Suprarenal aortic cross-clamp position: A reappraisal of its effects on outcomes for open abdominal aortic aneurysm repair

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Objectives: **With the increasing use of endovascular aneurysm repair, a greater proportion of open aneurysm repairs in the future are expected to be more complex and require suprarenal cross-clamping. We sought to evaluate the effects of suprarenal (SR) vs infrarenal (IR) aortic cross-clamp position in abdominal aortic aneurysm (AAA) repair in an updated single center series.**

Methods: **All elective open AAA repairs performed at our institution between 1990 and 2006 were entered into a prospective database and reviewed retrospectively. Our main stratification variable was SR vs IR. The SR group was further subdivided into those requiring an adjunctive renal revascularization procedure (SR+RRP; n = 54) and those who did not (SR−RRP; n = 117). Univariate and multivariate models were used to analyze the effect of baseline variables and operative variables on our primary endpoint 30-day mortality as well as secondary endpoints such as major adverse events, postoperative decline in renal function (defined as doubling of baseline creatinine to level >2 mg/dL, or new-onset dialysis) and long-term survival. A propensity score model was developed to control for confounding variables associated with the use of an SR cross-clamp.**

Results: **A total of 1020 patients underwent elective AAA repair, of which 849 (83.2%) were IR and 171 (16.8%) were SR. Diabetes (14.6% vs 9.1%, $P = .027$), hypertension (70.2% vs 61.4%, $P = .03$), and chronic renal failure (14.0% vs 4.7%, $P = .001$) were more prevalent in the SR group, and mean aneurysm size was larger (6.0 cm vs 5.6 cm, $P = .001$). Estimated blood loss was higher (1919 mL vs 1257 mL, $P = .001$) in the SR group, as was mean length of stay (12.6 days vs 10.7 days, $P = .047$). Perioperative (30-day) mortality rate was 1.8% for the SR group and 1.2% for the IR group ($P = .44$). Postoperative decline in renal function was 17.0% in SR vs 9.5% in IR ($P = .003$), however, new-onset dialysis was rare (0.6% SR, 0.8% IR, $P =$ NS). The combination of SR+RRP was associated with an increased risk for postoperative decline in renal function (14.8% SR+RRP, 4.3% SR−RRP, $P = .016$). Preoperative renal failure was strongly associated with postoperative renal decline (odds ratio [OR] 8.15, 2.92-22.8, $P < .0001$). Propensity score analysis demonstrated that the use of an SR cross-clamp was associated with an increased risk for postoperative renal decline (OR 2.66, 1.28-5.50, $P = .009$). Major adverse events were more prevalent in the SR group compared to the IR group (17.0% vs 9.5%, $P = .003$). Five-year survival was 69.1% + 1.9% for the IR group and 67.7% + 4.3% for the SR group ($P = 0.38$) by life table analysis.**

Conclusion: **Suprarenal cross-clamping is associated with low mortality and significant but acceptable morbidity, including postoperative decline in renal function. The results from this series may serve as relevant background data when evaluating emerging branched and fenestrated endograft technologies. (J Vasc Surg 2009;49:873-80.)**

The majority of abdominal aortic aneurysms (AAAs) are infrarenal (IR) which allows control of the aorta via an IR aortic cross-clamp. The use of a suprarenal (SR) cross-clamp has been associated with increased morbidity and mortality. Crawford et al[1] in 1986 described the first report on the results of SR cross-clamping in open aneurysm repair in 101 patients. They noted a 7.9% mortality rate and an 8% postoperative incidence of dialysis. Similar reports have appeared in the literature. Sarac et al[2] described the experience of The Cleveland Clinic in 138 juxta renal aneurysm repairs and noted a 5.1% mortality rate, a 28% postoperative renal insufficiency rate, and a 5.8% dialysis-dependence rate. More recently, West et al[3] reviewed the experience at the Mayo Clinic on 247 pararenal AAAs and found a 2.5% mortality rate and 3.7% dialysis rate.

In the current era, most centers are repairing IR AAAs utilizing endovascular options. As a result, an increasing proportion of open AAAs in the US require an SR aortic cross-clamp. Costin et al[4] concluded that the complexity of open AAA repair has increased in the era of endovascular stent grafting which included a greater proportion of patients requiring an SR cross-clamp and division of the left renal vein. Thus, we undertook this study to provide data on a series of patients requiring an SR cross-clamp and compare them to an updated cohort of patients who had an IR aneurysm repair. With the advent of newer stent graft technologies, there is great interest in exploring the use of fenestrated or branched endografts for the repair of juxtarenal and SR AAAs. This study also serves as an updated evaluation of open surgery for the comparative evalua-

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tion of emerging branched and fenestrated endograft technologies.

METHODS

We reviewed all elective open infrarenal and juxtarenal/SR AAA repairs performed at the Brigham and Women's Hospital between 1990 and 2006. The results of these procedures were reviewed retrospectively from a prospectively maintained database in the Division of Vascular Surgery. Operative notes were reviewed for cross-clamp location (IR or SR) and data were gathered from review of the medical records. Suprarenal cross-clamp location is defined as clamping above both main renal arteries. This clamp location was determined by the surgeon's preference, the presence of calcification, intraluminal thrombus, and anatomic suitability based on the aneurysm proximity to the renal arteries. Type 4 thoracoabdominal aneurysms were excluded from this study. The SR group was then subdivided into those that required a simultaneous adjunctive renal revascularization procedure (SR+RRP; aortorenal bypass, reimplantation of the renal artery, or renal endarterectomy) and those that did not (SR−RRP).

The open aneurysm repair was carried out via a transperitoneal or retroperitoneal approach at the surgeon's discretion. Auto-transfusion devices were routinely used. Anesthesia protocols were standardized and included a combination of epidural and general anesthesia in all cases (unless the epidural was contraindicated). Routine β-blockade has become standard (assuming no contraindication) over the past decade. This medication is started at our preoperative clinic to achieve a target heart rate of 60 beats per minute. Patients in the SR group routinely received intraoperative mannitol (1g/kg) 15 minutes prior to cross-clamping and 100 mg of furosemide 10 minutes prior to cross-clamping. We believe that mannitol acts as a free radical scavenger[5,6] while furosemide decreases renal tubular oxygen demand.[7] Patients in the IR group received only mannitol 15 minutes prior to cross-clamping at 0.5 g/kg dose. If the preoperative creatinine value was greater than 2 mg/dL then an equivalent dose was given 15 minutes after unclamping. Invasive monitoring includes an arterial line and central venous access for all cases.

Baseline variables that were captured included size of aneurysm, gender, age, and preoperative risk factors including diabetes, smoking (current), hypertension (diastolic blood pressure >90 mm Hg, or on one or more antihypertensive medications), coronary artery disease (history of myocardial infarction, coronary revascularization, or abnormal stress test), prior coronary artery bypass surgery, cerebrovascular disease (history of stroke, transient ischemic attack, or carotid surgery), chronic pulmonary disease (patient on supplemental oxygen or pulmonary function tests less than 80% of predicted), chronic renal failure, and congestive heart failure (data from cardiology report). Preoperative renal failure was defined as serum creatinine >2.0 mg/dL or dialysis dependence. Procedural variables recovered from the database included estimated blood loss (EBL), length of stay (LOS), and serum creatinine. Creatinine levels were recorded from two time intervals; preoperatively and within 24 hours of discharge. All of these preoperative variables were included in our multivariable analysis model.

A more detailed analysis of renal function by calculating Glomerular Filtration Rate (GFR) was performed using the simplified Modification of Diet in Renal Disease (MDRD) equation. This is calculated using the formula $GFR = 186 * Creatinine^{-1.154} * Age^{-0.203} * 1.21$ (if patient is African American) * 0.742 (if female)[8]. Using the GFR, postoperative renal failure was defined as GFR <30 mL/minute/1.73 m^2 and a >20% decrease from preoperative GFR levels.

Postoperative morbidity variables that were captured included cardiovascular complications (myocardial infarction defined as electrocardiogram [EKG] changes from baseline and elevation of cardiac enzymes to more than twice the upper limit of normal and verified by a staff cardiologist, arrhythmia, congestive heart failure), peripheral emboli, decline in renal function, pneumonia, stroke, reoperation for hemorrhage, wound dehiscence, deep venous thrombosis, wound infection, coagulopathy, hematoma/seroma, and gastrointestinal complications (protracted ileus, ischemic colon, gastrointestinal bleed, pancreatitis, and hepatic failure). Postoperative decline in renal function was defined as doubling of preoperative creatinine to levels >2.0 mg/dL or new-onset dialysis. Patients who already have preoperative renal failure are not included in the postoperative renal decline analysis.

Our primary endpoints were 30-day mortality and postoperative morbidity focusing on renal function. The secondary endpoints were postoperative morbidity focusing specifically on postoperative decline in renal function, major adverse events (MAE) and long-term survival. The main stratification variable in this study was the location of the aortic cross-clamp. Subset analyses of concomitant renal revascularization procedures were also performed.

Bivariate analyses of patient and operative factors associated with IR or SR clamping was performed with Fisher's exact test for categorical variables, and Wilcoxon rank sum test for continuous variables like age. Non parametric testing was used in all continuous variables as we did not assume any normal distribution in these variables. Multivariable logistic regression models were used to evaluate dichotomous outcomes, such as 30-day mortality. Cox proportional hazard models were used to analyze time-dependent outcomes. Subanalyses were performed using propensity score models to control for potential unknown confounding variables associated with clamp position. An alpha value of 0.05, corresponding to $P = .05$ and 95% confidence intervals (CI), were used as the criterion for statistical significance. Data analysis was performed using SAS version 9.1 (SAS Institute Inc, Cary, NC).

The propensity score approach provides a conceptual model for causal inference in observational studies.[9] Exposure groups in non-randomized studies may differ with respects to variables that may influence outcomes and any observed differences may be due to these variables. There-

Table I. Baseline demographics, risk factors, and operative variables

	Overall	*IR (n = 849)*	*SR (n = 171)*	P *values*	*SR+RRP (n = 54)*	*SR−RRP (n = 117)*	P *values*
Age (years)	70.9	70.9	71.0	.18	70.8	71.2	.80
Gender (male)	804 (78.8%)	676 (79.6%)	128 (74.8%)	.16	33 (61.1%)	95 (81.2%)	.005
Diabetes	102 (10.0%)	77 (9.1%)	25 (14.6%)	.27	10 (18.5%)	15 (12.8%)	.33
Smoking	346 (33.9%)	279 (32.9%)	67 (39.2%)	.11	25 (46.3%)	42 (35.9%)	.20
Hypertension	641 (62.8%)	521 (61.4%)	120 (70.2%)	.03	42 (77.8%)	78 (66.7%)	.14
Coronary artery disease	524 (51.4%)	429 (50.5%)	95 (55.6%)	.23	25 (46.3%)	70 (59.8%)	.10
Cerebrovascular disease	90 (8.8%)	71 (8.4%)	19 (11.1%)	.25	7 (13.0%)	12 (10.2%)	.60
Chronic pulmonary disease	165 (16.2%)	134 (15.8%)	31 (18.1%)	.45	9 (16.7%)	22 (18.8%)	.74
Chronic renal failure	64 (6.3%)	40 (4.7%	24 (14.0%)	<.0001	9 (16.7%)	15 (12.8%)	.22
Congestive heart failure	68 (6.7%)	56 (6.6%)	12 (7.0%)	.84	6 (11.1%)	6 (5.1%)	.16
Size of aneurysm	5.7 cm	5.6 cm	6.0 cm	.001	5.6 cm	6.2 cm	.015
Mean EBL (mL)	1368	1257	1919	.001	2133	1923	.57

IR, Infrarenal; *SR,* suprarenal; *SR+RRP,* suprarenal with renal revascularization procedure; *SR−RRP,* suprarenal without renal revascularization procedure; *EBL,* estimated blood loss.

fore, a propensity score model was developed to control for the biases associated with an SR cross-clamp in this non-randomized group of patients. Aside from the anatomy of the aneurysm being the primary guiding factor in the position of the cross-clamp, there may be hidden unknown variables that influence this decision. These hidden factors would be controlled for by a randomized trial design. In this case of a non-randomized patient population, the propensity score is a statistical method to control for these hidden factors in the two groups. Cox proportional hazard test was used utilizing the propensity score for the likelihood of SR cross-clamp to evaluate mortality risks. This analysis provides for a check against the routine multivariable analysis with the addition of the propensity score in an attempt to control for unknown variables that may affect the position of the cross-clamp. The variables included in our propensity score model are similar to those included in the multivariable analysis model.

RESULTS

General. From January 1, 1990, through December 31, 2006, 1020 open non-ruptured AAA repairs were performed at the Brigham and Women's Hospital. The mean age of the patients was 70.9 years. There were 804 males (78.8%) and 216 females (21.2%) in the group. A total of 849 (83.2%) were done with an IR aortic cross-clamp; 171 (16.8%) were done with an SR aortic cross-clamp of which 54 (31.6%) required an adjunctive renal artery procedure. These adjunctive renal artery procedures included 37 renal endarterectomies, 12 renal artery reimplantations, and 11 aortorenal bypasses. There were proportionally more males in the SR−RRP group (81%) than the SR+RRP group (61%, $P = .005$). In the SR group, 39 patients (23%) had supraceliac cross-clamping and 132 patients (77%) had an SR cross-clamp based on anatomic factors and the surgeon's discretion. The propensity for patients to get an SR clamp was influenced by the presence of hypertension (odds ratio [OR] 1.55, 1.06-2.28, $P = .024$), preoperative renal failure (OR 3.13, 1.62-6.03, $P = .0007$) and increased size of the aneurysm (OR 1.31, 1.15-1.49, $P < .0001$).

The mean follow-up interval was 57.6 months. A total of 250 (25%) were considered lost to follow-up (defined as having no patient contact for more than 18 months from last contact) for the purpose of long-term survival evaluation. Our routine follow-up schedule for open AAA repair patients would be a postoperative visit at 1 week, 1 month, and then routine follow-up at 1 year and subsequently at 5 years, unless there are problems encountered. For this study, we reviewed the information available from the social security death index to check if the patients in this study were still alive.

Baseline risk factors are depicted in Table I. Of note, the prevalence of diabetes (14.6% vs 9.1%, $P = .027$), hypertension (70.2% vs 61.4%, $P = .03$) and chronic renal failure defined as baseline creatinine >2.0 mg/dL or dialysis dependence (14.0% vs 4.7%, $P < .0001$) are all higher in the SR vs IR group. No other significant differences were noted between the IR and SR groups. There were no significant differences between the SR−RRP and SR+RRP groups.

The overall mean aneurysm size was 5.7 cm. Aneurysms in the SR group were significantly larger than those in the IR group (6.0 cm vs 5.6 cm, $P = .001$). The aneurysm size was also larger in the SR−RRP group compared to the SR+RRP group (6.2 cm vs 5.6 cm, $P = .015$).

Mean estimated blood loss (EBL) was 1368 cc (100-18,000 cc). The SR group had higher mean EBL compared to the IR group (1919 cc vs 1257 cc, $P = .001$). Median LOS was 8.0 days. It was shorter in the IR group compared to the SR group (8.0 vs 9.0 days, $P = .047$). Those requiring additional RRP in the SR group had longer median LOS of 10.0 days compared to those who did not, 9.0 days ($P = .018$). In a multivariate analysis, only mean EBL was associated with increased LOS ($P = .001$).

Perioperative mortality. The overall 30-day mortality rate was 1.2% for all patients. The SR group had a 30-day mortality of 1.8% vs 1.1% for the IR group ($P = .44$). The

Table II. Post-op morbidity

	Overall (n = 1020)	*IR (n = 849)*	*SR (n = 171)*	P *values*	*SR+RRP (n = 54)*	*SR−RRP (n = 117)*	P *values*
MI	26 (2.5%)	20 (2.4%)	6 (3.5%)	.20	4 (7.4%)	2 (1.7%)	.14
Arrhythmia	90 (8.8%)	67 (8.0%)	23 (13.4%)	.019	9 (16.7%)	14 (12.0%)	.40
Congestive heart failure	6 (0.6%)	5 (0.6%)	1 (0.6%)	1.0	0 (0%)	1 (0.8%)	.50
Peripheral emboli	11 (1.1%)	6 (0.7%)	5 (2.9%)	.01	2 (3.7%)	3 (2.6%)	.07
Renal decline	36 (3.5%)	23 (2.8%)	13 (7.6%)	.002	8 (14.8%)	5 (4.3%)	.016
Pneumonia	67 (6.6%)	52 (6.2%)	15 (8.8%)	.12	9 (16.7%)	6 (5.1%)	.013
Stroke	7 (0.7%)	5 (0.6%)	2 (1.2%)	.53	0 (0%)	2 (1.7%)	.33
Protracted ileus	47 (4.6%)	42 (5.0%)	5 (2.9%)	.25	1 (1.8%)	4 (3.4%)	.57
Colonic ischemia	11 (1.1%)	7 (0.8%)	4 (2.3%)	.08	3 (5.6%)	1 (0.8%)	.06
Gastrointestinal bleed	15 (1.5%)	10 (1.2%)	4 (2.3%)	.23	2 (3.7%)	2 (1.7%)	.42
Pancreatitis	10 (1.0%)	6 (0.7%)	4 (2.3%)	.048	2 (3.7%)	2 (1.7%)	.42
Hepatic failure	1 (0.1%)	1 (0.1%)	0 (0%)	NS	0 (0%)	0 (0%)	NS
Reoperation for hemorrhage	13 (1.3%)	8 (1.0%)	5 (2.9%)	.035	3 (5.6%)	2 (1.7%)	.17
Wound dehiscence	12 (1.2%)	8 (1.0%)	4 (2.3%)	.12	3 (5.6%)	1 (0.8%)	.06
Deep venous thrombosis	7 (0.7%)	6 (0.7%)	1 (0.6%)	.86	0 (0%)	1 (0.8%)	.50
Wound infection	13 (1.3%)	12 (1.4%)	1 (0.6%)	.38	0 (0%)	1 (0.8%)	.50
Coagulopathy	2 (0.2%)	1 (0.1%)	1 (0.6%)	.21	0 (0%)	1 (0.8%)	.50
Hematoma/seroma	11 (1.1%)	9 (1.1%)	2 (1.2%)	.90	2 (3.7%)	0 (0%)	.036

IR, Infrarenal; *SR,* suprarenal; *SR+RRP,* suprarenal with renal revascularization procedure; *SR−RRP,* suprarenal without renal revascularization procedure; *MI,* myocardial infarction.

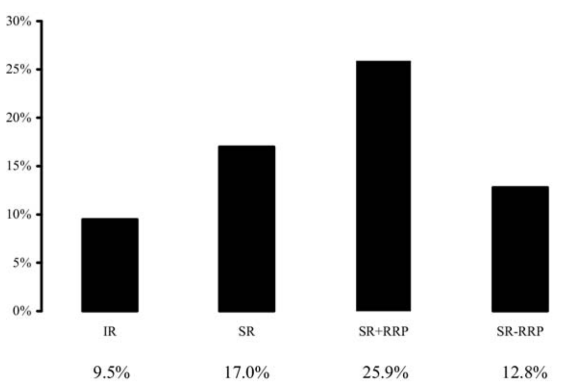

Fig 1. MAE rates. *IR,* Infrarenal; *SR,* suprarenal; *SR+RRP,* suprarenal with renal revascularization procedure; *SR−RRP,* suprarenal without renal revascularization procedure.

Table III. Creatinine values (mg/dL)

	IR	*SR*	P *values*	*SR+ RRP*	*SR− RRP*	P *values*
Pre-operation	1.3	1.5	0.001	1.5	1.6	.64
Discharge	1.2	1.6	0.001	1.8	1.5	.08

P = NS for all comparisons within groups between preoperation and discharge.
IR, Infrarenal; *SR,* suprarenal; *SR+RRP,* suprarenal with renal revascularization procedure; *SR−RRP,* suprarenal without renal revascularization procedure.

mortality rates were similar between the SR+RRP group and the SR−RRP group (1.8% vs 1.7%, *P* = NS). Multivariate analyses using logistic regression were performed to evaluate factors associated with 30-day mortality. Thirty-day death was associated with increased age (OR 1.18, 1.04-1.33, *P* = .009) and size of aneurysm (OR 1.72, 1.04-2.84, *P* = .034). Suprarenal cross-clamp position did not increase the risk of 30-day death. In the Cox proportional hazard model using the propensity score, the use of an SR cross-clamp did not increase the risk of 30-day death (OR 1.63, 0.43-6.12, *P* = NS).

General morbidity. Overall morbidity is shown in Table II. Major adverse events were defined as myocardial infarction, decline in renal function (doubling of pre-operative creatinine to value >2 mg/dL or new-onset dialysis), pneumonia, and stroke and occurred in 10.6% of all patients. The IR group had MAEs in 9.5% of patients while the SR group had a higher rate of 17.0% (*P* = .003). There is a significant difference in the MAE in the SR+RRP and the SR−RRP groups (25.9% vs 12.8%, *P* = .034) (Fig 1). Multivariate analysis of factors associated with MAEs shows an association with smoking (OR 2.15, 1.03-4.46, *P* = .04) and increasing age (OR 1.07, 1.02-1.13, *P* = .004). The use of an SR cross-clamp was not associated with MAEs (OR 0.49, 0.16-1.54, *P* = NS). Propensity score data confirms this finding that the SR cross-clamp was not associated with increased MAEs (OR 0.83, 0.37-1.87, *P* = NS) but did decrease the risk of complications (OR 0.55, 0.38-0.78, *P* = .0008).

Renal function. The mean values of serum creatinine were higher in the SR group at points of pre-operation and discharge (*P* = .001) (Table III). This effect was similar when comparing the SR+RRP and SR−RRP groups to the IR group. Between the two SR groups of SR+RRP and SR−RRP, there was no statistical difference in creatinine values at all time points. Within the SR+RRP group however, those patients with a normal creatinine at baseline had a significant increase in creatinine at discharge (1.3 mg/dL preoperation vs 1.7 mg/dL at discharge, *P* = .014). This contrasts with the SR−RRP group where there was no

Table IV. Impact on renal function

	IR	*SR*	P *value*	*SR+RRP*	*SR−RRP*	P *value*
Preoperative renal failure	40 (4.7%)	24 (14.0)	.001	9 (16.7%)	15 (12.8%)	.71
Postoperative renal decline	23 (2.8%)*	13 (7.6%)	.002	8 (14.8%)	5 (4.3%)*	.02
New-onset dialysis	7 (0.8%)	1 (0.6%)	.91	0 (0%)	1 (0.9%)	NS

IR, Infrarenal; *SR,* suprarenal; *SR+RRP,* suprarenal with renal revascularization procedure; *SR−RRP,* suprarenal without renal revascularization procedure.
**P* = .34.

statistical difference in the creatinine values at preoperation and at discharge for both the high and normal baseline creatinine groups.

The SR group had a higher rate of decline in renal function (doubling of creatinine from preoperative levels to a value >2 mg/dL or new-onset dialysis) at 7.6% vs the IR group at 2.7% (P = .002). The SR+RRP group had a significantly higher rate of postoperative renal decline rate at 14.8% vs 4.3% in the SR−RRP group (P = .016). It is noteworthy that the rates of postoperative decline in renal function are similar for the IR group vs the SR−RRP group (2.7% vs 4.3%, P = .34) (Table IV). Multivariate regression models show that preoperative renal failure (OR 8.15, 2.92-22.8, P < .0001) and increased EBL (OR 1.00, 1.00-1.00, P = .013) were associated with postoperative renal decline. The SR cross-clamp did not influence this result (OR 2.01, 0.81-4.97, P = .13). However, propensity score analysis showed that the use of an SR cross-clamp was associated with postoperative renal decline (OR 2.66, 1.28-5.50, P = .009).

Of note, in the SR group, there was only 1 patient who required permanent dialysis postoperatively (0.6%). This patient had a normal baseline creatinine of 1.0 mg/dL preprocedure. In the IR group, 7 patients needed permanent new-onset dialysis (0.8%). Three of these 7 patients had pre-existing renal failure (mean creatinine of 2.4 mg/dL preoperatively). The remaining 4 patients had a mean preoperative creatinine of 1.5 mg/dL.

Using GFR (mL/minute/1.73m^2) as a measure of renal function, patients were grouped into those with GFR >60, GFR between 30 and 60, and GFR <30 preoperatively and postoperatively. Table V shows the distribution of patients. In univariate analysis, preoperative renal failure (GFR <30 mL/minute/1.73m^2) was more common in the SR group vs the IR group (15.8% vs 4.7%, P = .001). Postoperative renal failure (GFR <30 mL/minute/1.73m^2 and a >20% decrease from preoperative GFR levels) was also more common in the SR vs IR group (10.5% vs 4.8%, P = .004). Looking at the SR subgroups, SR+RRP had a higher rate of renal failure compared to the IR group (16.7% vs 4.8%, P = .001) whereas SR−RRP compared to IR group did not (7.7% vs 4.8%, P = .19). The rates of preoperative renal failure were similar between the SR+RRP and SR−RRP groups (22.2% vs 12.8%, P = .12). In multivariable analysis, decline in discharge GFR was associated with preoperative GFR (OR 9.62, 5.69-16.3, P < .0001), the use of an SR clamp (OR 3.16, 2.04-4.91, P < .0001) and increasing age (OR 1.04, 1.02-1.07, P = .0003).

Table V. Association of preoperative and postoperative GFR

Preoperative GFR	*Postoperative GFR*	
Overall		
<30 (n = 60)	<30	43 (71.7%)
	30-60	16 (26.7%)
	>60	1 (1.7%)
30-60 (n = 521)	<30	37 (7.1%)
	30-60	308 (59.1%)
	>60	176 (33.8%)
>60 (n = 439)	<30	3 (0.7%)
	30-60	69 (15.7%)
	>60	367 (83.6%)
Infrarenal group		
<30 (n = 34)	<30	24 (70.6%)
	30-60	9 (26.5%)
	>60	1 (2.9%)
30-60 (n = 436)	<30	25 (5.7%)
	30-60	253 (58.0%)
	>60	1 (2.9%)
>60 (n = 379)	<30	2 (0.5%)
	30-60	47 (12.4%)
	>60	330 (87.1%)
Suprarenal group		
<30 (n = 26)	<30	19 (73.1%)
	30-60	7 (26.9%)
	>60	0 (0%)
<30 (n =85)	<30	12 (14.1%)
	30-60	55 (64.7%)
	>60	18 (21.2%)
>60 (n = 379)	<30	1 (1.7%)
	30-60	22 (36.7%)
	>60	37 (61.74%)

GFR, Glomerular Filtration Rate (mL/minute/1.73m^2).

Long term survival. Five-year survival was 69.1% ± 1.9% for the IR group and 67.7% ± 4.3% for the SR group (P = .38) (Fig 2). Multivariate analysis of baseline risk factors show female gender was protective of overall survival (hazard ratio [HR] 0.72, 0.55-0.93, P = .011). The presence of coronary artery disease (HR 1.36, 1.08-1.72, P = .009), chronic obstructive pulmonary disease (COPD) (HR 1.59, 1.21-2.09, P = .0009), chronic renal failure (HR 2.87, 1.90-4.33, P < .0001), congestive cardiac failure (HR 2.52, 1.78-3.57, P < .0001), increased age (HR 1.05, 1.03-1.06, P < .0001), and size of aneurysm (HR 1.10, 1.03-1.18, P = .008) were associated with increased long-term mortality. The use of an SR cross-clamp was not

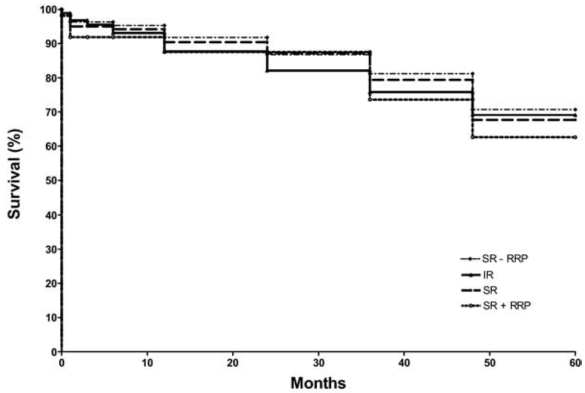

Fig 2. Long term survival. Standard error at all time points were <10% for all groups shown. *IR,* Infrarenal; *SR,* suprarenal; *SR+RRP,* suprarenal with renal revascularization procedure; *SR−RRP,* suprarenal without renal revascularization procedure.

associated with decreased survival (HR 1.04, 0.79-1.37, $P = .09$). Propensity score analysis did not associate long-term survival with the use of an SR cross-clamp (HR 1.2, 0.98-1.53, $P = .12$).

DISCUSSION

Open repair of AAA has been well described in many series and has been established as an effective and durable procedure.[10] Differences in operative technique such as transperitoneal vs retroperitoneal exposure have not yielded major differences.[11] At our institution, the widespread use of endovascular AAA stent graft repair has increased the relative complexity of open AAA repair. Proportionally, more of these open operations now require an SR cross-clamp to repair aneurysms which are increasingly juxtarenal, pararenal, or SR in nature. In light of this change in operative pattern, we undertook this review of our current experience with SR cross-clamping for aneurysmal repair. This review also helps establish a potential benchmark against which emerging endovascular technologies for juxtarenal and SR aneurysm may be compared.

The literature on SR cross-clamping for open aneurysm repair began from 1986 with Crawford et al[1] reporting on their experience with 101 patients. That report was focused primarily on diagnostic considerations to identify AAA patients requiring an SR cross-clamp but also described the sequelae from the SR cross-clamp.[1] The mortality rate was 7.9% and the dialysis rate was 8%. In general, these reports confirmed increased morbidity and mortality compared to aneurysm repair with IR cross-clamping. Shepard et al[12] reported a series of 23 patients requiring an SR cross-clamp for repair of AAA and noted a 4% early mortality rate. More recently in 1999, Jean-Claude et al[13] reviewed the experience at the University of California – San Francisco (UCSF) of 257 is the largest reported series thus far. Of these patients, 180 were operated on for pure aneurysmal disease while the remaining 77 had combined aneurysmal disease and renal artery occlusive disease. They found 5.8% overall mortality rate and a new-onset dialysis rate of 4.3%. The most frequent postoperative morbidity included a 7.4% incidence of developed respiratory insufficiency and a 5.8% incidence of myocardial infarction. Green et al[14] looked at difficult dissections of the aortic cuff and concluded that supraceliac clamping was preferable to SR clamping and resulted in lower mortality and postoperative renal failure rates. For SR clamping, they had an early mortality rate of 32% and a dialysis rate of 23%, whereas in supraceliac clamping, the rates were only 3% for both events.

More recently, Shortell et al[15] found no relationship between clamp placement (supraceliac vs IR) and any of the major outcomes parameters and a 6% overall mortality rate in elective juxtarenal aortic aneurysm repair. Knott et al[16] reported on 126 patients at the Mayo Clinic requiring SR cross-clamping for AAA repair and had a 0.8% 30-day mortality and postoperative renal insufficiency rate of 18%. Their 5-year cumulative survival rate was 63.8% which is very similar to our series, mortality was not predicted by any specific risk factor in their analysis.

The results of the current review are encouraging in that they have established that these complex operations may be performed with morbidity and mortality similar to standard open repair with an IR cross-clamp. The 1.8% 30-day mortality rate in this series for the SR group compares favorably to that previously reported in the literature and did not differ significantly from the 1.1% rate with IR cross-clamping in this series. Operative blood loss (1919 vs 1257 cc), length of stay (12.6 vs 10.7 days), and MAE rate (17% vs 9.5%) were all higher in the SR group. Multivariate analysis, however, confirmed that factors other than clamp position (ie, smoking history and age) were the major predictors of MAEs. It is reassuring that SR patients, despite increased co-morbidities at base line (Table I) and increased perioperative MAEs enjoyed nearly identical long-term survival to those patients undergoing IR repairs (69.1 ± 1.9% for the IR group and 67.7 ± 4.3% for the SR).

It was gratifying to establish the relative preservation of renal function in patients undergoing SR cross-clamping. The rate of new-onset dialysis, which was 0.8% for the SR group, is low compared to the historic literature and similar to the 0.6% rate for our IR patients. The SR group, however, had a higher rate of decline in renal function (doubling of creatinine from preoperative levels to a value >2 mg/dL or new-onset dialysis) at 7.6% vs the IR group at 2.7%. The propensity score analysis confirmed the SR clamp position was an independent predictor of postoperative decline in renal function. Subgroup analysis, however, confirmed that postoperative decline in renal function was significantly more likely in the SR+RRP group than the SR−RRP group (14.8% vs 4.3%). Conversely SR cross-clamp without the need for direct renal artery intervention could be performed with declines in renal function similar to the IR group (4.3% vs 2.7%, $P = .34$).

Several formulas have been used to calculate GFR. In the past, the Cockcroft-Gault formula has been most popular; more recently the MDRD equation proposed by

Levey et al has been validated for use.[8] Using the calculated GFR values in this context, multivariate logistic regression analysis show that preoperative GFR is strongest predictor of postoperative GFR and the use of SR clamp was weaker.

The results reported here offer an updated benchmark against which new technologies may be compared. Early reports of fenestrated and branched stent grafts offer endovascular options for many of the patients treated with open SR repair such as those reported in this series. Muhs et al[17] reviewed their results from 38 patients who underwent endovascular AAA repair with branched or fenestrated endografts and found a 2.6% 30-day mortality rate with a 13% 1-year mortality rate. They reported a postoperative renal failure rate of 5.2% (defined as a creatinine increase more than 50% from preoperative levels). Haddad et al[18] reviewed the experience at the Cleveland Clinic with fenestrated endografts and reported a 2.8% (2/72) long-term dialysis rate. Another 2/72 (2.8%) of patients required transient dialysis postoperatively. Their reported 1-year mortality was 6.9% (5/72).

In a systematic review of the literature by Sun et al[19] selecting six studies published on the results of fenestrated endovascular AAA grafts between 1999 and 2006, 13.3% (4.1%-22.5%) of patients had postprocedural renal dysfunction and 30-day mortality was 1.1% (0.4%-2.7%). They noted a correlation between preoperative renal insufficiency and postprocedural renal dysfunction, but due to the lack of sample size, it did not reach statistical significance ($P = .2$). The early reports of endovascular repair of aneurysms using branched and fenestrated grafts thus offer encouraging results. They clearly represent highly selected patients from specialized centers, but nonetheless have achieved results comparable to the SR group reported in this series.

The presence of renal artery occlusive disease and an AAA presents an interesting therapeutic dilemma. Options include open treatment of the AAA with an SR cross-clamp and repair of the renal lesion (with endarterectomy or bypass) or staging the procedure with either preoperative or postoperative angioplasty and stenting. Ballard et al[20] reviewed 50 patients who had combined renal artery stenosis and AAA. Thirty-two had simultaneous operative aortic and renal artery reconstruction; the remaining 18 had preoperative percutaneous renal artery angioplasty. Statistical analysis did not reveal any difference in preoperative creatinine value, LOS, EBL, postoperative hypertension, and postoperative creatinine. They concluded that preoperative percutaneous balloon angioplasty of the renal artery had no specific advantage over simultaneous open repair in patients with concomitant AAA. Our results corroborate these findings. Suprarenal repair with simultaneous renal reconstruction offers a safe and acceptable alternative. If, however, technical factors identified at surgery would make renal reconstruction difficult we do not hesitate to employ postoperative angioplasty and stenting.

This study has characteristic limitations. Although data was collected through a database in a prospective fashion, the study design is retrospective in nature. The database was not specifically designed for this study. The estimated GFR is not well validated for use in acute renal injury and although discharge creatinine is used here for this calculation, it is unclear how this value changes with time. In this patient population, we do not have routine long-term follow-up as these patients are not followed as closely as patients with occlusive disease. As such, many of our patients are not seen outside of their 30-day, 1-year, and subsequent 5-year follow-up. The social security death index was used to evaluate long-term follow-up.

CONCLUSION

This study confirms that AAA repair with an SR cross-clamp may be performed with a major morbidity and mortality rate similar to repair with an IR cross-clamp and with results superior to most historical series. Although simultaneous renal artery reconstruction confers an additional amount decline in renal function, it is similarly well tolerated with a minimal risk of postoperative dialysis. These results are reassuring in that an increasing proportion of open aneurysm repairs will require SR clamping. The results suggest that the benefits of endovascular repair of aneurysm with branched and fenestrated grafts must offer low-morbidity and mortality rates as well as excellent preservation of renal function to offer incremental benefits over open aneurysm repair with SR cross-clamp. Conversely, the results with SR cross-clamping reported here were largely achieved in an era where open IR aneurysm repair has been relatively common (although decreasing due to increasing endovascular repairs). It remains a concern whether future vascular surgeons, who have focused largely on endovascular repair, will have the operative experience necessary to perform aneurysm repairs with SR cross-clamping with results similar to IR cross-clamping.

AUTHOR CONTRIBUTIONS

Conception and design: TC, LN, CO, MC, MB
Analysis and interpretation: TC, LN, MC, MB
Data collection: TC
Writing the article: TC, LN, CO, MC, MB
Critical revision of the article: TC, LN, CO, MC, MB
Final approval of the article: TC, LN, CO, MC, MB
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Overall responsibility: TC, MB

REFERENCES

1. Crawford ES, Beckett WC, Greer MS. Juxtarenal infrarenal abdominal aortic aneurysm. Special diagnostic and therapeutic considerations. Ann Surg 1986;203:661-70.
2. Sarac TP, Clair DG, Hertzer NR, Greenberg RK, Krajewski LP, O'Hara PJ, Ouriel K. Contemporary results of juxtarenal aneurysm repair. J Vasc Surg 2002;36:1104-11.
3. West CA, Noel AA, Bower TC, Cherry KJ Jr, Gloviczki P, Sullivan TM, et al. Factors affecting outcomes of open surgical repair of pararenal aortic aneurysms: a 10-year experience. J Vasc Surg 2006;43:921-7; discussion 927-8.
4. Costin JA, Watson DR, Duff SB, Edmonson-Holt A, Shaffer L, Blossom GB. Evaluation of the complexity of open abdominal aneurysm repair in the era of endovascular stent grafting. J Vasc Surg 2006;43: 915-20; discussion 920.

5. Tiggeler RG, Berden JH, Hoitsma AJ, Koene RA. Prevention of acute tubular necrosis in cadaveric kidney transplantation by the combined use of mannitol and moderate hydration. Ann Surg 1985;201:246-51.
6. Zager RA, Mahan J, Merola AJ. Effects of mannitol on the postischemic kidney. Biochemical, functional, and morphologic assessments. Lab Invest 1985;53:433-42.
7. Hanley MJ, Davidson K. Prior mannitol and furosemide infusion in a model of ischemic acute renal failure. Am J Physiol 1981;241:F556-64.
8. Levey AS, Bosch JP, Lewis JB Greene T, Rogers N, Roth D. A more accurate method to estimate glomerular filtration rate from serum creatinine: a new prediction equation. Modification of Diet in Renal Disease Study Group. *Ann Intern Med*. 1999;130:461-470.
9. Drake C, Fisher L. Prognostic models and the propensity score. Int J Epidemiol 1995;24:183-7.
10. Forbes TL, Steiner SH, Lawlor DK, DeRose G, Harris KA. Risk-adjusted analysis of outcomes following elective open abdominal aortic aneurysm repair. Ann Vasc Surg 2005;19:142-8.
11. Sieunarine K, Lawrence-Brown MM, Goodman MA. Comparison of transperitoneal and retroperitoneal approaches for infrarenal aortic surgery: early and late results. Cardiovasc Surg 1997;5:71-6.
12. Shepard AD, Scott GR, Mackey WC, O'Donnell TF Jr, Bush HL, Callow AD. Retroperitoneal approach to high-risk abdominal aortic aneurysms. Arch Surg 1986;121:444-9.
13. Jean-Claude JM, Reilly LM, Stoney RJ, Messina LM. Pararenal aortic aneurysms: the future of open aortic aneurysm repair. J Vasc Surg 1999;29:902-12.
14. Green RM, Ricotta JJ, Ouriel K, DeWeese JA. Results of supraceliac aortic clamping in the difficult elective resection of infrarenal abdominal aortic aneurysm. J Vasc Surg 1989;9:124-34.
15. Shortell CK, Johansson M, Green RM, Illig KA. Optimal operative strategies in repair of juxtarenal abdominal aortic aneurysms. Ann Vasc Surg 2003;17:60-5.
16. Knott AW, Kalra M, Duncan AA, Reed NR, Bower TC, Hoskin TL, et al. Open repair of juxtarenal aortic aneurysms (JAA) remains a safe option in the era of fenestrated endografts. J Vasc Surg 2008;47:695-701.
17. Muhs BE, Verhoeven EL, Zeebregts CJ, Tielliu IF, Prins TR, Verhagen HJ, van den Dungen JJ. Mid-term results of endovascular aneurysm repair with branched and fenestrated endografts. J Vasc Surg 2006;44:9-15.
18. Haddad F, Greenberg RK, Walker E, Nally J, O'Neill S, Kolin G, et al. Fenestrated endovascular grafting: the renal side of the story. J Vasc Surg 2005;41:181-90.
19. Sun Z, Mwipatayi BP, Semmens JB, Lawrence-Brown MM. Short to midterm outcomes of fenestrated endovascular grafts in the treatment of abdominal aortic aneurysms: a systematic review. J Endovasc Ther 2006;13:747-53.
20. Ballard JL, Hieb RA, Smith DC, Bergan JJ, Bunt TJ, Killeen JD. Combined renal artery stenosis and aortic aneurysm: treatment options. Ann Vasc Surg 1996;10:361-4.

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