A comparison of open surgery versus endovascular repair of unstable ruptured abdominal aortic aneurysms

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Objective: **Two randomized trials to date have compared open surgery (OS) and endovascular (EVAR) repair for ruptured abdominal aortic aneurysm (rAAA); however, neither addressed optimal management of unstable patients. Single-center reports have produced conflicting data regarding the superiority of one vs the other, with the lack of statistical power due to low patient numbers. Furthermore, previous studies have not delineated between the outcomes of stable patients with a contained rupture vs those patients with instability. Our objective was to compare 30-day outcomes in patients undergoing OS vs EVAR for all rAAAs, focusing specifically on patients with instability.**

Methods: **Patients who underwent repair of rAAA were identified from the American College of Surgeons (ACS) National Surgical Quality Improvement Program (NSQIP) database (2005 to 2010). Unstable patients with rupture were identified as those who were American Society of Anesthesiologists Physical Status Classification 4 or 5 requiring emergency repair with at least one of the following: preoperative shock, preoperative transfusion of >4 units, preoperative intubation, or preoperative coma or impaired sensorium. Univariable and multivariable logistic regression analyses were performed.**

Results: **Of the 1447 patients with rAAA, 65.5% underwent OS and 34.5% EVAR. Forty-five percent were unstable, and for these patients, OS was performed in 71.3% and EVAR in 28.7%. The 30-day mortality rate was 47.9% (OS, 52.8%; EVAR, 35.6%; $P < .0001$) for unstable rAAAs and was 22.4% for stable rAAAs (OS, 26.3%; EVAR, 16.4%; $P = .001$). Amongst patients with unstable rAAA, 26% had a myocardial infarction or cardiac arrest ≤30 days (OS, 29.0%; EVAR, 19.1%; $P = .006$), and 17% needed postoperative dialysis (OS, 18.7%; EVAR, 12.8%; $P = .04$). Amongst patients with stable rAAA, 13.6% had a myocardial infarction or cardiac arrest ≤30 days (OS, 14.9%; EVAR, 11.6%; $P = .20$), and 11.5% needed postoperative dialysis (OS, 13.3%; EVAR, 8.7%; $P = .047$). Multivariable analyses showed OS was a predictor of 30-day mortality for unstable rAAA (odds ratio, 1.74; 95% confidence interval, 1.16-2.62) and stable rAAA (odds ratio, 1.64; 95% confidence interval, 1.10-2.43).**

Conclusions: **Approximately one-third of patients treated for rAAA undergo EVAR in NSQIP participating hospitals. Not surprisingly, unstable patients have less favorable outcomes. In both stable and unstable rAAA patients, EVAR is associated with a diminished 30-day mortality and morbidity. (J Vasc Surg 2014;60:1439-45.)**

Despite advances in trauma and critical care management, emergency systems, and operative techniques, treatment of ruptured abdominal aortic aneurysm (rAAA) is associated with significant morbidity and mortality. Endovascular aneurysm repair (EVAR) for this condition has recently gained acceptance.[1,2] For elective AAA repair, there are multiple randomized trials including Dutch Randomised Endovascular Aneurysm Management (DREAM),[3] Endovascular vs Open Abdominal Aortic Aneurysm Repair (EVAR I),[4] and Veterans Affairs Open vs Endovascular Repair (OVER),[5] that have compared open surgery (OS) with EVAR.

However, the Amsterdam Acute Aneurysm trial[6] has been the only randomized controlled trial (RCT) to date comparing OS vs EVAR for rAAA. Interestingly, the Amsterdam investigators did not find a perioperative survival benefit for EVAR. This trial, however, was isolated to patients with rAAA that were hemodynamically stable. Of significance, the trial excluded 78% of patients presenting with rAAA, many because of hemodynamic instability.

Earlier this year, the Immediate Management of the Patient with Rupture: Open vs Endovascular Repair (IMPROVE) trial[7] was published comparing EVAR vs OS for rAAA. Although this trial included unstable patients, the outcome of endovascular and open approaches were not compared in this cohort. Thus, no study in the current literature addresses the optimal management of unstable rAAAs. Our objectives with this evaluation were to

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use the American College of Surgeons (ACS) National Surgical Quality Improvement Program (NSQIP) database to compare 30-day outcomes in patients undergoing OS vs EVAR for all rAAAs and specifically for the subset of patients with unstable rAAAs.

METHODS

Data set. Data were extracted from the 2005 to 2010 NSQIP Participant Use Data Files. These are multicenter, prospective databases with 121 (years 2005 to 2006), 183 (year 2007), 211 (year 2008), 237 (year 2009), and 258 (year 2010) participating academic and community United States hospitals. Data are collected inclusive of >250 perioperative variables. In NSQIP, a participant hospital's surgical clinical reviewer (SCR) uses a variety of methods to capture, one of which is medical record abstraction. The data are collected based on strict criteria formulated by a committee. To ensure the data collected are of high quality, the NSQIP has developed training mechanisms for the SCR, and inter-rater reliability audit of participating sites is conducted. Inter-rater reliability audits revealed that in 2008, total disagreements were only 1.60% (>140,000 audited fields).[8] NSQIP hospitals are required to provide complete 30-day follow-up on at least 95% of patients.[9] The processes of SCR training, inter-rater reliability auditing, data collection, and sampling methodology have been previously described in detail.

Patients. Patients treated for rAAA were identified from the ACS NSQIP database (2005 to 2010) using the Current Procedural Terminology (CPT) code (American Medical Association, Chicago, Ill) of the procedures combined with International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) diagnosis code for rAAA (441.3). EVAR was defined with any of the CPT codes 34800, 34802, 34803, 34804, 34805, or 34825. OS repair was defined with CPT codes 35801 or 35102. Preoperative data included demographic, lifestyle, comorbidity, and other variables.[10] Because patient information was acquired from the publicly available NSQIP data set, with patients not being individually identified, Institutional Review Board approval was waived.

Definition of hemodynamic instability. There is not a specific code available that connotes hemodynamic instability; thus, we created a surrogate using a series of qualifying codes. A patient with a rAAA was considered "unstable" if all of the following three criteria were met:

1) The operation was an emergency;
2) The patient had an American Society of Anesthesiologists (ASA) Physical Status Classification of 4 (a patient with severe systemic disease that is a constant threat to life) or 5 (a moribund patient who is not expected to survive without the operation); and
3) One or more of (1) preoperative shock/systemic inflammatory response syndrome or (2) preoperative packed red blood cell transfusion >4 units or (3) preoperative intubation, or (4) preoperative impaired sensorium (defined in NSQIP as acute confusion/delirium/mental status changes ≤48 hours of surgical procedure).

Outcome. The primary outcome of interest was 30-day mortality. Secondary outcomes included 30-day cardiac arrest or myocardial infarction (MI), acute renal failure, and failure to wean from the ventilator ≤48 hours, as well as a number of other postoperative complications, which are reported in Table I. The NSQIP database captures outcomes for 30 postoperative days.

Statistical analysis. Univariable analysis was performed using the Pearson χ^2 test or the Fisher exact test for categoric variables and the *t*-test or *F* test for continuous variables. Forward stepwise multiple logistic regression analyses were performed to assess factors associated with the primary and all of the secondary study outcomes. The inclusion criterion for multivariable analysis was $P < .1$ on univariable analysis. Statistical analyses were performed using SPSS 17.0 software (SPSS Inc, Chicago, Ill). A P value of $< .05$ was considered significant.

RESULTS

From 2005 to 2010, 1447 patients underwent an operation for rAAA; of these, 793 patients (54.8%) were stable, and the rest (45.2%) were classified as unstable. The 30-day mortality rate for the overall cohort was 33.9% (OS, 39.3%; EVAR, 23.6%; $P < .0001$). Preoperative demographics and comorbidities are listed in Table II, and postoperative outcomes are included in Table I.

Patients with stable rAAAs. Amongst the 793 stable ruptures, 482 (60.8%) underwent OS and 311 (39.2%) underwent EVAR. The data in Table II show that in the stable rAAA cohort, patients with a higher ASA class tended to be selected for OS rather than EVAR ($P = .02$). There were more patients with diabetes (15% vs 10%; $P = .02$), chronic obstructive pulmonary disease (20.3% vs 14.9%; $P = .03$), and on dialysis (2.6% vs 0.6%; $P = .03$) in the EVAR subgroup than in the OS subgroup.

The 30-day mortality was significantly greater for OS vs EVAR (26.3% vs 16.4%; $P = .001$). The 30-day rate of acute renal failure requiring dialysis was 13.3% for OS vs 8.7% for EVAR ($P = .047$). The rate of cardiac arrest or MI was 14.9% for OS vs 11.6% for EVAR ($P = .20$). Although there was no difference in rate of cardiac arrest or MI, OS patients had a higher rate of cardiac arrest alone compared with EVAR (10.2% vs 5.5%; $P = .02$). The rate of ventilator dependence >48 hours was 44.6% for OS and 15.4% for EVAR ($P < .0001$). The two groups had a similar rate of return to the operating room (23% vs 21%; $P = .42$). The mean hospital length of stay was significantly shorter for EVAR vs OS (8.7 vs 13.8 days; $P < .0001$). Compared with EVAR patients, patients who underwent OS had a higher rate of urinary tract infection (5.6% vs 1.9%; $P = .01$), pneumonia (20.1% vs 8.4%; $P < .0001$), reintubation (11.8% vs 6.4%; $P = .01$), deep venous thrombosis (4.8% vs 1.9%; $P = .04$), and coma (1.9% vs 0; $P = .01$). Table I reports for details on univariable analysis of

Table I. Postoperative Events with Univariable Analysis

	Stable rAAA			*Unstable rAAA*		
Thirty-day outcomes[a]	*OS (n = 482)*	*EVAR (n = 311)*	P *value*[b]	*OS (n = 466)*	*EVAR (n = 188)*	P *value*[b]
Wound infection						
Superficial	8 (1.7)	9 (2.9)	.32	8 (1.7)	10 (5.3)	.02
Deep	3 (0.6)	2 (0.6)	.99	3 (0.6)	3 (1.6)	.4
Wound dehiscence	10 (2.1)	3 (1.0)	.27	12 (2.6)	3 (1.6)	.57
Urinary tract infection	27 (5.6)	6 (1.9)	.01	34 (7.3)	15 (8.0)	.75
Transfusion >4 units PRBC post-op	111 (23.0)	61 (19.6)	.26	138 (29.6)	58 (30.9)	.76
Pneumonia	97 (20.1)	26 (8.4)	<.0001	111 (23.8)	37 (19.7)	.25
Reintubation	57 (11.8)	20 (6.4)	.01	41 (8.8)	24 (12.8)	.13
Failure to extubate at 48 hours	215 (44.6)	48 (15.4)	<.0001	210 (45.1)	68 (36.2)	.04
Deep venous thrombosis	23 (4.8)	6 (1.9)	.04	18 (3.9)	9 (4.8)	.66
Pulmonary embolism	10 (2.1)	4 (1.3)	.58	5 (1.1)	4 (2.1)	.29
Renal insufficiency	22 (4.6)	7 (2.3)	.09	25 (5.4)	6 (3.2)	.31
Acute renal failure requiring dialysis	64 (13.3)	27 (8.7)	.047	87 (18.7)	24 (12.8)	.07
Stroke	8 (1.7)	4 (1.3)	.77	13 (2.8)	2 (1.1)	.18
Coma	9 (1.9)	0	.01	6 (1.3)	0	.19
Cardiac arrest	49 (10.2)	17 (5.5)	.02	114 (24.5)	26 (13.8)	.003
MI	26 (5.4)	21 (6.8)	.43	24 (5.2)	12 (6.4)	.53
Return to operating room	111 (23.0)	64 (20.6)	.42	98 (21.0)	45 (23.9)	.42
Hospital length of stay, days	13.8 ± 16.3	8.7 ± 13.8	<.0001	12.7 ± 16.9	12.4 ± 14.8	.87
Death	127 (26.3)	51 (16.4)	.001	246 (52.8)	67 (35.6)	<.0001

EVAR, Endovascular aortic repair; *MI,* myocardial infarction; *OS,* open surgery; *PRBC,* packed red blood cells; *rAAA,* ruptured abdominal aortic aneurysm.
[a]Categoric data are shown as number (%) and continuous data as mean ± standard deviation.
[b]The *P* value reflects univariate analysis: Pearson χ^2 test and analysis of variance *F* test comparing the preoperative variables between OS and EVAR. $P < .05$ is significant.

other postoperative outcomes. For all variables that were significant, outcomes favored EVAR.

Multivariable analyses showed OS was associated with higher risk than EVAR of 30-day mortality (odds ratio [OR], 1.64; 95% confidence interval [CI], 1.10-2.43) and failure to wean from the ventilator within 48 hours (OR, 4.08; 95% CI, 2.80-5.95). Although a trend was evident, multivariable analyses did not reveal a significant association of OS vs EVAR with 30-day acute renal failure requiring dialysis ($P = .09$). There was not an association of OS vs EVAR with 30-day cardiac arrest or MI ($P = .58$).

Unstable rAAAs. Amongst 654 patients with rAAAs that were unstable, 466 (71.3%) underwent OS and 188 (28.7%) were treated with EVAR. As reported in Table II, patients in the unstable rAAA cohort with a higher ASA class also tended to be selected for OS rather than EVAR ($P < .0001$). There were more patients with peripheral arterial disease with history of revascularization or amputation (7.4% vs 2.6%; $P = .004$) and history of stroke with neurologic deficit (6.9% vs 3.2%; $P = .05$) in the EVAR subgroup than in the OS subgroup. There were more patients with hypertension (67.6% vs 58.5%; $P = .03$) and impaired sensorium (23.8% vs 16.0%; $P = .03$) in the OS subgroup than in the EVAR subgroup.

The 30-day mortality was significantly higher for OS (52.8%) vs EVAR (35.6%; $P < .0001$). The 30-day rate of acute renal failure requiring dialysis was 18.7% for OS in contrast to 12.8% for EVAR ($P = .07$). The rate of cardiac arrest or MI was 29.0% for OS vs 19.1% for EVAR ($P = .006$). This finding was strongly influenced by a higher rate of cardiac arrest (24.5% vs 13.8%; $P = .003$). A significant difference was not found in the rate of MI (5.2% vs 6.4%; $P = .53$). Forty-five percent of patients undergoing OS remained on the ventilator 48 hours after the operation in contrast to 36% of EVAR patients ($P = .04$). The two interventions had similar rates of return to the operating room (21% vs 24%; $P = .42$) and mean hospital length of stay (12.7 vs 12.4 days; $P = .87$). OS had a lower rate of superficial wound infection (1.7% vs 5.3%; $P = .02$). Details on univariable analysis of other postoperative outcomes are reported in Table I. For all variables that were significant, outcomes favored EVAR.

Multivariable analyses showed OS was associated with higher risk for 30-day mortality than EVAR (OR, 1.74; 95% CI, 1.16-2.62), 30-day acute renal failure requiring dialysis (OR, 1.81; 95% CI, 1.04-3.13), failure to wean from the ventilator ≤48 hours (OR, 1.55; 95% CI, 1.08-2.23), and 30-day cardiac arrest or MI (OR, 1.75; 95% CI, 1.09-2.82).

Effect of year of operation on outcomes. From 2005 to 2010, the percentage of patients with rAAA who underwent an EVAR increased (Table II) in both the stable ($P < .0001$) and unstable rAAA cohorts ($P = .006$). There was no difference in major morbidity or mortality ($P > .05$) during those years, except for a decline in the rates of postoperative pneumonia in the stable ($P < .0001$) and unstable ($P = .004$) cohorts.

DISCUSSION

Although EVAR has an established role in the elective treatment of aneurysms, the evidence to support its use as the primary treatment for patients with rAAAs remains

Table II. Patient characteristics with univariable analysis

	Stable rAAA			*Unstable rAAA*		
Characteristics[a]	*OS (n = 482)*	*EVAR (n = 311)*	P *value*[b]	*OS (n = 466)*	*EVAR (n = 188)*	P *value*[b]
Preoperative						
Cardiac						
Prior cardiac surgery	87 (18.0)	45 (14.5)	.19	68 (14.6)	31 (16.5)	.54
Congestive heart failure	12 (2.5)	5 (1.6)	.46	6 (1.3)	2 (1.1)	1.0
MI ≤6 months	3 (0.6)	7 (2.3)	.06	16 (3.4)	10 (5.3)	.26
Prior PCI	49 (10.2)	40 (12.9)	.24	44 (9.4)	16 (8.5)	.71
Circulatory						
Bleeding disorder	73 (15.1)	56 (18.0)	.29	83 (17.8)	35 (18.6)	.81
PAD[c]	21 (4.4)	15 (4.8)	.76	12 (2.6)	14 (7.4)	.004
Transfusion >4 units pre-op	7 (1.5)	3 (1.0)	.75	79 (17.0)	38 (20.2)	.33
General						
Age, median years	74	73	.98	74	73	.86
ASA class						
2	6 (1.2)	5 (1.6)	.02	–	–	
3	83 (17.2)	81 (26.0)		–	–	
4	284 (58.9)	174 (55.9)		230 (49.4)	123 (65.4)	<.0001
5	105 (21.8)	50 (16.1)		236 (50.6)	65 (34.6)	
BMI, median kg/m^2	28.3	26.8	.09	29.2	29.4	.84
Diabetes mellitus	46 (9.5)	46 (14.8)	.02	51 (10.9)	21 (11.2)	.93
Dependent functional status	43 (8.9)	35 (11.3)	.55	108 (23.3)	35 (18.6)	.19
Hypertension	320 (66.4)	214 (68.8)	.48	315 (67.6)	110 (58.5)	.03
Race			.40			.98
American Indian	0	2 (0.6)		2 (0.4)	1 (0.5)	
Asian/Pacific Islander	6 (1.2)	1 (0.3)		5 (1.1)	2 (1.1)	
Hispanic	9 (1.9)	6 (1.9)		10 (2.1)	4 (2.1)	
Black	26 (5.4)	18 (5.8)		18 (3.9)	10 (5.3)	
Unknown	63 (13.1)	38 (12.2)		61 (13.1)	24 (12.8)	
White	378 (78.4)	246 (79.1)		370 (79.4)	147 (78.2)	
Sex			.49			.50
Male	370 (76.8)	243 (78.1)		353 (75.9)	138 (73.4)	
Female	110 (22.8)	68 (21.9)		112 (24.1)	50 (26.6)	
SIRS/shock, pre-op			.42			.59
SIRS	27 (5.6)	13 (4.2)		247 (53.1)	105 (56.1)	
Shock (SIRS + organ dysfunction)	8 (1.7)	8 (2.6)		74 (15.9)	24 (12.8)	
Year			<.0001			.006
2005	22 (4.6)	3 (1.0)		17 (3.6)	3 (1.6)	
2006	43 (8.9)	20 (6.4)		57 (12.2)	12 (6.4)	
2007	97 (20.1)	39 (12.5)		95 (20.4)	24 (12.8)	
2008	122 (25.3)	78 (25.1)		102 (21.9)	46 (24.5)	
2009	106 (22.0)	79 (25.4)		88 (18.9)	43 (22.9)	
2010	92 (19.1)	92 (29.6)		107 (23.0)	60 (31.9)	
Laboratory						
Mean creatinine, mg/dL	1.2	1.2	.23	1.5	1.5	.63
Mean hematocrit, %	35.9	35.5	.79	33.1	33.2	.99
Neurologic						
Coma	2 (0.4)	0 (0)	.5	46 (9.9)	13 (6.9)	.23
Impaired sensorium	4 (0.8)	2 (0.6)	1.0	111 (23.8)	30 (16.0)	.03
Stroke with neurologic deficit	11 (2.3)	12 (3.9)	.20	15 (3.2)	13 (6.9)	.05
Stroke without neurologic deficit	24 (5.0)	23 (7.4)	.16	22 (4.7)	9 (4.8)	1.0
Transient ischemic attack	19 (3.9)	13 (4.2)	.86	17 (3.6)	9 (4.8)	.51
Renal						
Dialysis, pre-op	3 (0.6)	8 (2.6)	.03	4 (0.9)	3 (1.6)	.42
Mean GFR, mL/min/1.73 m^2	59.3	59.8	.41	56.4	55.9	.84
Respiratory						
Chronic obstructive pulmonary disease	72 (14.9)	63 (20.3)	.03	91 (19.5)	29 (15.4)	.22
Dyspnea			.08			.26
At rest	34 (7.1)	17 (5.5)		92 (19.7)	29 (15.4)	
On moderate exertion	36 (7.5)	37 (11.9)		36 (7.7)	11 (5.9)	
On ventilator, pre-op	11 (2.3)	2 (0.6)	.06	170 (36.5)	56 (29.8)	.10
Social						
Alcohol intake within the last 2 weeks	28 (5.8)	20 (6.4)	.72	22 (4.7)	6 (3.2)	.38
Smoking within the past year	182 (37.8)	119 (38.3)	.47	153 (32.8)	60 (31.9)	.82

(*Continued on next page*)

Table II. Continued.

Characteristics[a]	*Stable rAAA*			*Unstable rAAA*		
	OS (n = 482)	*EVAR (n = 311)*	P *value*[b]	*OS (n = 466)*	*EVAR (n = 188)*	P *value*[b]
Intraoperative						
Therapy						
Regional anesthesia	0	29 (9.3)	<.0001	0	10 (5.3)	<.0001
Percutaneous approach	0	154 (49.5)	<.0001		89 (47.3)	<.0001
Intra-op RBC transfusion, mean units	9.1	3.2	<.0001	12	8	<.0001
Median operative time, minutes	198	149	<.0001	191	179	.13
Surgeon			.17			.30
Vascular	462 (60.3)	304 (39.7)		448 (71.7)	177 (28.3)	
General	20 (74.1)	7 (25.9)		18 (62.1)	11 (37.9)	

ASA, American Society of Anesthesiologists Physical Status Classification; *BMI,* body mass index; *EVAR,* endovascular aortic repair; *MI,* myocardial infarction; *PAD,* peripheral arterial disease; *rAAA,* ruptured abdominal aortic aneurysm; *OS,* open surgery; *PAD,* peripheral arterial disease; *RBC,* red blood cell; *SIRS,* systemic inflammatory response syndrome.

[a]Categoric data are shown as number (%) and continuous data as indicated.

[b]*P* value reflects univariate analysis: Pearson χ^2 test and analysis of variance *F* test, comparing the preoperative variables between OS and EVAR. $P < .05$ is significant.

[c]With a history of revascularization or amputation.

controversial. In the United States, there has been a yearly rise in the proportion of patients with rAAA treated with EVAR, from 6.6% in 2001 to 42.1% in 2010.[11] Most studies on the use of EVAR for rAAA are derived from single-center case series or population-based evaluations.[12] The Nottingham Pilot Trial conducted by Hinchliffe et al[13] was the first, single-center prospective RCT of EVAR compared with OS for rAAA. The trial was stopped because it was underpowered and slow to recruit; thus, no conclusions were made regarding mortality, but the authors did conclude that preoperative computed tomography scanning does not delay treatment of rAAAs.

The Amsterdam Acute Aneurysm Trial[6] was the first completed multicenter RCT comparing OS vs EVAR for rAAA; however, severe hemodynamic instability was an exclusion criterion for that study, and 78% of identified patients were not recruited into the trial. The results from the United Kingdom-based IMPROVE trial were published earlier this year.[7] This trial included unstable patients (48% of the total) but did not address the question of optimum management of this specific cohort. Thus, the primary goal of our analysis was to further evaluate the value of EVAR in the treatment of rAAA by using a relatively robust nationwide data set. Moreover, we aimed to compare the outcomes of EVAR and OS in the treatment of ruptured aneurysms in stable vs unstable patients.

We found that patients undergoing EVAR had a significantly improved 30-day mortality compared with OS for both cohorts, patients with rAAAs that were stable as well as those that were not. Data from several United States population-based studies have revealed a mortality rate for ruptured AAA that ranges from 31% to 58% after EVAR and from 38% to 56% after OS.[2,14-17] Veith et al[18] collected data from 49 centers around the world using EVAR for rAAA and found a 30-day mortality of 21.2% after EVAR in 1037 patients vs 36.3% for 763 patients in a comparative OS group ($P < .0001$). That study did not classify patients as stable vs unstable. The authors concluded that at high-volume centers, high-risk patients benefit from EVAR.

The Amsterdam Acute Aneurysm Trial revealed a 30-day mortality of 21% for EVAR vs 25% for OS in 116 hemodynamically stable patients that met the inclusion criteria. Thus, these investigators were not able to demonstrate an advantage of EVAR in a stable rupture population. In the IMPROVE trial, 275 rAAA patients randomized to an endovascular strategy had a 30-day mortality of 36.4% vs 40.6% in the 261 open repair patients ($P = .3$). However, of the 275 patients with rAAA in the endovascular strategy group, EVAR was attempted in only 154 (56%) due to anatomic unsuitability, crossover, and other reasons. Overall 30-day mortality in patients who underwent an EVAR in the IMPROVE trial was 25% compared with 38% for those who underwent OS.

Our data also demonstrate an advantage of EVAR with regard to overall morbidity in stable and unstable patients, except for wound infections. In terms of postoperative renal failure requiring dialysis, EVAR was superior to OS for unstable patients, with a similar trend for patients with stable rupture. A decreased incidence of moderate to severe renal failure was associated with EVAR in the Amsterdam Acute Aneurysm Trial. There are several possible explanations for the increased incidence of renal failure after OS, including greater fluid and electrolyte shifts after laparotomy, the need for a prolonged suprarenal clamp, hypotension after laparotomy, and decompression of the abdomen or retroperitoneum. Our data showed EVAR in the unstable cohort was also associated with lower rate of 30-day postoperative cardiac arrest or MI, and no differences were observed in cardiac outcomes observed in the stable patient cohort. These findings are identical to those of the Amsterdam Acute Aneurysm Trial, where severe

postoperative cardiac complications were similar between the two procedures.

Our study also demonstrates the superiority of EVAR with regard to postoperative respiratory failure in the stable and unstable cohorts. These findings are supported by Nedeau et al,[19] who also showed less postoperative respiratory failure in patients treated by EVAR for rAAA. Patients treated by EVAR had a higher rate of wound infection than patients treated with OS. This is probably because groin incisions are known to have higher risk of wound infections than abdominal incisions for cases without enteral contamination. The risk of wound infection is also higher in emergency settings than in elective procedures, as shown by the higher rates of wound infections among unstable rAAA patients who underwent EVAR compared with stable rAAA patients.

Despite our favorable findings, there are genuine concerns and impediments to the adoption of an EVAR-first approach for all rAAAs. There are disparities in institutional experience with EVAR, and outcomes of EVAR have been shown to be dependent on the institutional volume.[2] To this end, urgent EVAR for rAAAs in unstable patients requires (1) a broad selection of grafts readily available, (2) the availability of a call team inclusive of individuals experienced in catheter-based intervention, and (3) appropriate intraoperative imaging. The lack of experience or preparedness is greatly exacerbated when attempting to urgently treat an unstable patient.[12] Moreover, although advances in endograft technology have allowed up to 80% of patients to be anatomically suitable for EVAR, a cohort of patients remains for whom EVAR is not possible.[11] Despite these limitations, our study, which includes data from a wide variety of institutions, reveals a substantial benefit of EVAR over OS in stable and in unstable rAAA patients. Admittedly, institutions enrolled in NSQIP are selected from the larger cohort of hospitals that treat rAAA.

This study, based on the NSQIP database, has many strengths not found in other studies, including a large sample size that enables smaller CIs in the assessment of risk factors. The current study also presents a representative estimate of outcomes in a broad population derived from community and academic hospitals from across the nation. Moreover, the data from NSQIP are detailed and independently validated and audited.

Our study also has limitations. This is a retrospective analysis of prospectively recorded data. Variables analyzed were limited to those recorded by NSQIP. Despite the data set being fairly comprehensive, with >50 preoperative variables, information regarding anatomy, including vessel diameter, aneurysm size, length and diameter of the aortic neck, calcification, aortic thrombus, tortuosity, and presence of a suitable iliac anchoring segment was not available.

Another limitation is that the patients undergoing OS and EVAR were not anatomically matched. Patients undergoing EVAR may have been selected for favorable anatomy, whereas those selected for OS may have had more complex anatomy. Of course, if the EVAR patients with more favorable anatomy had been treated with OS, the outcomes of OS might have been improved. Unfortunately in NSQIP, anatomic details are not available. Similarly, we also do not know how many patients who underwent OS might have been candidates for EVAR, which was not performed due to the lack of an specialist trained in EVAR.

The duration and location of proximal control with clamp or balloon is not specified. The number of patients who were evaluated with a computed tomography scan before the operation is not known. Hospital volume and academic vs community status were not available. Long-term morbidity and mortality, which are important indicators of treatment success, are not available. The reasons for return to the operating room are also not known.

Importantly, patients were not randomized; thus, there is no surety that patient cohorts for OS and EVAR are identical. However, the data in Table II show that most of preoperative variables were statistically identical when the OS and EVAR groups were compared for both stable and unstable patients. There were some differences; however, most often these favored EVAR patients being the more ill of the two cohorts.

Another important limitation is that NSQIP does not have a designation for an unstable preoperative state. Thus, to conduct this analysis, it was necessary for us to create a surrogate for instability. We defined instability as urgently treated patients who (1) experienced preoperative shock, (2) received >4 units of preoperative transfusion, (3) required preoperative intubation, or (4) had preoperative coma or impaired sensorium. These definitions are by no means absolute; however, we are confident that these designations have created a cohort of patients with rAAA who are overall quite ill. This is the patient cohort that has not been fully evaluated in previous studies of rAAA comparing EVAR vs OS.

CONCLUSIONS

In NSQIP participating hospitals across the country, approximately one-third of patients with rAAA are treated with EVAR. Unstable patients have less favorable outcomes than patients that are stable. Our data show rather definitively that EVAR reduced mortality and morbidity when used to treat patient with rAAA, regardless of the patient's stability. Our findings suggest that in centers experienced with EVAR, this may be the preferred approach for all patients presenting with ruptured AAA who have a favorable anatomy for EVAR.

AUTHOR CONTRIBUTIONS

Conception and design: PG, BR
Analysis and interpretation: TE, GT, JH, KK
Data collection: PG, BR

Writing the article: PG, BR, TE
Critical revision of the article: GT, JH, KK
Final approval of the article: PG, BR, TE, GT, JH, KK
Statistical analysis: PG, BR
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