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Incidence of and risk factors for bowel ischemia after abdominal aortic aneurysm repair

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Background: Bowel ischemia is a rare but devastating complication after abdominal aortic aneurysm (AAA) repair. Its rarity has prohibited extensive risk-factor analysis, particularly since the widespread adoption of endovascular AAA repair (EVAR); therefore, this study assessed the incidence of postoperative bowel ischemia after AAA repair in the endovascular era and identified risk factors for its occurrence.

Methods: All patients undergoing intact or ruptured AAA repair in the Vascular Study Group of New England (VSGNE) between January 2003 and November 2014 were included. Patients with and without postoperative bowel ischemia were compared and stratified by indication (intact and ruptured) and treatment approach (open repair and EVAR). Criteria for diagnosis were endoscopic or clinical evidence of ischemia, including bloody stools, in patients who died before diagnostic procedures were performed. Independent predictors of postoperative bowel ischemia were established using multivariable logistic regression analysis.

Results: Included were 7312 patients, with 6668 intact (67.0% EVAR) and 644 ruptured AAA repairs (31.5% EVAR). The incidence of bowel ischemia after intact repair was 1.6% (open repair, 3.6%; EVAR, 0.6%) and 15.2% after ruptured repair (open repair, 19.3%; EVAR, 6.4%). Ruptured AAA was the most important determinant of postoperative bowel ischemia (odds ratio [OR], 6.4, 95% confidence interval [CI], 4.5-9.0), followed by open repair (OR, 2.9; 95% CI, 1.8-4.7). Additional predictive patient factors were advanced age (OR, 1.4 per 10 years; 95% CI, 1.1-1.7), female gender (OR, 1.6; 95% CI, 1.1-2.2), hypertension (OR, 1.8; 95% CI, 1.1-3.0), heart failure (OR, 1.8; 95% CI, 1.2-2.8), and current smoking (OR, 1.5; 95% CI, 1.1-2.1). Other risk factors included unilateral interruption of the hypogastric artery (OR, 1.7; 95% CI, 1.0-2.8), prolonged operative time (OR, 1.2 per 60-minute increase; 95% CI, 1.1-1.3), blood loss >1 L (OR, 2.0; 95% CI, 1.3-3.0), and a distal anastomosis to the femoral artery (OR, 1.7; 95% CI, 1.1-2.7). Bowel ischemia patients had a significantly higher perioperative mortality after intact (open repair: 20.5% vs 1.9%; _P_ < .001; EVAR: 34.6% vs 0.9%; _P_ < .001) as well as after ruptured AAA repair (open repair: 48.2% vs 25.6%; _P_ < .001; EVAR: 30.8% vs 21.1%; _P_ < .001).

Conclusions: This study underlines that although bowel ischemia after AAA repair is rare, the associated outcomes are very poor. The cause of postoperative bowel ischemia is multifactorial and can be attributed to patient factors and operative characteristics. These data should be considered during preoperative risk assessment and for optimization of both the patient and the procedure in an effort to reduce the risk of postoperative bowel ischemia. (J Vasc Surg 2016;64:1384-91.)

Bowel ischemia is a well-known complication after abdominal aortic aneurysm (AAA) repair. After elective AAA surgery, the occurrence of bowel ischemia is rare, with a reported incidence of 1% to 3% for open repair and 0.5% to 3% for endovascular AAA repair (EVAR).[1-9] Yet, the importance of postoperative bowel ischemia should not be underestimated, as the associated perioperative mortality has been reported to be as high as 50%.[2,9] Furthermore, the incidence of bowel ischemia is substantially higher in patients undergoing repair of a ruptured AAA, with similar increases in resulting mortality.[1,9-11]

Previous studies have identified several risk factors, including rupture, age, renal insufficiency, operative time, (micro) embolizations in supplying vessels, and proximal clamp location during open repair.[2,9,12,13] However, the rarity of postoperative bowel ischemia has prohibited extensive risk-factor analysis, particularly among EVAR patients. Aside from limited evidence, the role of several other factors that have previously been implicated remains disputed. Although some studies determined that hypogastric artery interruption—either through ligation/occlusion during open repair or embolization during EVAR—is an innocuous procedure,[4,14-16] other studies determined that disruption of hypogastric blood flow is associated with ischemic

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complications, including bowel ischemia.[2,5,12,17-19] There is also conflicting evidence on the benefits of EVAR compared with open repair. Perry et al[13] determined that EVAR was associated with significantly lower bowel ischemia rates. Becquemin et al,[9] however, reported no difference in the risk of bowel ischemia between open repair and EVAR patients and concluded that other factors, such as rupture and operative time, are more important predictors.

The primary aim of this study was to assess the incidence of postoperative bowel ischemia after AAA repair in the endovascular era and identify overall and procedure-specific risk factors for its occurrence. As a secondary aim, we sought to determine the effect of bowel ischemia on the perioperative prognosis.

METHODS

For this study, we used the Vascular Study Group of New England (VSGNE) database. The VSGNE is a voluntary, cooperative group of clinicians, hospital administrators, and research personnel from 30 academic and nonacademic centers who prospectively gather data for 12 commonly performed vascular procedures, including AAA repair. The group strives to improve quality, safety, effectiveness, and costs of caring for patients with vascular disease through monitoring and evaluation of 140 detailed patient demographic, operative, and clinical outcome variables. Trained nurses or clinical data abstractors enter the data in the registry, and surgeons are responsible for the documentation of operative details and intraoperative complications. Researchers using the VSGNE database are blinded to patient, surgeon, and hospital identifiers. The data are validated through audits of discharge claims from each of the participating institutions.[20] More details on this regional registry can be found at http://www.vsgne.org. The Beth Israel Deaconess Medical Center Institutional Review Board approved this study, and patient consent was waived due to the deidentified nature of the data.

All patients undergoing repair of intact or ruptured AAA between January 2003 and November 2014 were included. Criteria for the diagnosis of bowel ischemia were colonoscopic evidence of ischemia, bloody stools in a patient who died before colonoscopy or laparotomy could be performed, or a clinical diagnosis of bowel ischemia treated with medical management only, as defined by the Vascular Quality Initiative.

Baseline and intraoperative characteristics as well as postoperative outcomes were compared between patients with and without bowel ischemia. Baseline characteristics included demographics, comorbidities, and maximal aneurysm diameter. Heart failure was defined as any documented congestive heart failure. Intraoperative characteristics included operative time, blood loss, (un)intentional hypogastric artery coverage by the endograft, and interruption of a hypogastric artery because of ligation/occlusion during open repair or embolization during EVAR. Additional procedure-specific variables were evaluated, which for open repair included concomitant procedures, proximal clamp location, type of graft (tube vs bifurcation), and inferior mesenteric artery (IMA) management, and for EVAR included concomitant procedures, arterial injury, and endoleak at completion.

Postoperative outcomes included 30-day mortality and in-hospital adverse outcomes, including renal deterioration, leg ischemia, wound complication, myocardial infarction, congestive heart failure, respiratory complications, >3 units of transfusion, return to the operating room, prolonged length of stay in the intensive care unit (ICU), and prolonged postoperative hospital length of stay.

Deterioration of renal function was defined as an increase in postoperative creatinine >0.5 mg/dL or need for dialysis (peritoneal dialysis, hemodialysis, or hemofiltration), or both. Leg ischemia was considered in case of loss of a previously palpable pulse, previously measurable Doppler signals, decrease in the ankle-brachial index >.15, blue toe, or tissue loss. Wound complications ranged between a superficial wound separation or infection and return to the operating room. Myocardial infarction was considered when one of the following was documented: isolated troponin elevation, electrocardiogram change, or clinical evidence of myocardial infarction. Congestive heart failure was defined as a new onset of pulmonary edema requiring transfer or treatment in an ICU. Respiratory complications included pneumonia (lobar infiltrate on chest radiography and pure growth of a recognized pathogen), or need for reintubation after initial weaning from the ventilator. Prolonged length of stay was defined as >7 days postoperatively for open repair and >2 days for EVAR, in accordance with the Center for Medicare and Medicaid Services clinical benchmarks.[8] Prolonged ICU length of stay for open repair was considered when the ICU stay was >48 hours after open repair.

Statistical analysis. Comparisons between those with and those without postoperative bowel ischemia were performed using Pearson χ^2 and Fisher exact testing for categoric variables and the Student *t*-test and Mann-Whitney *U* test for continuous data, where appropriate. Analyses were stratified by indication for the procedure (intact and ruptured) and treatment approach (open repair and EVAR). Independent predictors of postoperative bowel ischemia were established using multivariable logistic regression analysis. Individual factors were first tested by univariate analysis. Variables with a P value $\leq .1$ were subsequently entered into the multivariable model, after which the final model was obtained using stepwise backward elimination (exit $P > .05$). EVAR patients were assigned a separate category for procedure characteristics specific to open repair, and vice versa, to avoid exclusion of patients when including procedure-specific variables into the multivariable model. All tests were two-sided, and significance was considered when the P value was $<.05$. Statistical analysis was performed using SPSS Statistics 21 software (IBM Corp, Armonk, NY).

RESULTS

We identified 7389 patients, of whom 77 (1.0%) were excluded because of missing data on bowel ischemia occurrence. The remaining 7312 patients (intact, 91.2%;

Table I. Baseline characteristics

Variables	Intact AAA					
	Open repair			EVAR		
	Bowel ischemia			Bowel ischemia		
	Yes (n = 78)	*No (n = 2118)*	P *value*	*Yes (n = 26)*	*No (n = 4446)*	P *value*
Age, mean (SD), years	73.1 (7.6)	70.0 (8.5)	<.001	77.2 (7.2)	74.0 (8.6)	.054
Female gender	29 (37)	596 (28.1)	.082	12 (46)	877 (19.7)	.001
Hypertension	73 (94)	1753 (82.8)	.012	26 (100)	3772 (84.9)	.025
Diabetes	7 (9)	298 (14.1)	.20	7 (27)	864 (19.4)	.34
CAD	23 (29)	662 (31.3)	.74	16 (62)	1484 (33.4)	.002
CHF	13 (17)	122 (5.8)	<.001	7 (27)	483 (10.9)	.009
CABG/PCI	20 (26)	610 (28.8)	.59	11 (42)	1371 (30.9)	.21
COPD	35 (45)	730 (34.5)	.058	10 (38)	1505 (33.9)	.62
Renal insufficiency	8 (11)	134 (6.4)	.16	4 (17)	262 (6.0)	.047
Dialysis			.003			<.001
Working transplant	1 (1)	3 (0.1)		0 (0)	7 (0.2)	
On dialysis	2 (3)	10 (0.5)		2 (8)	32 (0.7)	
Smoking			.29			.80
Never	9 (12)	179 (8.5)		4 (15)	608 (13.7)	
Past	31 (40)	1021 (48.3)		13 (50)	2512 (56.6)	
Current	38 (49)	916 (43.3)		9 (35)	1322 (29.8)	
Max diameter, mean (SD), mm	60.8 (15.2)	60.3 (13.9)	.78	56.1 (20.5)	56.9 (18.5)	.84
	Ruptured AAA					
	(n = 85)	*(n = 356)*		*(n = 13)*	*(n = 190)*	
Age, mean (SD), years	74.0 (7.8)	72.7 (9.4)	.44	72.8 (10.0)	73.3 (9.7)	.86
Female gender	22 (26)	69 (19.4)	.18	4 (31)	45 (23.7)	.52
Hypertension	65 (79)	273 (77.6)	.74	12 (92)	160 (84.7)	.70
Diabetes	13 (16)	45 (12.8)	.44	3 (23)	27 (14.4)	.42
CAD	26 (33)	96 (27.9)	.38	3 (23)	53 (28.2)	>.99
CHF	10 (12)	32 (9.2)	.39	0 (0)	24 (12.8)	.37
CABG/PCI	17 (21)	76 (21.7)	.89	1 (8)	32 (17.0)	.70
COPD	41 (49)	129 (37.1)	.048	7 (54)	53 (28.3)	.052
Renal insufficiency	15 (20)	47 (14.0)	.19	0 (0)	29 (16.0)	.36
Dialysis			.70			>.99
Working transplant	0 (0)	2 (0.6)		0 (0)	0 (0)	
On dialysis	0 (0)	1 (0.3)		0 (0)	3 (1.6)	
Smoking			.45			.49
Never	11 (14)	49 (14.3)		1 (8)	43 (22.8)	
Past	28 (36)	148 (43.1)		5 (42)	71 (37.6)	
Current	39 (50)	146 (42.6)		6 (50)	75 (39.7)	
Max diameter, mean (SD), mm	78.1 (20.1)	76.5 (19.6)	.53	83.6 (24.9)	73.0 (19.6)	.086

AAA, Abdominal aortic aneurysm; *CABG,* coronary artery bypass grafting; *CAD,* coronary artery disease; *CHF,* congestive heart failure; *COPD,* chronic obstructive pulmonary disease; *EVAR,* endovascular aneurysm repair; *PCI,* percutaneous coronary intervention; *SD,* standard deviation.
Data are presented as number (%) unless otherwise indicated.

rupture. 8.8%) were included, with 4675 (63.9%) undergoing EVAR and 2637 (36.1%) undergoing open repair. Among open repairs, 441 (16.7%) were performed for ruptured AAA, and 203 patients (4.3%) underwent EVAR for rupture. Bowel ischemia was diagnosed in 202 patients (2.8%), with 91 (1.2%) requiring surgical treatment. The incidence of bowel ischemia was significantly higher after open repair than after EVAR (6.2% vs 0.8%; $P < .001$). After stratification by indication, this difference remained for intact (3.6% vs 0.6%; $P < .001$) and ruptured AAA repair (19.3% vs 6.4%; $P < .001$).

Baseline characteristics. Baseline characteristics are detailed in Table I. Among intact open repair patients, those with postoperative bowel ischemia were significantly older than those without (73.1 vs 70.0 years, respectively; $P < .001$), and a trend was observed for intact EVAR (77.2 vs 74.0 years; $P = .054$). Patients with bowel ischemia after intact AAA repair more often had hypertension (open: 93.6% vs 82.8%; $P = .012$; EVAR: 100% vs 84.9%; $P = .025$), heart failure (open: 16.7% vs 5.8%; $P < .001$; EVAR: 26.9% vs 10.9%; $P = .009$), and were more frequently on dialysis preoperatively (open: 2.6% vs 0.5%; $P = .003$; EVAR: 7.7% vs 0.7%; $P < .001$). Patients with bowel ischemia treated with EVAR for intact aneurysms also had increased rates of coronary artery disease (61.5% vs 33.4%; $P = .002$).

Table II. A, Intraoperative characteristics of open repair

	Intact AAA			*Ruptured AAA*		
	Bowel ischemia			*Bowel ischemia*		
Variable	*Yes (n = 78)*	*No (n = 2118)*	P *value*	*Yes (n = 85)*	*No (n = 356)*	P *value*
Operative time, mean (SD), minutes	261.4 (108.1)	220.4 (89.5)	.001	227.2 (91.3)	199.4 (89.0)	.011
Blood loss >1 L	53 (68)	1126 (53.5)	.012	81 (96)	297 (83.9)	.001
Renal/visceral ischemia time >30 minutes	11 (14)	228 (11.0)	.34	14 (17)	54 (15.9)	.76
Transfusions ≥1 unit	38 (49)	617 (29.3)	<.001	81 (95)	305 (85.9)	.016
Retroperitoneal access	18 (23)	500 (23.7)	.90	5 (6)	26 (7.3)	.64
Proximal clamp location			<.001			.37
Infrarenal	42 (55)	1421 (67.8)		47 (57)	217 (62.5)	
Above one renal	7 (9)	225 (10.7)		5 (6)	27 (7.8)	
Above both renals	12 (16)	309 (14.7)		8 (10)	37 (10.7)	
Supraceliac	16 (21)	142 (6.8)		23 (28)	66 (19.0)	
Distal anastomosis			.049			.022
Aorta	37 (47)	1125 (53.5)		46 (55)	230 (66.3)	
Common iliac artery	18 (23)	536 (25.5)		15 (18)	70 (20.2)	
External iliac artery	3 (4)	137 (6.5)		5 (6)	9 (2.6)	
Common femoral artery	20 (26)	304 (14.5)		18 (21)	38 (11.0)	
Hypogastric artery digitation/occlusion			.21			.036
Unilateral	9 (12)	136 (6.5)		10 (12)	18 (5.2)	
Bilateral	2 (3)	66 (3.1)		1 (1)	14 (4.0)	
IMA			.012			.48
Occluded	32 (41)	914 (43.8)		45 (56)	204 (59.6)	
Ligated	28 (49)	1098 (52.6)		35 (43)	128 (37.4)	
Reimplanted	8 (10)	76 (3.6)		1 (1)	10 (2.9)	
Cold renal perfusion	3 (4)	141 (6.7)	.48	0 (0)	6 (1.7)	.60
Any concomitant procedure	13 (17)	325 (15.3)	.75	26 (31)	61 (17.1)	.005
Renal bypass	3 (4)	128 (6.0)	.62	0 (0)	3 (0.8)	>.99
Lower extremity bypass	2 (3)	35 (1.7)	.38	3 (4)	5 (1.4)	.19
Other abdominal procedure	4 (5)	120 (5.7)	>.99	8 (9)	20 (5.6)	.20
Thromboembolectomy	6 (8)	79 (3.7)	.075	19 (22)	39 (11.0)	.005
Delayed closure	0 (0)	0 (0)	–	36 (46)	72 (21.0)	<.001

AAA, Abdominal aortic aneurysm; *IMA,* inferior mesenteric artery; *SD,* standard deviation.
Data are presented as number (%) unless otherwise indicated.

Finally, among ruptured open repair patients, chronic obstructive pulmonary disease was more frequently present in those with postoperative bowel ischemia (48.8% vs 37.1%; $P = .048$).

Intraoperative characteristics. For both intact and ruptured open repair, operative time was significantly longer among patients with postoperative bowel ischemia (intact: 261 vs 220 minutes; $P = .001$; rupture: 227 vs 199 minutes; $P = .011$, respectively; Table II, *A*). Similarly, blood loss >1 L (intact: 67.9% vs 53.5%; $P = .012$; rupture: 96.4% vs 83.9%; $P = .001$), and intraoperative blood transfusion (intact: 49.4% vs 29.3%; $P < .001$; rupture 95.3% vs 85.9%; $P = .016$) occurred more frequently among those with postoperative bowel ischemia. In addition, the graft was anastomosed to the femoral artery more frequently in patients with bowel ischemia (intact: 25.6% vs 14.5%; $P = .049$; rupture: 21.4% vs 11.0%; $P = .022$). Among the intact open repair patients, those with postoperative bowel ischemia were more likely to have had the IMA reimplanted (10.3% vs 3.6%; $P = .012$) and the proximal clamp placed above the renal arteries (45.5% vs 32.2%; $P < .001$). Also, in patients undergoing open repair for ruptured AAA, bowel ischemia was associated with a higher rate of hypogastric artery ligation (12.0% vs 5.2%; $P = .036$), although this relation could not be established for bilateral hypogastric ligation (1.2% vs 4.0%).

Similar to open repair, intact EVAR patients with postoperative bowel ischemia had a longer operative time (255 vs 158 minutes; $P = .003$; Table II, *B*), extensive blood loss (15.4% vs 2.4%; $P = .003$), and intraoperative blood transfusion (30.8% vs 6.0%; $P < .001$) compared with those without bowel ischemia. In addition, arterial injury (19.2% vs 2.6%) and type III endoleak at completion (7.7% vs 0.3%; $P = .004$) occurred more often among those with bowel ischemia. Further, an iliac angioplasty or stenting procedure and a thromboembolectomy were also more often performed in patients with postoperative bowel ischemia (26.9% vs 9.9%; $P = .004$; 11.5% vs 0.8%; $P = .001$, respectively).

Postoperative outcomes. Postoperative outcomes are listed in Table III. Considerably higher rates of 30-day mortality were found in patients with postoperative bowel ischemia after open repair for intact aneurysms

Table II. B, Intraoperative characteristics endovascular aneurysm repair (EVAR)

	Intact AAA			*Ruptured AAA*		
	Bowel ischemia			*Bowel ischemia*		
Variable	*Yes (n = 26)*	*No (n = 4446)*	P *value*	*Yes (n = 13)*	*No (n = 190)*	P *value*
Operative time, mean (SD), minutes	254.8 (151.3)	158.4 (73.9)	.003	199.3 (98.6)	178.5 (86.4)	.41
Anesthesia			.81			.82
Local	0 (0)	55 (1.2)		2 (17)	29 (15.6)	
Locoregional	2 (8)	412 (9.3)		0 (0)	6 (3.2)	
General	24 (92)	3955 (89.4)		10 (83)	151 (81.2)	
Blood loss >1 L	4 (15)	106 (2.4)	.003	4 (31)	25 (13.4)	.10
Transfusions ≥1 unit	8 (31)	264 (6.0)	<.001	11 (85)	118 (62.1)	.14
Arterial injury	5 (19)	108 (2.6)	<.001	0 (0)	9 (5.0)	>.99
Endoleak						
I	1 (4)	116 (2.6)	.50	0 (0)	5 (2.7)	>.99
II	4 (15)	938 (21.2)	.63	1 (8)	21 (11.4)	>.99
III	2 (8)	15 (0.3)	.004	0 (0)	3 (1.6)	>.99
IV	1 (4)	74 (1.7)	.36	1 (8)	4 (2.2)	.27
Overall hypogastric coverage			.67			.33
Unilateral	3 (12)	497 (11.3)		0 (0)	26 (14.1)	
Bilateral	1 (4)	71 (1.6)		0 (0)	3 (1.6)	
Unintentional hypogastric coverage			.80			.66
Unilateral	1 (4)	92 (2.1)		0 (0)	3 (0)	
Bilateral	0 (0)	12 (0.3)		0 (0)	0 (0)	
Hypogastric embolization pre-op			.89			-
Unilateral	1 (4)	113 (2.5)		0 (0)	0 (0)	
Bilateral	0 (0)	10 (0.2)		0 (0)	0 (0)	
Any concomitant procedure	15 (58)	1282 (28.8)	.001	4 (31)	68 (35.8)	>.99
Hypogastric embolization			.39			.40
Unilateral	3 (12)	242 (5.4)		0 (0)	10 (5.3)	
Bilateral	0 (0)	10 (0.2)		0 (0)	0 (0)	
Graft extension	4 (15)	392 (8.8)	.28	2 (15)	29 (15.3)	>.99
Femoral endarterectomy	2 (8)	190 (4.3)	.31	0 (0)	13 (6.8)	>.99
Femorofemoral bypass	1 (4)	127 (2.9)	.53	2 (15)	30 (15.8)	>.99
Iliac angioplasty or stent	7 (27)	440 (9.9)	.004	1 (8)	17 (8.9)	>.99
Iliofemoral bypass	0 (0)	30 (0.7)	>.99	0 (0)	4 (2.1)	>.99
Renal angioplasty or stent	2 (8)	148 (3.3)	.22	1 (8)	3 (1.6)	.23
Other arterial reconstruction	2 (8)	104 (2.3)	.13	0 (0)	3 (1.6)	>.99
Thromboembolectomy	3 (12)	36 (0.8)	.001	1 (8)	10 (5.3)	.53
Repair arterial injury	0 (0)	48 (1.1)	>.99	0 (0)	2 (1.1)	>.99

AAA, Abdominal aortic aneurysm; *SD,* standard deviation.
Data are presented as number (%) unless otherwise indicated.

(20.5% vs 1.9%; $P < .001$), intact EVAR (34.6% vs 0.9%; $P < .001$), and open repair for ruptured AAA (48.2% vs 25.6%; $P < .001$). After EVAR for ruptured aneurysms, mortality was increased among patients with bowel ischemia, although significance was not achieved (30.8% vs 21.1%; $P = .49$). Bowel ischemia was also associated with various other complications, including wound, cardiovascular, and respiratory complications, acute kidney injury, leg ischemia, requirement for return to the operating room, and need for postoperative transfusions >3 units.

Predictors of bowel ischemia. Adjusted analysis (Table IV) showed surgery for a ruptured AAA was the most important determinant of postoperative bowel ischemia (odds ratio [OR], 6.4; 95% confidence interval [CI], 4.5-9.0). Also, open repair was associated with a considerable higher risk of bowel ischemia compared with EVAR (OR, 2.9; 95% CI, 1.8-4.7). Predictive demographic factors included advanced age (OR, 1.4 per 10 years; 95% CI, 1.1-1.7) and female gender (OR, 1.6; 95% CI, 1.1-2.2). Other patient factors associated with bowel ischemia included hypertension (OR, 1.8; 95% CI, 1.1-3.0), heart failure (OR, 1.8; 95% CI, 1.2-2.8), and current smoking (OR, 1.5; 95% CI, 1.1-2.1). Interruption of the hypogastric artery, because of ligation/occlusion during open repair or embolization during EVAR, was also associated with an increased risk of postoperative bowel ischemia (OR, 1.7; 95% CI, 1.0-2.8), although this association could not be established for bilateral occlusion. Additional operative risk factors for bowel ischemia were prolonged operative time (OR, 1.2 per 60-minute increase; 95% CI, 1.1-1.3), blood loss >1 L (OR, 2.0; 95% CI, 1.3-3.0), and aortofemoral artery anastomosis during open repair (OR, 1.7; 95% CI, 1.1-2.7).

DISCUSSION

This study demonstrates that although the incidence of bowel ischemia after AAA repair is low, it is

Table III. Postoperative outcomes

	Intact AAA					
	Open repair			EVAR		
	Bowel ischemia			Bowel ischemia		
Variable	*Yes (n = 78), No. (%)*	*No (n = 2118), No. (%)*	P *value*	*Yes (n = 26), No. (%)*	*No (n = 4446), No. (%)*	P *value*
Thirty-day mortality	16 (21)	41 (1.9)	<.001	9 (35)	41 (0.9)	<.001
Renal deterioration	36 (46)	252 (11.9)	<.001	15 (58)	144 (3.3)	<.001
Dialysis	11 (14)	39 (1.8)	<.001	6 (23)	15 (0.3)	<.001
Leg ischemia	9 (12)	36 (1.7)	<.001	5 (19)	41 (0.9)	<.001
Wound complication	14 (18)	71 (3.4)	<.001	2 (8)	30 (0.7)	.014
Myocardial infarction	11 (14)	105 (5.0)	<.001	2 (8)	70 (1.6)	.065
Congestive heart failure	12 (15)	78 (3.7)	<.001	5 (19)	46 (1.0)	<.001
Respiratory complication	38 (49)	222 (10.5)	<.001	15 (58)	83 (1.9)	<.001
>3 transfusions	21 (34)	131 (6.8)	<.001	6 (24)	54 (1.2)	<.001
Return to OR	37 (47)	118 (5.6)	<.001	14 (54)	70 (1.6)	<.001
Prolonged length of stay						
Hospital[a]	56 (72)	845 (39.9)	<.001	25 (96)	1110 (25.0)	<.001
ICU[b]	70 (90)	959 (45.3)	<.001	19 (73)	286 (6.4)	<.001
	Ruptured AAA					
	(n = 85)	*(n = 356)*		*(n = 13)*	*(n = 190)*	
Thirty-day mortality	41 (48)	91 (25.6)	<.001	4 (31)	40 (21.1)	.49
Renal deterioration	51 (65)	99 (28.0)	<.001	8 (67)	42 (22.2)	.002
Dialysis	16 (20)	21 (5.9)	<.001	2 (17)	9 (4.8)	.13
Leg ischemia	22 (26)	16 (4.5)	<.001	1 (8)	6 (3.2)	.38
Wound complication	17 (20)	39 (11.0)	.022	3 (23)	11 (5.8)	.050
Myocardial infarction	29 (35)	52 (14.6)	<.001	2 (15)	24 (12.6)	.68
Congestive heart failure	15 (18)	35 (9.9)	.038	2 (15)	17 (8.9)	.35
Respiratory complication	58 (69)	147 (41.4)	<.001	8 (67)	34 (17.9)	<.001
>3 transfusions	45 (74)	134 (47.3)	<.001	9 (82)	82 (45.8)	.028
Return to OR	50 (59)	86 (24.2)	<.001	9 (69)	32 (16.8)	<.001
Prolonged length of stay						
Hospital[a]	49 (58)	229 (64.3)	.25	9 (69)	151 (79.5)	.48
ICU[b]	63 (74)	259 (73.2)	.86	13 (100)	121 (63.7)	.005

AAA, Abdominal aortic aneurysm; *EVAR,* Endovascular aneurysm repair; *ICU,* intensive care unit; *OR,* operating room.
[a]Defined as >7 days for open repair, and >2 days for EVAR.
[b]Defined as >48 hours after open repair, and any ICU stay after EVAR.

associated with very poor outcomes. In addition to various complications, 30-day mortality was much worse in those with postoperative bowel ischemia, ranging between a factor of two among patients undergoing open repair for ruptured AAA and a factor of 38 among those undergoing EVAR for intact AAA. Adjusted analysis demonstrated that repair for a ruptured AAA and open repair were the most dominant predictors of bowel ischemia. Other factors included patient factors, such as age, gender, hypertension, heart failure, and smoking, as well as operative factors such as prolonged operative time and increased blood loss. Further, interruption of the hypogastric artery, because of ligation/occlusion during open repair or embolization during EVAR, and using the femoral artery for the distal anastomosis during open repair were also independent predictors of bowel ischemia.

Because the risks of bowel ischemia differ according to the indication of the AAA repair (intact vs ruptured) and the operative approach (open repair vs EVAR), the reported incidence varies according to the composition of the studied cohort. The study by Becquemin et al[9] with similar proportions of operative approach and ruptures as the present study found an overall bowel ischemia rate of 2.9%, which is comparable to the 2.8% in this study. When our results are compared with studies conducted among open repair patients only, the incidence of 3.6% for intact AAA is on the higher end, with previous studies showing occurrence rates between 1% and 3%.[1-3] This may be related to the fact that the diagnosis of bowel ischemia in our study could be established by a clinical basis or colonoscopy, whereas other studies required confirmation through colonoscopy for all cases. For open repair of ruptured AAA, the rate of 19.3% falls well within the reported range of 7% to 36%.[1,9,10,21] Furthermore, our results for EVAR are on the lower end of what has previously been reported for EVAR series, with 0.6% vs

Table IV. Independent predictors of bowel ischemia after abdominal aortic aneurysm (AAA) repair

Variable	*OR*	*95% CI*	*P value*
Age (per 10 years)	1.4	1.1-1.7	.002
Female gender	1.6	1.1-2.2	.008
Hypertension	1.8	1.1-3.0	.015
Heart failure	1.8	1.2-2.8	.008
Current smoking	1.5	1.1-2.1	.010
Open repair	2.9	1.8-4.7	<.001
Rupture	6.4	4.5-9.0	<.001
Hypogastric interruption			
Unilateral	1.7	1.0-2.8	.040
Bilateral	0.7	0.2-2.1	.55
Procedure time (per 60 min)	1.2	1.1-1.3	<.001
Blood loss >1 L	2.0	1.3-3.0	.002
Distal anastomosis			
Femoral artery	1.7	1.1-2.7	.012

CI, Confidence interval; *OR,* odds ratio.

0.5% to 3% for intact, and 6.4% vs 4% to 23% for ruptured EVAR.[4-8,11]

Although crude analysis in the study by Becquemin et al[9] demonstrated that open repair was followed by a higher rate of bowel ischemia compared with EVAR, no relation was established in adjusted analysis.[9] A study using the Nationwide Inpatient Sample, however, did show that open repair was an independent risk factor for bowel ischemia.[13] In line with the latter report, open surgery was associated with a 2.7-fold increased risk of bowel ischemia in our study. Confirming previous studies,[9,12] longer operative time and excessive blood loss were also established as predictive of bowel ischemia. As addressed previously, this risk should not be attributed to the duration of the procedure but rather to the technical difficulty it represents.[9]

Apart from operative stress, our adjusted analysis demonstrated that women were at a higher risk of bowel ischemia than men. The relation between female gender and higher risks of bowel ischemia has been demonstrated before[13] and is most likely because intraoperative difficulties are encountered more often in women as a result of their smaller vasculature.[22-24] These difficulties include embolic complications, which have been implicated as an important cause of postoperative bowel ischemia after open repair and EVAR.[4,6,25]

The role of the hypogastric arteries and their management remains disputed. Although some studies demonstrated that interruption the hypogastric arteries, because of ligation/occlusion during open repair or embolization or coiling during EVAR, can safely be performed,[4,14-16] others concluded that hypogastric artery interruption is associated with ischemic complications, including spinal, pelvic, and bowel ischemia.[2,5,7,12,17-19] In the present study, we found that disruption of one hypogastric artery was associated with increased risks of bowel ischemia postoperatively. The relation was demonstrated for unilateral interventions but could not be confirmed for two-sided interruption. This is most likely the result of the limited number of patients receiving bilateral hypogastric artery interruption ($n = 98$), the rarity of bowel ischemia ($n = 4$), and consequent lack of statistical power rather than a lack of association. These demonstrated risks emphasize the need to assess patency of the superior mesenteric artery and to evaluate any history of colonic surgery that could affect collateral flow in the colon. These data also highlight the potential benefit of using iliac branch graft systems in those with a high a priori risk of bowel ischemia. Of note, coverage of the hypogastric artery by the endograft during EVAR—unilateral or bilateral—was not associated with an increased risk of bowel ischemia. This is likely related to the fact that a large number of patients in this group did not undergo hypogastric embolization, indicating that their hypogastric artery may not have been patent at the time of surgery or that with a short seal zone in the distal common iliac and no hypogastric aneurysm, embolization was not needed and collateral circulation was maintained. Notably, no distinction could be made between the use of coils and plugs in this database.

Similar to previous studies,[9,12] we found that the femoral artery as the target for the distal anastomosis was also predictive of bowel ischemia. The choice for femoral anastomosis is often related to aneurysmal or occlusive disease in the common or external iliac arteries. Although the hypogastric artery is typically not ligated in case of aortofemoral anastomosis, occlusive disease in the external iliac may limit retrograde flow into the hypogastric arteries. Patients with a femoral anastomosis also typically have a more advanced state of atherosclerosis generally, with the potential of (micro)embolization of dislodged atherothrombotic debris, atherosclerosis of the mesenteric vessels, and poor collateral flow through the marginal artery in case of IMA or hypogastric interruption.[4,6,25] Because smoking is a strong etiologic contributor to atherosclerosis, these factors may also explain the increased risks associated with current smoking.

Interestingly, Brewster et al[2] found that IMA ligation was the most important predictor for bowel ischemia after open repair. Yet in our study, not ligation but rather reimplantation of the IMA was associated increased risks of bowel ischemia. Although this association was lost in multivariable analysis, our results indicate that IMA reimplantation is currently not standard practice and that it is only performed in those at the highest risk of suffering from postoperative bowel ischemia.

This study has several limitations: First, because the VSGNE collects data through a registry, the potential exists for under-reporting of data.

Second, the severity of the bowel ischemia beyond the need for surgery and the extent of the bowel resection were unknown.

Third, we were unable to distinguish patients with a clinical diagnosis of postoperative bowel ischemia from those who underwent endoscopic diagnostic procedures, which precluded subanalysis or sensitivity analysis between these patients. Also, the importance of prior abdominal surgery, particularly previous bowel resection, has been addressed in prior studies[4,6,9] but remains unclear. Unfortunately, data on prior abdominal surgery were not documented, precluding its consideration in the multivariable model.

In addition, although many operative characteristics were evaluated for their association with postoperative bowel ischemia, other factors, including hypogastric artery revascularization and mesenteric vessel stenting, were unfortunately not documented in this data set. It should also be noted that the bowel ischemia was presumed to be in the colon, but the data set did not distinguish small-bowel ischemia from colonic ischemia.

Finally, owing to the limited follow-up data, we were unable to determine the incidence of late laparotomy and the effect of perioperative bowel ischemia on long-term survival.

CONCLUSIONS

This study underlines that although bowel ischemia after AAA repair is rare, the associated outcome is very poor. Postoperative bowel ischemia is caused by multiple factors. In contrast to some previous work, open repair proved to be an important predictor. Other risk factors included age, gender, hypertension, heart failure, and factors indicative of more operative stress, including longer operative time and extensive blood loss. Interruption of the hypogastric artery and the distal anastomosis to the femoral artery were also established as risk factors for bowel ischemia. These data should be considered during operative planning in an effort to adequately assess patient risk for bowel ischemia and undertake efforts to reduce it.

AUTHOR CONTRIBUTIONS

Conception and design: KU, SZ, PS, JD, DB, MS
Analysis and interpretation: KU, SZ, PS, MS
Data collection: Not applicable
Writing the article: KU
Critical revision of the article: KU, SZ, PS, DB, HV, MS
Final approval of the article: KU, SZ, PS, JD, DB, HV, MS
Statistical analysis: KU
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