any postoperative complication.

Conclusions: PAAA repair can be performed with low mortality. Renal insufficiency is the most frequent complication, but avoiding renal artery bypass, prolonged mesenteric ischemia time, or left renal vein transection may improve results. (J Vasc Surg 2006;43:921-8.)

Pararenal abdominal aortic aneurysms (PAAAs) are characterized by the absence of normal aorta between the upper extent of the aneurysm and the renal arteries.1 Contemporary series report that 8% to 20% of AAAs are pararenal by classification, both juxtarenal and suprarenal.2,4 In the United States, Food and Drug Administration-approved endovascular grafts are not yet available to treated aortic branches; therefore, repair of PAAAs requires open aortic reconstruction.

The surgical risks of PAAA repair are understandably greater than standard open infrarenal aneurysm repairs because of obligatory renal ischemia, possible mesenteric ischemia, increased alterations in cardiovascular physiology, and the inherent danger of atheroembolization.6,7 Renal insufficiency has been reported as the most frequent complication owing to suprarenal clamping.3 In addition, concomitant renal reconstruction is often required during PAAA repair, potentially increasing the risk of renal failure. Mortality is 5% to 8% after PAAA repair compared with 1% to 3% after elective infrarenal repair at high-volume tertiary referral centers.8-10

The technique of open AAA repair is waning in vascular surgery practices and training programs as more thoracic and abdominal aortic aneurysms are treated with endograft techniques. As endovascular grafts with branch fenestrations or branch grafts become a viable option in managing PAAAs, it is increasingly important to determine whether endovascular options represent an improvement on current open techniques. We present our current decade of experience with pararenal aneurysms to delineate mortality and morbidity and to define factors that affect outcome.

METHODS

Between January 1, 1993, and December 31, 2003, 3058 AAAs were repaired at the Mayo Clinic. This study reviewed pararenal aneurysms that were treated electively...
or urgently for stable symptoms. All acute and chronically ruptured AAAs were excluded. Data were collected retrospectively through electronic and manual chart reviews in all patients after appropriate authorization.

**Aneurysm definitions.** PAAAs are defined as aortic aneurysms that extend to the juxtagenial aorta or to the base of the superior mesenteric artery (SMA) involving the renal artery origins that require aortic clamping between the suprarenal aorta and the supraceliac aorta to safely perform the repair. Aneurysms are further subdivided into juxtarenal and suprarenal categories. Juxtarenal aneurysms are those that extend up to but not including the renal arteries, but require clamping above one or both renal arteries. Suprarenal aneurysms involve a renal artery origin but also extend above the renal origins to the base of the SMA, requiring aortic clamping above the SMA or the celiac artery. The assignment of pararenal aneurysms into the study was based on preoperative radiographic findings and on specific details found at operation. The study excluded type IV thoracoabdominal aneurysms and paravisceral aneurysms.

**Preoperative variables.** Coronary artery disease was detected by cardiac stress testing, previous myocardial infarction on 12-lead electrocardiograph (Q wave or ST-T wave changes) or patients with a history of coronary artery bypass. Congestive heart failure was defined clinically by a cardiologist, after hospital admission for acute exacerbation of congestive heart failure, or by an ejection fraction of <30%. All patients underwent preoperative cardiac evaluation with stress echocardiography, nuclear studies, or coronary catheterization.

Chronic obstructive pulmonary disease (COPD) was defined as patients requiring inhaler or steroid treatment or those with COPD based on pulmonary function studies. No patients in this study required home oxygen therapy preoperatively.

Preoperative renal insufficiency was present if serum creatinine values were 1.6 to 3.6 mg/dL. Preoperative diabetes, hyperlipidemia, and hypertension were defined by patients undergoing active medical or dietary treatment. Cerebrovascular disease was considered present in those with a history of stroke, transient ischemic attack, or carotid endarterectomy.

**Operative conditions and reconstructive techniques.**

A transperitoneal midline incision with an infracolic aortic exposure was used in most cases. All patients were systematically treated with 70 to 100 U/kg of heparin before aortic cross-clamping. Activated clotting time was routinely used to confirm adequate systemic anticoagulation.

Renal protection in most cases included intravenous mannitol (12.5 to 25 g) and furosemide (40 to 60 mg) to induce diuresis before the initial aortic cross-clamp placement. Activated clotting time was routinely used to confirm adequate systemic anticoagulation.

Renal protection in most cases included intravenous mannitol (12.5 to 25 g) and furosemide (40 to 60 mg) to induce diuresis before the initial aortic cross-clamp placement, followed by direct renal artery instillation with cold heparinized normal saline or lactated Ringer’s solution. When necessary, the left renal vein was transected, leaving intact the lumbar renal, adrenal, and gonadal veins. Aortic cross-clamps were placed supraceliac, supra-SMA, suprarenal, or inter-renal (between two main renal arteries).

Methods of reconstructing the proximal anastomosis included suturing the graft to the juxtagenial aorta in an end-to-end fashion or spatulating the graft to incorporate the renal arteries into the suture line. The renal arteries and visceral vessels, when indicated, were routinely isolated individually and clamped before aortic cross-clamp placement.

At the time of reperfusion, the aortic cross-clamp was released first to allow forward flushing of blood into the aortic graft followed by visceral reperfusion and then renal reperfusion. Renal artery endarterectomy, reimplantation, or renal artery bypass was used if the patient had concomitant renal artery stenosis or the renal artery origin was in an aneurysmal segment, or both.

Operative times were recorded in minutes. Renal ischemia times refer to total renal occlusion from the time of the aortic clamp placement until the last renal artery was reperfused. In the case of renal artery bypass, the ischemia time for each kidney was recorded separately. In cases where the clamp was placed inter-renal, the ischemia time refers to a single renal ischemia time. The volume of blood transfused during the operation was recorded in units and included both cell saver and banked blood.

Intra-operative completion studies included ultrasound for all patients undergoing endarterectomy, and either ultrasonic or ultrasonic flow measurements (mL/min), or both, for patients with renal artery bypass. Intraoperative imaging was not routine in patients with renal artery reimplantation.

**Morbidity and mortality.** The primary study end point was 30-day mortality, and the secondary end points were major cardiac, pulmonary, and renal complications. Myocardial infarction (MI) was established by using biochemical criteria and electrocardiographic evidence of myocardial injury on a 12-lead electrocardiogram (Q wave or ST-T wave changes). Patients were considered to have an MI based on enzyme criteria alone. Pulmonary failure was defined as ventilator dependence of >72 hours, need for postoperative reintubation, clinical data or culture confirmation of pneumonia, or the need for tracheostomy.

The normal serum creatinine value was chosen as ≤1.5 mg/dL. Renal insufficiency was defined as a rise in serum creatinine concentration by >.5 mg/dL when peak postoperative creatinine levels were compared with baseline preoperative creatinine. Patients with postoperative renal insufficiency were further categorized as persistent renal insufficiency vs recovered renal insufficiency. Persistent renal insufficiency was defined as failure of creatinine to return to ≤30% of normal baseline serum creatinine values at the time of hospital discharge. Renal function was considered recovered if the discharge serum creatinine value was ≤1.5 mg/dL or was ≤30% of the baseline value. The need for temporary or permanent dialysis was recorded.

**Data analysis.** Continuous variables are summarized with the mean ± standard deviation or median (range). Categoric variables are summarized with frequencies and percentages.
were 203 men (82%) and 44 women (18%), with a mean aneurysms and 43 were suprarenal aneurysms. There
8.1% (247/3058) of all AAAs, of which 204 were juxtarenal

RESULTS

using SAS (version 9) software (SAS Institute, Inc, Cary, NC).
Statistical analysis was performed for all analyses. Statistical analysis was performed on the ranks of
values because of strongly skewed distributions for the length-of-stay variables. Analysis of binary outcomes such as
30-day death, temporary postoperative dialysis, pulmonary
complications, cardiac complications, and postoperative
renal insufficiency was performed by using univariate
and multiple linear regression analysis. These analyses excluded
two patients who died intraoperatively; renal insufficiency was performed by using univariate
preoperatively.

Stepwise and backward model selection procedures
were used for both the linear and logistic multiple regression models. Univariately significant variables or variables
identified by these model selection procedures were
considered candidate variables for the final multiple regression
model. Variables meeting the criteria for statistical signifi-
cance ($P < .05$) were considered statistically significant for all analyses. Statistical analysis was performed
using SAS (version 9) software (SAS Institute, Inc, Cary, NC).

Analysis of variables associated with hospital length of
stay and intensive care unit (ICU) length of stay excluded
seven patients who died in-hospital. These analyses used
Spearman’s rank correlation with $P$ values in the case of
continuous variables and Wilcoxon rank-sum tests in the
case of binary variables. Multiple linear regression modeling of
these two outcomes was performed on the ranks of the
values because of strongly skewed distributions for the
length-of-stay variables. Analysis of binary outcomes such as
30-day death, temporary postoperative dialysis, pulmonary
complications, cardiac complications, and postoperative
renal insufficiency was performed by using univariate
and multiple linear regression analysis. These analyses excluded
two patients who died intraoperatively; renal insufficiency analyses also excluded three patients on dialysis
preoperatively.

Stepwise and backward model selection procedures
were used for both the linear and logistic multiple regression
models. Univariately significant variables or variables
identified by these model selection procedures were
considered candidate variables for the final multiple regression
model. Variables meeting the criteria for statistical signifi-
cance ($P < .1$) were retained in the final multiple variable
models. Values of $P < .05$ were considered statistically significant for all analyses. Statistical analysis was performed
using SAS (version 9) software (SAS Institute, Inc, Cary, NC).

Demographics. Pararenal aortic aneurysms comprised
8.1% (247/3058) of all AAAs, of which 204 were juxta-
renal aneurysms and 43 were suprarenal aneurysms. There
were 203 men (82%) and 44 women (18%), with a mean
age of 73.0 years (range, 44 to 96 years).

Preoperative variables. Coronary artery disease was
present in 157 patients (64%), with 33% of all patients
undergoing previous coronary artery bypass, and 37 % with
previous myocardial infarction (Table I). Ejection fraction
was documented in 180 patients and ranged from 15% to
82% (mean, 55% ± 14%); 10 patients (6%) had an ejection
fraction of <30%. Eighty-six (35%) patients had an estab-
lished diagnosis of COPD, and 45 (18%) patients had
preoperative renal insufficiency. Of the 243 patients with
recorded tobacco use history, 163 (67%) were past smok-
ers, 39 (16%) actively smoked, and 41 (17%) never smoked.
All other comorbidities represented active medical issues
for the patients preoperatively. Risk factors for atheroscle-
rotic vascular disease and other comorbidities are outlined in
Table I.

Aneurysm etiology was described in all but one patient
and included degenerative in 218 (89.0%), inflammatory
in 8 (7.4%), pseudoaneurysm in 4 (1.6%), chronic dissection
in 3 (1.2%), and infected in 2 (0.82%). Nineteen (8%) patients had previous aortic surgery, and 104 (42%) had a
history of aneurysms in either the iliac or infrainguinal
arteries. No patients in this group had had an endograft
repair.

Operative management. Thirty-three patients (13%)
had symptomatic aneurysms; seven were treated urgently
within 24 hours of presentation. Mean aneurysms size was 6.4
cm (median, 6 cm; range, 3.0 to 11.4 cm). Surgical ap-
proach was midline, transabdominal in 200 patients (81%),
medial visceral rotation via a midline incision in 30 (13%),
via a retroperitoneal incision in 14 (6%), and via a thoraco-
abdominal incision in two (0.8%).

Twenty patients (8%) required left renal vein division.
Five left renal veins were divided and reanastomosed. They
were not considered in the group of patients with left renal
vein division. Distal reconstructions were tube grafts in 111
(45%) and bifurcated in 135 (54%). Clamp placement and
renal and mesenteric ischemia times are summarized in
Table II.

Concomitant renal artery reconstruction was required
in 53 patients (21%) (Table II) There were 62 renal artery
procedures in 53 patients. Seven patients had two renal
arteries revascularized, and one had three arteries revascu-
arized. Renal artery reimplantation was performed in 10%
(25/247), renal artery endarterectomy in 9% (23/247),
and renal artery bypass in 5% (13/247). Mean and median
renal ischemia times (minutes) for renal endarterectomy
were 29 and 30; for reimplantation, 29 and 27; and for
renal artery bypass, 39 and 37. The mean operative time

<table>
<thead>
<tr>
<th>Table I. Preoperative comorbidities</th>
<th>Patients, n (%)</th>
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<tr>
<td>Congestive heart failure</td>
<td>26 (11)</td>
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<tr>
<td>Coronary artery disease</td>
<td>157 (64)</td>
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<tr>
<td>Previous myocardial infarction</td>
<td>91 (37)</td>
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<tr>
<td>Hypertension</td>
<td>201 (82)</td>
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<tr>
<td>Hyperlipidemia</td>
<td>162 (66)</td>
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<tr>
<td>Cerebrovascular disease</td>
<td>41 (17)</td>
</tr>
<tr>
<td>COPD</td>
<td>87 (35)</td>
</tr>
<tr>
<td>Preoperative dialysis</td>
<td>3 (1)</td>
</tr>
<tr>
<td>Serum creatinine &gt;1.5 mg/dl</td>
<td>45 (18)</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>27 (11)</td>
</tr>
<tr>
<td>History of tobacco use</td>
<td>203 (83)</td>
</tr>
</tbody>
</table>

COPD, Chronic obstructive pulmonary disease.

<table>
<thead>
<tr>
<th>Table II. Operative variables</th>
<th>Patients, n (%)</th>
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<tbody>
<tr>
<td>Clamp location</td>
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<tr>
<td>Supraceliac</td>
<td>34 (14)</td>
</tr>
<tr>
<td>Supra-SMA</td>
<td>49 (20)</td>
</tr>
<tr>
<td>Suprarenal</td>
<td>164 (67)</td>
</tr>
<tr>
<td>Bilateral</td>
<td>105</td>
</tr>
<tr>
<td>Interrenal</td>
<td>59</td>
</tr>
<tr>
<td>Renal artery procedures*</td>
<td>53/245 (21)</td>
</tr>
<tr>
<td>Reimplantation</td>
<td>25</td>
</tr>
<tr>
<td>Endarterectomy</td>
<td>24</td>
</tr>
<tr>
<td>Bypass</td>
<td>13</td>
</tr>
<tr>
<td>Renal ischemia time (minutes)</td>
<td>23.2 ± 9.7 (5–60)†</td>
</tr>
<tr>
<td>Mesenteric ischemia time (minutes)‡</td>
<td>25.5 ± 7.8 (8–46)‡</td>
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SMA, Superior mesenteric artery.
*62 procedures in 53 patients.
†Mean ± SD (range).
‡83 patients with supraceliac or supra-SMA clamp location.

<table>
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<tr>
<th>Operative variables</th>
<th>Patients, n (%)</th>
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was 327 minutes (75 to 648 minutes), and 5.6 units was the mean blood volume transfused intraoperatively. Eight patients (3.2%) had inferior mesenteric artery reimplantations.

**Morbidity and mortality.** Morbidity included MI in 32 (13%), pulmonary complications in 38 (16%), and renal insufficiency in 54 (22%) (**Table III**). Dialysis was required in 3.7% (9/242) of postoperative patients, excluding three patients with chronic renal insufficiency who were receiving dialysis preoperatively. Thirty-four patients had a unilateral renal artery procedure. Bilateral renal procedures (revascularization, endarterectomy, or reimplantation, or a combination) were done in 19 patients, and 18 survived. Of the survivors, six (33%) had postoperative renal insufficiency compared with 14 (41%) of 34 patients who had the unilateral procedure \((P = .77)\). Two percent (5/202) of the patients in the normal preoperative serum creatinine group required temporary dialysis vs 10% (4/41) of those with abnormal preoperative values \((P = .04)\). No patients required new postoperative permanent dialysis. Significantly more patients \((P = .0002)\) recovered renal function if they had a normal preoperative serum creatinine level (93%, 40/43) vs those that did not (4/11).

Three patients had significant visceral ischemia that resulted in death. Two patients had clinically suspected bowel ischemia that was diagnosed as mild, superficial disease on flexible sigmoidoscopy. These patients were managed with hydration and intravenous antibiotics, and had no short-term sequelae before dismissal from the hospital.

Thirty-day mortality was 2.5% (6/247), and in-hospital mortality was 2.8% (7/247). Two patients died from intraoperative cardiac arrest. Three patients died, one each on postoperative day 2, 8, and 24, of complications of visceral ischemia. The first patient died on postoperative day 2 after re-exploration identified extensive visceral infarction. The other two patients underwent colon resections and ultimately died of complications of multisystem organ failure. Another patient died on day 7 of multisystem organ failure that resulted in respiratory arrest. The final patient died on day 73 after multiple chronic infections and failure to thrive. Median ICU and hospital stay were 3 days and 9 days. The mean ICU and hospital lengths of stay were 5.2 (range, 2 to 72) and 11.3 days (range, 2 to 372).

**Clinical predictors.** MI was associated multivariately with increased age \((P = .01)\) and a preoperative serum creatinine level of >1.5 mg/dL \((P = .08)\) (**Table IV**). Pulmonary complications were associated with advanced age \((P = .03)\), renal artery bypass \((P = .02)\), increased mesenteric ischemic time \((P = .01)\), suprarenal aneurysm repair \((P < .0008)\), and left renal vein division \((P = .01)\) (**Table IV**; Appendix, online only). Postoperative renal insufficiency was associated with increased mesenteric ischemic time \((P = .001)\), supravisceral clamping \((P = .04)\), and renal artery bypass \((P = .0002)\), but not renal artery reimplantation or endarterectomy, and left renal vein division \((P = .04)\) (**Table IV**; Appendix, online only).

Because only 9 patients required temporary postoperative dialysis, statistical assessment of associated variables was limited primarily to univariate analysis. Several variables had a significant or nearly significant univariate association with need for temporary postoperative dialysis: age at surgery \((OR, 1.18 per 1 unit; 95\% CI, 1.07 to 1.31; P = .0007)\), supravisceral clamp location \((OR, 7.4; 95\% CI, 1.5 to 36.4; P = .01)\), and amount of blood transfused intraoperatively \((OR, 1.18 per 1 unit; 95\% CI, 1.07 to 1.31; P = .0007)\). The small number of postoperative dialysis events \((9)\) made it impossible to perform a complete multivariable analysis due to low power for assessing more than a single predictor variable. However, an exploratory analysis including the univariately significant variables in a single model showed that the variables of renal artery bypass \((P = .0004)\), supravisceral clamp location \((P = .02)\), and age at surgery...
(P = .01) all remained significant predictors of temporary dialysis when included together in the model.

A subgroup analysis of the patients with previous AAA repair (19 patients, 8%) showed that they had no increase in morbidity or mortality compared with primary PAAA repair; therefore, they were included with the entire group. Of the eight patients who had inferior mesenteric artery reimplantations, only one had major complications unrelated to mesenteric ischemia. This group was too small to identify associations with morbidity or mortality.

No associations were found with multivariate analysis between preoperative characteristics or surgical data that predicted 30-day mortality, although the small number of six events limited the analysis of variables. However, the amount of blood transfused intraoperatively was significantly higher among patients who later died ≤30 days than for those who survived >30 days (14 ± 4.5 units vs 5.4 ± 4.3 units, respectively, P = .003). Although not reaching statistical significance, the following variables also showed a trend toward association with 30-day death: preoperative serum creatinine level of >1.5 mg/dL (OR, 4.7; 95% CI, 0.9 to 24.3; P = .06), renal artery endarterectomy (OR, 5.0; 95% CI, 0.9 to 28.7; P = .07), and supravisceral clamp location (OR, 4.1; 95% CI, 0.7 to 22.9; P = .11).

Multivariate associations were identified with in-hospital mortality. The amount of blood transfused was significantly higher among patients who died in-hospital compared with those who survived to discharge (mean 13.4 ± 4.2 units vs 5.4 ± 4.3 units, P = .0007). Also, the following variables were significantly associated with increased odds of in-hospital death: preoperative serum creatinine >1.5 mg/dL (OR, 6.5; 95% CI, 1.4, 3.0; P = .02), supravisceral clamp location (OR, 5.2; 95% CI, 1.0 to 27.4; P = .05), and mesenteric ischemia time (OR per 5 minutes, 1.3; 95% CI, 1.0 to 1.7; P = .04).

Multiple regression modeling suggested that the following variables were independently associated with ICU length of stay: age at surgery (P = .007), renal artery bypass (P = .01), postoperative pulmonary complication (P < .0001), postoperative cardiac complication (P = .01), and postoperative renal insufficiency (P = .06). The multiple regression model demonstrated hospital length of stay was associated with aneurysm type (P = .02), age at surgery (P = .0002), renal ischemia time (P = .04), supravisceral clamp location (P = .02), postoperative pulmonary complication (P < .0001), postoperative cardiac complication (P = .05), and postoperative renal insufficiency (P = .02).

**DISCUSSION**

Pararenal aneurysms comprise a small but not insignificant portion (8% to 20%) of all AAAs. As more infrarenal aneurysms are repaired by endovascular techniques, PAAs represent an increasing percentage of patients undergoing open aortic aneurysm repair at tertiary referral centers. Although several series document surgical outcomes, many reports are difficult to interpret when juxtarenal, pararenal, suprarenal, or even type IV thoracoabdominal aneurysms are lumped in a single study.²⁻²²,¹⁰⁻¹² Our goal was to study a well-defined group of patients who required suprarenal or supravisceral aortic clamp placement to repair an AAA and to assess outcomes and factors affecting outcomes.

In 1986, Crawford et al¹³ reported the first series of juxtarenal aneurysms, with a mortality rate of 7.9% and dialysis dependency in 8%. The University of California San Francisco (UCSF) experience reported by Jean-Claude et al⁶ in 1999 has provided the largest series of 257 patients. The authors concluded that although they are more complex than infrarenal AAA, PAAA repairs are performed with similar mortality rates but increased renal morbidity. A low incidence of fatal cardiac events was attributed to the limited use of supraceliac aortic cross-clamping (13%).

In 2002, Sarac et al⁴ published The Cleveland Clinic series of 138 juxtarenal aneurysm repairs, with 27% undergoing concomitant renal artery reconstruction. The mortality rate was 5.1%, with two deaths attributed to mesenteric ischemia. Postoperative renal insufficiency occurred in 28%. Supravisceral aortic cross-clamping was the only factor associated with early mortality and was also associated with postoperative renal insufficiency.

Shortell et al⁵ recently reported 6% early mortality in a series of 112 patients, with juxtarenal aneurysm cardiac complications in 23% and pulmonary in 20%.⁵ Supraceliac clamping predominated in this series at 83% (92/112), and MI caused five of seven deaths. In this study and in the earlier report of Green et al,¹⁴ supraceliac clamping was considered safe and was the preferred clamp location for repairing juxtarenal aneurysms.

Our data confirmed the association of supravisceral clamping with postoperative renal insufficiency and with a trend for increased mortality. Obviously, patient anatomy may force the placement of a supraceliac clamp. However, based on our results and the data from UCSF and The Cleveland Clinic, we would not recommend the practice of routine or preferred supraceliac clamping.

Cardiac morbidity in our series was associated only with advanced age at surgery and an abnormal preoperative serum creatinine level. These factors are often unavoidable. When elderly patients with elevated serum creatinine levels are considered for operation, this increased morbidity should be discussed during preoperative counseling. As noted by Messina,¹ cardiac complications were not as common as anticipated in this patient group. We have not routinely used transeosophageal echocardiography, although evidence suggests that this may be a useful intraoperative adjunct in high-risk patients.³,⁷

Pulmonary complications in the PAAA patients was associated with increased age, suprarenal aneurysm, renal artery bypass, left renal vein division, and mesenteric ischemic time. These associations are very similar to the risk factors for predicting renal insufficiency. In the presence of renal failure, fluid management is often difficult in the perioperative period, necessitating prolonged intubation.

Renal insufficiency is the most common postoperative complication and is alarming because of the potential negative affect it may have on long-term survival.⁷ Postoperative renal complications are clearly more frequent after...
The Mayo Clinic and 1% to 3% at other institutions. The mortality rates of pararenal aortic aneurysm repair are crucial in PAAA repair, including concomitant suprarenal aortic cross-clamp placement as well as meticulous exposure techniques are necessary to avoid fatal visceral complications and prolonged mesenteric ischemia time. In light of these associations, we recommend avoiding suprarenal aortic cross-clamping and left renal vein ligation when possible. In cases of suprarenal aneurysms and circumstances where one renal artery origin is in a more caudal location, reimplantation is often possible. In our practice, we favor reimplantation and endarterectomy over bypass in an effort to decrease renal ischemia time. Within the limits of this retrospective study, patients with renal artery bypass did worse, potentially reflecting more complex disease.

Current juxtarenal and pararenal series report 5% to 8% mortality. The early mortality rate in our series was 2%. The mortality rates of pararenal aortic aneurysm repair are consistently higher than infrarenal repair, which is 1.1% at the Mayo Clinic and 1% to 3% at other institutions. Achieving equivocal results with PAAA repairs outside of larger vascular centers might be difficult for the inexperienced who seldom treat these AAAs. Perpetuating excellent surgical results in the future may also be affected by the fact that up to 60% of AAA repairs can be performed with an endovascular aneurysm repair, implying that vascular trainees get less exposure to open operations.

Of the six deaths ≤30 days in this report, two patients had suprarenal aortic cross-clamping, two were supramesenteric, and two were supraceliac. The cause of death in our report was visceral ischemia in three of six. Although the numbers were too small to create statistical significance, mesenteric ischemia remains a critical concern when treating patients with PAAAs, as noted in several other series. Since not all patients with mesenteric ischemia had prolonged mesenteric ischemia times, the role of embolization cannot be underestimated as a contributor to both mesenteric and renal ischemia during PAAA repair.

Accurate preoperative radiographic assessment of the pararenal aorta to guide appropriate aortic cross-clamp placement as well as meticulous exposure techniques are crucial elements to avoid fatal visceral complications and minimize complications from atheroembolization. Of the three patients reoperated on for visceral ischemia, the patient with massive bowel ischemia had an acutely occluded SMA. The other two patients with colon ischemia had a previously occluded inferior mesenteric artery not amenable to reimplantation.

Careful attention to superior mesenteric artery circulation is crucial in PAAA repair, including concomitant superior mesenteric artery revascularization in symptomatic patients. The surgeon must also be cognizant of hypogastric artery patency and have a low threshold to reimplant the inferior mesenteric artery to protect the reserve of the mesenteric circulation. Although only eight of our patients underwent inferior mesenteric artery reimplantations, an additional 19 patients (8%) had already had had aortic operation and previous management of the inferior mesenteric artery.

In our series, length-of-hospital stay after PAAA repair was not significantly different from what is reported after infrarenal aortic aneurysm repairs. Older age (>75 years), COPD, and poor functional status are known to increase length of stay after aortic surgery. Mean length of stay was prolonged in patients with increased age, suprarenal aortic cross-clamping, renal artery bypass, left renal vein division, and prolonged renal ischemic time. Again, these predictors parallel those for postoperative renal failure, as length of stay is often prolonged in patients with renal insufficiency.

Endovascular aneurysm repair has been realized in most aortic segments. PAAAs have limited suitable fixation and altered reliable scaling of a fenestrated endograft into visceral vessels. The threat of renal complications and fatal atheroembolization are still problems for endoluminal therapy, including one of two deaths that occurred in a recent endovascular series in which fenestrated endografts were used treat juxtarenal aortic aneurysms. The development of hybrid endovascular and open adjunctive visceral reconstructive procedures has been recently popularized to minimize the extent of open surgery in aneurysms involving thoracoabdominal and pararenal segments. Ultimately, hybrid techniques, and new devices should be directly compared with the results of open PAAA repair to determine superiority before universal use.

CONCLUSION

Pararenal abdominal aortic aneurysms can be repaired with mortality rates that are nearly equal to open infrarenal aneurysm repairs; however, overall morbidity is greater. We have demonstrated that advanced age, increased mesenteric ischemic time, the need to perform renal artery bypass, and left renal vein ligation were significant predictors of cardio-pulmonary and renal complications as well as prolonged hospital stay. By avoiding these factors when undertaking open repairs, outcomes from surgical treatment of pararenal aortic aneurysms may be improved.

AUTHOR CONTRIBUTIONS

Analysis and interpretation: AAN, CAW, PG, TMS, MK, TLH, JRH
Data collection: CAW, AAN
Writing the article: AAN, CAW, TCB
Critical revision of the article: AAN, CAW, TCB, KJC, PG, TMS, MK, TLH, JRH
Final approval of the article: AAN, CAW, TCB, KJC, PG, TMS, MK, TLH, JRH
Statistical analysis: CAW, AAN, TLH, JRH
Obtained funding: AAN
Overall responsibility: AAN

REFERENCES

DISCUSSION
Dr. Dalsing. Very nice presentation. I just have one question. It looks like most of your mortality is associated with mesenteric ischemia, more specifically colonic ischemia. Did you do anything with the IMA? Was it usually occluded? Did you reimplant it?
Dr. West. Well it was hard to really know how to break ischemia down into hindgut and foregut. We did reimplant eight IMAs and those patients did very well, and we feel it is important to do that. I hope that answers your question. As far as looking at CT scans, not every patient had a CT scan and it was difficult to tell from the records whether the IMA was patent in all of these cases or not. It was something that was an intraoperative observation.
Dr. Greenberg. I enjoyed the presentation as well and have a couple of questions. Your last conclusion about avoiding supraceliac clamping is an interesting conclusion except that generally supraceliac clamps are applied only when it is required to repair an aneurysm. Thus, although there may be a desire to avoid such a clamp position, if anatomy precludes more distal clamp placement, it would be difficult to criticize such a practice. My question really relates to the renal issues which I think are the Achilles heel of aortic operations. The followup that you presented, I assume, relates to the in-hospital renal function. Much of this is not an accurate representation of renal dysfunction. When these patients are reevaluated at one month or a year or two years later, there is considerably more renal dysfunction than we had originally appreciated. I wanted to know if you had any additional followup on these patients with respect to their renal dysfunction. Were there any CT scans that were done to evaluate renal anatomy? Were you able to assess renal infarcts or other etiologies of the renal issues?
Dr. Shepard. My question has to do with your conclusion that division of the left renal vein is a factor predictive of a poor outcome. I’m wondering if in fact division of the left renal vein is a marker for complexity of the operative procedure or whether you feel that division of the left renal vein really leads to some deleterious effects. Obviously if the latter is the case, then utilization of a left flank retroperitoneal approach would avoid division of the left renal vein and lead to improved outcomes.
Dr. West. Thank you for your question. That’s a great point. It’s hard to know exactly. I believe it is a marker for a more proximal aneurysm and often was divided for a more difficult case. It was interesting that there was some surgeon selectivity in that, so we don’t know the exact answer to that, but we do know that there were 20 patients with left renal vein division and 6 of those 20 had some renal insufficiency postoperatively and 3 of those had renal artery procedures done which may have some influence on that but 3 did not, so that remains statistically significant. I’m not able to fully answer that but I think a marker is certainly a plausible answer to that.
**APPENDIX (online only).** Univariate association of preoperative and operative factors with postoperative morbidities

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pulmonary complications*</th>
<th>Cardiac complications*</th>
<th>Renal insufficiency†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR (95% CI)</td>
<td>OR (95% CI)</td>
<td>OR (95% CI)</td>
</tr>
<tr>
<td>Age, per 5 years</td>
<td>1.4 (1.1, 1.8)</td>
<td>1.5 (1.1, 1.9)</td>
<td>0.9 (0.8, 1.1)</td>
</tr>
<tr>
<td>Male gender</td>
<td>0.8 (0.3, 1.9)</td>
<td>2.2 (0.6, 7.6)</td>
<td>1.6 (0.7, 3.8)</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>1.4 (0.5, 4.0)</td>
<td>1.9 (0.6, 5.4)</td>
<td>1.7 (0.7, 4.3)</td>
</tr>
<tr>
<td>Coronary artery disease</td>
<td>0.8 (0.4, 1.5)</td>
<td>1.8 (0.8, 4.1)</td>
<td>1.4 (0.7, 2.6)</td>
</tr>
<tr>
<td>Cerebrovascular disease</td>
<td>0.7 (0.3, 2.0)</td>
<td>1.9 (0.8, 4.6)</td>
<td>0.8 (0.4, 2.0)</td>
</tr>
<tr>
<td>History of cancer</td>
<td>0.9 (0.4, 2.1)</td>
<td>1.1 (0.5, 2.5)</td>
<td>0.8 (0.4, 1.6)</td>
</tr>
<tr>
<td>Preop SCr, per 0.5 mg/dL</td>
<td>1.1 (0.8, 1.5)</td>
<td>1.2 (0.9, 1.6)</td>
<td>1.5 (1.0, 2.0)</td>
</tr>
<tr>
<td>Abnormal pre-op SCr (&gt;1.5 mg/dl)</td>
<td>1.9 (0.8, 4.2)</td>
<td>2.6 (1.1, 6.0)</td>
<td>1.4 (0.6, 3.0)</td>
</tr>
<tr>
<td>Suprarenal aneurysm (vs juxtarenal)</td>
<td>4.8 (2.3, 10.4)</td>
<td>&lt;.0001</td>
<td>1.1 (0.4, 3.0)</td>
</tr>
<tr>
<td>Supravisceral clamp</td>
<td>5.4 (1.7, 17.0)</td>
<td>1.1 (0.5, 2.4)</td>
<td>2.7 (1.4, 5.0)</td>
</tr>
<tr>
<td>Renal artery bypass</td>
<td>5.4 (1.7, 17.0)</td>
<td>1.3 (0.3, 6.0)</td>
<td>14.0 (3.7, 53.1)</td>
</tr>
<tr>
<td>Renal artery endarterectomy</td>
<td>1.6 (0.6, 4.6)</td>
<td>0.6 (0.1, 6.8)</td>
<td>2.0 (0.8, 5.0)</td>
</tr>
<tr>
<td>Renal artery reimplantation</td>
<td>1.04 (0.3, 3.2)</td>
<td>1.9 (0.6, 5.4)</td>
<td>1.4 (0.6, 3.6)</td>
</tr>
<tr>
<td>Any renal artery procedure</td>
<td>3.0 (1.4, 6.3)</td>
<td>1.3 (0.6, 3.2)</td>
<td>2.9 (1.5, 5.6)</td>
</tr>
<tr>
<td>Left renal vein division</td>
<td>3.4 (1.2, 9.1)</td>
<td>1.8 (0.6, 5.9)</td>
<td>2.6 (1.0, 6.6)</td>
</tr>
<tr>
<td>Renal ischemia time, per 5 min</td>
<td>1.2 (1.04, 1.5)</td>
<td>1.1 (0.9, 1.3)</td>
<td>1.4 (1.2, 1.6)</td>
</tr>
<tr>
<td>Mesenteric ischemia time, per 5 min†</td>
<td>1.1 (0.8, 1.6)</td>
<td>1.2 (0.8, 1.8)</td>
<td>1.7 (1.2, 2.4)</td>
</tr>
</tbody>
</table>

SCr, Serum creatinine.

Results reported are odds ratios (OR) and 95% confidence intervals (CI), and *P* values from logistic regression.

*Excluding 2 patients who died intraoperatively.

†Excluding 3 patients on dialysis preoperatively.

‡Including only patients with supra celiac or suprasuperior mesenteric artery clamp location.