ELSEVIER

Clinical Research

Effect of Body Mass Index on Early Outcomes of Endovascular Abdominal Aortic Aneurysm Repair

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Background: This study compares the presentation, management, and outcomes of patients undergoing endovascular abdominal aortic aneurysm repair (EVAR), based on their weight status as defined by their body mass index (BMI).

Methods: Patients with primary EVAR for ruptured and intact abdominal aortic aneurysm (AAA) were identified in the National Surgical Quality Improvement Program database (2016–2019). Patients were categorized by weight status (underweight: BMI < 18.5 kg/m^2, normal weight: 18.5–24.9 kg/m^2, overweight: 25–29.9 kg/m^2, Obese I: 30–34.9 kg/m^2, Obese II: 35–39.9 kg/m^2, Obese III: > 40 kg/m^2). Preoperative characteristics and 30-day outcomes were compared.

Results: Of 3,941 patients, 4.8% were underweight, 24.1% normal weight, 37.6% overweight, and 22.5% with Obese I, 7.8% Obese II, and 3.3% Obese III status. Underweight patients presented with larger (6.0 [5.4–7.2] cm) and more frequently ruptured (25.0%) aneurysms than normal weight patients (5.5 [5.1–6.2] cm and 4.3%, $P < 0.001$ for both). Pooled 30-day mortality was worse for underweight (8.5%) compared to all other weight status (1.1–3.0%, $P < 0.001$), but risk-adjusted analysis demonstrated that aneurysm rupture (odds ratio [OR] 15.9, 95% confidence interval [CI] 8.98–28.0) and not underweight status (OR 1.75, 95% CI 0.73–4.18) accounted for increased mortality in this population. Obese III status was associated with prolonged operative time and respiratory complications after ruptured AAA, but not 30-day mortality (OR 0.82, 95% CI 0.25–2.62).

Conclusions: Patients at either extreme of the BMI range had the worst outcomes after EVAR. Underweight patients represented only 4.8% of all EVARs, but 21% of mortalities, largely attributed to higher incidence of ruptured AAA at presentation. Severe obesity, on the other hand, was associated with prolonged operative time and respiratory complications after EVAR for ruptured AAA. BMI, as an independent factor, was however not predictive of mortality for EVAR.

Disclosure: ACS NSQIP and the hospitals participating in the ACS NSQIP are the source of the data used herein; they have not verified and are not responsible for the statistical validity of the data analysis or the conclusions derived by the authors.

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INTRODUCTION

Nutritional status is an important determinant of surgical outcomes. In vascular surgery, the relationship between body mass index (BMI) and morbidity and mortality has been described as ''U''-shaped or reverse ''J''-shaped with the highest incidence of complications occurring in underweight patients and those with morbid obesity.[1] Interestingly, numerous studies have reported that overweight or mild obesity status is associated with improved outcomes in vascular surgery patients.[1,2] Termed the obesity paradox, this phenomenon is well documented in the cardiac literature, with reports of reduced in-hospital complications and mortality in overweight and obese cohorts undergoing percutaneous coronary intervention and cardiac surgery.[3,4] The relationship between weight status and aortic surgery, however, is less clear. Hypertension and hypercholesterolemia are associated with obesity and known risk factors for AAA, while diabetes appears to be protective.[5] Increasing BMI and waist circumference have also been associated with presence but not progression of AAA.[6,7]

Malnutrition, on the other hand, is common in surgical patients and may be related to insufficient nutrient intake, chronic disease such as organ failure and systemic inflammatory disorders, or acute disease and injury as in trauma and infection.[8,9] Malnutrition has been defined as 2 or more of insufficient energy intake, weight loss, loss of muscle mass, loss of subcutaneous fat, localized or generalized fluid accumulation, and diminished functional status as measured by grip strength.[8] It is associated with prolonged hospital length of stay[10,11] and increased postoperative complications.[10] In vascular surgery, malnutrition is present in up to 24% of patients, especially females and smokers,[12] and is associated with prolonged length of stay and increased risk of postoperative complications and readmission.[13]

Given that endovascular repair is now the most common approach for treating AAA, understanding the impact of BMI on EVAR outcomes may help with preoperative risk assessment and surgical planning. Thus, by comparing aneurysm characteristics, acuity of illness, and surgical outcomes in patients of various weight statuses undergoing EVAR, this study aims to inform clinicians on national practice patterns and highlight areas for improvement in the endovascular management of AAA.

METHODS

Database and Patient Selection

This study was deemed exempt from review by the University of Miami Institutional Review Board as the data used are deidentified and publicly available. We accessed the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP 2016−2019) database, which contains risk-adjusted data from more than 700 hospitals in the United States and merged cases with the corresponding vascular procedure-targeted files containing additional case information from 98 participating hospitals. NSQIP hospitals self-select to provide additional data including indication for EVAR, prior history of aortic surgery, aneurysm anatomy, and operative technique and we limited our analysis to cases having these complete EVAR procedure-targeted data. Both elective and emergency surgery performed for indications of diameter, symptomatic intact AAA, and ruptured AAA with or without hypotension were included in the initial cohort. To limit heterogenicity, only infrarenal aneurysms were included for analysis and those with a history of prior abdominal aortic surgery were excluded.

Weight Status and Variable Definitions

BMI was calculated and used to categorize patients as per Center for Disease Control weight status categories: underweight (< 18.5 kg/m^2), normal weight (18.5−24.9 kg/m^2), overweight (25.0−29.9 kg/m^2), Obese I (30.0−34.9 kg/m^2), Obese II (35.0−39.9 kg/m^2), and Obese III (> 40 kg/m^2). Demographic and preoperative patient characteristics including rates of various comorbidities and urgency of repair were compared across weight status. Per NSQIP, bleeding disorder was defined as any condition that places the patient at risk for excessive bleeding due to deficiency of blood clotting elements and includes vitamin K deficiency, hemophilia, thrombocytopenia, and chronic anticoagulation therapy that has not been discontinued prior to surgery. Elective cases required that a patient was brought from their home or normal living environment on the day of surgery for a nonemergent/nonurgent scheduled procedure. In contrast, emergency cases were performed during the same hospital admission as the initial diagnosis and within a short interval of time between patient diagnosis and onset of related preoperative symptomology. Procedures not meeting criteria for elective or emergent surgery were classified as urgent. Postoperative outcomes included total hospital and intensive care unit lengths of stay, in-hospital and 30-day mortality, and 30-day incidence of readmission, reoperation, and various complications.

Table I. Demographic and preoperative risk factor distribution by weight status

Variable N (%) or median [IQR]	UW 188 (4.8)	NW 949 (24.1)	OW 1481 (37.6)	Obese I 885 (22.5)	Obese II 306 (7.8)	Obese III 132 (3.3)	P
Age, years	75 [69–82]	75 [69–81]	74 [68–80]	71 [66–77]	70 [64–75]	68 [64.5–73]	<0.001
Female sex	41 (21.8)	205 (21.6)	189 (12.8)	107 (12.1)	46 (15.0)	24 (18.2)	<0.001
Non-White race[a]	13 (12.0)	108 (13.4)	88 (7.2)	46 (6.4)	20 (8.0)	10 (8.8)	<0.001
Hispanic ethnicity[b]	1 (0.9)	20 (2.5)	37 (3.0)	10 (1.4)	4 (1.6)	2 (1.7)	0.26
ASA class[c]	4 [3–4]	3 [3–4]	3 [3–4]	3 [3–4]	3 [3–4]	3 [3–4]	<0.001
Dependent functional status[c]	8 (4.3)	29 (3.1)	29 (2.0)	10 (1.1)	0 (0)	4 (3.1)	<0.001
Current smoker	77 (41.0)	409 (43.1)	514 (34.7)	265 (29.9)	101 (33.0)	43 (32.6)	<0.001
Dyspnea, at rest or on exertion	24 (12.8)	143 (15.1)	208 (14.0)	127 (14.4)	51 (16.7)	42 (31.8)	<0.001
Severe COPD	51 (27.1)	178 (18.8)	188 (12.7)	133 (15.0)	51 (16.7)	37 (28.0)	<0.001
Hypertension	128 (68.1)	678 (71.4)	1,114 (75.2)	707 (79.9)	256 (83.7)	119 (90.2)	<0.001
Congestive heart failure	7 (3.7)	19 (2.0)	17 (1.1)	12 (1.4)	3 (1.0)	11 (8.3)	<0.001
Diabetes	22 (11.7)	88 (9.3)	198 (13.4)	186 (21.0)	69 (22.5)	46 (34.8)	<0.001
Currently on dialysis	1 (0.5)	17 (1.8)	15 (1.0)	5 (0.6)	0 (0)	0 (0)	0.037*
Disseminated cancer	0 (0)	12 (1.3)	2 (0.1)	6 (0.7)	4 (1.3)	0 (0)	0.004
Open wound or infection	3 (1.6)	8 (0.8)	14 (0.9)	6 (0.7)	4 (1.3)	2 (1.5)	0.59
Steroid use	4 (2.1)	39 (4.1)	48 (3.2)	28 (3.2)	8 (2.6)	5 (3.8)	0.69
>10% weight loss in 6 months	13 (6.9)	21 (2.2)	5 (0.3)	4 (0.5)	2 (0.7)	0 (0)	<0.001
Bleeding disorder	24 (12.8)	104 (11.0)	179 (12.1)	89 (10.1)	28 (9.2)	16 (12.1)	0.51
Transfusion <72 hr preop	11 (5.9)	17 (1.8)	19 (1.3)	12 (1.4)	8 (2.6)	6 (4.5)	<0.001
Preop hematocrit, %[d]	39.3 [35.0–42.3]	40.2 [36.3–43.4]	41.9 [38.3–44.5]	42.4 [38.8–45.3]	42.0 [39.5–45.0]	42.1 [38.5–44.3]	<0.001
Preop creatinine, mg/dL[e]	1.0 [0.8–1.3]	1.0 [0.8–1.2]	1.0 [0.9–1.3]	1.0 [0.9–1.2]	1.0 [0.9–1.3]	1.0 [0.8–1.3]	0.12
Preop albumin, g/dL[f]	3.6 [3.2–4.1]	3.8 [3.4–4.2]	3.9 [3.5–4.2]	4.0 [3.6–4.2]	3.9 [3.5–4.3]	3.9 [3.6–4.1]	<0.001
Pre-op INR[g]	1.1 [1.0–1.1]	1.0 [1.0–1.1]	1.0 [1.0–1.1]	1.0 [1.0–1.1]	1.0 [1.0–1.1]	1.1 [1.0–1.1]	0.014*

IQR, interquartile range; UW, underweight; NW, normal weight; OW, overweight; ASA, American Society of Anesthesiology; COPD, chronic obstructive pulmonary disease; INR, international normalized ratio.

[a]N = 3,216.

[b]N = 3,264.

[c]N = 3,937.

[d]N = 3,733.

[e]N = 3,785.

[f]N = 1,710.

[g]N = 2,578.

*Nonsignificant after Bonferroni correction.

Table II. Perioperative and technical factors across weight statuses

Variable *N* (%) or median [IQR]	UW 188 (4.8)	NW 949 (24.1)	OW 1481 (37.6)	Obese I 885 (22.5)	Obese II 306 (7.8)	Obese III 132 (3.3)	*P*
Indication							<0.001
Intact	141 (75.0)	932 (86.1)	1,465 (88.3)	865 (87.6)	307 (89.0)	122 (82.4)	<0.001
Asymptomatic	110 (78.0)	823 (90.6)	1,311 (92.8)	779 (92.7)	273 (95.1)	109 (93.2)	<0.001
Symptomatic	31 (22.0)	85 (9.4)	102 (7.2)	61 (7.3)	14 (4.9)	8 (6.8)	<0.001
Ruptured	47 (25.0)	41 (4.3)	68 (4.6)	45 (5.1)	19 (6.2)	15 (11.4)	<0.001
Without hypotension	23 (48.9)	24 (58.5)	31 (45.6)	28 (62.2)	7 (36.8)	4 (26.7)	0.11
With hypotension	24 (51.1)	17 (41.5)	37 (54.4)	17 (37.8)	12 (63.2)	11 (73.3)	0.11
AAA diameter, cm[a]	6.0 [5.4–7.2]	5.5 [5.1–6.2]	5.5 [5.2–6.0]	5.5 [5.2–6.1]	5.5 [5.2–6.1]	5.6 [5.2–6.3]	<0.001
Intact	5.8 [5.3–6.9]	5.5 [5.1–6.1]	5.5 [5.1–6.0]	5.5 [5.1–6.0]	5.5 [5.1–6.0]	5.6 [5.1–6.2]	0.003
Ruptured	7.0 [6.2–9.0]	6.5 [5.3–8.2]	7.5 [5.6–8.8]	7.8 [5.9–8.6]	8.0 [7.3–9.0]	7.9 [6.8–9.0]	0.22
Case urgency[b]							<0.001
Elective	69 (36.7)	751 (79.1)	1,219 (82.4)	729 (82.4)	260 (85.0)	101 (76.5)	
Urgent	25 (13.3)	122 (12.9)	148 (10.0)	88 (9.9)	20 (6.5)	16 (12.1)	
Emergent	94 (50.0)	76 (8.0)	113 (7.6)	68 (7.7)	26 (8.5)	16 (12.1)	
Operative time, min	113 [82–159]	112 [81–156]	106 [78–145]	108 [81–144]	113 [86–157]	126 [95–174]	<0.001
Access[c]							0.16
Percutaneous bilateral	120 (63.8)	578 (61.0)	953 (64.4)	570 (64.7)	192 (62.7)	82 (62.1)	
Percutaneous converted to open	4 (2.1)	11 (1.2)	22 (1.5)	19 (2.2)	6 (2.0)	1 (0.8)	
One groin cutdown	12 (6.4)	49 (5.2)	100 (6.8)	40 (4.5)	11 (3.6)	8 (6.1)	
Bilateral groin cutdown	52 (27.7)	310 (32.7)	404 (27.3)	252 (28.6)	97 (31.7)	41 (31.1)	
Acute conversion to open[d]	1 (0.5)	8 (0.8)	10 (0.7)	5 (0.6)	4 (1.3)	2 (1.5)	0.70
Distal Extent[e]							0.57
Aortic	76 (48.7)	386 (48.2)	622 (49.4)	368 (49.3)	126 (49.6)	49 (45.0)	
Common iliac	59 (37.8)	307 (38.3)	505 (40.1)	296 (39.6)	93 (36.6)	48 (44.0)	
Internal iliac	9 (5.8)	71 (8.9)	79 (6.3)	50 (6.7)	25 (9.8)	7 (6.4)	
External iliac	12 (7.7)	37 (4.6)	52 (4.1)	33 (4.4)	10 (3.9)	5 (4.6)	
Access vessel repair	10 (5.3)	39 (4.1)	55 (3.7)	34 (3.8)	17 (5.6)	8 (6.1)	0.51
Aortic stent	18 (9.6)	86 (9.1)	125 (8.4)	85 (9.6)	29 (9.5)	12 (9.1)	0.95
Renal stent	12 (6.4)	39 (4.1)	54 (3.6)	37 (4.2)	16 (5.2)	7 (5.3)	0.47
Iliac stent	32 (17.0)	194 (20.4)	283 (19.1)	159 (18.0)	57 (18.6)	22 (16.7)	0.72
Iliac branched device	22 (11.7)	164 (17.3)	265 (17.9)	167 (18.9)	60 (19.6)	22 (16.7)	0.26
Hypogastric embolization	8 (4.3)	56 (5.9)	60 (4.1)	43 (4.9)	15 (4.9)	10 (7.6)	0.26

Hypogastric revascularization	11 (5.9)	33 (3.5)	45 (3.0)	37 (4.2)	9 (2.9)	6 (4.5)	0.31
Lower extremity revascularization	10 (5.3)	37 (3.9)	50 (3.4)	28 (3.2)	9 (2.9)	2 (1.5)	0.51

IQR, interquartile range; UW, underweight; NW, normal weight; OW, overweight.
[a]*N* = 3,885.
[b]*N* = 3,940.
[c]*N* = 3,934.
[d]*N* = 3,935.
[e]*N* = 3,325.

Statistical Analysis

Continuous data were nonparametric and analyzed by Kruskal-Wallis test. Categorical variables were compared using Chi-square or Fisher-Freeman-Halton exact test, as appropriate, with Bonferroni corrections applied for multiple comparisons. Thirty-day outcomes were evaluated both pooled and separately for ruptured and intact AAA. To identify independent predictors of 30-day mortality, we first included all preoperative demographic and comorbidity variables including age, sex, race, American Society of Anesthesiologists class, smoking, severe chronic obstructive pulmonary disease (COPD), hypertension, congestive heart failure (CHF), diabetes, dialysis, dependent functional status, bleeding disorder, and general anesthesia in a backward stepwise logistic regression model using entry and removal criteria of $P < 0.20$ and $P < 0.05$, respectively. Weight status was then forced into the final model and fit assessed by Hosmer-Lemeshow Test and C-statistic. Preoperative laboratory data were excluded as missing values would have significantly reduced sample sizes for modelling. Surgical urgency was not included due to correlation with rupture status. Regression analysis was first performed including all indications for repair with ruptured AAA as an independent variable. Then, the analysis was repeated for ruptured and intact AAA separately with addition of symptomatic AAA and hypotension as independent variables for the intact and ruptured AAA models, respectively. Statistical analyses were performed in SPSS statistical software version 27 (IBM Corp, Armonk, New York) and statistical significance defined as $P < 0.05$. Data are presented as *N* (%) or median [interquartile range] and results from multivariate analyses as odds ratios (ORs) with 95% confidence intervals (CIs).

RESULTS

We identified 3,941 EVAR cases, of whom 188 (4.8%) were underweight, 949 (24.1%) normal weight, 1,481 (37.6%) overweight, and 885 (22.1%) with Obese I, 306 (7.8%) Obese II, and 132 (3.3%) Obese III status. Demographic and comorbidity information are summarized in Table I. The proportion of female patients was significantly higher in underweight (21.8%) and normal weight (21.6%) patients compared to overweight (12.8%) and Obese I (12.1%) patients ($P < 0.001$). Obese I, II, and III patients were also significantly younger than underweight, normal weight, and overweight patients. Median American Society of

Table III. Distribution of in-hospital and 30-day outcomes across weight statuses following EVAR for intact and ruptured AAA

Variable *N* (%) or median [IQR]	UW 188 (4.8)	NW 949 (24.1)	OW 1481 (37.6)	Obese I 885 (22.5)	Obese II 306 (7.8)	Obese III 132 (3.3)	*P*
30-day reoperation	17 (9.0)	45 (4.7)	55 (3.7)	39 (4.4)	11 (3.6)	6 (4.5)	0.034
ICU length of stay, days	0 [0−2]	0 [0−1]	0 [0−1]	0 [0−1]	0 [0−1]	0 [0−1]	<0.001
Total length of stay, days	3 [1−7]	1 [1−3]	1 [1−2]	1 [1−2]	1 [1−2]	1 [1−3]	<0.001
Still in hospital > 30 days	2 (1.1)	2 (0.2)	4 (0.3)	2 (0.2)	0 (0)	1 (0.8)	0.25
30-day readmission	16 (8.5)	78 (8.2)	89 (6.0)	59 (6.7)	19 (6.2)	12 (9.1)	0.27
In-hospital mortality	13 (6.9)	12 (1.3)	11 (0.7)	9 (1.0)	3 (3.0)	2 (1.5)	<0.001
30-day mortality	16 (8.5)	22 (2.3)	17 (1.1)	12 (1.4)	4 (1.3)	4 (3.0)	<0.001
Lower extremity ischemia	4 (2.1)	15 (1.6)	25 (1.7)	15 (1.7)	5 (1.6)	0 (0)	0.77
Ischemic colitis[a]	6 (3.2)	10 (1.1)	9 (0.6)	5 (0.6)	0 (0)	3 (2.3)	0.003
Medical treatment	2 (33.3)	6 (66.7)	6 (66.7)	2 (50.0)	0 (0)	1 (33.3)	0. 69
Surgical treatment	4 (66.7)	3 (33.3)	3 (33.3)	2 (50.0)	0 (0)	2 (66.7)	0.69
Superficial surgical site infection	0 (0)	4 (0.4)	13 (0.9)	4 (0.5)	2 (0.7)	3 (2.3)	0.16
Pneumonia	5 (2.7)	11 (1.2)	16 (1.1)	10 (1.1)	4 (1.3)	5 (3.8)	0.097
Unplanned intubation	11 (5.9)	14 (1.5)	13 (0.9)	12 (1.4)	4 (1.3)	2 (1.5)	<0.001
Pulmonary embolism	2 (1.1)	0 (0)	0 (0)	2 (0.2)	2 (0.7)	0 (0)	0.002
Ventilator > 48 hr	8 (4.3)	8 (0.8)	13 (0.9)	7 (0.8)	8 (2.6)	6 (4.5)	<0.001
Acute renal failure	5 (2.7)	9 (0.9)	8 (0.5)	4 (0.5)	2 (1.0)	3 (2.3)	0.016
Progressive renal insufficiency	4 (2.1)	5 (0.5)	5 (0.3)	3 (0.3)	2 (0.7)	0 (0)	0.088
Urinary tract infection	3 (1.6)	9 (0.9)	15 (1.0)	6 (0.7)	3 (1.0)	2 (1.5)	0.71
CVA/stroke with neurological deficit	4 (2.1)	1 (0.1)	3 (0.2)	3 (0.3)	2 (0.7)	0 (0)	0.010
Cardiac arrest requiring CPR	6 (3.2)	7 (0.7)	6 (0.4)	8 (0.9)	2 (0.7)	2 (1.6)	0.007
Myocardial infarction	8 (4.3)	21 (2.2)	25 (1.7)	9 (1.0)	2 (0.7)	1 (0.8)	0.025
Bleeding requiring transfusion	48 (25.5)	102 (10.7)	108 (7.3)	60 (6.8)	22 (7.2)	16 (12.1)	<0.001
DVT requiring therapy	3 (1.6)	0 (0)	2 (0.1)	2 (0.2)	2 (0.7)	0 (0)	0.006
Sepsis	2 (1.1)	6 (0.6)	5 (0.3)	1 (0.1)	0 (0)	0 (0)	0.19
Septic shock	4 (2.1)	1 (0.1)	6 (0.4)	3 (0.3)	0 (0)	1 (0.8)	0.015

IQR, interquartile range; UW, underweight; NW, normal weight; OW, overweight; ICU, intensive care unit; CVA, cerebrovascular accident; CPR, cardiopulmonary resuscitation; DVT, deep venous thrombosis.
[a]$N = 33$; missing data for NW and Obese I status.

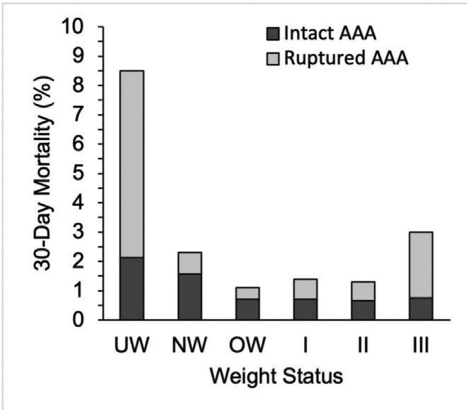

Fig. 1. Distribution of 30-day mortality by weight status after EVAR for intact and ruptured AAA. AAA, abdominal aortic aneurysm; UW, underweight (body mass index [BMI] < 18.5 kg/m^2); NW, normal weight (BMI 18.5−24.9 kg/m^2); OW, overweight (BMI 25.0−29.9 kg/m^2); I, Obese I (BMI 30.0−34.9 kg/m^2); II, Obese II (BMI 35.0−39.9 kg/m^2); III, Obese III (BMI > 40 kg/m^2).

Anesthesiologists Class was 4 in underweight but 3 in all other weight status. Preoperative hematocrit was significantly lower for underweight patients (39.3% [35.0−42.3%]) with a corresponding increased preoperative transfusion requirement (5.9%). Albumin levels were also lower in underweight (3.6 g/dL) compared to all other weight status (3.8−4.0 g/dL) but still within normal range. Rates of diabetes and hypertension increased with BMI and patients with Obese III status had significantly higher rates of CHF (8.3%) and dyspnea (31.8%) than all others. The proportion of patients with dependent functional status and severe COPD was lowest for overweight and Obese I and II status.

Perioperative and technical factors are summarized in Table II. Incidence of ruptured aneurysm at presentation was significantly higher in underweight (25.0%) patients compared to all others, but Obese III (11.4%) patients also had a greater proportion of ruptured aneurysms than normal weight (4.3%) and overweight (4.6%) patients. There were similar differences in case urgency with only 36.7% of underweight patients undergoing elective EVAR compared to more than 75% for all other weight status ($P < 0.001$). Conversely, 50.0% of EVAR cases in underweight patients were emergency compared with 7.6−12.1% for all other weight status ($P < 0.001$). Underweight patients were also less likely to undergo general anesthesia compared to Obese II patients (87.8% vs. 96.1%, $P = 0.015$). There were no differences in presence of hypotension with ruptured AAA but underweight patients with intact AAA were more likely to be symptomatic than all other weight status (22.0% vs. 4.9−9.4%, $P < 0.001$). Median diameters of ruptured aneurysms were similar across weight status but intact aneurysms were significantly larger in underweight (6.0 cm) patients compared to all others (5.5−5.6 cm, $P < 0.001$). Operative time was prolonged in Obese III (126 [96−173] min) compared to overweight (106 [78−145 min]) and Obese I (108 [81−144] min) patients ($P < 0.001$). There were no significant differences in distal aneurysm extent, access method, or need for hypogastric or lower extremity revascularization among different weight status.

Pooled in-hospital and 30-day outcomes for intact and ruptured AAA are summarized in Table III. Compared to normal weight patients, underweight patients had overall prolonged length of stay, worse in-hospital and 30-day mortality, and increased rates of various complications including stroke, unplanned intubation, ventilator requirement > 48 hr, bleeding requiring transfusion, deep venous thrombosis, pulmonary embolism, and septic shock. On the other hand, Obese III status was associated with increased ventilator requirement > 48 hr, while patients of overweight and Obese I and II status had significantly reduced length of stay and rates of bleeding than normal weight patients.

The distribution of mortalities within 30 days by aneurysm rupture status is shown in Figure 1. When evaluating outcomes of intact (Table IV) and ruptured (Table V) AAA separately, in-hospital and 30-day mortality rates were not statistically different across weight status. For intact AAA, underweight status was associated with prolonged length of stay (3 vs. 1 days), unplanned intubation (4.3% vs. 1.3%), ventilator requirement > 48 hr (2.8% vs. 0.3%), and ischemic colitis (2.8% vs. 0.3%). Reoperation rates were also significantly higher for underweight (9.2%) compared to overweight (3.3%) and Obese I (3.4%) patients with intact AAA. Of the 173 total reoperations that occurred within 30 days, 120 were coded by NSQIP as being related to the initial procedure and the most common diagnoses were embolic or thrombotic complications (28%), endoleak (9%), wound infection (6%), and ischemic colitis (6%). There was also a trend toward increased surgical site infections with increasing BMI but this result did not reach statistical significance. While wound infections were more common with open cutdown compared to percutaneous femoral access (1.1% vs. 0.4%, $P = 0.008$), there was no significant difference in access

Table IV. Distribution of in-hospital and 30-day outcomes across weight statuses following EVAR for intact AAA

Variable *N* (%) or median [IQR]	UW 141 (3.8)	NW 908 (24.5)	OW 1413 (38.1)	Obese I 840 (22.7)	Obese II 287 (7.7)	Obese III 117 (3.2)	*P*
30-day reoperation	13 (9.2)	40 (4.4)	48 (3.4)	28 (3.3)	9 (3.1)	4 (3.4)	0.018
ICU length of stay, days	0 [0−1]	0 [0−1]	0 [0−1]	0 [0−1]	0 [0−1]	0 [0−1]	0.002
Total length of stay, days	3 [1−6]	1 [1−3]	1 [1−2]	1 [1−2]	1 [1−2]	1 [1−2]	<0.001
Still in hospital > 30 days	2 (1.4)	1 (0.1)	1 (0.1)	1 (0.1)	0 (0)	0 (0)	0.059
30-day readmission	14 (9.9)	75 (8.3)	86 (6.1)	54 (6.4)	18 (6.3)	9 (7.7)	0.25
In-hospital mortality	2 (1.4)	6 (0.7)	7 (0.5)	3 (0.4)	1 (0.3)	0 (0)	0.58
30-day mortality	4 (2.8)	15 (1.7)	11 (0.8)	6 (0.7)	2 (0.7)	1 (0.9)	0.090
Lower extremity ischemia	4 (2.8)	13 (1.4)	24 (1.7)	12 (1.4)	4 (1.4)	0 (0)	0.61
Ischemic colitis[a]	5 (3.5)	6 (0.7)	7 (0.5)	3 (0.4)	0 (0)	1 (0.9)	0.008
Medical treatment	2 (40.0)	3 (50.0)	5 (71.4)	2 (100)	0 (0)	0 (0)	0.39
Surgical treatment	3 (60.0)	3 (50.0)	2 (28.6)	0 (0)	0 (0)	1 (100)	0.39
Superficial surgical site infection	0 (0)	4 (0.4)	12 (0.8)	3 (0.4)	2 (0.7)	3 (2.6)	0.12
Pneumonia	4 (2.8)	10 (1.1)	11 (0.8)	6 (0.7)	2 (0.7)	1 (0.9)	0.27
Unplanned intubation	6 (4.3)	12 (1.3)	8 (0.6)	6 (0.7)	1 (0.3)	0 (0)	0.005
Pulmonary embolism	0 (0)	0 (0)	0 (0)	2 (0.2)	1 (0.3)	0 (0)	0.12
Ventilator > 48 hr	4 (2.8)	3 (0.3)	5 (0.4)	1 (0.1)	1 (0.3)	0 (0)	0.015
Acute renal failure	2 (1.4)	5 (0.6)	5 (0.4)	1 (0.1)	0 (0)	0 (0)	0.20
Progressive renal insufficiency	2 (1.4)	1 (0.1)	3 (0.2)	1 (0.1)	1 (0.3)	0 (0)	0.14
Urinary tract infection	2 (1.4)	9 (1.0)	14 (1.0)	6 (0.7)	2 (0.7)	2 (1.7)	0.75
CVA/stroke with neurological deficit	1 (0.7)	1 (0.1)	3 (0.2)	1 (0.1)	0 (0)	0 (0)	0.59
Cardiac arrest requiring CPR	0 (0)	5 (0.6)	4 (0.3)	6 (0.7)	1 (0.)	1 (0.9)	0.53
Myocardial infarction	5 (3.5)	19 (2.1)	18 (1.3)	6 (0.7)	1 (0.3)	0 (0)	0.013
Bleeding requiring transfusion	17 (12.1)	76 (8.4)	64 (4.5)	37 (4.4)	9 (3.1)	5 (4.3)	<0.001
DVT requiring therapy	1 (0.7)	0 (0)	0 (0)	1 (0.1)	1 (0.3)	0 (0)	0.026
Sepsis	0 (0)	6 (0.7)	5 (0.4)	0 (0)	0 (0)	0 (0)	0.20
Septic shock	2 (1.4)	1 (0.1)	3 (0.2)	0 (0)	0 (0)	0 (0)	0.065

IQR, interquartile range; UW, underweight; NW, normal weight; OW, overweight; ICU, intensive care unit; CVA, cerebrovascular accident; CPR, cardiopulmonary resuscitation; DVT, deep venous thrombosis.

[a] $N = 22$; missing data for Obese I status.

Table V. Distribution of in-hospital and 30-day outcomes across weight statuses following EVAR for ruptured AAA

Variable *N* (%) or median [IQR]	UW 47 (20.0)	NW 41 (17.4)	OW 68 (28.9)	Obese I 45 (19.1)	Obese II 19 (8.1)	Obese III 15 (6.4)	*P*
30-day reoperation	4 (8.5)	5 (12.2)	7 (10.3)	11 (24.4)	2 (10.5)	2 (13.3)	0.26
ICU length of stay, days	2 [1−3]	2 [1−4]	2 [1−4]	2 [1−5]	3 [1−7.5]	4 [3−10]	0.020
Total length of stay, days	5 [2−11]	5.5 [2−11]	6 [3−10]	6 [3−10]	8 [3.5−15.5]	14 [5−17]	0.10
Still in hospital > 30 days	0 (0)	1 (2.4)	3 (4.4)	1 (2.)	0 (0)	1 (6.7)	0.52
30-day readmission	2 (4.3)	3 (7.3)	3 (4.4)	5 (11.1)	1 (5.3)	3 (20.0)	0.29
In-hospital mortality	11 (23.4)	6 (14.6)	4 (5.9)	6 (13.3)	2 (10.5)	2 (13.3)	0.16
30-day mortality	12 (25.5)	7 (17.1)	6 (8.8)	6 (13.3)	2 (10.5)	3 (20.0)	0.23
Lower extremity ischemia	0 (0)	2 (4.9)	1 (1.5)	3 (6.7)	1 (5.3)	0 (0)	0.30
Ischemic colitis[a]	1 (2.1)	4 (9.8)	2 (2.9)	2 (4.4)	0 (0)	2 (13.3)	0.23
Medical treatment	0 (0)	3 (100)	1 (50.0)	0 (0)	0 (0)	1 (50.0)	0.20
Surgical treatment	1 (100)	0 (0)	1 (50.0)	2 (100)	0 (0)	1 (50.0)	0.20
Superficial surgical site infection	0 (0)	0 (0)	1 (1.5)	1 (2.2)	0 (0)	0 (0)	0.88
Pneumonia	1 (2.1)	1 (2.4)	5 (7.4)	4 (8.9)	2 (10.5)	4 (26.7)	0.045
Unplanned intubation	5 (10.6)	2 (4.9)	5 (7.4)	6 (13.3)	3 (15.8)	2 (13.3)	0.58
Pulmonary embolism	2 (4.3)	0 (0)	0 (0)	0 (0)	1 (5.3)	0 (0)	0.12
Ventilator > 48 hr	4 (8.5)	5 (12.2)	8 (11.8)	6 (13.3)	7 (36.8)	6 (40.0)	0.011*
Acute renal failure	3 (6.4)	4 (9.8)	3 (4.)	3 (6.7)	3 (15.8)	3 (20.0)	0.24
Progressive renal insufficiency	2 (4.3)	4 (9.8)	2 (2.9)	2 (4.4)	1 (5.3)	0 (0)	0.66
Urinary tract infection	1 (2.1)	0 (0)	1 (1.5)	0 (0)	1 (5.3)	0 (0)	0.56
CVA/stroke with neurological deficit	3 (6.4)	0 (0)	0 (0)	2 (4.4)	2 (10.5)	0 (0)	0.045*
Cardiac arrest requiring CPR	6 (12.8)	2 (4.9)	2 (2.9)	2 (4.4)	1 (5.3)	1 (67)	0.39
Myocardial infarction	3 (6.4)	2 (4.9)	7 (10.3)	3 (6.7)	1 (5.3)	1 (6.7)	0.95
Bleeding requiring transfusion	31 (66.0)	26 (63.4)	44 (64.7)	23 (51.1)	13 (68.4)	11 (73.3)	0.56
DVT requiring therapy	2 (4.3)	0 (0)	2 (2.9)	1 (2.2)	1 (5.3)	0 (0)	0.78
Sepsis	2 (4.3)	0 (0)	0 (0)	1 (2.2)	0 (0)	0 (0)	0.43
Septic shock	2 (4.3)	0 (0)	3 (4.4)	3 (6.7)	0 (0)	1 (6.7)	0.56

IQR, interquartile range; UW, underweight; NW, normal weight; OW, overweight; ICU, intensive care unit; CVA, cerebrovascular accident; CPR, cardiopulmonary resuscitation; DVT, deep venous thrombosis.
[a]$N = 11$; missing data for NW status.
*Nonsignificant after Bonferroni correction.

Table VI. Independent predictors of 30-day mortality

Variable	OR	95% CI	*P*
All indications[b]			
Ruptured AAA	15.9	8.98–28.0	<0.001
Dialysis	5.91	1.68–20.8	0.006
Bleeding disorder	2.68	1.49–4.81	0.001
Dyspnea	2.45	1.33–4.51	0.004
Weight status[a]			0.012
Underweight	1.75	0.73–4.18	0.21
Overweight	0.38	0.18–0.78	0.008
Obese I	0.58	0.27–1.25	0.163
Obese II	0.40	0.11–1.41	0.15
Obese III	0.82	0.25–2.62	0.73
Intact AAA[c]			
Dialysis	9.40	2.57–34.5	0.001
Steroid use	4.27	1.44–12.6	0.009
Symptomatic AAA	3.76	1.64–8.63	0.002
Diabetes	2.77	1.23–6.24	0.014
Weight status[a]			0.40
Underweight	1.55	0.34–7.17	0.58
Overweight	0.49	0.21–1.18	0.11
Obese I	0.53	0.20–1.46	0.22
Obese II	0.26	0.03–2.08	0.21
Obese III	0.50	0.06–4.04	0.52
Ruptured AAA[d]			
Bleeding disorder	3.52	1.49–8.33	0.004
Hypotension	2.87	1.19–6.91	0.019
Weight status[a]			0.073
Underweight	1.92	0.56–6.56	0.30
Overweight	0.29	0.08–1.06	0.061
Obese I	0.53	0.14–1.98	0.35
Obese II	0.36	0.06–2.15	0.26
Obese III	0.87	0.17–4.32	0.86

OR, odds ratio; CI, confidence interval.
[a]Reference normal weight.
[b]Hosmer-Lemeshow = 0.75, C-statistic = 0.72.
[c]Hosmer-Lemeshow = 0.49, C-statistic = 0.76.
[d]Hosmer-Lemeshow = 0.90, C-statistic = 0.82.

technique to explain the trend in wound infections across weight status ($P = 0.56$). Similarly, there was no association between BMI and need for access vessel repair ($P = 0.51$). For ruptured AAA, the incidence of pneumonia increased with BMI and Obese III patients had significantly higher rates (26.7%) compared to underweight (2.1%) patients only ($P = 0.045$). Trends toward increased length of stay and unplanned intubation in Obese III patients, and stroke in underweight patients were nonsignificant after Bonferroni correction.

We then performed logistic regression to determine whether weight status was independently associated with 30-day mortality (Table VI). When all indications for EVAR were included, ruptured aneurysm (OR 15.9, 95% CI 8.98–28.0, $P < 0.001$) was the most important risk factor for 30-day mortality. Whereas overweight status was associated with 62% reduction of mortality risk (OR 0.38, 95% CI 0.18–0.78, $P = 0.008$), underweight status was not an independent predictor of mortality. On the other hand, dialysis requirement, bleeding disorder, and preoperative dyspnea were associated with increased 30-day mortality. To better differentiate predictors of mortality, we then applied this model to ruptured and intact AAA, separately. In addition to dialysis requirement, steroid use for chronic condition, and diabetes, symptomatic AAA conferred a greater risk of 30-day mortality for intact AAA (OR 3.76, 95% CI 1.64–8.63, $P = 0.002$). In contrast, preoperative bleeding disorder and hypotension were the only independent predictors of 30-day mortality after EVAR for ruptured AAA. For both ruptured and intact AAA, no single-weight status reached statistical significance as an independent predictor of 30-day mortality.

DISCUSSION

The prevailing trend in our data mirrors that of prior studies,[1,14] notably that the highest complication and mortality rates occur in patients at either extreme of the BMI range. Conversely, the best outcomes, which are represented by the nadir of the ''U'' or reverse ''J'' mortality distribution, often occur in overweight and mild-to-moderately obese rather than normal weight patients. Whereas this observation points to a benefit of obesity for patients undergoing EVAR, our multivariate analysis showed that after adjusting for demographic and preoperative risk factors, obesity was not protective against 30-day mortality. Thus, the observed paradoxical benefit of obesity on unadjusted EVAR outcomes may instead reflect epidemiological differences in age, sex, and comorbidities rather than any inherent advantage of obesity. For example, multiple studies have shown that female sex is associated with increased mortality following EVAR,[14–16] and in our study, overweight and obese patients were both younger and had the lowest proportion of females.

Severe obesity, on the other hand, was associated with increased rates of ruptured AAA compared to normal weight and overweight status. This finding is in contrast to a prior NSQIP study but may be explained by higher prevalence of hypertension in this group and selection bias from surgeons delaying elective repair in a group considered to be at higher operative risk.[17] Obese III status was also associated with prolonged operative time and respiratory complications after EVAR for ruptured AAA but it was not an independent predictor of 30-day mortality regardless of rupture status. These findings highlight that a minimally invasive approach can mitigate much of the additional risk of wound, cardiac, and renal complications and mortality seen in open repair.[17–19] In fact, the benefit of EVAR relative to open repair seems to be especially pronounced in obese patients with a reduction in 2-year all-cause mortality of 48% compared to 17% in nonobese patients.[14,18]

The most striking observation from our study was that underweight patients accounted for only 5% of cases but 21% of EVAR mortalities. Although pooled 30-day outcomes were worse for underweight patients, this group disproportionately presented with ruptured aneurysms which carried a 15-fold increased risk of death at 30 days compared to intact AAA. After adjusting for rupture status, weight status did not affect 30-day mortality. These findings suggest that underweight status may not confer significant perioperative risk but that increased overall EVAR mortality in this population is attributable to more ruptured and symptomatic AAA and demographic factors such as advanced age, higher proportion of female patients, and increased rates of smoking, COPD, and CHF.

In addition to more frequently ruptured aneurysms at presentation, intact AAA in underweight patients were larger and more likely to be symptomatic. This finding may be indicative of delayed treatment which could be related to access to care but also hesitancy in offering elective repair in a group considered to be at high perioperative risk. Such delays can predispose underweight patients to eventual aneurysm rupture and the significant morbidity and mortality associated with emergent compared to elective EVAR. This treatment hesitancy may be unjustified as we did not find higher 30-day mortality for underweight patients undergoing EVAR for intact AAA. These disparities highlight the need for patient-centered discussions and shared decision-making during surgical consultation. If anatomic criteria for AAA repair are met, patients should be counseled on the risks of surgery and medically and nutritionally optimized prior to elective intervention. On the other hand, if surgical risk is deemed prohibitive, goals of care should be discussed and documented to avoid unwarranted interventions in the case of eventual AAA rupture and presentation in an emergency setting.

Despite its convenience, there are limitations to the use of BMI as an indicator of nutritional status. As an anthropometric measurement, it cannot identify protein and micronutrient deficiencies or the relative proportion of fat to lean body mass. Sarcopenia, which is defined as reduced muscle mass and function, may be a better measure of physiological reserve. Sarcopenia can be indirectly measured as total psoas muscle area on cross-sectional imaging and has been shown to correlate with mortality after both open[20] and endovascular AAA repair.[21] Although this finding could not be replicated in other cohorts,[22] a meta-analysis of 7 studies including 1,440 patients found that, overall, those with low skeletal muscle mass had a higher hazard of mortality after EVAR (hazard ratio 1.86, 95% CI 1.00–3.43, $P = 0.05$) or any AAA repair (hazard ratio 1.66, CI 1.15–2.40, $P = 0.007$).[23] Multiple NSQIP studies have also shown that preoperative hypoalbuminemia is associated with increased postoperative morbidity and mortality for both emergent and nonemergent, open, and endovascular aneurysm repair.[24,25] As such, the European Society for Vascular Surgery recommends assessment of nutritional status by measuring serum albumin with preoperative correction for levels < 2.8 g/dL.[26] Beyond nutritional status, the concept of frailty has also gained attention for predicting surgical outcomes. The modified 5-item frailty index (CHF, COPD or pneumonia, diabetes mellitus, dependent functional status, and hypertension)[27] predicts major adverse cardiac and cerebrovascular events[28] and 30-day,[29−31] 1-year,[32] and 5-year[32,33] survival after EVAR. Subjective measures such as the ''unfit for open repair'' variable in the Vascular Quality Initiative are also associated with increased cardiopulmonary complications and greater perioperative, 1-year, and 5-year mortality following EVAR[34] and can be supplemented by objective scoring systems such as the Vascular Quality Initiative−derived Risk Analysis Index to identify high-risk patients under consideration for elective EVAR.[35]

Our study is limited by its retrospective design which may fail to account for additional confounders. We also included only cases with EVAR-targeted data as these were necessary to define the inclusion and exclusion criteria. Whereas focusing on this smaller subset of cases could introduce selection bias, a prior study compared open AAA repair and EVAR cases between targeted and nontargeted NSQIP hospitals and found no differences in outcomes.[36] We also evaluated demographic trends and complication rates in the larger NSQIP dataset and found similar results as the targeted cohort, notably that underweight patients more often presented with ruptured AAA but had similar mortality rates as normal weight patients when examining intact and ruptured AAA separately. Since our analysis was limited to infrarenal disease, we could not study association between BMI, proximal aneurysm extent, and effect of aneurysm morphology on outcomes. As with other multicenter databases, the source data are also subject to quality and interpretation of health record documentation, although NSQIP data are entered by certified Surgical Clinical Reviewers and audited for inter-rater reliability.

CONCLUSION

In this study using a national database, we demonstrate that underweight patients present with larger and more often ruptured and symptomatic AAA. As a result, underweight patients account for a disproportionate number of EVAR mortalities despite similar risk-adjusted mortality as normal weight patients. Earlier identification of underweight, malnourished, or otherwise frail patients in the clinic with clear goals of care discussions and preoperative optimization before elective intervention may reduce overall EVAR mortality in this population. Severe obesity, on the other hand, is associated with prolonged operative time and respiratory complications but not 30-day mortality. Further studies are needed to assess the long-term effects of weight status on EVAR outcomes.

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