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ORIGINAL RESEARCH

Characteristics and Prognosis of Abdominal or Thoracic Aortic Aneurysm Patients Admitted to Intensive Care Units After Surgical Treatment: A Multicenter Retrospective Observational Study

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Objective: To investigate the characteristics and prognosis of abdominal or thoracic aortic aneurysm (AAA or TAA) patients admitted to intensive care unit (ICU) postoperatively.

Methods: Patients admitted to ICU postoperatively with a primary diagnosis of AAA or TAA were screened in the eICU Collaborative Research Database, which contained data from multiple ICUs throughout the continental United States in 2014 and 2015. Baseline characteristics and comorbidities and were investigated and factors associated with ICU mortality were explored using univariable logistic regression. Receiver operating characteristic (ROC) curve analysis was performed to evaluate the prognosis predictive performance of the widely used severity scoring system APACHE IVa.

Results: A total of 974 patients including 677 AAA and 297 TAA patients admitted to ICU postoperatively were included. Compared with TAA, AAA patients had a significantly higher median age (72 versus 64 years, P<0.001). 89.07% AAA and 84.51% TAA patients underwent elective surgery (P=0.046), 8.71% AAA and 31.99% TAA patients were with aortic dissection (P<0.001), and 10.19% AAA and 2.36% TAA patients suffered from rupture of aortic aneurysm (P<0.001). Hypertension requiring treatment was the most common comorbidity (57.31% for AAA and 61.95% for TAA). TAA patients had significantly higher ICU mortality (9.43% versus 2.36%, P<0.001) than AAA. Several factors were found to be significantly associated with ICU mortality, including urgent surgery, with aortic dissection, rupture of aortic aneurysm, TAA, and a higher APACHE IVa score on ICU admission. APACHE IVa showed a good predictive performance for ICU mortality with an area under the ROC curve of 0.9176 (95% CI 0.8789–0.9390).

Conclusion: The prognosis of aortic aneurysm patients admitted to ICU postoperatively is yet to improve, and factors associated with prognosis are mainly related to the condition itself. APACHE IVa can be used for prognosis prediction.

Keywords: vascular surgery, intensive critical care, epidemiology

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Introduction

Aortic aneurysm (AA) is the enlargement of the aorta defined as a segmental, full-thickness dilation of the blood vessel having at least a 50% increase in diameter compared with the expected normal diameter.[1–3] It usually located in the abdominal aorta, but can also be located in the thoracic aorta. AA usually causes no symptoms; however, it is with an increased risk of aortic rupture due to weakness in the wall of the aorta and could be fatal when ruptured.[4]

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As a clinically silent disease, the prevalence and incidence of abdominal aortic aneurysm (AAA) and thoracic aortic aneurysm (TAA) are low though varied between studies. AAA was reported to have a prevalence of 4–8%[5–8] and TAA was 0.16–0.34%[9,10] in screening studies. The relatively low prevalence and incidence make it difficult to conduct researches with enough sample sizes to obtain evidence, while obviously it is very important to have a working knowledge of the characteristics and prognosis of AA to aid with clinical decision-making.

In the past three decades, the greatest advance in the treatment of AA was the introduction of endovascular aneurysm repair (EVAR), which used stent grafts and caused a major paradigm shift in the field of AA surgery.[11] For elective AAA repair, the mortality is 3–5% for open surgery but decreases to 0.5–2% for EVAR.[12–14] However, the overall prognosis of AA is still not satisfactory, especially for ruptured AA. The 30-day and 90-day all-cause mortality rates were reported to be 22.9% and 33.3%, respectively, for ruptured AAA patients after surgical treatment.[15] To further improve the prognosis of AA, no doubt postoperative management should be improved.[16]

Although not all AA patients need intensive care unit (ICU) admissions after surgical treatment,[17] subsequent ICU admissions postoperatively at least are not rare for patients with AAA or TAA. A study from Denmark reported that 62% of AAA patients after open AAA repair surgery had ICU stays >24 hours.[18] A study investigated patients undergoing elective infrarenal EVAR between 2009 and 2015 and found that 57.3% were admitted to ICU after the surgery.[19] In order to further improve the management of AA patients admitted to ICU postoperatively, an overview of their characteristics and risk profiles of prognosis is needed. However, as far as we know, a large-scale investigation on these patients is absent. Therefore, the study aimed to investigate the characteristics and prognosis of AAA or TAA patients admitted to ICU postoperatively.

Methods

Data Source

The study used data from the eICU Collaborative Research Database (version 2.0), which was made available largely by Philips Healthcare and collaborators at Massachusetts Institute of Technology (MIT) Laboratory for Computational Physiology.[20] It consisted of data of patients admitted to one of 335 critical care units at 208 hospitals that participated in the Philips eICU program throughout the continental United States in 2014 and 2015. The database is released under the Health Insurance Portability and Accountability Act (HIPAA) safe harbor provision. The re-identification risk was certified as meeting safe harbor standards by Privacert (Cambridge, MA) (HIPAA Certification no. 1,031,219–2). Access to the database was approved after completing the CITI "Data or Specimens Only Research" course. This study was exempt from institutional review board approval due to the retrospective design, lack of direct patient intervention, and the security schema for the re-identification risk.

Study Population

Patients admitted to ICU postoperatively with a primary diagnosis of AAA or TAA were screened in the database. Data on primary diagnosis were extracted from the table "admissiondx" which contained the primary diagnosis for admission to the ICU per the Acute Physiology And Chronic Health Evaluation (APACHE) scoring criteria. AAA or TAA was identified based on structured text including "Aneurysm, abdominal aortic", "Aneurysm, abdominal aortic; with dissection", "Aneurysm, abdominal aortic; with rupture", "Aneurysm, thoracic aortic", "Aneurysm, thoracic aortic; with dissection", and "Aneurysm, thoracic aortic; with rupture". Detailed inclusion criteria were: 1) a primary diagnosis of AAA or TAA; 2) first ICU admission only (for patients who had more than 1 ICU admission during the same hospitalization); 3) admitted from operating room, recovery room, or post-anesthesia care unit (PACU); 4) age ≥18 years. Detailed exclude criteria were: 1) instead of "admit", patients with an ICU stay type of "stepdown/other", "readmit for undo", "pre-admit", "transfer", or "readmit"; 2) patients who had more than 1 hospitalization records in the database; 3) length of ICU stay is missing. Flow chart of the study population is presented in Figure 1.

Baseline Characteristics, Comorbidities, and Study Outcomes

The following baseline characteristics were collected from the database, including age, sex, ethnicity, body mass index (BMI, defined as the body mass in kilograms divided by the square of the body height in meters), year of the hospital discharge date, type of surgery (elective or not), with or without aortic dissection, type of AA (ruptured or not), type

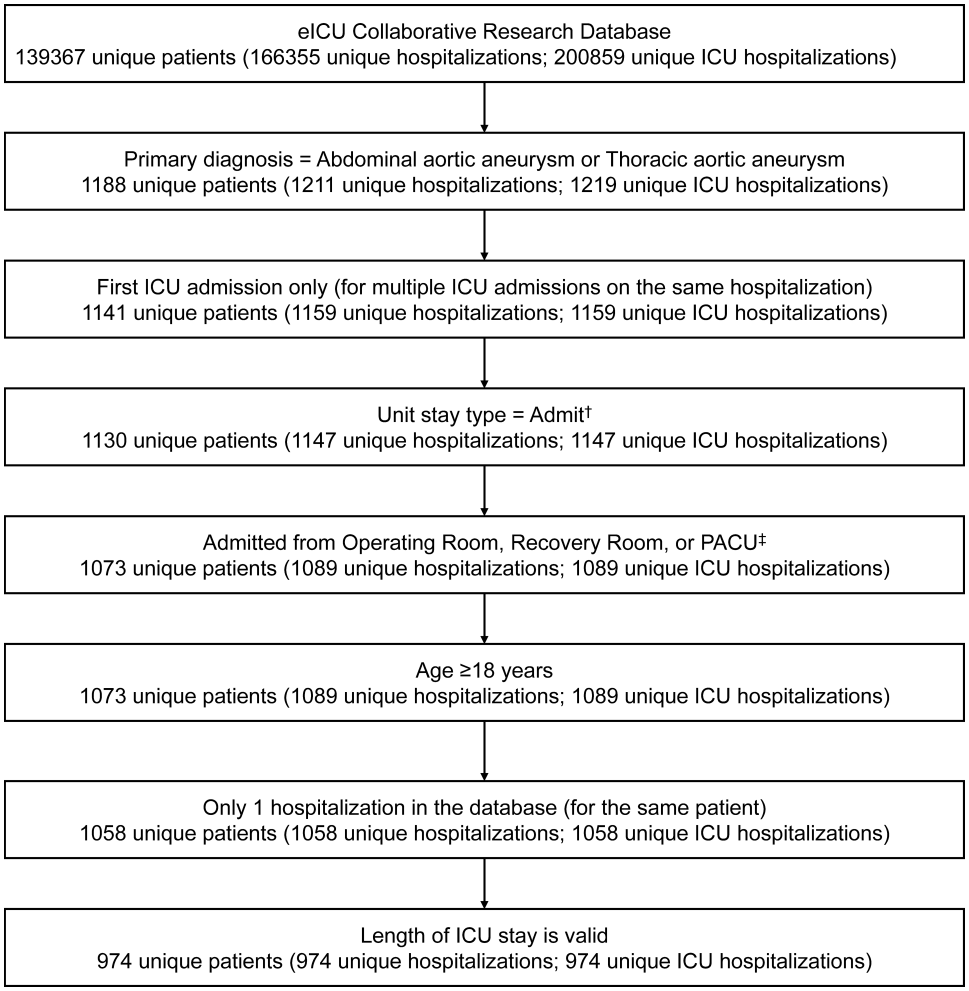

Figure 1 Flow chart of the study.
Notes: †Exclude unit stay type of readmit, stepdown/other, transfer. ‡Exclude admission from acute care/floor, direct admit, emergency department, floor, other hospital, other ICU, step-down unit (SDU).
Abbreviations: ICU, intensive care unit; PACU, post-anesthesia care unit.

of ICU, admitted location, acute physiology IVa score, APACHE IVa score, several lab parameters of the APACHE IVa scoring system, intubation, ventilation, and dialysis on the first day after ICU admission. Various comorbidities were also collected. ICU mortality was the primary outcome of the study. Length of ICU stay, hospital mortality, and length of hospital stay were also studied but only for description. All the variables above were extracted from the tables in the database, including "patient", "apachePatientResult", "apacheApsVar", and "pastHistory".

Statistical Analysis

Continuous variables were presented as median (25% percentile – 75% percentile) and categorical variables were presented as number (percentage). Comparisons between groups were tested by Kruskal–Wallis *H*-test for continuous variables or Chi-squared test (or Fisher's exact test) for categorical variables. The study population was also categorized based on length of ICU stay (<2 days, 2–7 days, and ≥7 days) and study outcomes of each category were described. Factors associated with ICU mortality were explored using univariable logistic regression. Kaplan–Meier curves for ICU mortality together with Log rank test were employed to compare the survival distribution of AAA and TAA. Receiver operating characteristic (ROC) curve analysis was performed to evaluate the prognosis predictive performance of APACHE IVa. A P value less than 0.05 was considered to indicate statistical significance. Empower(R) (www.empowerstats.com; X&Y solutions, Inc., Boston, MA, USA) and R software, version 3.4.3 (http://www.r-project.org; R Foundation for Statistical Computing, Vienna, Austria) were used for statistical analyses.

Results

Baseline Characteristics and Comorbidities of the Study Population

A total of 974 AA patients admitted to ICU postoperatively were included finally. Among them, 549 (56.37%) were AAA, 59 (6.06%) were AAA with dissection, and 69 (7.08%) were AAA with rupture; 195 (20.02%) were TAA, 95 (9.75%) were TAA with dissection, and 7 (0.72%) were TAA with rupture. As presented in Table 1, the median age of the study population was 70 (62–77) years and 74.54% (726/974) were male. Compared with TAA, AAA patients had a significantly higher median age (72 versus 64 years, P<0.001), and more patients were male (79.17% versus 63.97%, P<0.001). Proportions of patients who received elective surgery were broadly the same (89.07% for AAA versus 84.51% for TAA, P=0.046). 8.71% (59/677) AAA patients were with aortic dissection, while 31.99% (95/297) for TAA patients. 10.19% (69/677) AAA patients suffered from rupture of aortic aneurysm, but only 2.36% (7/297) for TAA patients. TAA patients had significantly higher acute physiology IVa score (41 versus 30, P<0.001) and APACHE IVa score (52 versus 45, P<0.001) on admission compared with AAA patients, and more needed intubation (45.45% versus 17.73%, P<0.001) or ventilation (44.11% versus 20.38%, P<0.001). The above characteristics after stratified by (with or without) aortic dissection were presented in Table S1.

Comorbidities of the study population were presented in Table 2. The 5 most frequent comorbidities for AAA were hypertension requiring treatment (57.31%), diabetes (16.10%), chronic obstructive pulmonary disease (COPD, 14.62%), cancer (13.00%), and myocardial infarction (11.82%), while for TAA, the 5 most frequent comorbidities were hypertension requiring treatment (61.95%), heart valve disease (14.81%), renal insufficiency (11.11%), diabetes (10.44%), and congestive heart failure (10.10%).

Prognosis of the Study Population

The overall ICU mortality for the study population was 4.52% (44/974), and the hospital mortality was 6.26% (61/974). Compared with AAA, TAA patients had significantly higher ICU mortality (9.43% versus 2.36%, P<0.001) and hospital mortality (12.12% versus 3.69%, P<0.001). Consistent result was observed in Kaplan–Meier survival curves for ICU mortality (Figure 2), which showed a poorer survival in TAA patients compared with AAA patients (Log rank test, P=0.0072). When the study population was categorized based on length of ICU stay (<2 days, 2–7 days, and ≥7 days), patients with longer length of ICU stay had worse prognosis (Table 3). Prognosis of the study population after stratified by (with or without) aortic dissection was presented in Table S2, which showed higher ICU mortality in patients with aortic dissection compared to those without aortic dissection.

Factors Associated with ICU Mortality

Several baseline characteristics were found to be significantly associated with ICU mortality in univariable logistic regression (Table 4). Elective surgery was associated with reduced risk of ICU mortality (Odds ratio (OR) 0.22, 95% confidence interval (CI) 0.12–0.42), while with aortic dissection (OR 4.04, 95% CI 2.16–7.57) and rupture of AA (OR 3.31, 95% CI 1.53–7.18) were both associated with increased risk of ICU mortality. Compared with AAA, TAA was associated with an increased risk of ICU mortality (OR 4.30, 95% CI 2.29–8.08). Acute physiology score IVa (OR 1.05 per 1 score increase, 95% CI 1.04–-1.06) and APACHE IVa score on admission (OR 1.05 per 1 score increase, 95% CI 1.04–1.06) were also associated with poor prognosis. However, no comorbidities were found to be significantly associated with ICU mortality (Table 5).

Prognosis Predictive Performance of APACHE IVa

As presented in Table 6, APACHE IVa on ICU admission showed a good predictive performance for ICU mortality with an area under the ROC curve (AUC) of 0.9176 (95% CI 0.8789–0.9390). Compared with AA patients without rupture, the predictive performance of APACHE IVa decreased in patients with rupture of AA (AUC 0.8795 versus 0.9158). TAA patients also saw a poorer predictive performance of APACHE IVa compared with AAA patients (AUC 0.8660 versus 0.9233).

Discussion

The study focused on AA patients who were admitted to ICU after surgical treatment and investigated the characteristics and prognosis of these patients. Predictors associated with prognosis and prognosis predictive performance of the widely used severity scoring system APACHE IVa were also explored. The main findings of the study were: 1) there were some great differences in

Table 1 Baseline Characteristics of the Study Population

Variables	All Patients (n=974)	Abdominal Aortic Aneurysm (n=677)	Thoracic Aortic Aneurysm (n=297)	P value
Age (years)	70 (62–77)	72 (65–78)	64 (54–74)	**<0.001**
Male	726 (74.54%)	536 (79.17%)	190 (63.97%)	**<0.001**
Ethnicity				**<0.001**
Caucasian	801 (82.24%)	577 (85.23%)	224 (75.42%)	
African American	96 (9.86%)	47 (6.94%)	49 (16.50%)	
Asian	12 (1.23%)	7 (1.03%)	5 (1.68%)	
Hispanic	12 (1.23%)	10 (1.48%)	2 (0.67%)	
Native American	3 (0.31%)	0 (0.00%)	3 (1.01%)	
Other/Unknown	50 (5.13%)	36 (5.32%)	14 (4.71%)	
BMI (kg/m^2)	27.59 (24.22–31.46)	27.46 (24.20–31.10)	28.04 (24.28–32.92)	0.129
Year of the hospital discharge date				0.887
2014	482 (49.49%)	334 (49.34%)	148 (49.83%)	
2015	492 (50.51%)	343 (50.66%)	149 (50.17%)	
Elective surgery	854 (87.68%)	603 (89.07%)	251 (84.51%)	**0.046**
With aortic dissection	154 (15.81%)	59 (8.71%)	95 (31.99%)	**<0.001**
Rupture of aortic aneurysm	76 (7.80%)	69 (10.19%)	7 (2.36%)	**<0.001**
Type of ICU				**<0.001**
Med-Surg ICU	287 (29.47%)	232 (34.27%)	55 (18.52%)	
CSICU	154 (15.81%)	115 (16.99%)	39 (13.13%)	
CTICU	184 (18.89%)	87 (12.85%)	97 (32.66%)	
CCU-CTICU	169 (17.35%)	95 (14.03%)	74 (24.92%)	
SICU	124 (12.73%)	97 (14.33%)	27 (9.09%)	
Cardiac ICU	30 (3.08%)	27 (3.99%)	3 (1.01%)	
Neuro ICU	20 (2.05%)	18 (2.66%)	2 (0.67%)	
MICU	6 (0.62%)	6 (0.89%)	0 (0.00%)	
Location admitted from				0.079
Operating Room	767 (78.75%)	523 (77.25%)	244 (82.15%)	
Recovery Room	169 (17.35%)	122 (18.02%)	47 (15.82%)	
PACU	38 (3.90%)	32 (4.73%)	6 (2.02%)	
Acute physiology IVa score	32 (24–47.75)	30 (22–42)	41 (29–61)	**<0.001**
APACHE IVa score	47 (37–62)	45 (36–57)	52 (37.25–75)	**<0.001**
Lab variables in APACHE IVa score				
Temperature (°C)	36.3 (35.8–36.6)	36.3 (36.0–36.6)	36.1 (35.5–36.6)	**<0.001**
Mean blood pressure (mmHg)	68 (56–132)	71 (57–133)	62 (52–128)	**<0.001**
Heart rate (/min)	96 (59–109)	96 (58–108)	99 (82–112)	**0.006**
Respiratory rate (/min)	13 (9–31)	14 (9–32)	12 (8–30)	**0.004**
FiO_2 (%)	50 (40–80)	50 (40–80)	60 (40–87.50)	0.087
PaO_2 (mmHg)	102.90 (80.00–154.45)	103.00 (80.00–159.00)	101.65 (79.00–151.00)	0.553
$PaCO_2$ (mmHg)	42.00 (37.00–46.25)	42.00 (37.00–46.10)	42.00 (37.38–46.77)	0.875
Arterial pH	7.36 (7.31–7.40)	7.34 (7.30–7.39)	7.37 (7.33–7.41)	**0.002**
Sodium (mEq/L)	139 (136–141)	139 (136–141)	140 (138–143.5)	**<0.001**
Urine output (mL/24h)	1621.99 (987.60–2586.69)	1585.01 (907.72–2472.42)	1691.02 (1172.02–2791.11)	0.096
Creatinine (mg/dL)	1.00 (0.80–1.40)	1.00 (0.80–1.36)	1.02 (0.75–1.50)	0.888
Blood urea nitrogen (mg/dL)	17 (13–23)	16.5 (13–22)	17 (13–24.5)	0.171

(*Continued*)

Table 1 (Continued).

Variables	All Patients (n=974)	Abdominal Aortic Aneurysm (n=677)	Thoracic Aortic Aneurysm (n=297)	P value
Glucose (mg/dL)	141 (105–182)	138 (107.25–180)	151 (99–184.5)	0.564
Albumin (g/dL)	2.90 (2.50–3.30)	2.90 (2.50–3.30)	2.90 (2.48–3.30)	0.930
Bilirubin (mg/dL)	0.90 (0.50–1.55)	0.80 (0.50–1.33)	1.10 (0.60–1.90)	**0.008**
Hematocrit (%)	31.50 (27.40–35.60)	32.55 (28.83–36.50)	29.10 (25.50–33.20)	**<0.001**
WBC (x1000/mm^3)	10.50 (7.98–14.70)	10.30 (7.90–14.10)	12.20 (8.20–16.60)	**0.003**
Intubated	255 (26.18%)	120 (17.73%)	135 (45.45%)	**<0.001**
Ventilation	269 (27.62%)	138 (20.38%)	131 (44.11%)	**<0.001**
Dialysis	7 (0.72%)	4 (0.59%)	3 (1.01%)	0.442

Note: P value <0.05 was presented in bold.

Abbreviations: BMI, body mass index; ICU, intensive care unit; Med-Surg ICU, medical-surgical intensive care unit; CSICU, cardiac surgery intensive care unit; CTICU, cardiothoracic intensive care unit; CCU-CTICU, coronary care unit-cardiothoracic intensive care unit; SICU, surgical intensive care unit; MICU, medical intensive care unit; PACU, post-anesthesia care unit; APACHE, Acute Physiology And Chronic Health Evaluation; FiO_2, fraction of inspired oxygen; PaO_2, partial pressure of oxygen; $PaCO_2$, partial pressure of carbon dioxide; WBC, white blood cell.

Table 2 Comorbidities of the Study Population

Variables	All Patients (n=974)	Abdominal Aortic Aneurysm (n=677)	Thoracic Aortic Aneurysm (n=297)	P value
History of coronary artery bypass surgery	87 (8.93%)	72 (10.64%)	15 (5.05%)	**0.005**
History of angina	24 (2.46%)	20 (2.95%)	4 (1.35%)	0.179
History of myocardial infarction	96 (9.86%)	80 (11.82%)	16 (5.39%)	**0.002**
History of percutaneous coronary intervention	63 (6.47%)	51 (7.53%)	12 (4.04%)	**0.041**
History of congestive heart failure	66 (6.78%)	36 (5.32%)	30 (10.10%)	**0.006**
History of atrial fibrillation	80 (8.21%)	56 (8.27%)	24 (8.08%)	0.920
History of AICD/pacemaker	25 (2.57%)	16 (2.36%)	9 (3.03%)	0.518
History of hypertension requiring treatment	572 (58.73%)	388 (57.31%)	184 (61.95%)	0.176
History of heart valve disease	71 (7.29%)	27 (3.99%)	44 (14.81%)	**<0.001**
History of COPD	125 (12.83%)	99 (14.62%)	26 (8.75%)	**0.012**
History of asthma	35 (3.59%)	20 (2.95%)	15 (5.05%)	0.106
History of respiratory failure	5 (0.51%)	4 (0.59%)	1 (0.34%)	1.000
History of restrictive pulmonary disease	7 (0.72%)	4 (0.59%)	3 (1.01%)	0.442
History of cirrhosis	16 (1.64%)	13 (1.92%)	3 (1.01%)	0.416
History of peptic ulcer disease	22 (2.26%)	17 (2.51%)	5 (1.68%)	0.492
History of renal insufficiency	86 (8.83%)	53 (7.83%)	33 (11.11%)	0.096
History of dialysis	8 (0.82%)	5 (0.74%)	3 (1.01%)	0.705
History of non-cancerous hematology disease	5 (0.51%)	4 (0.59%)	1 (0.34%)	1.000
History of anemia	3 (0.31%)	2 (0.30%)	1 (0.34%)	1.000
History of ITP	1 (0.10%)	1 (0.15%)	0 (0.00%)	1.000
History of peripheral vascular disease	88 (9.03%)	72 (10.64%)	16 (5.39%)	**0.009**
History of VTE	40 (4.11%)	24 (3.55%)	16 (5.39%)	0.182
History of DVT	26 (2.67%)	18 (2.66%)	8 (2.69%)	1.000
History of PE	18 (1.85%)	10 (1.48%)	8 (2.69%)	0.203
History of diabetes	140 (14.37%)	109 (16.10%)	31 (10.44%)	**0.020**
History of hyperthyroidism	6 (0.62%)	4 (0.59%)	2 (0.67%)	1.000

(*Continued*)

Table 2 (Continued).

Variables	All Patients (n=974)	Abdominal Aortic Aneurysm (n=677)	Thoracic Aortic Aneurysm (n=297)	P value
History of hypothyroidism	68 (6.98%)	43 (6.35%)	25 (8.42%)	0.244
History of stroke	57 (5.85%)	37 (5.47%)	20 (6.73%)	0.437
History of TIA	34 (3.49%)	23 (3.40%)	11 (3.70%)	0.810
History of dementia	3 (0.31%)	3 (0.44%)	0 (0.00%)	0.557
History of neuromuscular disease	1 (0.10%)	1 (0.15%)	0 (0.00%)	1.000
History of seizures	19 (1.95%)	12 (1.77%)	7 (2.36%)	0.616
AIDS	4 (0.41%)	3 (0.44%)	1 (0.34%)	1.000
Immunosuppression within past 6 months	4 (0.41%)	3 (0.44%)	1 (0.34%)	1.000
History of rheumatic disease	13 (1.33%)	11 (1.62%)	2 (0.67%)	0.364
History of rheumatoid arthritis	13 (1.33%)	11 (1.62%)	2 (0.67%)	0.364
History of SLE	1 (0.10%)	1 (0.15%)	0 (0.00%)	1.000
History of heart transplant	2 (0.21%)	2 (0.30%)	0 (0.00%)	1.000
History of liver transplant	1 (0.10%)	1 (0.15%)	0 (0.00%)	1.000
History of renal transplant	4 (0.41%)	2 (0.30%)	2 (0.67%)	0.590
History of cancer	116 (11.91%)	88 (13.00%)	28 (9.43%)	0.113
History of metastases cancer	4 (0.41%)	2 (0.30%)	2 (0.67%)	0.590
History of head neck cancer	6 (0.62%)	6 (0.89%)	0 (0.00%)	0.186
History of esophagus cancer	4 (0.41%)	4 (0.59%)	0 (0.00%)	0.320
History of lung cancer	16 (1.64%)	14 (2.07%)	2 (0.67%)	0.170
History of breast cancer	12 (1.23%)	6 (0.89%)	6 (2.02%)	0.203
History of liver cancer	2 (0.21%)	1 (0.15%)	1 (0.34%)	0.517
History of stomach cancer	3 (0.31%)	2 (0.30%)	1 (0.34%)	1.000
History of bladder cancer	10 (1.03%)	9 (1.33%)	1 (0.34%)	0.298
History of kidney cancer	10 (1.03%)	5 (0.74%)	5 (1.68%)	0.183
History of colon cancer	5 (0.51%)	5 (0.74%)	0 (0.00%)	0.331
History of melanoma	8 (0.82%)	6 (0.89%)	2 (0.67%)	1.000
History of ovary cancer	2 (0.21%)	1 (0.15%)	1 (0.34%)	0.517
History of uterus cancer	1 (0.10%)	1 (0.15%)	0 (0.00%)	1.000
History of prostate cancer	22 (2.26%)	17 (2.51%)	5 (1.68%)	0.492
History of chemotherapy	3 (0.31%)	2 (0.30%)	1 (0.34%)	1.000
Radiation therapy within past 6 months	2 (0.21%)	2 (0.30%)	0 (0.00%)	1.000

Note: P value <0.05 was presented in bold.

Abbreviations: AICD, automatic implantable cardioverter defibrillator; COPD, chronic obstructive pulmonary disease; ITP, immune thrombocytopenic purpura; VTE, venous thromboembolism; DVT, deep vein thrombosis; PE, pulmonary embolism; TIA, transient ischemic attack; AIDS, acquired immune deficiency syndrome; SLE, systemic lupus erythematosus.

baseline characteristics and comorbidities between AAA and TAA patients who were admitted to ICU postoperatively; 2) prognosis of these patients is yet to improve, especially for TAA patients; 3) instead of comorbidities, factors associated with prognosis were mainly related to the condition itself; 4) APACHE IVa showed good prognosis predictive performance. Based on a relatively large sample size and the recent data (year 2014 and 2015), these findings provided an updated overview of AA patients (either AAA or TAA) admitted to ICU after receiving surgical treatment, which might help to improve postoperative management of AA patients and therefore to further improve their prognosis.

Compared with most other studies, the baseline characteristics and comorbidities of AA patients in our study were broadly similar, including an advanced age, predominantly males, and a higher prevalence of hypertension comorbidity. For example, in a cohort from Japan who underwent open or endovascular repair for AAA,[21] only 1.4% (14/999) of patients aged 50 years or younger, 85.3% (852/999) were male, and 79.9% (798/999) had hypertension. In a retrospective cross-sectional study from Iran,[22]

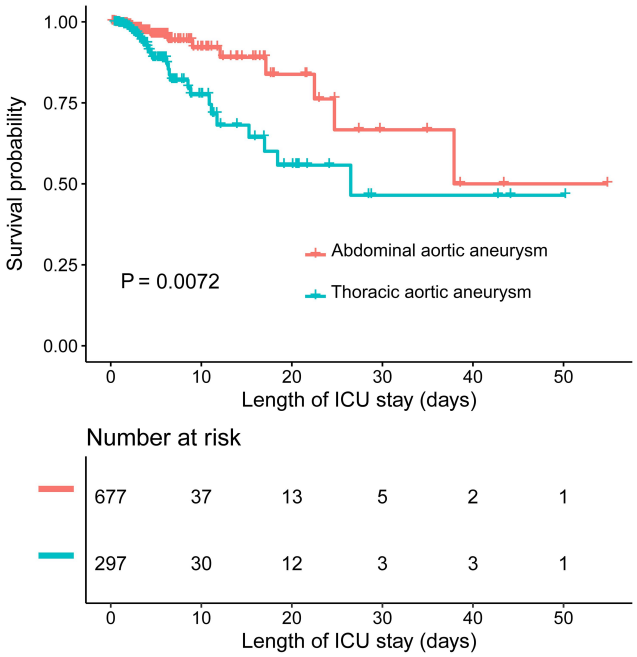

Figure 2 Kaplan–Meier survival curves for ICU mortality.
Abbreviation: ICU, intensive care unit.

the mean age of AAA patients in emergency department was 68.11±11.98 years, 84% were male, and 51.6% had hypertension. In a cohort of 107 untreated TAA patients,[23] the average age was 59.3 years, 73.8% (79/107) patients were male, and 47% had diastolic hypertension. Similarities between these studies might be related to the nature of the diseases, but it should be noticed that in our study, the study population were only AA patients who survived after the surgical treatment and needed an admission to ICU. This might explain the slight difference in these characteristics between studies. A recent study found that female AAA patients might have a higher risk of rupture due to gender differences in morphological and hemodynamic characteristics of AAA,[24] and considering that patients with rupture were more likely to be admitted to ICU after surgery,[17] our study thus included more female AAA patients. However, given the limited sample size of all these studies, variations in statistics of these characteristics could also explain the difference. In terms of ethnicity, most patients were Caucasian in our study, which was consistent with several other studies[25–27] that supported Caucasian race might be a risk factor for the development of AAA. Researches that compared AAA with TAA were rare, making it impossible to compare our results with others. In our study, the TAA patients were younger, with a much lower proportion of rupture, and different patterns of comorbidities when compared with AAA patients. These differences might be related to the "selection bias" of our study population. As mentioned above, only patients who underwent a surgery, survived, and at the same time needed to be admitted to ICU would be included in our study. Considering TAA had worse prognosis,[28] it is not strange to find that patients who survived and therefore were enrolled were younger and presented a different pattern of comorbidities compared with the AAA patients who were much elder.

Reports about the prognosis of AA patients varied. A study included 138 ruptured AAA patients who received open surgical repair and survived at least 48 hours in ICU

Table 3 Clinical Outcomes of the Study Population Stratified by Length of ICU Stay

Clinical Outcomes	All Patients (n=974)	Abdominal Aortic Aneurysm (n=677)	Thoracic Aortic Aneurysm (n=297)	P value
ICU mortality	44 (4.52%)	16 (2.36%)	28 (9.43%)	**<0.001**
Length of ICU stay <2 days	9 (1.56%)	5 (1.08%)	4 (3.57%)	
Length of ICU stay 2–7 days	20 (6.58%)	5 (3.07%)	15 (10.64%)	
Length of ICU stay ≥7 days	15 (15.96%)	6 (12.00%)	9 (20.45%)	
P value	**<0.001**	**<0.001**	**0.004**	
Hospital mortality	61 (6.26%)	25 (3.69%)	36 (12.12%)	**<0.001**
Length of ICU stay <2 days	12 (2.08%)	7 (1.51%)	5 (4.46%)	
Length of ICU stay 2–7 days	29 (9.54%)	10 (6.13%)	19 (13.48%)	
Length of ICU stay ≥7 days	20 (21.28%)	8 (16.00%)	12 (27.27%)	
P value	**<0.001**	**<0.001**	**<0.001**	
Length of ICU stay (days)	1.54 (0.99–3.24)	1.17 (0.94–2.68)	2.37 (1.36–4.67)	**<0.001**
Length of hospital stay (days)	4.79 (2.10–8.33)	3.25 (1.40–7.33)	6.40 (4.36–10.44)	**<0.001**

Note: P value <0.05 was presented in bold.
Abbreviation: ICU, intensive care unit.

Table 4 Univariable Logistic Regression Analysis of Baseline Characteristics Associated with ICU Mortality

Variables	OR	95% CI	P value
Age (years)	0.98	0.95–1.00	0.0356
Sex			
Male	1.0		
Female	1.55	0.82–2.94	0.1818
Ethnicity			
Caucasian	1.0		
African American	1.28	0.49–3.36	0.6177
Asian	0.00	0.00-Inf	0.9845
Hispanic	4.65	0.98–22.10	0.0530
Native American	46.55	4.12–526.41	**0.0019**
Other/Unknown	0.97	0.23–4.16	0.9670
BMI (kg/m^2)	0.99	0.95–1.04	0.8133
Year of the hospital discharge date			
2014	1.0		
2015	1.08	0.59–1.97	0.8112
Elective surgery			
No	1.0		
Yes	0.22	0.12–0.42	**<0.0001**
With aortic dissection			
No	1.0		
Yes	4.04	2.16–7.57	**<0.0001**
Rupture of aortic aneurysm			
No	1.0		
Yes	3.31	1.53–7.18	**0.0024**
Type of ICU			
Med-Surg ICU	1.0		
CSICU	1.78	0.79–4.01	0.1627
CTICU	0.71	0.27–1.90	0.4966
CCU-CTICU	0.64	0.22–1.84	0.4088
SICU	1.26	0.49–3.24	0.6302
Cardiac ICU	0.00	0.00-Inf	0.9840
Neuro ICU	1.11	0.14–8.94	0.9224
MICU	0.00	0.00-Inf	0.9928
Location admitted from for ICU			
Operating Room	1.0		
Recovery Room	0.57	0.22–1.47	0.2430
PACU	0.00	0.00-Inf	0.9818
Type of aortic aneurysm			
Abdominal aortic aneurysm	1.0		
Thoracic aortic aneurysm	4.30	2.29–8.08	**<0.0001**
Type of aortic aneurysm			
Abdominal aortic aneurysm	1.0		
Abdominal aortic aneurysm with dissection	4.15	1.04–16.49	**0.0434**
Abdominal aortic aneurysm with rupture	7.37	2.40–22.63	**0.0005**
Thoracic aortic aneurysm	4.19	1.57–11.15	**0.0042**
Thoracic aortic aneurysm with dissection	14.52	5.74–36.70	**<0.0001**
Thoracic aortic aneurysm with rupture	58.07	10.91–309.22	**<0.0001**
Acute physiology score IVa	1.05	1.04–1.06	**<0.0001**
APACHE IVa score	1.05	1.04–1.06	**<0.0001**
Lab variables in APACHE IVa score			
Temperature (°C)	0.58	0.47–0.72	**<0.0001**
Mean blood pressure (mmHg)	1.00	0.99–1.00	0.2350
Heart rate (/min)	1.03	1.02–1.04	**<0.0001**
Respiratory rate (/min)	0.97	0.95–1.00	**0.0356**
FiO_2 (%)	1.03	1.02–1.05	**<0.0001**
PaO_2 (mmHg)	1.00	0.99–1.00	0.6106
$PaCO_2$ (mmHg)	1.01	0.97–1.06	0.6192
Arterial pH	0.00	0.00–0.00	**<0.0001**
Sodium (mEq/L)	1.19	1.13–1.26	**<0.0001**
Urine output (mL/24h)	1.00	1.00–1.00	**0.0021**
Creatinine (mg/dL)	1.75	1.39–2.20	**<0.0001**
Blood urea nitrogen (mg/dL)	1.06	1.03–1.08	**<0.0001**
Glucose (mg/dL)	1.01	1.00–1.01	**0.0005**
Albumin (g/dL)	0.22	0.11–0.44	**<0.0001**
Bilirubin (mg/dL)	1.83	1.30–2.57	**0.0005**
Hematocrit (%)	0.82	0.77–0.87	**<0.0001**
WBC (x1000/mm^3)	1.05	1.00–1.09	**0.0284**
Intubated			
No	1.0		
Yes	8.45	4.28–16.69	**<0.0001**
Ventilation			
No	1.0		
Yes	19.16	8.00–45.92	**<0.0001**
Dialysis			
No	1.0		
Yes	3.58	0.42–30.41	0.2424

Note: P value <0.05 was presented in bold.

Abbreviations: ICU, intensive care unit; OR, odds ratio; CI, confidence interval; Inf, infinity; BMI, body mass index; Med-Surg ICU, medical-surgical intensive care unit; CSICU, cardiac surgery intensive care unit; CTICU, cardiothoracic intensive care unit; CCU-CTICU, coronary care unit-cardiothoracic intensive care unit; SICU, surgical intensive care unit; MICU, medical intensive care unit; PACU, post-anesthesia care unit; APACHE, Acute Physiology And Chronic Health Evaluation; FiO_2, fraction of inspired oxygen; PaO_2, partial pressure of oxygen; $PaCO_2$, partial pressure of carbon dioxide; WBC, white blood cell.

between 1999 and 2003 reported a 30-day mortality of 22%.[29] This mortality rate was much higher than that of our study population, which might be related to the different study population since ruptured AA had a significantly

Table 5 Univariable Logistic Regression Analysis of Comorbidities Associated with ICU Mortality

Variables	OR*	95% CI	P value
History of coronary artery bypass surgery	0.23	0.03–1.68	0.1467
History of angina	0.92	0.12–6.95	0.9332
History of myocardial infarction	0.20	0.03–1.50	0.1186
History of percutaneous coronary intervention	0.33	0.04–2.40	0.2712
History of congestive heart failure	1.01	0.30–3.34	0.9909
History of atrial fibrillation	1.12	0.39–3.22	0.8284
History of AICD/pacemaker	0.00	0.00-Inf	0.9853
History of hypertension requiring treatment	0.92	0.50–1.70	0.7924
History of heart valve disease	0.93	0.28–3.07	0.9020
History of COPD	0.87	0.33–2.24	0.7656
History of asthma	0.00	0.00-Inf	0.9826
History of respiratory failure	0.00	0.00-Inf	0.9847
History of restrictive pulmonary disease	3.58	0.42–30.41	0.2424
History of cirrhosis	1.42	0.18–10.99	0.7378
History of peptic ulcer disease	1.01	0.13–7.66	0.9949
History of renal insufficiency	1.68	0.69–4.09	0.2551
History of dialysis	3.07	0.37–25.48	0.2997
History of non-cancerous hematology disease	0.00	0.00-Inf	0.9847
History of anemia	0.00	0.00-Inf	0.9881
History of ITP	0.00	0.00-Inf	0.9896
History of peripheral vascular disease	0.73	0.22–2.40	0.6011
History of VTE	0.53	0.07–3.96	0.5371
History of DVT	0.00	0.00-Inf	0.9850
History of PE	1.25	0.16–9.60	0.8308
History of diabetes	0.58	0.21–1.66	0.3122
History of hyperthyroidism	4.30	0.49–37.63	0.1873
History of hypothyroidism	0.30	0.04–2.21	0.2368
History of stroke	1.19	0.36–3.96	0.7802
History of TIA	1.34	0.31–5.76	0.6975
History of dementia	0.00	0.00-Inf	0.9881
History of neuromuscular disease	0.00	0.00-Inf	0.9896
History of seizures	1.18	0.15–9.03	0.8745
AIDS	0.00	0.00-Inf	0.9863
Immunosuppression within past 6 months	7.19	0.73–70.52	0.0905
History of rheumatic disease	1.78	0.23–14.00	0.5841
History of rheumatoid arthritis	1.78	0.23–14.00	0.5841
History of SLE	0.00	0.00-Inf	0.9896
History of heart transplant	0.00	0.00-Inf	0.9853
History of liver transplant	Inf	0.00-Inf	0.9841
History of renal transplant	7.19	0.73–70.52	0.0905
History of cancer	0.16	0.02–1.21	0.0761
History of metastases cancer	0.00	0.00-Inf	0.9863
History of head neck cancer	0.00	0.00-Inf	0.9890
History of esophagus cancer	0.00	0.00-Inf	0.9863
History of lung cancer	0.00	0.00-Inf	0.9820
History of breast cancer	0.00	0.00-Inf	0.9844
History of liver cancer	0.00	0.00-Inf	0.9853
History of stomach cancer	0.00	0.00-Inf	0.9881
History of bladder cancer	0.00	0.00-Inf	0.9858
History of kidney cancer	0.00	0.00-Inf	0.9858
History of colon cancer	0.00	0.00-Inf	0.9847
History of melanoma	0.00	0.00-Inf	0.9873
History of ovary cancer	0.00	0.00-Inf	0.9853
History of uterus cancer	0.00	0.00-Inf	0.9896
History of prostate cancer	1.01	0.13–7.66	0.9949
History of chemotherapy	0.00	0.00-Inf	0.9881
Radiation therapy within past 6 months	0.00	0.00-Inf	0.9853

Note: *Compared with patients without the specific comorbidity.

Abbreviations: ICU, intensive care unit; OR, odds ratio; CI, confidence interval; AICD, automatic implantable cardioverter defibrillator; Inf, infinity; COPD, chronic obstructive pulmonary disease; ITP, immune thrombocytopenic purpura; VTE, venous thromboembolism; DVT, deep vein thrombosis; PE, pulmonary embolism; TIA, transient ischemic attack; AIDS, acquired immune deficiency syndrome; SLE, systemic lupus erythematosus.

higher risk of mortality. In our study, we also found that compared with patients without ruptured AA, the risk of ICU mortality of patients with ruptured AA increased (OR 3.31, 95% CI 1.53–7.18). Another reason could be the different surgery treatments received, since EVAR was found to have lower perioperative mortality than open surgery.[30] Although in our study detailed information about surgical treatment was unavailable, given the study period was between 2014 and 2015, and most cases received elective surgery, they might be less likely to receive open surgery. We also found that patients with longer length of ICU stay had worse prognosis, which was consistent with the study conducted by Gavali et al.[31]

Among the many variables, only a few factors that related to the condition itself were significantly associated with prognosis, including elective surgery, with aortic dissection, rupture of AA, and type of AA, while none of the comorbidities show a significant association. These results suggested at least the short-term prognosis was mainly determined by the condition itself. APACHE IVa was also found to be associated with ICU mortality of the study population, and ROC curve analysis showed it had good discriminatory capability. This is consistent with Kabbani et al[32] study where they found APACHE III

Table 6 Predictive Performance of APACHE IVa for ICU Mortality

	AUC	95% CI	Best Threshold	Specificity	Sensitivity
All patient	0.9176	0.8789–0.9390	58.5	0.7399	0.9767
Rupture of aortic aneurysm					
No	0.9158	0.8704–0.9419	58.5	0.7653	0.9706
Yes	0.8795	0.6879–0.9614	94	0.8209	0.8889
Type of aortic aneurysm					
Abdominal aortic aneurysm	0.9233	0.8440–0.9649	65.5	0.8438	1.0000
Thoracic aortic aneurysm	0.8660	0.7961–0.9090	58.5	0.6391	0.9643

Abbreviations: APACHE, Acute Physiology And Chronic Health Evaluation; ICU, intensive care unit; AUC, area under the receiver operating characteristic curve; CI, confidence interval.

score on ICU admission was an excellent discriminator of hospital mortality (AUC 0.92, 95% CI 0.83–1.00) for patients after open thoracoabdominal and open AAA repair. As far as know, there is no study evaluating the predictive performance of APACHE IVa in AAA and TAA patients after surgical treatment, and thus our finding could be seen as a validation of this scoring system in AA patients.

The strengths of the study included a multiple centers design and the updated data. The relatively large sample size also increased the power of the study. In addition, benefiting from the great abundance of variables in the database, various variables about baseline characteristics and comorbidities were investigated in the study. However, the study inevitably had some limitations. First, as a retrospective study, all the data we used were directly extracted from the available database without validation, and therefore measurement error should be considered as the main source of bias in the study. For example, it is possible that a diagnosis of AAA, TAA, or a TAA that also involves the aortic valve could be entered into the database incorrectly, since it was usually entered by nurses instead of clinicians. Second, since the database only contained data during the ICU hospitalization, information about surgical treatment before ICU was unavailable. We, therefore, applied strict inclusion criteria on the study population, and only included patients who were with a primary diagnosis of AAA or TAA and were directly admitted to ICU from operating room, recovery room, or PACU. Another concern was the potential selection bias of the study population. Since not every ICU or hospital participated in the eICU program, AA patients admitted to those unanticipated ICU/hospitals would always be missed in our study. Nevertheless, further studies are needed to validate the findings in our study.

Conclusion

Prognosis of aortic aneurysm patients admitted to ICU postoperatively is yet to improve, and factors associated with prognosis are mainly related to the condition itself, while APACHE IVa is a reliable tool for prognosis prediction.

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The authors declare that there are no conflicts of interest.

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