Open surgical repair of ruptured juxtarenal aortic aneurysms with and without renal cooling: Observations regarding morbidity and mortality

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Objectives: **Little is known about the outcome of ruptured juxtarenal aortic aneurysm (RJAA) repair. Surgical treatment of RJAAs requires suprarenal aortic cross-clamping, which causes additional renal ischemia-reperfusion injury on top of the pre-existing hypovolemic shock syndrome. As endovascular alternatives rarely exist in this situation, open repair continues to be the gold standard. We analyzed our results of open RJAA repair during an 11-year period.**
Design: **Retrospective observational study.**
Materials and methods: **Between July 1997 and December 2008, all consecutive patients with RJAAs were included in the study. Part of these patients received cold perfusion of the kidneys during suprarenal aortic cross-clamping. Perioperative variables, morbidity, and 30-day or in-hospital mortality were assessed. Renal insufficiency was defined as an acute rise of ≥0.5 mg/dL in serum creatinine level. Multiple organ failure (MOF) was scored using the sequential organ failure assessment score (SOFA score).**
Results: **A total of 29 consecutive patients with an RJAA, confirmed by computed tomography-scanning, presented to our hospital. In eight patients, the operation was aborted before the start of aortic repair, because no blood pressure could be regained in spite of maximal resuscitation measures. They were excluded from further analysis. Of the remaining 21 patients, 10 died during hospital stay. Renal insufficiency occurred in 11 out of 21 of the patients. Eleven out of 21 patients developed MOF postoperatively. In a subgroup of patients who received renal cooling during suprarenal aortic clamping, the 30-day or in-hospital mortality was two of 10 vs eight of 11 in patients who did not receive renal cooling (P = .03); renal insufficiency occurred in one out of 10 patients in the subgroup with renal cooling vs 10 out of 11 without renal cooling (P < .001) and MOF in two of 10 vs nine of 11, respectively (P = .009).**
Conclusions: **Open surgical repair of RJAAs is still associated with high mortality and morbidity. To our knowledge, this is the first report of cold perfusion of the kidneys during RJAA repair. Although numbers are small, a beneficial effect of renal cooling on the outcome of RJAA repair is suggested, warranting further research with this technique. (J Vasc Surg 2010;51:551-8.)**

Juxtarenal aortic aneurysms (JAAs) are characterized by the absence of normal aorta between the upper extent of the abdominal aneurysm and the renal arteries requiring suprarenal aortic cross-clamping for repair.[1] In the last decade, elective open JAA repair has been the topic of many studies.[2-4] However, not much is known about the outcome of ruptured JAAs (RJAAs). Mortality rate after ruptured abdominal aortic aneurysm repair has not changed over the past 15 years.[5] RJAAs are too complex for emergency endovascular repair and therefore still require open surgery with suprarenal aortic cross-clamping, which causes additional renal ischemia-reperfusion injury on top of the pre-existing hypovolemic shock syndrome.[6,7] Patients who subsequently develop renal failure have a particularly poor outlook, often involving a prolonged and ultimately unsuccessful stay in the intensive care unit. Acute renal failure in itself has a mortality rate of more than 50% and is even higher in critically ill patients who have multiple organ failure (MOF).[8-10] To preserve the kidney function, we have applied renal hypothermia routinely in elective settings of JAA repair.[11]

Literature reports about the mortality and morbidity of RJAA repair are scarce, with the largest study reporting a mortality rate of 81%.[10] The objective of this study was to review an 11-year period of experience with open RJAA repair, in which some of the patients received cold renal perfusion during suprarenal aortic cross-clamping and to evaluate renal function, MOF, and mortality.

MATERIALS AND METHODS

All RJAAs registered in our hospital between July 1997 and December 2008 were analyzed. Data were collected retrospectively through electronic and manual chart reviews of all patients. The aneurysm was defined as juxtarenal if it extended up to the renal arteries and repair required

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aortic cross-clamping just above the renal arteries, which was based on preoperative radiographic findings and confirmed intraoperatively. Aneurysms that required supra-superior mesenteric artery or supraceliac aortic repair were excluded. Rupture was confirmed intraoperatively.

Preoperative variables. Preoperative hemodynamic instability was defined as systemic arterial blood pressure <80 mm Hg with lowered consciousness and tachycardia. Chronic obstructive pulmonary disease (COPD) was identified based on previous pulmonary function studies or the need of inhaler or steroid treatment. Ischemic heart disease was detected by a history of previous myocardial infarction or coronary artery bypass. Preoperative renal insufficiency was defined as serum creatinine values >1.5 mg/dL. Diabetes, hypertension, claudication, and hypercholesterolaemia were identified in patients undergoing active medical and/or dietary treatment. Previous aortic surgery includes a history of any repair of the aorta.

Operative conditions and reconstructive techniques. All patients received 20% Mannitol at the start of RJAA repair. Esophageal temperature was used to measure body temperature, which was actively maintained according to general anaesthesia protocols. The surgical approach was transabdominal or retroperitoneal. After identification of the hematoma and mobilization and lateral retraction of the duodenum, the left renal vein was identified and mobilized. After exposure of the aortic neck, an aortic cross-clamp was placed proximal to both renal arteries. In case of hemodynamic collapse or cardiac arrest prior to control of the aortic neck, a Foley balloon catheter was advanced via the pressureless aneurysmal sac blindly into the thoracic aorta and inflated. If at that time, with maximal resuscitative measures, no blood pressure could be regained, the operation was aborted. If the patient recovered, the aortic neck was exposed and, following removal of the occlusion balloon catheter, an aortic-cross clamp was placed just above the renal arteries and the aneurysm was opened. The choice to use renal cooling was determined by preference of the surgeon on duty, the availability of appropriate perfusion catheters, and anatomic suitability depending on the orifices of the renal arteries. Cold perfusion of the kidneys was applied during the whole period of renal ischemia. A simple 0.9% NaCl solution without any additives, readily at hand, was chosen to keep this emergency procedure simple. One liter of 0.9% NaCl solution with an initial temperature of 4° was placed 1 meter above each kidney. In the orifices of the renal arteries, 9- or 6-F balloon-tipped Pruitt irrigation catheters (LeMaitre Vascular Inc, Burlington, Mass) were inserted from within the opened aneurysm. First, a 300 mL bolus of this solution was rapidly infused in each kidney to instantly induce renal hypothermia. Then renal perfusion was continued at a (slowly dripping) rate of ±20 mL/min. Earlier measurements of the temperature of this solution at the point of entrance into the kidney revealed a rise from 4°C at initiation to 15 °C at the end of perfusion.[11] Separate, end-to-side reimplantation into the graft of one or both renal arteries was performed if the aneurysm included the renal artery orifices. In case of renal cooling, a Pruitt irrigation catheter was then placed into the (buttoned) orifice of the renal artery, to be removed just before completion of the anastomosis. After near completion of the proximal aortic anastomosis, both cooling catheters were removed and renal perfusion was restored by replacing the clamp onto the aortic graft. Operative times (in minutes) and blood losses during the operation were recorded.

Morbidity and mortality. Mortality was monitored during hospital stay and 30 days after. Renal insufficiency was defined according to the RIFLE criteria (Risk Injury Failure Loss End-stage renal disease criteria) as an acute rise of serum creatinine > 0.5 mg/dL.[12,13] The need for temporary or permanent dialysis was recorded. To define MOF (ie, failure of two or more systems), the sequential organ failure assessment (SOFA) score was used.[14-16] Organ failure was defined as a SOFA score of 3 or 4 (0 = no failure, 1-2 = mild dysfunction, 3-4 = severe dysfunction).

Statistical analysis. Data are expressed as mean ± standard deviation (SD), or as median and range in case of a too-skewed distribution. Statistical program SPSS 15.0 (SPSS Inc, Chicago, Ill) was used for analysis of data. Categorical variables are summarized with frequencies and analyzed with Fischer's exact test. To avoid possible violations of the assumptions for parametric testing, we employed nonparametric methods such as Spearman rank correlation and Mann-Whitney U test. All tests were performed two-sided, and *P* smaller than .05 was considered as statistically significant.

RESULTS

Of the 29 consecutive patients undergoing RJAA repair, in eight patients the abdomen was opened and the aorta controlled; however, no blood pressure could be regained in spite of maximal resuscitation measures. Because their operation was aborted before the start of aortic repair, they were excluded from further analysis (all males, 66-83 years). In the other 21 patients, 15 males and six females (with a mean age of 75 ± 6 years), 12 were hemodynamically unstable upon admission (Table I). The mean diameter of the aneurysm was 7.9 ± 1.7 cm. Body temperature on presentation in the operating room was 35.1± 1.1°C and did not affect the decision to initiate renal cooling. Median preoperative serum creatinine level was 1.47 mg/dL (range, 0.96-3.44 mg/dL). Nine patients had preoperative renal insufficiency as defined above. Comorbidities and previous operations are listed in Table I. Of the total group of 21 patients undergoing RJAA repair, 10 patients received cold perfusion of the kidneys during suprarenal aortic cross-clamping. The characteristics of the patients, divided in two subgroups (with and without renal cooling), are also described in Table I.

Operative details. In the 21 remaining patients, the surgical approach was transabdominal in 18 patients and retroperitoneal in three patients. Tube grafts were used in 15 patients and bifurcated grafts in six patients. In one patient who lost blood pressure upon opening the abdominal cavity, adequate circulation and suprarenal aortic control were obtained using a short period of thoracic aortic

Table I. Baseline characteristics in the overall group of patients and divided in two subgroups of patients with and without renal cooling

	Total group of patients (N = 21)	*Subgroup patients WITH renal cooling (N = 10)*	*Subgroup patients WITHOUT renal cooling (N = 11)*
Age (years)	75 ± 6	74 ± 8	76 ± 4
Diameter of aneurysm (mean ± SD)	7.8 ± 1.7	8.0 ± 1.7	7.9 ± 1.7
Body temperature on presentation at operating room (°C)	35.1 ± 0.9	35.3 ± 0.9	34.9 ± 0.9
	N	*N*	*N*
Male/female	15/6	8/2	7/4
Shock or hemodynamic instability upon admission	12	5	7
Associated disease			
COPD	7	3	4
Coronary heart disease	12	5	7
Hypertension	7	4	3
Diabetes mellitus	0	0	0
Claudication	5	2	3
Hypercholesterolemia	4	2	2
Smoking	9	5	4
Preoperative renal insufficiency	9	4	5
Previous surgery			
Abdominal surgery	12	7	5
Aortic stent grafting	1	1	0

COPD, Chronic obstructive pulmonary disease; *N,* number.
Values presented are mean ± standard deviation.

Table II. Operative details of the 21 patients undergoing RJAA repair

Year of RJAA repair	*Surgeon*	*Renal cooling*	*30-day survival*	*Hemodynamic status*	*Additional operative details*
1997	D	Yes	Yes	Stable	–
1998	C	No	No	Unstable	Temporary Foley balloon catheter
2000	C	No	No	Unstable	–
2001	D	No	No	Unstable	–
2002	D	No	No	Stable	–
2003	B	Yes	Yes	Stable	–
2004	C	Yes	Yes	Stable	–
2005	C	Yes	Yes	Unstable	–
2005	C	Yes	Yes	Unstable	Reimplantation of left renal artery
2005	B	Yes	No	Unstable	Previous thoracic aortic stentgraft
2005	C	No	Yes	Stable	–
2006	C	Yes	Yes	Unstable	–
2006	C	No	No	Unstable	–
2006	C	No	No	Unstable	9 F Pruitt catheter could not be applied
2006	A	No	No	Stable	–
2007	C	Yes	Yes	Unstable	Reimplantation of left renal artery
2007	A	No	Yes	Unstable	–
2007	D	No	No	Stable	9 F Pruitt catheter could not be applied
2008	A	Yes	No	Unstable	Reimplantation of left renal artery
2008	C	Yes	Yes	Stable	–
2008	C	No	No	Unstable	–

F, French.
Surgeons as shown are anonymous.
In one patient, blood pressure was regained within minutes following supraceliac inflation of a Foley balloon catheter, which was subsequently removed when suprarenal control was achieved.
In three patients receiving renal cooling, reimplantation of the left renal artery was necessary, because the aneurysm included the orifice of these renal arteries. The placement of cooling catheters was attempted but failed in two patients because the orifices of the renal arteries were too small for placement of 9 F Pruitt catheters, and 6 F catheters were not available. The thoracic aortic stent graft did not interfere with the RJAA repair.

balloon occlusion as described above (Table II). In three patients who received renal cooling, reimplantation of the left renal artery was necessary. In one of the latter, thrombectomy of the left leg was also performed (Table II; year 2007). The placement of cooling catheters was attempted but failed in two patients because the orifices of the renal arteries were too small for placement of 9 F Pruitt catheters, and 6 F catheters were not available (Table II; year 2006

Table III. Operative details and length of stay in the intensive care unit in the total group of patients and divided in two subgroups of patients with and without renal cooling

	Total group of patients (N = 21)	*Subgroup of patients WITH renal cooling (N = 10)*	*Subgroup of patients WITHOUT renal cooling (N = 11)*	P *value*
Suprarenal aortic-cross clamp time (min)	38 ± 16	34 ± 15	41 ± 17	.30
Total aortic clamp time (min)	77 ± 41	67 ± 27	86 ± 50	.36
Total operation time (min)	185 ± 49	185 ± 52	186 ± 49	.94
Total blood loss during RJAA repair (mL)	2398 ± 1092	2388 ± 887	2412 ± 1414	.66
Body temperature at the end of operation (°C)	34.5 ± 0.5	34.6 ± 0.6	34.4 ± 0.4	.86
Length of stay in intensive care (days)	4 (1-50)	2 (1-48)	8 (2-50)	.04

Min, Minutes; *N,* number; *RJAA,* ruptured juxtarenal aortic aneurysm.
Values presented are mean ± standard deviation or median with range and the *P* values.

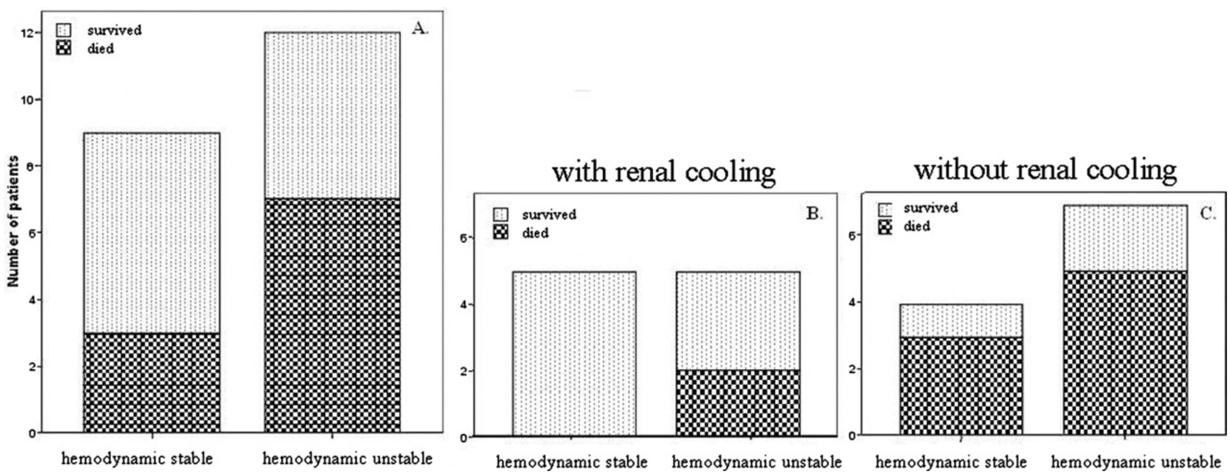

Fig 1. Preoperative hemodynamic instability and postoperative mortality (**A**) in the overall patient group, (**B**) in patients with renal cooling, and (**C**) in patients without renal cooling. Light shaded bars represent the patients who survived, and the dark shaded bars represent those who died postoperatively.

and 2007). Table II also shows that all surgeons performed renal cooling. The surgeon who repaired most RJAAs applied renal cooling in half of his cases. Suprarenal aortic cross-clamping time and total aortic clamping time in all patients were 38 ± 16 minutes and 77 ± 41 minutes, respectively (Table III). The total operation time in all patients was 185 ± 49 minutes. Average estimated blood loss during operation for the total group was 2398 ± 1092 mL. Body temperature at the end of the operation was 34.5 ± 0.5°C with a median decline in the subgroup with renal cooling of 0.7°C vs 0.2°C without renal cooling ($P = .12$; Table III).

Morbidity and mortality. The thirty-day or in-hospital mortality rate was 48% (10 out of 21) for all patients undergoing RJAA repair. In the subgroup of patients who received renal cooling, two out of 10 patients died vs eight out of 11 without cooling ($P = .03$; Fig 1). Mortality was not significant related to age, gender, operation time, surgeon, changes in body temperature, (suprarenal) aortic cross-clamping time, or type of graft. Of the 21 patients, 11 developed renal insufficiency postoperatively, of which one patient had received renal cooling (Fig 2; $P < .001$). Six patients, none of which received renal cooling, required continuous venovenous hemodialysis postoperatively; they all died (Fig 2). The maximum rise in creatinine level from baseline in the overall patient group was 0.51 mg/dL (range, −0.08-4.06 mg/dL); in the subgroup of patients with renal cooling, the rise was 0.23 mg/dL (range, −0.08-0.61 mg/dL) vs 0.93 mg/dL without renal cooling (range, −0.02-4.06 mg/dL; $P = .002$). This rise occurred on average on the third (± 2) postoperative day and did not correlate with suprarenal aortic cross-clamping time (Fig 3; Rs = 0.34, $P = .14$) or with the preoperative serum creatinine level (Rs = −0.21, $P = .36$). Postoperative MOF was seen in 11 out of 21 patients, of which two patients had received renal cooling and nine did not (Table IV; $P = .009$). Eight patients died due to MOF, none of which had received renal cooling (Fig 4). The median stay in the intensive care unit for all patients was 4 days (range, 1-50

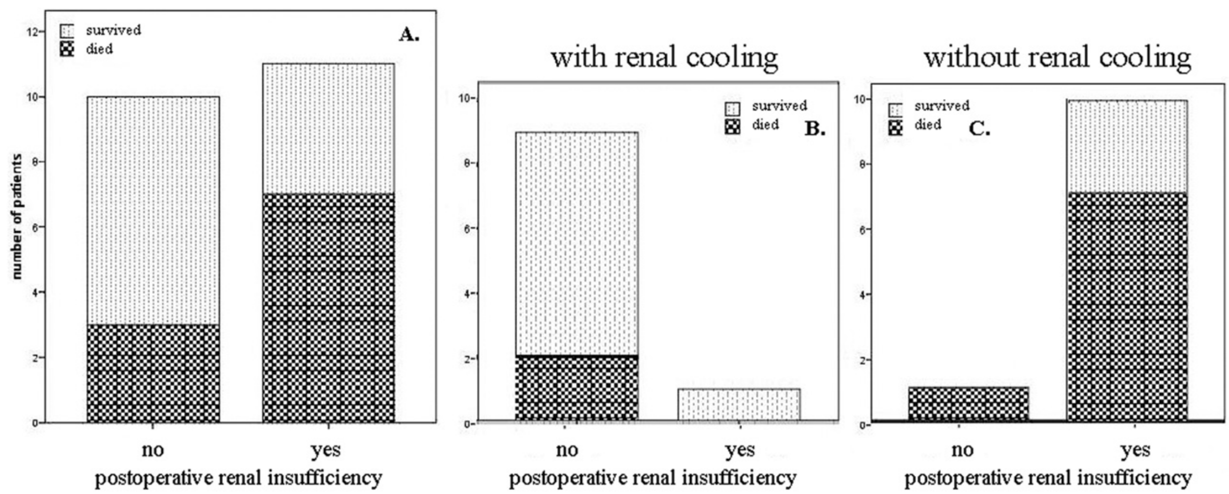

Fig 2. Postoperative renal insufficiency and postoperative mortality (**A**) in the overall patient group, (**B**) in patients with renal cooling, and (**C**) in patients without renal cooling. Light shaded bars represent the patients who survived, and the dark shaded bars represent the patients who died postoperatively.

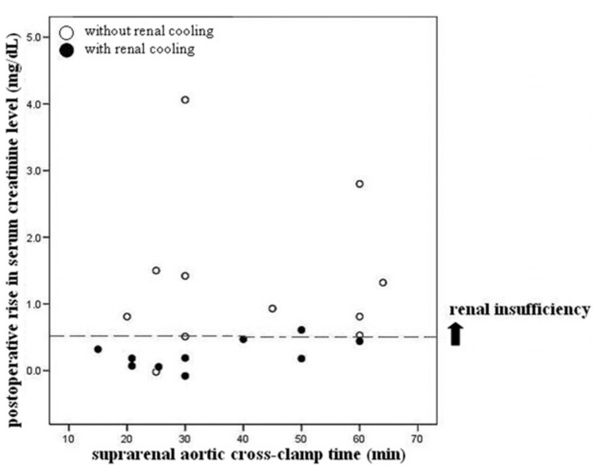

Fig 3. Suprarenal aortic cross-clamp time (minutes) and postoperative rise in serum creatinine level. The dark filled symbols are the patients with renal cooling. Dashed line indicates a rise of 0.5 mg/dL, above which postoperative renal insufficiency was considered to be present.

days) and in the patients with renal cooling 2 days (range, 1-48 days; Table III).

DISCUSSION

The present study shows that RJAA repair continues to be associated with high mortality and morbidity. We report the largest patient series of RJAA repair to date, with an overall mortality rate of 48%. In about half of our patients, we have been able to apply renal cooling during suprarenal aortic-cross clamping. Interestingly, in this small subgroup of patients, we observed remarkably lower mortality and morbidity rates. To our knowledge, this is the first report of cold perfusion of the kidneys during RJAA repair.

Literature reports about the outcome of RJAA repair are scarce. In the few existing studies, the mortality rate was up to 81%.[10,17-19] It has been shown that 75% of the patients who develop acute renal failure following ruptured abdominal aortic aneurysm repair die in the hospital, and more than half of the survivors are dead at 5 years due to renal failure.[8,10,20-23] Rises in serum creatinine level after abdominal aortic surgery frequently occur in combination with other organ dysfunction.[24] It remains a question, however, if renal failure plays a causative role in the development of MOF or if they both are a consequence of shock.[25] Often, renal insufficiency precedes respiratory distress or sepsis.[25,26] It also plays an important role in the delayed recovery of lung injury or decreased cardiac function.[25,27] Renal failure is related to MOF,[24,25] which has been reported as a common complication after ruptured aortic surgery and is highly correlated with lethal outcome.[8,10,20,21]

Preoperative measures to preserve renal function with cooling have been applied previously in thoracoabdominal aortic aneurysm repair[28] and during elective repair of juxtarenal aortic aneurysms[11] with beneficial effects on postoperative renal function. Also, in the current study of RJAA, we observed a tendency toward preservation of renal function and better outcome with the application of cold renal perfusion.

Limitations of the present study are its retrospective nature, absence of randomization for the evaluation of renal cooling, and the small group sizes. Our protocol of renal cooling was initiated at the beginning of the study period by one of the surgeons. Although other surgeons have adopted the procedure, cooling was inconsistently applied throughout the entire study period, mainly because of the emergency character of the procedure, inconsistent availability of materials, and/or familiarity of the nurses with the procedure, as well as lack of evidence

Table IV. Postoperative complications and MOF with their number of occurrence in the overall group of patients and in the subgroups with and without renal cooling

	Total group of patients (N = 21)	*Subgroup of patients WITH renal cooling (N = 10)*	*Subgroup of patients WITHOUT renal cooling (N = 11)*	P *value*
MOF (N)	11	2	9	.009
2 organs	5	2	3	
3 organs	2	0	2	
>4 organs	4	0	4	
SOFA score parameters				
Respiration				
PaO_2/FiO_2 (mm Hg)	143 (51-404)	157 (68-404)	142 (51-258)	.82
Coagulation				
Platelets ($\times 10^3/mm^3$)	55 (10-404)	79 (24-106, 401)	34 (10-79)	.02
Liver				
Bilirubin (mg/dL)	1.6 (0.7-12.8)	1.2 (0.7-2.7)	2.3 (0.9-5.3, 12.8)	.06
Cardiovascular				
Hypotension (SOFA score: 1-4)	1 (1-4)	1 (1-2)	2 (1-4)	.16
Central nervous system				
Coma (SOFA score: 1-4)	1 (1-4)	1 (1-2)	2 (1-4)	.16
Renal				
Highest creatinine level (mg/dL)	1.99 (1.00-5.05)	1.74 (1.00-2.45)	2.70 (1.83-5.05)	.002

FiO_2, Fraction of inhaled O_2; *MOF,* multiple organ failure; *N,* number; *PaO_2,* systemic arterial partial O_2-pressure; *SOFA,* sequential organ failure assessment.
The SOFA score parameters were used to define MOF.
Presented are medians with range and the *P* values.

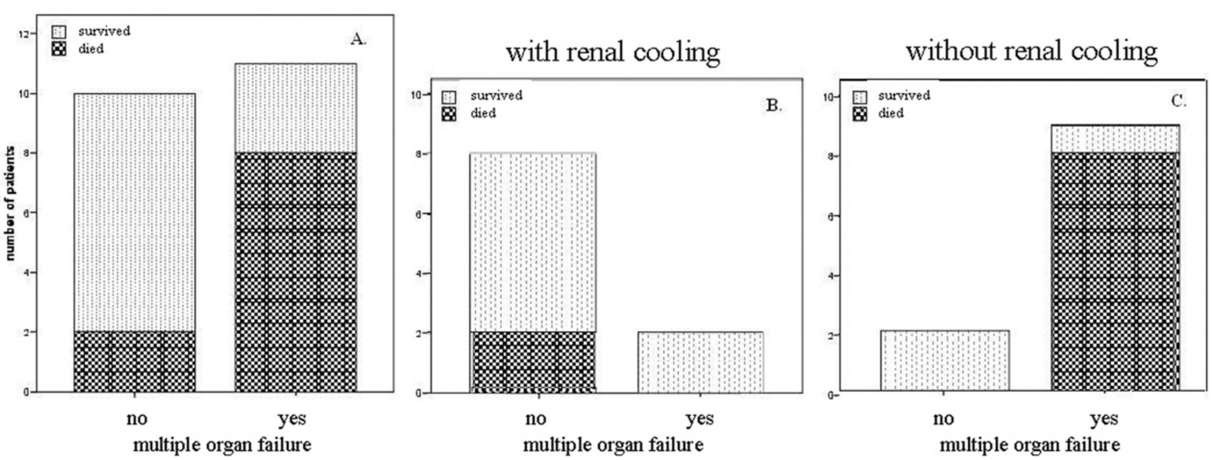

Fig 4. Postoperative multiple organ failure and postoperative mortality (**A**) in the overall patient group, (**B**) in patients with renal cooling, and (**C**) in patients without renal cooling. Light shaded bars represent the patients who survived, and the dark shaded bars represent the patients who died postoperatively.

regarding its usefulness. All operations were performed by, or under direct supervision of, board-certified vascular surgeons. A bias due to differences in surgeons' experience and expertise cannot completely be ruled out, although it does not seem likely since each surgeon did at some point use renal cooling, and the surgeon who performed most of the repairs had similar mortality and morbidity rates.

Cross-clamp times were longer than would be expected in elective suprarenal aortic reconstruction, probably because of time required to obtain full aortic exposure and mobilization of the left renal vein after initial clamping to control the bleeding. Furthermore, suprarenal and total aortic cross-clamp times were longer in the group without renal perfusion, albeit not significantly. Therefore, a selection bias toward less complex anatomy or more rapid aortic control in favor of the renal perfusion group cannot be completely ruled out. The body temperature declined 0.7°C in the subgroup with renal cooling, which is in line with the use of renal cooling in the elective situation.[11] Use of perfusion catheters might interfere with performing the proximal anastomosis and therefore increase cross-clamp time; however, we did not experience this problem, as our study showed that with adequate preparation of the cooling procedure, suprarenal aortic cross-clamping time is not significantly lengthened.

Besides prolonging cross-clamp time, catheterization of the renal arteries could conceivably cause complications such as dissection or embolization. However, with careful insertion of the soft- and round-tipped Pruitt catheter, as well as sensible inflation of its compliant balloon just past the renal artery orifice, these complications were not observed in our study. In very small or stenosed renal arteries, we have used 6 F Pruitt catheters in elective cases; however, unfortunately, these were not available in two of our emergency cases, precluding renal cooling.

Our observation that cold perfusion of the kidneys during suprarenal aortic cross-clamping might decrease the occurrence of postoperative renal failure, MOF, and even mortality is interesting, not only from a clinical but also from a pathophysiological point of view. It has been suggested that the kidney is not just a passive bystander but a driving force of a detrimental spiral leading to MOF.[25] It has been noted that in critically ill patients, acute renal failure adds more than its own share to morbidity.[25,29,30] Hence, our observation could suggest a need to protect the kidneys during RJAA repair beyond renal preservation itself. Obviously, this is speculative and further clinical and experimental research on this phenomenon is needed.

Endovascular repair of a ruptured abdominal aortic aneurysm has become more and more widespread, but it remains unclear whether perioperative mortality is reduced significantly.[31] Because of technical limitations, branched endografts have hardly been applied yet for RJAA repair.[32] Therefore, open repair is still the gold standard.

In conclusion, open surgical repair of RJAA is still associated with high mortality and morbidity rates. We observed a trend toward benefit from renal cooling during RJAA repair with regard to postoperative renal function, morbidity, and mortality. Although selection bias could have been present because of the retrospective nature and small group sizes, our data warrant prospective studies on intention-to-treat basis.

AUTHOR CONTRIBUTIONS

Conception and design: KY, HC, WW
Analysis and interpretation: KY, GT, WY, AH, PL, WW
Data collection: KY, HC, WY
Writing the article: KY, GT, AH, PL, WW
Critical revision of the article: KY, AH, GT, WW
Final approval of the article: WW
Statistical analysis: KY, EL, GT
Obtained funding: N/A
Overall responsibility: WW

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