Clinical Investigation

Suprarenal or Supraceliac Aortic Clamping

during Repair of Infrarenal Abdominal Aortic Aneurysms

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Suprarenal or supraceliac aortic clamping during repair of infrarenal abdominal aortic aneurysms can be complicated by renal, hepatic, and intestinal ischemia. To determine whether suprarenal or supraceliac clamping increases morbidity and mortality, we retrospectively reviewed our recent nonrandomized experience. Between January 1993 and December 1998, 716 patients underwent elective (n=682) or urgent (n=34) infrarenal abdominal aortic aneurysm repair. Infrarenal clamping was used in 516 (72.1%) and suprarenal or supraceliac clamping in 200 (27.9%). The suprarenal/supraceliac group had significantly more older patients (³70 years of age) (65.5% vs 47.7%) and a higher incidence of preoperative renal insufficiency (7.5% vs 5.5%). Suprarenal or supraceliac clamping was used during repair of ruptured (n=25), juxtarenal (n=7), or inflammatory abdominal aortic aneurysms (n=4); during concomitant renal or visceral revascularization (n=43); in other difficult settings (n=13); or at the surgeon's discretion (n=108). The decision for such clamping was always made during surgery. In treating ruptured aneurysms, suprarenal/supraceliac clamping (25/200) was used more often than infrarenal clamping (9/516) (12.5% vs 1.74%). Operative times were similar in both groups, but transfusion requirements and length of hospital stay were slightly greater in the suprarenal/supraceliac group. Perioperative mortality was 3.1% overall, but higher in the suprarenal/supraceliac group than in the infrarenal (7.5% vs 1.4%). Postoperative complications developed in 26 (13%) of patients who underwent suprarenal/supraceliac clamping. Abdominal re-exploration was required in 9 other patients. We conclude that, despite associated comorbidities, elective suprarenal/supraceliac clamping during infrarenal abdominal aortic aneurysm repair is safe, facilitates repair, and does not significantly increase mortality. ***(Tex Heart Inst J 2001;28:254-64)***

Key words: *Aortic aneurysm, abdominal; supraceliac clamping; suprarenal clamping*

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Most infrarenal (IR) abdominal aortic aneurysms (AAAs) can be repaired safely under IR aortic cross-clamping. However, unusual lesions and other patient-related factors can occasionally make IR clamping difficult or impossible. In such circumstances, several technical variations can be used to control the IR aorta,[1,2] including clamping of the suprarenal (SR), visceral, or supraceliac (SC) aortic segments.

Deciding on the optimal level of proximal aortic control in the treatment of aortic aneurysmal disease has been controversial. Some researchers say that IR clamping minimizes distal embolization but may cause renal embolization[3] and can result in the later development of para-anastomotic pseudoaneurysms.[4] Interrenal clamping, on the other hand, is associated with more renal and gastrointestinal complications than either SR or SC clamping.[5] Others have argued that visceral clamping (that is, between the renal arteries and the superior mesenteric artery) is associated with a disturbingly high rate of complications and therefore should be avoided entirely.[6] The SC aortic segment is less likely than the IR and visceral aortic segments to have significant atherosclerotic disease.[7] Supraceliac clamping also avoids the need for retraction and manipulation of large aneurysms and might reduce the risk of embolization during dissection.

Still, some authors have expressed reluctance to clamp the aorta at the SR or SC level, since such clamping requires more extensive dissection and can be attended by excessive cardiac morbidity, paraplegia, acute renal failure, and hepatic or intestinal ischemia.[8,9] In a study by Green and colleagues,[10] patients whose aortas were clamped immediately above the renal arteries had higher perioperative mortality rates and a higher incidence of kidney failure requiring dialysis than did patients whose aortas were clamped at the SC or IR level. However, some researchers have noted no differences in mortality rates with regard to the site of aortic clamping and comparable or even favorable cardiac morbidity rates with more proximal clamping.[11,12]

To clarify the advantages and disadvantages of SR and SC clamping in comparison with IR clamping in the setting of IR AAA repair—including their comparative effects on morbidity and mortality—we retrospectively reviewed our recent 6-year experience with these approaches in a tertiary referral center. We have found some differences in early mortality and complications and, despite the nonrandomized nature of our patient series, have made a number of useful observations about SR and SC clamping in this setting.

Patients and Methods

Between January 1993 and December 1998, 716 patients underwent surgical repair of IR AAAs at our institution (Tables IA and IB). Patients fell into 2 groups in accordance with the level of aortic clamping: patients whose aortas were clamped at the SR or the SC level (SR/SC group) and those whose aortas were clamped at the IR level (IR group). Patients were examined clinically by members of our vascular surgery service before and every 2 to 3 months after surgery. The data gathered for analysis were patients' demographic information, including aneurysm status (ruptured or intact) and preoperative risk factors (e.g., prior myocardial revascularization, peripheral or cerebrovascular disease, obesity, chronic obstructive pulmonary disease, and level of renal function). We also analyzed operative data, such as the level and duration of clamping, concomitant renal revascularization, inferior mesenteric artery reimplantation, estimated blood loss, and amount of blood replaced. Outcome analysis included early (30-day) mortality and incidence of complications such as renal dysfunction, mesenteric ischemia, distal thromboembolism, and cardiac events.

TABLE IA. Summary of Patients' Characteristics by Clamping Type

Characteristic	SR/SC Group (n=200)	IR Group (n=516)	Total (n=716)
Sex			
Male	152 (76%)	420 (81.4%)	572 (79.9%)
Female	48 (24%)	96 (18.6%)	144 (20.1%)
Age			
Mean (range), yr	64.7 (45–87)	56 (49–84)	56.3 (45–87)
Younger vs older			
<70 yr	69 (34.5%)	270 (52.3%)	339 (47.3%)
≥70 yr	131 (65.5%)	246 (47.7%)	377 (52.7%)
Aneurysm status			
Ruptured*	25 (12.5%)	9 (1.7%)	34 (4.7%)
Intact	175 (87.5%)	507 (98.3%)	682 (95.3%)

*Includes 2 patients in the SR/SC group who were in cardiorespiratory arrest preoperatively.

IR = infrarenal; SR/SC = suprarenal or supraceliac

Results

Preoperative and Operative Data

SR/SC Group. A total of 200 patients (152 men and 48 women; mean age, 64.7 years; age range, 45–87 years; 65.5% ≥70 years) underwent SR or SC clamping during repair of an AAA (Tables IA and IB). Indications for SR or SC clamping included ruptured aneurysm in 25 cases (including 2 cases in which the patient suffered preoperative cardiorespiratory arrest), concomitant renal revascularization in 40, visceral revascularization in 3, juxtarenal aneurysm in 7, and inflammatory aneurysm in 4. In 121 cases, SR or SC clamping was indicated by difficult exposure of the IR aorta (n=13) or was the surgeon's preference (n=108).

Most patients in the SR/SC group had multiple comorbid risk factors (Table II). Seventy-one of the 200 patients (35.5%) had undergone previous coronary revascularization; 10 (5%), cardiac valve replacement;

TABLE IB. Summary of Patients' Characteristics by Aneurysm Status (n = 716)

Characteristic	Ruptured* SR/SC Group (n=25)	Ruptured* IR Group (n=9)	Intact SR/SC Group (n=175)	Intact IR Group (n=507)
Sex				
Male	17 (68%)	8 (88.9%)	135 (77.1%)	412 (81.3%)
Female	8 (32%)	1 (11.1%)	40 (22.9%)	95 (18.7%)
Age (younger vs older)				
<70 yr	8 (32%)	4 (44.4%)	61 (34.9%)	266 (52.5%)
≥70 yr	17 (68%)	5 (55.6%)	114 (65.1%)	241 (47.5%)

*Includes 2 patients in the SR/SC group who were in cardiorespiratory arrest preoperatively.

IR = infrarenal; SR/SC = suprarenal or supraceliac

TABLE II. Comorbid Risk Factors

Risk Factors	SR/SC (n=200)	IR (n=516)
Preoperative factors		
Cirrhosis	1	2
Chronic renal insufficiency	10	15
Acute renal failure	1	1
Hemodialysis	10	10
Jehovah's Witness	3	1
Failed stent	2	1
COPD	92	312
Obesity (BMI ≥25)	87	296
Cancer		
At a single site	22	97
At multiple sites	2	11
Other aneurysms		
Thoracic aortic	4	6
Cerebral	0	2
Coronary	0	1
Popliteal	0	1
Subclavian	0	1
Previous procedures		
ACB (redo)	63 (11)	153 (15)
PTCA/stenting	8	45
Peripheral vascular disease	5	32
Carotid endarterectomy	16	37
Valve replacement	10	13
Renovascular intervention	2	4
Renal transplantation	1	1
Other		
Aortic coarctation repair	0	1

ACB = aortocoronary bypass; BMI = body mass index; COPD = chronic obstructive pulmonary disease; IR = infrarenal; PTCA = percutaneous transluminal coronary angioplasty; SR/SC = suprarenal or supraceliac

and 16 (8%), carotid endarterectomy. Preoperative acute or chronic renal insufficiency was present in 15 patients (7.5%), including 4 in whom the patient required chronic hemodialysis. The average aneurysm size (± SD) was 6.5 ± 1.46 cm.

The mean SR/SC clamping time was 22 min (range, 12–69 min). The clamping time was less than 15 min in 58 patients, 15 to 30 min in 59, 30 to 45 min in 10, 45 to 60 min in 4, and more than 60 min in 1. The average blood loss was 1684 ± 1328 mL, and the average volume of packed red blood cells transfused was 1063 ± 868 mL. Autotransfusion was used in 74 cases; in those cases, the average volume of returned blood was 914 ± 747 mL.

Concomitant procedures performed in the SR/SC group are listed in Table III. Tube grafts were used in 103 patients; bifurcated grafts to the iliac (n=51) or the femoral arteries (n=46) were used in the remaining 97 patients. The inferior mesenteric artery was reimplanted in 46 patients (23%).

IR Group. A total of 516 patients (420 men and 96 women; mean age, 56 years; age range, 49–84 years; 47.7% ≥70 years old) underwent IR clamping (Tables IA and IB). Nine of them (1.7%) presented with ruptured aneurysms. Comorbid factors included acute or chronic renal insufficiency in 26 patients, including 10 patients who required chronic hemodialysis (Table II). One hundred ninety-eight patients (38.4%) had undergone previous myocardial revascularization; 37 (7.2%), carotid endarterectomy; and 32 (6.2%), lower-extremity revascularization. Six patients had undergone previous repairs of aneurysms of the thoracic aorta.

Concomitant procedures performed in the IR group included those listed in Table III. Inferior mesenteric artery reimplantation was performed in 136 cases (26.4%). A total of 31 renal revascularization procedures were performed, which included renal artery bypass or reimplantation (or both) in 26 cases and renal artery endarterectomy in 5.

Early Postoperative Mortality and Complications

Overall, 21 of 716 patients (2.9%) died in the early postoperative period (within 30 days) (Table IV). The early postoperative mortality rate was higher in patients with ruptured aneurysms (5/34, 14.7%) than in those with intact aneurysms (16/682, 2.35%). Most early postoperative deaths (9/21, 43%) were cardiac related. Intestinal ischemia complicated AAA re-

TABLE III. Concomitant Procedures

Concomitant Procedures	SR/SC (n=200)	IR (n=516)
Aortocoronary bypass	2	4
Aortic valve repair	0	1
Carotid endarterectomy	1	5
Lower-extremity revascularization	11	43
Lumbar sympathectomy	0	3
Cholecystectomy	18	37
Hernia repairs	5	24
Cancer-related surgery		
Esophagogastrectomy	0	1
Adrenalectomy	0	1
Radical nephrectomy	1	1
SB resection (liposarcoma)	0	1
Others		
SMA bypass	0	1
SMA/celiac bypass	3	0
Gastrostomy	1	0
Hepatic artery repair	0	1
Colectomy	1	0
Arteriovenous graft creation	0	1
Colostomy revision	0	1
Hysterectomy	1	0
Minor procedures	10	15
Renal revascularization		
Renal artery bypass/reimplantation	23	26
Renal artery endarterectomy	14	5
Renal artery dilation	3	0
Total no. renal revascularizations (%)	40 (20%)	31 (6%)

IR = infrarenal; SB = small bowel; SMA = superior mesenteric artery; SR/SC = suprarenal or supraceliac

TABLE IV. Early Postoperative Mortality (n = 21)

Pt. No.	Age (yr)/ Sex	Rupture	Previous Procedures and Other Associated Risk Factors	Associated Procedures	EBL (mL)	Blood Transf. (mL)	Graft	Clamp Time (min)	Inferior Mesenteric Reimpl.	POD	Cause of Death
SR/SC Group (n=14)											
1	81/F	N	L femoropopliteal bypass	—	700	250	ABI	24	Y	3	Distal thrombosis, colon ischemia, sepsis
2	77/F	Y*	ACB, AVR, HD	—	2500	1000	Tube	22	N	25	Colon ischemia, sepsis
3	73/M	N	HD	IABP	0	0	Tube	15	N	1	Sudden cardiac death
4	71/M	N	Redo ACB, CRI	—	1500	750	ABF	16	N	15	RI, MI, CHF, colon ischemia
5	83/M	Y	Preop cardiac arrest	—	1500	750	Tube	11	Y	11	Thrombosis, colon ischemia
6	77/M	N	ACB, cirrhosis	Ventral hernia repair	1500	750	Tube	19	Y	14	Liver failure
7	78/M	N	PTCA, ACB	L renal artery bypass	2250	1000	Tube	6	N	12	RI, HD, stroke, colon ischemia
8	78/M	N	—	—	1200	0	ABF	40	Y	13	Cholecystitis, mesenteric ischemia
9	69/F	N	ADTA	Renal endarterectomy	300	0	Tube	20	N	5	Sudden cardiac death
10	80/F	N	ADTA, CRI	Gastrostomy, bilateral renal artery bypass	2750	1250	ABI	20	N	26	Embolization, RI, MI
11	74/M	N	Bladder cancer	L renal artery angioplasty	1600	1000	ABI	24	N	1	MI
12	74/M	N	ACB, AVR, CEA	—	1250	750	Tube	18	N	15	Stroke
13	64/M	Y	Redo ACB	—	5000	1250	Tube	32	Y	13	Respiratory failure
14	72/M	Y	Preop cardiac arrest	R iliac bypass, R hemicolectomy	7000	3500	Tube	25	N	4	Multiorgan failure syndrome
IR Group (n=7)											
1	74/M	Y	—	—	12000	7250	ABI		N	7	Pulmonary embolism/MI
2	74/M	N	PTCA, HD, JW	Umbilical hernia repair	200	0	Tube		N	4	Stroke/MI
3	76/M	N	ACB	—	750	0	ABI		N	26	Post-redo ACB
4	76/F	N	ACB, HD	Bilateral femoral endarterectomy, splenectomy	1000	450	ABF		N	2	Distal embolization, MI, arrhythmia
5	81/F	N	ACB, CEA	—	400	0	Tube		N	3	CHF
6	76/F	N	—	—	1600	750	ABI		N	7	HD, bleeding, multiorgan failure syndrome, ARDS
7	71/M	N	Esophageal cancer, lip cancer, CRI	Retroperitoneal lymph node biopsy (cancer), cholecystectomy	1000	500	ABI		N	11	RI, HD, colectomy

*Post-ACB

ABF = aortobifemoral bypass; ABI = aortobiiliac bypass; ACB = aortocoronary bypass; ADTA = aneurysm of descending thoracic aorta; ARDS = adult respiratory distress syndrome; AVR = aortic valve replacement; CEA = carotid endarterectomy; CHF = congestive heart failure; CRI = chronic renal insufficiency; EBL = estimated blood loss; F = female; HD = hemodialysis; IABP = intra-aortic balloon pump; IR = infrarenal; JW = Jehovah's Witness; L = left; M = male; MI = myocardial infarction; N = no; POD = postoperative day; preop = preoperative; PTCA = percutaneous transluminal coronary angioplasty; R = right; reimpl. = reimplantation; RI = renal insufficiency; SR/SC = suprarenal or supraceliac; transf. = transfusion; Y = yes pair in 12 cases, 6 of which ended in death. Preoperative renal function temporarily worsened in 19 patients, 5 of whom required temporary dialysis support.

SR/SC Group. Fourteen patients in the SR/SC group (7%) died in the early postoperative period (Table IV). These included 4 of 25 patients with ruptured aneurysm (16% early mortality) and 10 of 175 patients with intact aneurysm (5.7% early mortality). Causes of early death included sepsis due to mesenteric ischemia in 6 cases, sudden death after an uneventful early recovery in 2, liver failure in 1, stroke in 1, myocardial infarction in 2, respiratory failure in 1, multiorgan failure syndrome in 1, and preoperative cardiopulmonary arrest (as previously mentioned) in 2.

Early postoperative complications in this group included nonfatal myocardial infarction or congestive heart failure in 8 cases, nonfatal arrhythmia in 3, and stroke in 4 (Table V). Abdominal reexploration was required for bleeding in 5 cases, perforated chronic peptic ulcer in 1, small bowel fistula in 2, and pancreatic débridement in 1. Transient renal dysfunction developed in 25 patients (12.5%), 8 of whom required temporary dialysis. In addition, intestinal ischemia requiring reoperation developed in 3 patients (1.5%). The rate of postoperative complications was markedly higher after repair of ruptured aneurysms, in comparison with intact aneurysms (8% vs 4.6%). Early graft-related complications (graft thrombosis and distal atheroembolism) developed in 6 patients (3%).

IR Group. Seven patients in the IR group (1.4%) died in the early postoperative period (Table IV). These included 1 of 9 patients with ruptured aneurysm (11.1% early mortality) and 6 of 507 patients with intact aneurysm (1.2% early mortality). Causes of early death included cardiac-related causes in 4 cases, multiorgan failure syndrome in 1, colon ischemia in 1, and complication of redo aortocoronary bypass in 1.

Early postoperative complications in the IR group are listed in Table V. Early renal dysfunction complicated repair in 19 patients (3.7%), 7 of whom required temporary dialysis (1.4%). Nonfatal intestinal ischemia complicated repair in 3 patients (0.6%), all after repair of intact aneurysms. Nonfatal myocardial infarction or congestive heart failure complicated repairs in 10 patients (1.9%), 3 of whom required aortocoronary bypass. Four patients developed nonfatal arrhythmias. Nine patients (1.7%) suffered strokes of varying degrees postoperatively. Distal thromboembolic complications requiring graft thrombectomy or revision developed in 18 patients (3.5%). Abdominal reexploration was indicated by bleeding in 6 patients, acute cholecystitis in 4, perforated chronic peptic ulcer in 2, gastric fistula following esophagogastrectomy for esophageal cancer in 1, and other causes in 3.

Late Postoperative Mortality

Overall, during a mean follow-up period of 27 months (range, 2 months to 7 years), 31 patients died of various causes (Table VI). Of these deaths, 10 were cardiac related, 7 were due to complications of cancer, and 5 were due to sepsis and multiorgan failure syndrome.

TABLE V. Early Postoperative Complications in Accordance with Aneurysm Status

	SR/SC Group			IR Group		
Early Complication	**Ruptured** (n=25)	**Intact** (n=175)	**Total** (n=200)	**Ruptured** (n=9)	**Intact** (n=507)	**Total** (n=516)
Cardiac	2	9	11 (2.1%)	0	14	14 (2.7%)
Myocardial infarction/CHF	1	7	8	0	10	10
Arrhythmia	1	2	3	0	4	4
Stroke	0	4	4 (2%)	0	9	9 (1.7%)
Renal						
Renal dysfunction	3	22	25 (12.5%)	1	18	19 (3.7%)
Temporary dialysis	2	6	8 (4%)	0	7	7 (1.4%)
Nonfatal intestinal ischemia	2	1	3 (1.5%)	0	3	3 (0.6%)
Distal thromboembolism	0	6	6 (3%)	0	18	18 (3.5%)
Reoperation						
Bleeding	0	5	5	1	5	6
Perforated peptic ulcer	0	1	1	1	1	2
Acute cholecystitis	0	0	0	0	4	4
Pancreatitis	1	0	1	0	1	1
Intestinal fistula	0	2	2	0	1	1
Small bowel obstruction	0	0	0	0	1	1
Intraabdominal abscess	0	0	0	0	1	1
Total no. reoperations	1	8	9 (4.5%)	2	14	16 (3.1%)

CHF = congestive heart failure; IR = infrarenal; SR/SC = suprarenal or supraceliac

TABLE VI. Late Postoperative Mortality (n = 31)

Pt. No.	Age (yr)/ Sex	Previous Procedures	Late Procedures	Cause of Late Death*
SR/SC Clamping (n=12)				
1	70/F	Common femoral artery repair	ACB (2 mo)	S/P ACB (2 mo)
2	80/M	—	—	Metastatic cancer (6 mo)
3	65/M	ACB, redo ACB	—	? cardiac (9 mo)
4	76/F	—	—	Unknown (41 mo)
5	77/F	Dissecting ADTA	Gastrostomy (2 mo)	Respiratory failure (4 mo)
6	77/F	—	—	MOFS (3 mo)
7	73/F	Post-stenting rupture	—	Sepsis (3 mo)
8	79/F	Hysterectomy, appendectomy, AVG	Wound débridement	Sepsis (3 mo)
9	71/M	—	Lung cancer (2 mo)	Cerebral aneurysm rupture (51 mo)
10	73/F	R nephrectomy, ACB, ADTA	—	End-stage renal disease (3 mo)
11	79/F	—	ACB (2 mo)	Myocardial infarction (3 mo)
12	80/M	—	Dissecting ADTA	Metastatic prostate cancer (12 mo)
IR Clamping (n=19)				
1	69/M	—	ACB (21 mo)	S/P ACB (21 mo)
2	75/F	Esophageal cancer	—	MOFS (2 mo)
3	83/M	—	—	Unknown (10 mo)
4	70/F	AVR, ACB, R adrenalectomy (cancer)	Wound closure (3 mo)	Metastatic cancer (14 mo)
5	69/M	ACB, redo ACB	—	Myocardial infarction (29 mo)
6	67/M	L sympathectomy, ACB	Lung cancer (30 mo)	Lung cancer (31 mo)
7	74/M	R ureter stone removal, appendectomy	—	Metastatic cancer (2 mo)
8	52/M	ACB	ACB, AATA, AVR (61 mo)	S/P ACB, AATA, AVR (61 mo)
9	63/M	On heart transplant list	—	CHF, sepsis (5 mo)
10	65/F	ACB	Wound débridement; L femoral pseudoaneurysm	Vulvar cancer (8 mo)
11	85/M	Cholecystectomy	—	Unknown (56 mo)
12	70/F	Hysterectomy, cholecystectomy, bilateral carotid endarterectomy	ACB (31 mo)	Sepsis (33 mo)
13	70/M	L femoral embolectomy, cervical spine fusion	—	Lung cancer (32 mo)
14	76/M	ACB	—	Pulmonary fibrosis (9 mo)
15	68/M	Renal artery bypass, ACB	AVR-redo ACB (39 mo)	S/P ACB (39 mo)
16	74/F	—	—	Unknown (24 mo)
17	64/M	—	AVG (20 mo)	End-stage renal disease (38 mo)
18	78/M	PTCA, ACB, hiatal hernia, radical prostatectomy	RCEA, PTCA, stenting (18 mo)	Coronary artery disease (22 mo)
19	80/M	PTCA	ACB (2 mo)	S/P ACB (2 mo)

*Numbers in parentheses indicate, in months, the interval between the AAA repair and the late procedure or late death.

ACB = aortocoronary bypass; AATA = aneurysm of ascending thoracic aorta; ADTA = aneurysm of descending thoracic aorta; AVG = arteriovenous graft; AVR = aortic valve replacement; CHF = congestive heart failure; F = female; IR = infrarenal; L = left; M = male; mo = month; MOFS = multiple organ failure syndrome; PTCA = percutaneous transluminal coronary angioplasty; R = right; RCEA = right carotid endarterectomy; S/P = status post; SR/SC = suprarenal or supraceliac

Discussion

In a retrospective review of our recent 6-year nonrandomized experience with SR/SC clamping during IR AAA repair in which the decision to use SR/SC clamping was always made during surgery, we found that patients who underwent SR/SC clamping were disproportionately older and had a higher incidence of preoperative renal insufficiency. We also found that SR/SC clamping was used more often than IR clamping in repairing ruptured aneurysms. These factors were reflected in a higher postoperative mortality rate for patients who underwent SR/SC clamping, in comparison with IR clamping.

These findings are important because, as endovascular[13] and other minimally invasive techniques[14] for IR aortic aneurysm repair become more widely applied, an increasing proportion of patients with AAAs for whom conventional open repair is indicated will have aneurysms deemed unsuitable for IR clamping. Such lesions will include juxtarenal aneurysms with short IR necks, aneurysms associated with renal or visceral arterial disease, aneurysms associated with excessive calcification and atherosclerotic disease of the juxtarenal aorta, and inflammatory aneurysms. Consequently, alternatives to IR clamping during AAA repair (such as SR, SC, and visceral clamping) will have to be used.

Controversy continues to surround the relative merits of IR in comparison with SR/SC clamping. In a study by Green and colleagues,[10] the rates of operative mortality (32% vs 3%) and renal failure requiring dialysis (23% vs 3%) after AAA repair were much higher when clamping was done between the superior mesenteric artery and the renal arteries, rather than proximal to the celiac artery. This difference was attributed to the greater likelihood of dislodging atherosclerotic débris in the pararenal aorta than in the SC aorta, which is usually less diseased. Clamping-related complications included atheroembolization to the kidneys, legs, and intestines, and injury to the aorta or renal arteries.

Some surgeons are reluctant to clamp the aorta above the level of the renal arteries during elective aneurysm repair because of the risks of death, renal failure, and atheroembolization. Surgical mortality rates of 15% or more after SR or SC clamping, usually due to cardiac complications and visceral ischemic syndromes, have been reported.[15] However, many of the studies that argue against SR and SC clamping have included patients with SR aneurysms. More recent studies that were restricted to IR and juxtarenal aneurysms have shown more encouraging results, including mortality rates for SR and SC clamping that are indistinguishable from those associated with conventional IR clamping.[12,16]

Breckwoldt and associates[11] noted the relative safety of clamping the SC aorta, which can be easily accessed by dividing the gastrohepatic ligament and the diaphragmatic crus. In patients with juxtarenal aneurysms, hiatal clamping enables safe and easy anastomosis to the healthy aorta, which in turn helps prevent the formation of late anastomotic aneurysms. Giulini and coworkers[12] compared the outcomes of treatment of juxtarenal AAAs after SR clamping (56 patients) with those of IR clamping (634 patients) and found no significant difference between the 2 groups in terms of 30-day mortality (3.6% vs 1.9%), the incidence of acute myocardial infarction (3.6% vs 2.3%), or the need for homologous blood transfusion. On the other hand, when they compared the incidence of renal dysfunction in the 2 groups, they found that the SR group had higher rates of renal dysfunction (14% vs 0) and that one of the patients in the SR group who developed renal dysfunction required permanent dialysis. The rate of ischemic colitis was also higher after SR clamping (7% vs 2%).

In our experience, accurate preoperative evaluation of the extent of disease in the aorta at the planned level of cross-clamping is not always possible. We have found that the midline approach provides adequate exposure of the SR and subdiaphragmatic portions of the aorta and affords fast exposure in cases of ruptured aneurysms. Careful dissection around the aorta in the presence of a complex aneurysm is always important. Adherence of the aorta to surrounding tissues in the region of the left renal vein should contraindicate further exploration of the juxtarenal segment. Left renal vein ligation is associated with notable morbidity rates[17,18] and is rarely necessary.

Perioperative Mortality

The overall perioperative mortality rate of 2.9% in our current series compares favorably with rates cited in other recent reports.[19-21] The early mortality rate of 14.7% for patients with ruptured aneurysms (including 2 patients who suffered preoperative cardiac arrest and were operated on while undergoing continuous cardiopulmonary resuscitation) is remarkable. Similarly, our 2.49% mortality rate for patients with intact aneurysms is remarkable when one considers this subgroup's high rates of preoperative renal insufficiency (4.1%), renal revascularization (10%), and other concomitant procedures (27%).

At first, our direct comparison of early mortality after SR/SC clamping with IR clamping appeared to reveal a strikingly higher mortality rate after SR/SC clamping (7.5% vs 1.4% overall and 6.3% vs 1.19% in patients with intact aneurysms). However, in-depth analysis revealed that most patients in the SR/SC group had considerably more risk factors and underwent more extensive procedures (such as renal revascularization) than did those in the IR group. A higher death rate was to be expected, since poor preoperative renal function is strongly associated with postoperative death,[22] and since the mortality rate is high for patients who need postoperative renal replacement therapy.[23] Moreover, due to the very nature of their illness, sicker patients more often underwent SR/SC clamping.

Cardiac Complications

In a prospective review of surgical results after elective AAA repair, Blankensteijn[21] found a 30-day hospital-based mortality rate of 3.0% to 4.8% and a cardiac complication rate of 0.5% to 13.9%. The most frequent complications in that series were cardiac related.

Several authors have described the various physiologic and cardiac consequences of clamping the aorta above the level of the renal arteries.[24-26] These consequences are more severe in patients with coronary artery disease (CAD)[27-29] and increase in severity with higher levels of clamping. In a study by Bush's group,[30] cardiac depression was minimal after aortic clamping and appropriate preoperative volume loading of the left ventricle. In a more recent study by Hafez and colleagues,[31] SC clamping was associated with significant release of the myocardial injury marker troponin-T. However, this finding corresponded with the severity of oxidative rather than hemodynamic stresses, which suggests that ameliorating oxidative injury during AAA surgery may be cardioprotective.

Our current experience confirms that cardiac-related death is a serious problem in the setting of IR AAA repair. Clinical predictors of perioperative cardiac death include a history of heart failure, angina pectoris, or myocardial infarction; an abnormal resting electrocardiogram; a history of stroke or other vascular disease; previous vascular operation; hypertension; and diabetes mellitus. Patients with angina, CAD, or a history of myocardial infarction should undergo coronary angiography. Patients whose clinical findings are equivocal should be evaluated by stress testing and, if the results are positive, by subsequent coronary angiography. Aggressive correction of significant CAD, either before or during AAA repair, substantially decreases the risk of postoperative cardiac-related death.[24,27,28,32-39]

In our current experience, left ventricular failure complicated repair in only 1 case and necessitated temporary placement of an intra-aortic balloon pump. Myocardial infarction or congestive heart failure in the early postoperative period developed more often after SR/SC clamping than after IR clamping (4% vs 2%) and was more often fatal to affected patients in the SR/SC group (63% vs 40%) (Table V). The difference, however, is partly explained by the higher average age of patients (a large proportion of whom had undergone prior or concomitant myocardial revascularization) and partly by the higher incidence of ruptured aneurysms in the SR/SC group.

Renal Complications and Outcomes

Several factors influence renal outcome after open repair of IR AAAs.[40] These include preoperative renal function, the presence of renovascular disease, the site and duration of aortic clamping, and intraoperative and major postoperative complications.[41,42] Preoperative renal insufficiency is a significant risk factor for death after elective repair of IR AAAs.[43] Although the indications for AAA repair in patients with chronic renal failure are the same as those for patients with normal renal function, the operative mortality rate for those with renal failure is 5 times higher (2.0% vs 0.4%).[44] However, the 5-year survival rate for patients with renal dysfunction and treated aneurysms is still significantly higher than it is for patients with renal dysfunction and untreated aneurysms (44% vs 20%).[45] In a study by Sasaki and associates,[46] postoperative renal dysfunction (defined by a serum creatinine level >2.0 mg/dL) developed in 50% of patients after bilateral SR clamping, in comparison with only 8.4% after IR clamping. In that study, the postoperative peak BUN level was significantly higher after a longer (>30 min), as opposed to shorter, SR clamping time, although no patient required either temporary or permanent hemodialysis.

In our present study, chronic renal insufficiency was present preoperatively in 3.5% of our patients, including 14 patients (2%) who required hemodialysis support. The risk of postoperative renal dysfunction was occasionally greater with SR/SC clamping, although this trend was transient and eventual outcomes after SR/SC clamping were otherwise indistinguishable from outcomes after IR clamping. The rates of transient postoperative renal dysfunction after elective SR/SC clamping were 12.6% as opposed to 3.35% after IR clamping, which rates are significantly lower than those observed in other comparative series.[47]

Several measures can be implemented to lower the risk of renal damage during SR/SC clamping. One is to place the aortic clamp in a manner that preserves flow into the renal parenchyma. However, this placement is anatomically possible in only 22% of patients with AAA. Another measure is to create a beveled proximal aortic anastomosis that incorporates one of the renal artery orifices in order to expeditiously restore perfusion to one of the kidneys and leave only one renal artery to be reimplanted or grafted. However, this technique is restricted to patients with juxtarenal aneurysms. A 3rd measure, used only occasionally, is interrenal clamping of the aorta.[5] However, this increases the risk of renal damage.

Irrigation of the aortic lumen with saline while keeping the renal arteries occluded minimizes the risk of renal embolization. Topical renal cooling, however, appears to confer no clear benefit; it may even be associated with increased morbidity rates and can be made cumbersome by the hypothermic perfusion systems needed for such cooling.[48-50] We find intravenous volume loading and induction of diuresis with mannitol to be necessary before SC clamping.[51] In our current series, expeditious and meticulous proximal anastomosis decreased the mean clamping time in the SR/SC group. In general, we have found that the renal dysfunction attendant upon SR or SC clamping can be minimized by meticulously monitoring and rapidly treating intraoperative and postoperative hypotension.

Poorer outcomes, including a higher mortality rate, are often cited as reasons for avoiding concomitant renal revascularization during AAA surgery,[52] and there are no well established indications for the procedure in this circumstance. However, our experience and those of others[15,53,54] suggest that, despite adding to the surgical complexity, concomitant renal revascularization does not substantially increase the risk of death. Selected patients with associated renovascular disease should undergo full renal revascularization. In addition to the preservation of renal function, the indications for renal revascularization in patients with renal artery stenosis include poorly controlled hypertension, ischemic nephropathy, recurrent episodes of "flash" pulmonary edema, and congestive heart failure.[55] The added benefit of ameliorating renovascular hypertension and preventing further deterioration in renal function outweighs the added complexity of the combined procedure.

Postoperative acute renal failure after repair of intact or ruptured AAAs has a high mortality rate.[47,56] To avert acute failure, various therapeutic maneuvers for accelerating the recovery of glomerular filtration have been introduced. Modern dialysis—performed without anticoagulation and with the use of biocompatible membranes—reduces recovery time by activating fewer neutrophils and less complement. Using bicarbonate (rather than acetate) as a buffer reduces cardiovascular instability and provides more precise regulation of volume removal.

Intestinal and Other Visceral Complications

Intestinal and other visceral ischemia is a significant risk factor for early postoperative death, especially when complicated by bowel infarction and perforation. Several prospective studies have shown an incidence of 1% to 2% and associated mortality rates of 40% to 100%.[57,58] In our current series, mesenteric ischemia developed in 6 patients (3%) in the SR/SC group (2 with ruptured and 4 with intact AAAs), in comparison with 3 patients (0.6%) in the IR group (all with intact AAAs). Moreover, 2 of the 4 patients with intact aneurysms in the SR/SC group died of their aneurysms, versus none in the IR group. The mechanism for intestinal ischemia after AAA repair is atheroembolization or temporary or permanent interruption of blood flow by clamping or ligation. Recent studies using multivariate regression analysis have shown no statistically significant correlation between clamping level and the development of visceral ischemia or infarction.[11,12,59,60] However, the fact that the incidence of intestinal and other visceral ischemia is higher after operation for ruptured AAAs underscores the important causative role of poor hemodynamics in mesenteric vasoconstriction, hypoperfusion, and nonocclusive intestinal ischemia.[61]

Reimplantation of the inferior mesenteric artery is warranted when a preoperative angiogram shows occlusion of both internal iliac arteries, or when backflow from the patent inferior mesenteric artery is absent or poor. In at least 1 report, a stump pressure of less than 40 mmHg was cited as an indication for reimplantation,[62] although in that instance higher pressure failed to avert colonic necrosis.

Postoperative identification of mesenteric ischemia requires a high index of suspicion, and diagnosis is greatly complicated by the systemic and abdominal changes that typically occur after aortic surgery. However, 95% of ischemic lesions in this setting affect the rectum or the sigmoid or descending colon, and so are within reach of the sigmoidoscope.[63]

Other Considerations

In our current series, consequential infrainguinal arterial disease that required concomitant AAA repair and peripheral revascularization arose in 11 patients in the SR/SC group versus 46 in the IR clamp group (5.5 % vs 8.9%). Early graft-related complications that required revision (graft thrombosis and distal atheroembolism) arose in 6 patients in the SR/SC clamp group versus 18 in the IR group (3% vs 3.5%), a statistically insignificant difference. Anastomotic hemorrhage that required abdominal reexploration developed in 3 patients in the SR/SC group versus 5 in the IR group (1.5% vs 1%). No patient in either clamp group developed a pseudoaneurysm, graft-enteric erosion or fistula, or graft infection. In addition, we have found only a slightly greater transfusion requirement with SC clamping and have seen no cases of clinically apparent coagulopathy in patients undergoing either SC or IR clamping.

Several authors have cautioned against performing other procedures concomitantly with AAA repair[64] on the grounds that this will prolong operating time or complicate the primary surgical procedure. While we do not dispute the extra time and complexity, we have found that such combinations add very little to morbidity or mortality, but tend instead to shorten convalescence and thereby to decrease the overall cost of the hospital stay.

Conclusions

In the setting of IR AAA repair, when cuff dissection is a likely hazard, SR or SC clamping is our preferred method of achieving proximal control of the IR aorta. Selection of the best approach to gain the needed arterial exposure, careful dissection of the pararenal and paravisceral aorta, and close adherence to the proper sequence for clamping and unclamping the aorta and visceral branches are paramount and might be even more crucial than the actual cross-clamp position in reducing associated mortality and morbidity.

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