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Editor's Choice – Mortality is High Following Elective Open Repair of Complex Abdominal Aortic Aneurysms

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WHAT THIS STUDY ADDS

In this study, 30 day mortality for elective open complex abdominal aortic aneurysm repair was 6.8%, higher than previously reported data. After inverse probability weighting with similar patients having undergone endovascular aneurysm repair, odds of 30 day mortality was nearly twice that of endovascular repair. Factors associated with death included greater aneurysm extent, low body mass index, more severe chronic kidney disease, increased age, and history of chronic obstructive pulmonary disease.

Objective: To evaluate the 30 day mortality of elective open complex abdominal aortic aneurysm (cAAA) repair and identify factors associated with death.

Methods: This was a retrospective cohort study using a Targeted Vascular Module from the American College of Surgeons National Surgical Quality Improvement Program (NSQIP). All patients undergoing elective repair for juxta- and suprarenal abdominal aortic aneurysm (AAA), or type IV thoraco-abdominal aneurysms (TAAA) from 2011 to 2017 were identified. Thirty day mortality and complication rates for open repair were established. A comparison endovascular aneurysm repair (EVAR) group was extracted from the same time period, and inverse probability weighting was applied for comparison. Logistic regression was used to identify factors independently associated with open repair mortality.

Results: Of the 957 patients who underwent an elective open cAAA repair over the study period, 65 (6.8%) died. The mean age of the patient was 71.3 $\pm$ 8.0 years. The distribution by aneurysm type was 605 juxtarenal AAA (28 deaths, 4.6%); 284 suprarenal AAA (16 deaths, 9.5%), and 68 type IV TAAA (10 deaths, 14.7%). During the same time period, there were 1149 endovascular repairs for cAAA, with 43 deaths (3.7%). After inverse probability weighting and weighted logistic regression, open repair 30 day mortality yielded an OR 1.9, 95% CI 1.2—3.1, $p = .01$ compared with EVAR. Factors independently associated with death included more proximal extent aneurysm (referent [ref]: juxtarenal: OR 2.0 per extent increase, 95% CI 1.4—3.0, $p < .001$), BMI < 18.5 (OR 4.0, 95% CI 1.6—10.1, $p = .003$), history of severe chronic obstructive pulmonary disease (COPD) (OR 2.6, 95% CI 1.5—4.4, $p = .001$), more severe chronic kidney disease (CKD) (ref: none/mild): OR 1.9, 95% CI 1.2—2.8, $p = .004$), and age (OR 1.06/year, 95% CI 1.02—1.09, $p = .002$.

Conclusion: The 30 day mortality was 4.6% for juxtarenal AAA, 9.5% for suprarenal AAA, and 14.7% for type IV TAAA. The open repair odds of 30 day mortality was nearly twice that of endovascular repair for cAAA. Independent associations with death included BMI <18.5, more severe CKD level, more proximally extending aneurysm, age, and history of advanced COPD.

Keywords: Complex abdominal aortic aneurysm, Elective abdominal aortic aneurysm repair, Open abdominal aortic aneurysm
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INTRODUCTION

Although endovascular aneurysm repair (EVAR) is the predominant method of repair for infrarenal abdominal aortic aneurysms (AAA), there are still many patients for whom open repair is the preferred or only possible modality.[1] Additionally, long term comparisons with EVAR are important as rupture, branch vessel patency, and re-interventions

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can all impact survival and should be considered when choosing between EVAR and open repair.

With rapidly evolving technology, more patients with complex AAA are candidates for EVAR.[2] To place endovascular results into context, it is important to accurately define outcomes of contemporary open complex AAA repair. Mortality for juxta- and suprarenal AAA ranges from 0.8% to 6.1% in single centre studies,[3–6] with one meta-analysis reporting a pooled mortality of non-ruptured juxtarenal AAA of 2.9%.[7] Lesions that require suprarenal clamping (suprarenal AAA and type IV TAAA) are associated with a higher mortality, ranging from 1.8% to 13.4%.[8–12] In 2016, Deery *et al.* determined the juxta-, para-, and suprarenal AAA repair 30 day mortality rate to be 3.6% in a regional analysis evaluating centres in New England.[8]

Many of the previous single centre studies included emergency cases, and most of the literature regarding open repair focuses on data from high volume centres of excellence.[5,6,9,11] Low patient and event numbers limit the generalisability of these studies. Additionally, these data are prone to publication bias, probably underestimating the true mortality and morbidity. Therefore, the goal of this project was to quantify the mortality for elective open repair of complex abdominal aortic aneurysms and identify factors associated with death.

METHODS

Study design

This was a retrospective cohort study.

Data source

The American College of Surgeons National Surgical Quality Improvement Program (NSQIP) Targeted Vascular Module is a registry that draws from a collection of surgical procedures performed at 95 participating centres, primarily in the United States. Data collection is performed by trained clinical nurses and data abstractors and includes patient demographics, comorbid conditions, procedural information, and outcomes 30 days after the index procedure. The participating centres do so voluntarily and pay nurse abstractors to review patient charts for procedural and outcome details. The makeup of the participating centres is confidential. All patients' charts are reviewed for 30 day follow up, and those without 30 day follow up receive a phone call from the nurse abstractor. The NSQIP registry has been validated previously,[13,14] as has the targeted AAA module.[15] Some centres have a monthly limit on the number of cases submitted, secondary to limitations on data abstracting resources, but these data are not disclosed. All cases are entered consecutively, and any limits are determined prior to surgery. Additional information is available at www.facs.org/quality-programs/acs-nsqip. The Institutional Review Board of Beth Israel Deaconess Medical Centre exempted this study from informed consent, because of the de-identification of subjects.

Patient cohort

All patients undergoing open repair for a juxta-, para-, suprarenal, and type IV thoraco-abdominal aneurysm between 2011 and 2017 were identified. Given that the anatomic distinction between the NSQIP's definition of pararenal and suprarenal AAA extents is subject to interpretation by the data abstractors and both extents are treated similarly clinically, those extents were combined in this study and referred to as suprarenal. Those with an infrarenal clamp location were excluded, as were those that underwent emergency repair. Two additional analyses were performed, one which eliminated repairs for symptomatic aneurysms, and another where only non-symptomatic repairs performed for reaching a diameter threshold were considered.

Clinical and outcome variables

Baseline characteristics, including demographics and comorbid conditions, as well as procedural and anatomical characteristics were compared between groups. Estimated glomerular filtration rate (eGFR; mL/min/1.72 m^2) was calculated according to the Chronic Kidney Disease (CKD) Epidemiology Collaboration equation.[16] Renal function was categorised as no to mild CKD (eGFR $>$ 60), moderate CKD (eGFR 30–60), or severe CKD (eGFR $\leq$ 30 or on dialysis).

The primary outcome of this study was 30 day mortality. The secondary outcome was a combined endpoint of major adverse events (MAE), including death, organ space surgical site infection, ischaemic colitis, pulmonary embolism, unplanned re-intubation, failure to wean from ventilation, acute renal failure, stroke, cardiac arrest, myocardial infarction, and re-operation. The outcomes were stratified by proximal aneurysm extent.

Non-arterial repair refers to mention in the operative report of a secondary non-vascular procedure (i.e. small bowel resection, splenectomy etc.). Juxtarenal aneurysms were defined as those that do not involve the renal arteries but require clamping above at least one renal artery to perform the proximal anastomosis in an open repair. Suprarenal AAAs start proximal to at least one main renal artery but are below the visceral segment. Type IV thoraco-abdominal aortic aneurysms extend above the visceral segment but below the diaphragm. These definitions were the same in the open and EVAR cohorts. Severe chronic obstructive pulmonary disease (COPD) is defined as functional disability resulting from COPD (dyspnoea, difficulty performing activities of daily living), history of hospitalisation for COPD, an FEV1 of $<$75% on prior pulmonary function testing or chronic bronchodilator therapy with oral or inhaled agents with a diagnosis of COPD. Congestive heart failure was considered to be present in patients with a new diagnosis of congestive heart failure within the 30 days or those with new signs or symptoms within the 30 days prior to surgery. Bleeding disorder referred to any patient with a chronic, active condition that placed them at a higher risk of bleeding, including a diagnosis of thrombocytopaenia and low platelets at the time of the operative procedure or use of anticoagulation not discontinued prior to surgery. Renal

Table 1. Demographics and clinical variables of 957 patients undergoing elective repairs for juxta- and suprarenal abdominal aortic aneurysm (AAA) or type IV thoraco-abdominal aortic aneurysm in 2011–2017 identified from the American College of Surgeons National Surgical Quality Improvement Program (NSQIP) Targeted Vascular Module registry

Variable	Open cohort (n = 957)	Dead (n = 65; 6.8%)	p*
Female	278 (29.1)	23 (35.4)	.26
Mean age ± SD – y	71.3 ± 8.0	74.6 ± 7.8	.003
Clamp location			.001
Above one renal	325 (36.6)	16 (27.6)	
Suprarenal	325 (36.6)	14 (24.1)	
Supracoeliac	239 (26.9)	28 (48.3)	
Proximal aneurysm extent			.001
Juxtarenal	605 (63.2)	28 (43.1)	
Suprarenal	284 (29.7)	27 (41.5)	
Type IV TAAA	68 (7.1)	10 (15.4)	
Surgical approach			.98
Retroperitoneal	400 (42.3)	28 (43.8)	
Transperitoneal midline	489 (51.8)	33 (51.6)	
Transperitoneal transverse	56 (5.9)	3 (4.7)	
Prior abdominal surgery	259 (28.7)	22 (33.9)	.19
Renal revascularisation	235 (24.6)	20 (30.8)	.23
Visceral revascularisation	60 (6.3)	12 (18.5)	<.001
Abdominal non-arterial	44 (4.6)	6 (9.2)	.11
Management of IMA			.16
Chronically occluded	85 (17.1)	6 (18.8)	
Implanted	41 (8.2)	6 (18.8)	
Ligated	372 (74.7)	20 (62.5)	
Severe COPD	215 (22.5)	27 (41.5)	<.001
Congestive heart failure	16 (1.7)	3 (4.6)	.089
Top quartile of operative time	205 (21.4)	24 (36.9)	.003
Functional status			1.0
Independent	938 (98.0)	64 (98.5)	
Partially dependent	17 (1.8)	1 (1.5)	
Completely dependent	2 (0.2)	0 (0.0)	
ASA category			.014
1 or 2	41 (4.3)	0 (0.0)	
3	519 (54.2)	28 (43.1)	
4 or 5	397 (41.5)	37 (56.9)	
Diabetes	105 (11.1)	5 (7.7)	.23
Bleeding disorder	80 (8.4)	7 (10.8)	.48
Chronic kidney disease			.001
eGFR >60 (none/mild)	668 (69.8)	33 (50.8)	
eGFR 30–60 (moderate)	260 (27.1)	27 (41.5)	
eGFR <30/dialysis (severe)	29 (3.0)	5 (7.7)	
Current smoker	450 (47.0)	24 (36.9)	.96
Hypertension	785 (82.0)	55 (84.6)	.74
Distal extent			.26
Aortic	475 (56.0)	35 (53.9)	
Iliac	373 (43.9)	19 (35.1)	
Body mass index			.016
<18.5	29 (3.0)	6 (9.2)	
18.5–24.9	290 (30.3)	25 (38.5)	
25–29.9	369 (38.6)	19 (29.2)	
30–39.9	236 (24.7)	12 (18.5)	
>40	33 (3.5)	3 (4.6)	
Indication			
Diameter	808 (84.4)	48 (6.3)	
Dissection	9 (1.0)	0 (0.0)	
Embolisation	3 (0.3)	0 (0.0)	
Non-ruptured symptomatic	69 (7.2)	10 (14.5)	
Not documented	8 (0.8)	1 (0.8)	
Other indication for surgery	9 (0.1)	1 (11.1)	
Prior endovascular, open revision	27 (2.8)	1 (3.7)	
Prior open surgery, revision	8 (0.1)	2 (25.0)	
Thrombosis	16 (1.7)	2 (12.5)	

Data are presented as n (%) unless stated otherwise. SD = standard deviation; TAAA = thoraco-abdominal aortic aneurysm; IMA = inferior mesenteric artery; COPD = chronic obstructive pulmonary disease; ASA = American Society of Anesthesiologists; eGFR = estimated glomerular filtration rate.

* p values derived from Fisher's exact test for categorical variables and Student t test for continuous variables.

revascularisation referred to an open bypass to a renal vessel or renal stent placement in an endovascular procedure.

Statistical analysis

Categorical and dichotomous variables are presented as counts and percentages, whereas continuous variables are presented as mean ± standard deviation. Differences in baseline, procedural, and outcome variables between study groups were tested for significance using the Fisher's exact test for categorical variables, and the Student t test or Wilcoxon rank sum test for continuous variables, where appropriate. Operative time was split into quartiles and adjusted for proximal extent.

To place open mortality into appropriate context, inverse probability weighting followed by weighted logistic regression was used to compare odds of 30 day mortality between those that received EVAR and those that received open repair. The propensity score for the probability of undergoing open repair was created using a non-parsimonious logistic regression model, using all measured pre-operative demographic variables. Weighted regression modelling was created using weights from the propensity scores. The inverse probability of treatment weight was defined as the inverse probability of receiving the treatment. To test for overlap, the distributions were plotted of the estimated propensity scores and the overlap examined graphically. For covariable balance, standardised differences were evaluated after weighting. These were all ≤0.20, except for smoking status, proximal aneurysm extent, aneurysm diameter, and age, which were removed from the propensity model but adjusted for in the weighted logistic regression model. This method was mimicked for each individual extent to better contextualise the data.

A logistic regression model was constructed to identify independent factors associated with death. Variables for this model were selected by forward stepwise selection, starting with a null model and adding the most significant variable stepwise with an exit criterion of $p > .05$, with forced inclusion of known confounders, including CKD status, history of severe COPD, and proximal aneurysm extent if not already included. These factors were selected as they have been previously

Table 2. 30 day mortality after 957 elective and symptomatic open complex abdominal aortic aneurysm (AAA) repairs, stratified by proximal extent, identified from the American College of Surgeons National Surgical Quality Improvement Program (NSQIP) Targeted Vascular Module registry in 2011–2017

Aneurysm type	All complex AAA		Elective AAA open repair*		Symptomatic AAA open repair	
	Total ($n = 957$)	Dead ($n = 65$; 6.8%)	Total ($n = 888$)	Dead ($n = 55$; 6.2%)	Total ($n = 69$)	Dead ($n = 10$; 15.4%)
Juxtarenal	605 (63.2)	28 (4.6)	572 (64.4)	25 (4.4)	33 (47.8)	3 (9.1)
Suprarenal	284 (29.7)	27 (9.5)	253 (28.5)	22 (8.7)	31 (44.9)	5 (16.1)
Type IV TAAA	68 (7.1)	10 (14.7)	63 (7.1)	8 (12.7)	5 (7.3)	2 (20.0)

Data are presented as n (%). AAA = abdominal aortic aneurysm; TAAA = thoraco-abdominal aortic aneurysm.
* Death included in total major adverse event counts.

identified as independent associations in the literature and may be missed by a traditional stepwise selection process. Proximal extent was considered as an ordinal variable from juxtarenal to suprarenal to Type IV TAAA, and CKD level was also considered as an ordinal variable. Missing data were handled by creating a separate categorical variable for all variables missing >2.5% of the data, and by multiple imputation for continuous variables. If < 2.5% of the data were missing for a categorical variable, a null value was assigned. CKD status was missing in 1.9% of the open group and 4.1% in the propensity analysis, distal extent was missing in 13.2%, prior abdominal surgery in 7.6%, and aneurysm diameter in 6.3%. During propensity scoring, age and aneurysm diameter were treated as scalar. All other variables had no missing values. Model fit was assessed by the Hosmer and Lemeshow's goodness of fit test, combining patterns formed by predictor variables into 10 groups. To evaluate internal validity, the mortality was evaluated in the traditional (non-targeted) NSQIP, which lacks the increased detail collected in the targeted NSQIP, for patients undergoing open elective repair of the abdominal aorta involving visceral vessels. Analyses were performed using Stata 15.1 (StataCorp, College station, TX, USA), an α level of 0.05 was used throughout; all tests were two sided.

RESULTS

There were 957 patients who underwent elective open complex AAA repair. Of these, there were 605 juxtarenal AAA, 284 suprarenal AAA, and 68 type IV TAAAs. The mean age of the patients was 71.3 ± 8.0 years (Table 1). Sixty-nine (7.2%) patients were symptomatic. The primary analysis, including all non-emergency cases revealed a mortality of 6.8% for the entire cohort, 4.6% for juxtarenal, 9.5% for suprarenal, and 14.7% for type IV TAAA repairs. Excluding all symptomatic patients, the 30 day mortality was 6.2% for the entire cohort, 4.4% for juxtarenal AAA, 8.7% for suprarenal, and 12.7% for type IV TAAA (Table 2). Limiting the analysis to non-symptomatic patients repaired after reaching a diameter threshold, 30 day mortality was 5.9% overall, 4.2% in the juxtarenal group, 8.9% for the suprarenal cohort, and 10.7% for type IV TAAA (Table 3). The mean aneurysm diameter was 6.2 ± 1.2 cm (median 6 cm, interquartile range 5.5, 6.7 cm, and the 10th percentile was 5.1 cm). The MAE rate was 24.1% for juxtarenal AAA, 28.9% for suprarenal, and 41.2% for type IV TAAA (Table 4). Fifty-five patients (6.2%) had a non-symptomatic aneurysm that was repaired by open surgery at a diameter threshold < 5.0 cm. The discharge destination for 656 patients (68.5%) was home or a facility that is home, for 240 (25.1%) a rehabilitation facility or acute/skilled care facility, for 59 (6.2%) expired and for two (0.2%) unknown.

Univariable associations with death included increased age, supracoeliac clamp location, more proximal aneurysm extent, visceral revascularisation, severe COPD, operative time in the top quartile (314 min for juxtarenal, 318 min for suprarenal, and 305 min for type IV TAAA), higher ASA category, worse CKD level, and body mass index (BMI) < 18.5 (Table 1). Those with BMI <18.5 were most likely to undergo re-intubation (17.2%), compared with 11.4% with BMI 18.5–25, 6.0% with BMI 25–29.9, 7.2% with BMI 30–39.9, and 9.1% with BMI > 40 ($p = .04$).

Independent associations with death included more proximal aneurysm extent from juxtarenal to suprarenal to type IV TAAA (ref: juxtarenal; OR 2.0 per extent, 95% CI 1.4–3.0, $p < .001$); BMI < 18.5 (OR 4.0, 95% CI 1.6–10.1, $p = .003$), severe COPD (OR 2.6, 95% CI 1.5–4.4, $p = .001$) severity of CKD (ref mild: OR 1.7, 95% CI 1.1–2.5, $p = .02$), and age (OR 1.06 per year, 95% CI 1.02–1.09, $p = .002$, Table 5).

A comparison of demographics between EVAR and open can be found in Table 6. Compared with EVAR, the unadjusted OR of mortality for open repair was 1.87 (95% CI 1.26–2.78, $p = .002$), and the adjusted OR (AOR) was 1.90

Table 3. 30 day mortality after 808 non-symptomatic open repairs of complex AAAs performed for reaching diameter threshold (as determined by surgeon) or rapid growth, identified from the American College of Surgeons National Surgical Quality Improvement Program (NSQIP) Targeted Vascular Module registry in 2011–2017

Aneurysm type	Total ($n = 808$)	Dead* ($n = 48$; 5.9%)
Juxtarenal	527 (65.2)	22 (4.2)
Suprarenal	225 (27.8)	20 (8.9)
Type IV TAAA	56 (6.9)	6 (10.7)

Data are presented as n (%). AAA = abdominal aortic aneurysm; TAAA = thoraco-abdominal aortic aneurysm.
* Mortality by extent Fisher's exact $p = .011$.

Table 4. 30 day major adverse events after 957 open complex abdominal aortic aneurysm repairs, identified from the American College of Surgeons National Surgical Quality Improvement Program (NSQIP) Targeted Vascular Module registry in 2011–2017

Major adverse event	Juxtarenal (*n* = 605)	Suprarenal (*n* = 284)	Type IV TAAA (*n* = 68)	*p*[†]
Any major complication[*]	146 (24.1)	82 (28.9)	28 (41.2)	.008
Organ space surgical site infection	8 (1.3)	2 (0.7)	3 (4.4)	.064
Re-intubation	47 (7.8)	25 (8.8)	8 (11.8)	.44
Failure to wean from ventilation >48 h	62 (10.3)	43 (15.1)	14 (20.6)	.013
Acute renal failure	25 (4.1)	21 (7.4)	11 (16.2)	.001
Stroke	3 (0.50)	1 (0.4)	1 (1.47)	.54
Cardiac arrest	14 (2.3)	14 (4.9)	6 (8.8)	.008
Myocardial infarction	34 (5.6)	10 (3.5)	2 (2.9)	.35
Unplanned re-operation	78 (9.1)	40 (14.1)	14 (20.6)	.20
Ischaemic colitis	25 (4.1)	16 (5.6)	10 (14.7)	.003

Data are presented as *n* (%). TAAA = thoraco-abdominal aortic aneurysm.
* Death included in total major adverse event counts.
† *p* value derived from Fisher's exact test.

(95% CI 1.16–3.12, $p = .01$). When broken down by extent, the AOR for juxtarenal AAA was 0.87 (0.47–1.61, $p = .66$); for suprarenal 6.32 (2.64–15.13, $p < .001$); and for type IV TAAA 4.53 (1.15–17.83, $p = .031$, Table 7).

In the generic (non-targeted) NSQIP module, there were 1604 elective AAA cases involving visceral vessels from 2011 to 2017, and the mortality was 7.5%.

DISCUSSION

Using a national registry it was found that 30 day mortality for open repair of complex AAA was high at 4.6% for juxtarenal, 9.5% for suprarenal, and 14.7% for type IV TAAA repairs (6.8% overall). Even the most conservative estimates, with only non-symptomatic aneurysms electively repaired for reaching a diameter threshold for repair still had a mortality rate of nearly 6%. The propensity weighted odds of death for open repair was nearly double that of endovascular repair. Morbidity rates were similarly high, with MAE rates >30% for all complex open repairs. Looking

Table 5. Logistic regression analysis of factors associated with 30 day mortality in 957 open complex abdominal aortic aneurysm repairs, identified from the American College of Surgeons National Surgical Quality Improvement Program (NSQIP) Targeted Vascular Module registry in 2011–2017

Independent associations	30 day mortality	
	OR (95% CI)	*p*
More proximal extent aneurysm (ref: juxtarenal)[*]	2.0 (1.4–3.0)	<.001
Severe chronic obstructive pulmonary disease	2.6 (1.5–4.4)	.001
Body mass index <18.5	4.0 (1.6–10.1)	.003
Age per year	1.06 (1.02–1.09)	.002
More severe CKD level (ref: none/mild, moderate, severe)	1.7 (1.1–2.5)	.021

OR = odds ratio; CI = confidence interval; ref: = reference; CKD = chronic kidney disease; TAAA = thoraco-abdominal aortic aneurysm.
* Proximal extent measured as an ordinal variable increasing from juxtarenal to suprarenal to type IV TAAA. Model fit as determined Hosmer and Lemeshow's goodness of fit test, which exhibited a *p* value of .46.

Table 6. Demographics and clinical variables between patients undergoing open vs. endovascular repair (EVAR) of complex abdominal aortic aneurysm, identified from the American College of Surgeons National Surgical Quality Improvement Program (NSQIP) Targeted Vascular Module registry in 2011–2017

Variable	Open cohort (*n* = 957; 45.4%)	EVAR (*n* = 1149; 54.6%)	*p*
Female	278 (29.1)	262 (22.8)	.001
Mean age ± SD – y	71.5 ± 8.0	74.4 ± 8.4	<.001
Aneurysm diameter (IQR) – cm	6 (5.5, 6.8)	5.6 (5.1, 6.3)	<.001
Proximal aneurysm extent			
Juxtarenal	605 (63.2)	482 (42.0)	
Suprarenal	284 (29.7)	608 (52.9)	<.001
Type IV TAAA	68 (7.1)	59 (5.1)	
Surgical indication			<.001
Diameter	808 (80.2)	921 (80.2)	
Symptomatic	69 (7.2)	55 (4.8)	
Other	80 (8.4)	173 (15.1)	
Prior abdominal surgery	259 (28.7)	346 (33.1)	.001
Renal revascularisation	235 (24.6)	371 (32.3)	<.001
Severe COPD	215 (22.5)	241 (21.0)	.43
Congestive heart failure	16 (1.7)	32 (2.8)	.11
Partially or completely dependent functional status	19 (2.0)	32 (2.8)	.26
ASA category			<.001
1 or 2	41 (4.3)	43 (3.7)	
3	519 (54.2)	747 (65.0)	
4 or 5	397 (41.5)	359 (31.2)	
Diabetes	105 (11.1)	171 (14.9)	.009
Bleeding disorder	80 (8.4)	159 (13.8)	<.001
Chronic kidney disease			<.001
eGFR >60 (none/mild)	198 (21.2)	218 (20.1)	
eGFR 30–60 (moderate)	708 (75.7)	806 (74.4)	
eGFR <30/dialysis (severe)	29 (3.1)	60 (5.5)	
Current smoker	450 (47.0)	507 (32.8)	<.001
Hypertension	785 (82.0)	953 (82.9)	.60
Distal extent			<.001
Aortic	475 (56.0)	293 (30.0)	
Iliac	373 (44.0)	688 (70.0)	
Body mass index			.42
<18.5	29 (3.0)	24 (2.1)	
18.5–24.9	290 (30.3)	343 (29.9)	
25–29.9	369 (38.6)	446 (38.8)	
30–39.9	236 (24.7)	292 (25.4)	
>40	33 (3.5)	44 (0.7)	

Data are presented as *n* (%) unless stated otherwise. SD = standard deviation; IQR = interquartile range; TAAA = thoraco-abdominal aortic aneurysm; COPD = chronic obstructive pulmonary disease; ASA = American Society of Anesthesiologists; eGFR = estimated glomerular filtration rate.
**p* values derived by Fisher's exact testing and Student *t* test or Wilcoxon rank sum testing, where appropriate.

Table 7. Odds ratios (OR) for 30 day mortality after open (n=957) compared with endovascular repair (n=1149) of complex abdominal aortic aneurysm identified from the American College of Surgeons National Surgical Quality Improvement Program (NSQIP) Targeted Vascular Module registry in 2011–2017

Outcome variable	30 day mortality (unadjusted)		30 day mortality (adjusted)	
	OR (95% CI)*	p	OR (95% CI)*	p
All extents	1.87 (1.26–2.78)	.002	1.99 (1.22–3.25)	.006
Juxtarenal only	0.82 (0.48–1.41)	.47	0.87 (0.47–1.61)	.66
Suprarenal only	5.22 (2.60–10.46)	<.001	6.32 (2.64–15.13)	<.001
Type IV TAAA	2.37 (0.70–8.00)	.16	4.53 (1.15–17.83)	.031

OR = odds ratio; CI = confidence interval; TAAA = thoraco-abdominal aortic aneurysm.

* ORs derived by logistic regression model in unadjusted cohort and after adjustment with weighted logistic regression. Adjusted OR propensity weighted for treatment group with additional adjustment for smoking status, age, aneurysm diameter, and proximal aneurysmal extent.

at the subgroup analysis, this benefit appears to be driven by the more proximal extents (suprarenal and type IV TAAA). It should be noted that the subgroup analyses are probably underpowered to draw any major conclusions.

Both mortality and morbidity increased as expected with more proximal aneurysm extent. Additionally, as only 30 day outcomes were available, the peri-operative mortality may be underestimated. Mani *et al.* and Schermerhorn *et al.* showed that mortality after open AAA repair is increased until 90 days after surgery.[17,18]

Concerns could be raised about bias in the data, as the 95 institutions in the database are self selected. However, this bias is likely to be toward larger institutions, at which greater numbers of open abdominal aortic aneurysm procedures are performed, as these institutions are willing to pay to participate in the open aortic NSQIP module, meaning that nationwide data may be worse. Indeed, a recent comparison between the targeted NSQIP module and the Nationwide Inpatient Sample (NIS), which uses random samples of all non-federal inpatient admissions throughout the United States to estimate national data, demonstrated that the NIS has a higher open AAA in hospital mortality rate than the targeted NSQIP. In particular, from 2012 to 2015, there were 21, 800 intact open AAA repairs estimated in the United States by the NIS compared with 1647 captured in the targeted NSQIP, with a mortality rate of 5.4% *vs.* 4.7%.[19] Therefore, the targeted NSQIP appeared to represent ~7.6% of the nation's total. This comparison included AAAs of all extents, as the NIS is unable to discern infrarenal from complex AAA. Furthermore, in the non-targeted NSQIP, which collects less specific data from over 700 hospitals (without additional costs associated with participation in the targeted module), there were 647 additional cases for a total of 1604 cases, with a mortality rate higher than the vascular targeted subset, at 7.5%.

A small portion of the aneurysms were repaired at diameters <5.0 cm. These may have represented concurrent repairs for large iliac aneurysms, repairs for saccular aneurysms, or rapid growth. It is unlikely that these patients received a large open surgical procedure without an established indication. However, this analysis highlights the need to carefully consider the indication to be certain that the operative risk is warranted.

Independent associations with death included more proximal aneurysm extent, severe COPD, low BMI, increasing age, and more severe CKD. Perhaps the most interesting finding was the discovery that BMI <18.5 was independently associated with over fourfold higher odds of death. A previous study hypothesised that this is a result of malnutrition and respiratory muscle weakness leading to re-intubation and prolonged intubation time.[20] Indeed, the cohort with low BMI did suffer from more re-intubations and this may have contributed to their lower survival in this study. Surgeons should take this high risk into account for patients with low BMI when evaluating the merit of open aneurysm repair.

According to the most recent SVS guidelines on AAA management, elective open surgical repair should be performed at centres with a documented peri-operative mortality of ≤5%.[21] This study demonstrates that, in this national database, this threshold is only being met for juxtarenal aneurysms and not for other cAAAs. According to the most recent ESVS guidelines, open repair should be considered as the preferred treatment modality in patients with long life expectancy, with EVAR preferred for those with suitable anatomy and reasonable life expectancy (both Class IIa, Level B).[22] The results herein support that endovascular repair has lower peri-operative mortality for suprarenal and type IV TAAAs, and each centre should monitor their mortality rates and consider the decision for open repair on a case by case basis. However, as with infrarenal AAA repair, long term survival, rupture, and re-intervention rates will be equally important to guide treatment decisions. Given the high mortality, particularly involving suprarenal and type IV thoraco-abdominal aneurysms, surgeons should have a high threshold to offer an open repair for these lesions until strict repair indications are met.

Participation in a registry such as the targeted NSQIP is the only way to document adequate outcomes as there is currently no other mechanism in the United States to measure and compare with benchmarks and other institutions. The individual hospital level data from NSQIP are given only to the centre itself and allow comparison with the pooled rates from all other participating institutions. Given that many of the targeted vascular NSQIP sites are probably referral centres, it is likely that outcomes more broadly may be worse. Additionally, the mortality and complication rates identified in this study can be used as a benchmark for complex endovascular interventions performed under elective conditions.

Limitations

Limitations of this study include incomplete recording of pre-operative cardiac comorbid data limiting the ability to identify cardiac comorbidities other than congestive heart failure. Also, several granular procedure specific details, such as visceral and total cross clamp times are missing from these data. NSQIP is a quality improvement collaborative and thus results from these sites may not be reflective of results in all hospitals nationwide, especially those sites that choose to pay extra to participate in the targeted vascular module for open AAA repair. Additionally, the mean case volume per centre is low, but it was not possible to discern a volume/outcome relationship using this database, as hospitals are purposefully de-identified. It is not known whether any centres excluded cases after volume thresholds were met, nor the nature of such cases. However, volume limits are pre-specified, and cases are collected consecutively. Similarly, it is not known how patients were selected for surgery, as granular pre-operative testing data were not available (i.e. pulmonary function tests, echocardiogram, stress test) on these patients. There was also no way of ascertaining the turn down rate for surgery. Moreover, certain outcomes of interest such as paraplegia rates were not captured, nor the exact configuration of branched/fenestrated grafts, and it cannot be discerned whether a graft was custom made or physician modified; given that access to devices beyond two fenestrations and a scallop is limited in the United States, there may have been less extensive pathology treated in the endovascular cohort, perhaps artificially lowering the mortality rate. However, aneurysm extent is defined the same for endovascular and open repair and it was possible to account for this. Finally, NSQIP only reports 30 day outcomes, meaning it was not possible to discern important outcomes at later time points such as re-interventions, visceral vessel patency, and late survival.

Conclusion

The 30 day mortality was 4.6% for juxtarenal AAA, 9.5% for suprarenal AAA, and 14.7% for type IV TAAA. Open repair odds of 30 day mortality was nearly twice that of endovascular repair for cAAA. Independent associations with death included BMI <18.5, more severe CKD level, more proximal aneurysm extent, age, and severe COPD. These data may serve as a benchmark for complex endovascular procedures.

CONFLICT OF INTEREST

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COUP D'OEIL

COVID Fingers: Another Severe Vascular Manifestation

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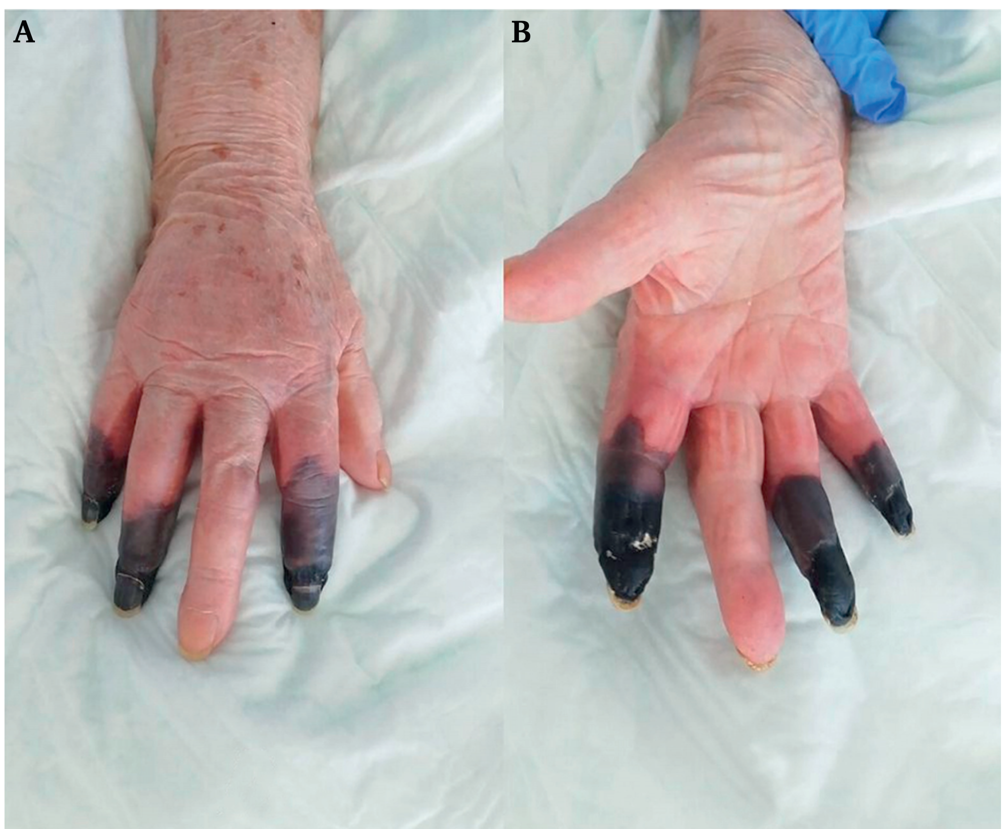

An 86 year old woman presented in April 2020 with black fingers. She had dry gangrene of the second, fourth, and fifth fingers of the right hand (A and B). In March, she had acute coronary syndrome and was put on dual antiplatelet therapy. Because of the COVID-19 pandemic, she underwent oropharyngeal swab testing, which was positive for COVID-19. Arterial duplex ultrasonography showed monophasic flow with fast diastolic drop in the common digital arteries. She had no other clinical manifestations of COVID-19. After receiving a therapeutic dose of low molecular weight heparin, her necrotic fingers were amputated without complications; histopathology revealed digital intravascular thrombosis.

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