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Original Article
Efficacy and safety of endovascular repair versus open surgery for ruptured abdominal aortic aneurysm: a comparative study

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Abstract: Objective: Ruptured abdominal aortic aneurysm (rAAA) is a life-threatening condition with high mortality. This study compared the efficacy and safety of open surgical repair (OSR) and endovascular aortic repair (EVAR) in the treatment of rAAA. Methods: A retrospective analysis of clinical data was conducted for 232 rAAA patients treated at Taizhou Central Hospital and the First Affiliated Hospital of Wenzhou Medical College. Patients were divided into two groups based on surgical methods: OSR group (n=84) and EVAR group (n=148). Perioperative indicators, perioperative complication rates, and 1-year mortality rates were compared. Patients were further divided into a survival group (n=160) and a death group (n=72) based on their 1-year survival status, and the risk factors affecting the prognosis of rAAA patients were analyzed. Postoperative pain was evaluated using the Visual Analog Scale (VAS), Verbal Rating Scale (VRS), and Present Pain Intensity (PPI). Serum levels of C-reactive protein (CRP) and white blood cells (WBC), pro-inflammatory interleukins (IL-1α, IL-6, IL-8), and tumor necrosis factor-α (TNF-α) were measured before and after treatment using enzyme-linked immunosorbent assays (ELISA). Results: Compared with the OSR group, the EVAR group had significantly shorter surgical time, less intraoperative bleeding (IOB) and intraoperative blood transfusion volume, reduced intraoperative infusion volume, shorter fasting and first walk time, and shorter ICU and hospital days. The incidence of complications in the EVAR group was significantly lower than that in the OSR group ($P<0.05$). Pain scores (VAS, VRS, and PPI) and serum levels of CRP, WBC, IL-1α, IL-6, IL-8, and TNF-α were significantly lower in the EVAR group than those in the OSR group (all $P<0.05$). There was no significant difference in perioperative mortality between the two groups (28.95% vs. 11.80%, $P>0.05$). However, the 1-year mortality rate was significantly lower in the EVAR group (38.1% vs. 27.0%, P<0.05). Multivariate logistic regression analysis identified Alb<40 g/L ($P=0.004$), Cre≥1.5 mg/dL ($P=0.007$), urea nitrogen ≥25 mg/dL ($P=0.001$), ALT≥40 U/L ($P=0.002$), and treatment method (OSR) ($P=0.024$) as independent risk factors for poor postoperative prognosis. Conclusion: EVAR demonstrates significant advantages over OSR in reducing surgical trauma, decreasing postoperative complications, alleviating pain and inflammatory responses, and improving postoperative survival rates.

Keywords: rAAA, OSR, EVAR, perioperative complications, mortality rate, inflammatory response

Introduction

Abdominal aortic aneurysm (AAA) is the most prevalent type of aneurysms, characterized by progressive enlargement of the aneurysm sac. Rupture is the most severe and life-threatening complication of AAA [1]. Atherosclerosis, infection, congenital developmental defects, and inflammatory responses are all inducers of AAA [2]. The mortality rate for ruptured AAA (rAAA) is extremely high, ranging from 40% to 90%, with most patients dying within 24 hours if not treated promptly. As the aneurysm sac enlarges, the vessel wall become progressively thinner, losing elasticity and increasing in brittleness, especially with age. The rupture risk is approximately 50% within 5 years when the aneurysm diameter exceeds 5 cm, and over 90% when it exceeds 7 cm [3]. Additional risk factors, including smoking, chronic obstructive pulmonary disease, systolic hypertension, and increased intra-abdominal pressure from chr-

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onic coughing or constipation, can also cause rAAA [4].

Early open surgical repair (OSR) was historically considered the standard treatment for rAAA, aiming to improve patient survival rates [5]. However, OSR for rAAA is associated with high perioperative morbidity and mortality. With the advancement of endovascular aortic repair (EVAR), this minimally invasive approach has been applied in the treatment of both elective AAA and rAAA, showing promising outcomes [6, 7]. EVAR involves the placement of a stent via vascular intervention, which minimizes surgical trauma and reduces patient suffering [8]. Compared with traditional surgery, EVAR typically results in fewer complications and less disruption to cardiopulmonary functions [9]. However, EVAR is limited by anatomical factors, such as the morphology, size, and surrounding blood vessels of the aneurysm, making it not suitable for all patients. Therefore, for patients with poor anatomical conditions, OSR remains the preferred option. OSR is particularly useful for aneurysms in challenging locations or those with unfavorable anatomical conditions, while EVAR is more suitable for patients with large aneurysms, advanced age, multiple complications, and poor overall health conditions [10]. Despite the widespread use of both EVAR and OSR, there remains ongoing debate regarding their comparative efficacy and safety in treating rAAA. Therefore, selecting the appropriate treatment strategy is crucial for improving patient outcomes.

This study aimed to compare the efficacy and safety of EVAR and OSR for treating rAAA. The innovation of this study lies in its systematic comparative analysis, which not only highlights the advantages of EVAR in reducing surgical trauma, lowering postoperative complications, and improving postoperative recovery but also further explores the impact of different treatment methods on inflammatory response and postoperative survival rates. This research fills a gap in the existing literature regarding the optimization of treatment strategies for rAAA and provides clinicians with a more comprehensive and scientifically grounded basis for treatment decisions.

Subjects and methods

Subjects

Clinical data from 232 patients with rAAA treated at Taizhou Central Hospital and the First Affiliated Hospital of Wenzhou Medical College between March 2018 and June 2024 were retrospectively analyzed. All patients presented with sudden abdominal or back pain and were diagnosed with rAAA through imaging examinations.

Inclusion criteria: (1) Diagnosis of rAAA confirmed by CT angiography (CTA) or other imaging modalities; (2) Patients who underwent either OSR or EVAR under general anesthesia; (3) Patients aged 18 years or older; (4) Patients with complete preoperative, intraoperative, and postoperative follow-up data, including surgical records, imaging, and laboratory test results; (5) At least 1 year of follow-up data. Exclusion criteria: (1) Non-rAAA patients; (2) Patients with severe heart, lung, liver, kidney, or other organ dysfunction, or major comorbidities; (3) Preoperative infectious diseases; (4) Malignant tumors; (5) Incomplete clinical data; (6) Presence of multiple vascular diseases. This study was approved by the Ethics Committee of Taizhou Central Hospital.

Treatment methods

The included 232 rAAA patients were divided into two groups based on the surgical method: OSR group (n=84) and EVAR group (n=148). These patients were further categorized based on 1-year postoperative survival status into the survival group (160 patients) and the death group (72 patients). Twelve patients died within 24 hours of surgery, leaving 76 OSR patients and 144 EVAR patients with complete postoperative data. The patient inclusion flowchart is shown in **Figure 1**.

Upon admission and confirmation of diagnosis, all subjects received immediate resuscitation, including electrocardiogram monitoring, blood transfusion, and fluid infusion. Once the subjects' hemodynamic stability was achieved, the anatomical location of the ruptured aneurysm was confirmed using CT angiography. Surgical intervention was then performed under general anesthesia for all patients.

OSR: under general anesthesia, the patient was placed in the supine position. Under fluoroscopic guidance, a Coda balloon was placed above the aneurysm to achieve temporary occlusion. A midline abdominal incision was made to access the peritoneal cavity, and the proximal and distal necks of the aneurysm were carefully dissected. Bilateral iliac arteries

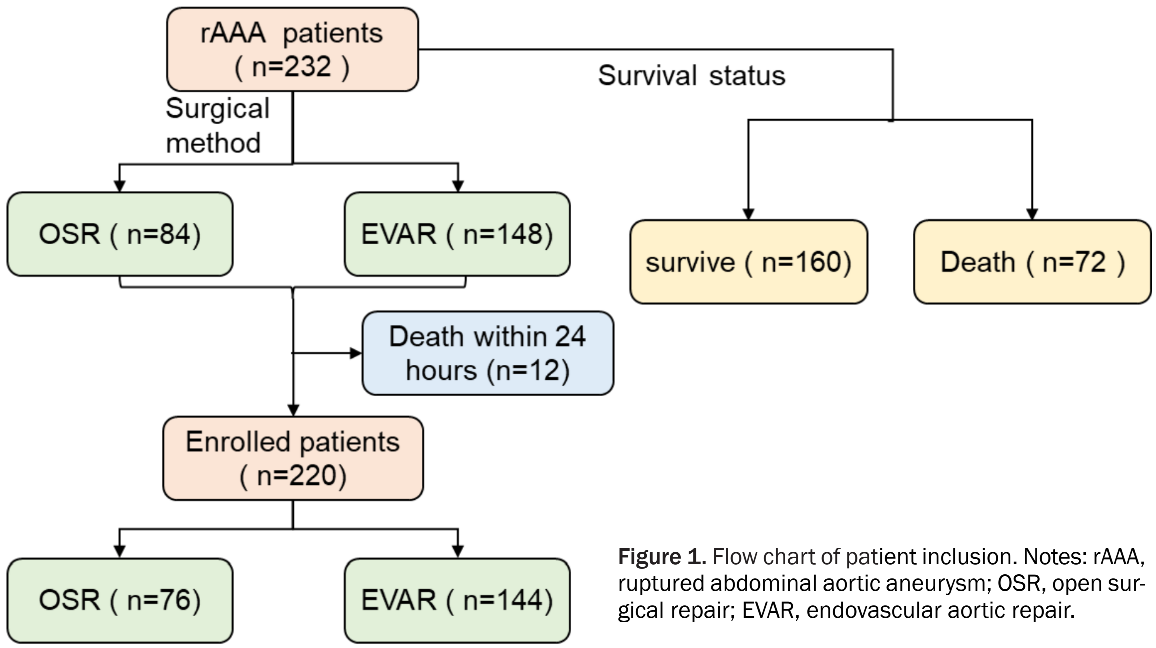

Figure 1. Flow chart of patient inclusion. Notes: rAAA, ruptured abdominal aortic aneurysm; OSR, open surgical repair; EVAR, endovascular aortic repair.

were occluded, and the hematoma was removed while carefully stripping the aortic aneurysm wall. An appropriately sized "Y"-shaped synthetic graft was selected, and end-to-end anastomosis was performed between the proximal end of the synthetic graft and the abdominal aorta. After the anastomosis was completed, the distal end of the graft was clamped, and the proximal circulation was restored. Blood flow was checked for patency, and any leakage at the anastomosis site was assessed. After no issues were confirmed, bilateral iliac arteries were transected below the anastomosis sites, and the distal end of the synthetic graft was anastomosed to both iliac arteries. Once the anastomoses were completed, circulation was restored, and blood flow was again checked for patency and leakage. Following confirmation of no issues, the peritoneum was sutured, and the abdominal incision was closed in layers. Postoperatively, bowel edema was observed. If abdominal hypertension was present, abdominal wall closure was delayed, and a second-stage closure strategy was employed with sterile dressings covering the abdominal incision.

EVAR: Under general anesthesia, a 4-5 cm inguinal incision was made to fully expose and free the bilateral femoral arteries. Using the Seldinger technique, one femoral artery was punctured, and a vascular sheath was placed. A calibrated catheter was introduced through the sheath for abdominal aorta angiography, which allowed for clear identification of key anatomical landmarks, such as the aneurysm rupture site, renal arteries, and the bifurcation of the abdominal aorta. Measurements of these sites were taken to select an appropriate stent graft (Medtronic, Minneapolis, USA). If hemodynamic instability occurred, a compliant balloon was used to temporarily occlude the aorta above the aneurysm neck. The stent graft system was delivered through the femoral artery, along with a stiff guidewire, and the main body of the stent was positioned in the abdominal aorta, just below the renal arteries, where the main body and short legs were deployed. Through the contralateral femoral artery, the iliac branch of the stent system was introduced, and after docking the main body with the short leg, the deployment of the long leg of the stent was completed. An extension was then added, and the Coda balloon was used to expand the proximal and distal anchoring zones and the connecting region. Finally, the placement was confirmed using imaging, and the incision was sutured.

Postoperatively, respiratory status, abdominal pressure, urine output, and arterial blood gas parameters were closely monitored. In cases of decreased oxygen partial pressure (or increased carbon dioxide partial pressure) and reduced urine volume, intra-abdominal pressure was measured. If necessary, abdominal CT was performed to identify the cause and prevent abdominal hypertension or compartment syndrome.

Data extraction

Data extraction was performed independently by two researchers to ensure consistency and accuracy. The following information was extracted from the patient electronic medical records: (1) Patient demographic information: age, gender, body mass index (BMI), smoking history, alcohol consumption history. (2) Comorbidities: hypertension, diabetes, coronary artery disease, chronic obstructive pulmonary disease (COPD), renal insufficiency. (3) Laboratory results: complete blood count, coagulation profile, liver and kidney function, electrolyte levels. (4) Imaging findings: size, location, and shape of the abdominal aortic aneurysm. (5) Surgical-related data: surgical method (EVAR or OSR), operation time, intraoperative blood loss, fluid infusion volume. (6) Postoperative recovery: time to first oral intake, time to first mobilization, ICU stay duration, total hospital stay, visual analog scale (VAS), verbal rating scale (VRS), current pain intensity (PPI) score, and incidence of adverse events. (7) Follow-up data: results from follow-up imaging, including CTA or MRA.

Outcome measures

Primary observation indicator: The overall survival rate at one year postoperatively.

Secondary outcome measures: Surgery time, intraoperative blood loss (IOB), blood transfusion volume, infusion volume, fasting time, time to first postoperative mobilization, ICU stay time, total hospital stay, and incidence of various adverse events. Pain symptoms of the patients at 48 hours post-treatment were assessed using the VAS, VRS, and PPI score.

Hematological parameters: The levels of albumin (Alb), creatinine (Cre), blood urea nitrogen (BUN), alanine aminotransferase (ALT), and aspartate aminotransferase (AST), as well as serum levels of pro-inflammatory interleukins (IL-1α, IL-6, IL-8) and tumor necrosis factor-alpha (TNF-α) were measured preoperatively and 48-hour postoperatively, using enzyme-linked immunosorbent assay (ELISA) kits (Shanghai Enzyme-linked Biotechnology Co., Ltd.). The levels of C-reactive protein (CRP) and white blood cells (WBC) in patients were measured before and after treatment.

Follow-up: At 12 months postoperatively, all patients underwent color Doppler ultrasound or abdominal aortic imaging (CTA or MRA). Annual follow-up was recommended if no anastomotic bleeding, aneurysm recurrence, or endoleaks, displacement, deformation, or rupture of the endovascular stent graft were detected. Clinical symptoms were dynamically monitored and compared with imaging data, with follow-up conducted via telephone one year later. Two patients in the EVAR group were lost to follow-up, while the remaining patients were successfully monitored. The follow-up period ranged from 4 to 48 months.

Statistical processing

SPSS 23.0 was used for statistical analysis. Quantitative data with a normal distribution were presented by ($\bar{x} \pm s$), and comparisons between groups were performed using the independent samples *t*-test. Count data were presented by n (%) and analyzed using the χ^2 test. Multivariate logistic regression analysis was used to evaluate the impact of surgical methods on 30-day mortality. A *P*-value less than 0.05 was considered statistically significant.

Results

Baseline data of subjects

No statistically significant differences were found in age, gender, smoking history, comorbidities, aneurysm maximum diameter, aneurysm neck diameter, length, angle, or the diameter iliac artery diameters between the groups (all $P>0.05$) (**Table 1**).

Comparison of preoperative preparation time between the two groups

As shown in **Figure 2**, the time from admission to examination, examination to surgery, and admission to surgery in the EVAR group were all significantly shorter than those in the OSR group (all $P<0.05$).

Table 1. Comparison of baseline characteristics between the two groups

	OSR (n=84)	EVAR (n=148)	t/χ^2	*P*
Age, years	60.7±10.5	61.1±11.4	-0.642	0.792
Gender, *n* (%)			0.207	0.649
Male	48 (57.1)	80 (54.1)		
Female	36 (42.9)	68 (45.9)		
Smoking history, *n* (%)			0.020	0.888
Yes	56 (66.7)	100 (67.6)		
No	28 (33.3)	48 (32.4)		
Comorbidities, *n* (%)				
Diabetes	12 (14.3)	16 (10.8)	0.610	0.435
Hypertension	48 (57.1)	84 (56.8)	0.003	0.954
Coronary heart disease	24 (28.6)	44 (29.7)	0.035	0.852
Cerebral infarction	12 (14.3)	24 (16.2)	0.152	0.696
Hyperlipidemia	20 (23.8)	36 (24.3)	0.008	0.930
Peripheral vascular disease	28 (33.3)	48 (32.4)	0.020	0.888
Chronic obstructive pulmonary disease	44 (52.4)	80 (54.1)	0.060	0.806
Chronic renal insufficiency	8 (9.5)	16 (10.8)	0.096	0.757
Maximum diameter of the aneurysm, cm	7.3±1.4	7.5±1.8	-0.878	0.381
Diameter of aneurysm neck, cm	2.1±0.9	2.0±0.6	1.013	0.312
Aneurysm neck length, cm	2.4±0.7	2.5±0.9	-0.104	0.336
Aneurysm neck angle, °	35.0±4.4	35.7±3.9	-1.254	0.211
Iliac artery diameter, cm				
Left side	16.6±4.1	17.2±5.5	-0.871	0.384
Right side	18.3±2.7	17.9±4.3	0.770	0.442

Notes: OSR, open surgical repair; EVAR, endovascular aortic repair.

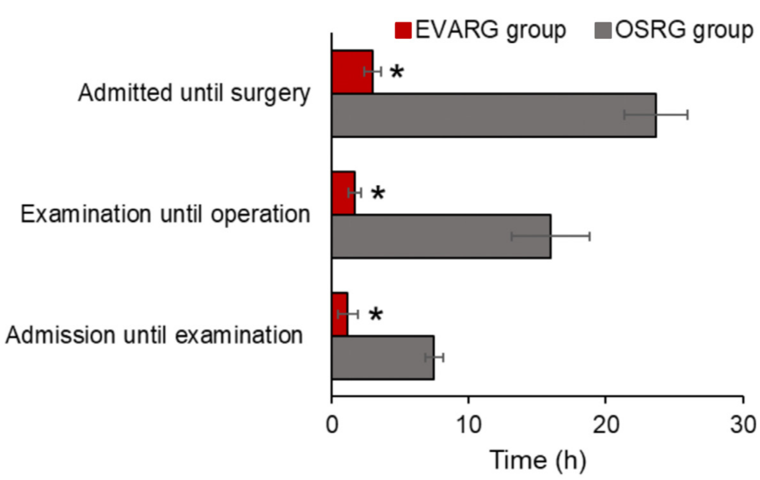

Figure 2. Comparison of preoperative preparation time between the two groups. Notes: *P<0.05 vs. OSR. OSR, open surgical repair; EVAR, endovascular aortic repair.

Comparison of intraoperative parameters between the two groups

As shown in **Figure 3**, the surgical time, IOB, intraoperative blood transfusion volume, and intraoperative fluid infusion volume in the EVAR group were all markedly less than those in the OSR group (all *P*<0.05).

Comparison of postoperative parameters between the two groups

As shown in **Figure 4**, the EVAR group demonstrated significantly shorter fasting time, time to first ambulation, ICU stay, and hospital stay compared to the OSR group (all *P*<0.05).

Comparison of preoperative and postoperative hematological parameters between the two groups

No significant differences were observed in preoperative and postoperative levels of Alb, Cre, BUN, ALT, or AST between the two groups (all *P*>0.05). However, compared to preoperative values, the levels of Alb, BUN, and ALT significantly elevated, while Cre levels significantly

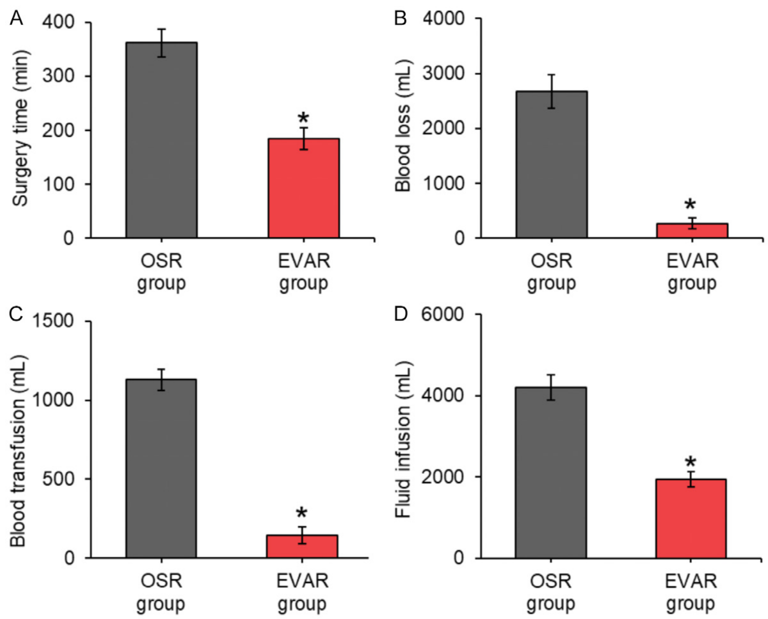

Figure 3. Comparison of intraoperative parameters between the two groups. A: Duration of surgery; B: IOB; C: Intraoperative blood transfusion volume; D: Volume of intraoperative fluid transfusion; *P<0.05 vs. ORS. Notes: OSR, open surgical repair; EVAR, endovascular aortic repair; IOB, intraoperative bleeding.

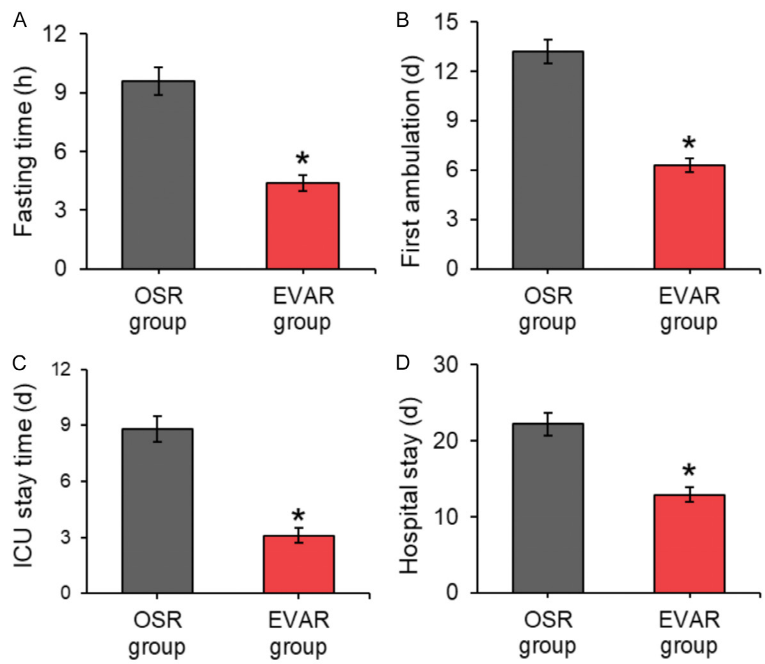

Figure 4. Comparison of postoperative parameters between the two groups. A: Fasting time; B: Time to first ambulation; C: Length of ICU stay; D: Length of hospital stay; *P<0.05 vs. ORS. Notes: OSR, open surgical repair; EVAR, endovascular aortic repair; ICU, intensive care unit.

decreased in both groups (*P*<0.05). No significant differences were observed between pre- and post-treatment AST levels in both groups (all *P*>0.05) (**Table 2**).

Comparison of post-operative pain levels between the two groups

As shown in **Figure 5**, the VAS, VRS, and PPI scores of the EVAR group were all significantly lower than those of the OSR group (all *P*<0.05).

Comparison of inflammatory markers between the two groups before and after treatment

Figure 6 presents the comparison of CRP, WBC, IL-1α, IL-6, IL-8, and TNF-α levels before and after treatment in both groups. No significant differences were found in pre-treatment levels of these markers between the two groups (all *P*>0.05). After treatment, the levels of CRP, WBC, IL-1α, IL-6, IL-8, and TNF-α significantly decreased in both groups (*P*<0.05). Additionally, the levels of these inflammatory markers in the EVAR group were lower than those in the OSR group (all *P*<0.05).

Comparison of adverse events between the two groups

Adverse events occurred in both groups during the perioperative period, including myocardial infarction, cardiac arrest, acute coronary syndrome, respiratory failure, pulmonary infection, acute renal insufficiency, abdominal compartment syndrome, endoleaks, graft infection, multiple organ dysfunction syndrome (MODS), and deep venous thrombosis. Among these, endoleaks and graft infection required secondary surgical interven-

Table 2. Comparison of preoperative and postoperative hematological parameters between the two groups

Hematological parameters	OSR (*n*=76)	EVAR (*n*=144)	*t value*	*P*
Alb (g/L)				
Before surgery	34.96±3.19	35.03±3.26	-0.153	0.879
After surgery	101.05±8.76*	99.44±8.89*	1.284	0.201
Cre (μmol/L)				
Before surgery	92.33±13.62	89.49±12.24	1.573	0.117
After surgery	78.08±2.91*	77.86±2.37*	0.604	0.546
BUN (mg/d)				
Before surgery	4.48±0.42	4.39±0.38	1.610	0.109
After surgery	6.93±0.57*	6.77±0.63*	1.850	0.066
ALT (U/L)				
Before surgery	28.97±2.44	29.42±3.97	-0.902	0.368
After surgery	34.96±3.19*	34.27±3.65*	1.391	0.166
AST (U/L)				
Before surgery	32.84±3.25	33.56±3.05	-1.627	0.105
After surgery	30.78±2.12	31.25±2.19	-1.530	0.127

Notes: *$P<0.05$ vs. before surgery. OSR, open surgical repair; EVAR, endovascular aortic repair; Alb, albumin; Cre, creatinine; BUN, blood urea nitrogen; ALT, alanine aminotransferase; AST, aspartate aminotransferase.

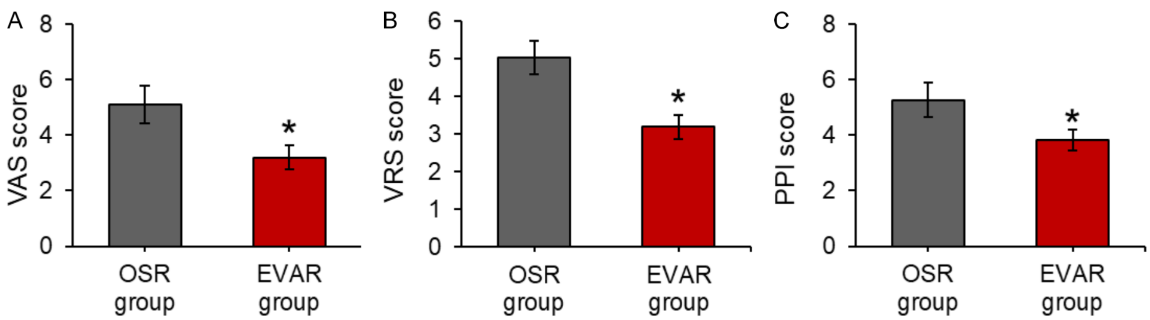

Figure 5. Comparison of postoperative pain scores between the two groups. A: VAS score; B: VPS score; C: PPI score; *P<0.05 vs. ORS. Notes: OSR, open surgical repair; EVAR, endovascular aortic repair; VAS, visual analog scale; VRS, verbal rating scale; PPI, present pain intensity.

tions. Overall, the incidence of adverse events in the EVAR group was markedly lower than in the OSR group (*P*<0.05) (**Figure 7**).

The incidence of postoperative complications after discharge is shown in **Figure 8**. The complication rate was 14.50% in the OSR group and 17.40% in the EVAR group, with no significant difference between the groups (*P*>0.05).

Comparison of perioperative mortality rate and 1-year survival between the two groups

In the OSR group, perioperative mortality rate was 28.95% (22 deaths), with 14 intraoperative deaths (4 due to cardiac arrest and 10 due to hemorrhagic shock) and 8 postoperative deaths (4 due to abdominal compartment syndrome with family withdrawal, 1 from multiple organ failure despite resuscitation, and 3 from malignant arrhythmias). In the EVAR group, the perioperative mortality rate was 11.80% (17 deaths), with 10 intraoperative deaths (due to hemorrhagic shock and failed conversion to open surgery) and 7 postoperative deaths (2 due to hemorrhagic shock, 2 due to multiple organ failure despite resuscitation, and 3 due to ventricular fibrillation). Although the perioperative mortality rate was lower in the EVAR group, the difference was not statistically significant (*P*>0.05).

As shown in **Figure 9**, the 1-year survival rate was 61.9% in the OSR group and 73.0% in the EVAR group, with the EVAR group demonstrating a significantly higher survival rate (*P*<0.05).

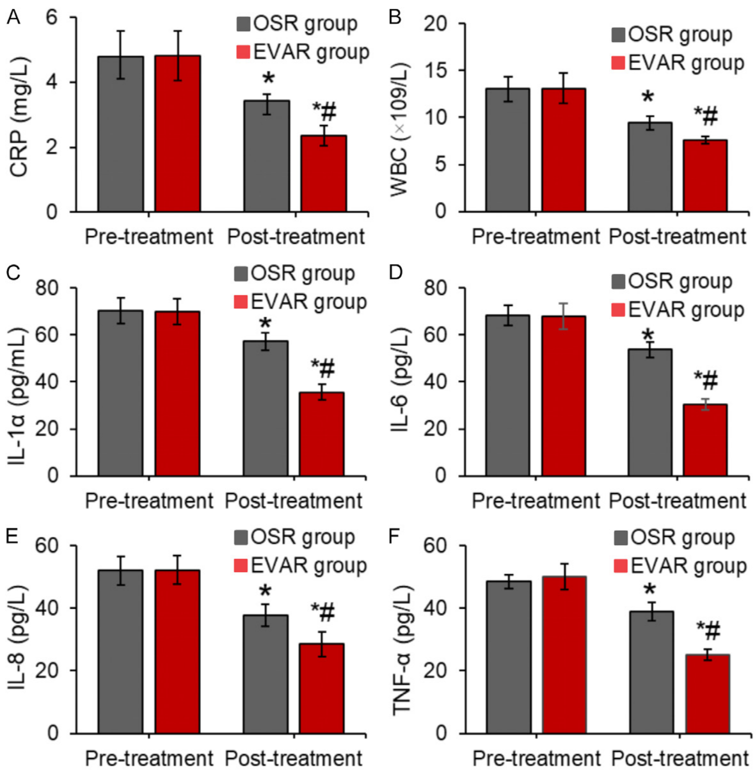

Figure 6. Comparison of inflammatory marker levels between the two groups before and after treatment. A: CRP; B: WBC; C: IL-1a; D: IL-6; E: IL-8; F: TNF-α; *P<0.05, vs. pre-treatment; #P<0.05, vs. OSR. Notes: OSR, open surgical repair; EVAR, endovascular aortic repair; CRP, C-reactive protein; WBC, white blood cells; IL, interleukins (IL-1α, IL-6, IL-8); TNF-α, tumor necrosis factor-α.

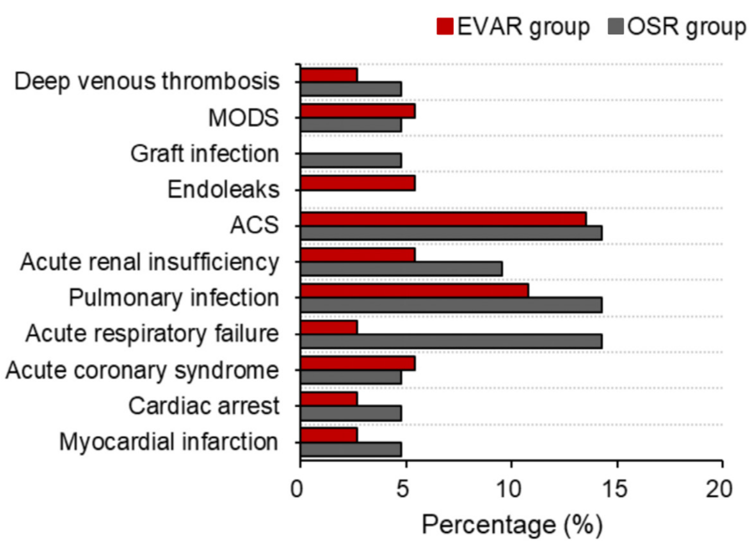

Figure 7. Comparison of perioperative adverse events between two groups. Notes: OSR, open surgical repair; EVAR, endovascular aortic repair; ACS, Abdominal compartment syndrome; MODS, Multiple organ dysfunction syndrome.

Multivariate logistic regression analysis of postoperative prognosis

Univariate analysis (**Table 3**) revealed that coronary artery disease (P<0.001), peripheral vascular disease (P<0.001), chronic renal insufficiency (P< 0.001), smoking (P <0.001), albumin (Alb, P<0.001), creatinine (Cre, P<0.001), urea nitrogen (P<0.001), ALT (P< 0.001), and treatment method (P = 0.0003) were significantly associated with patient mortality.

These significant factors were incorporated into the multivariate analysis, and the results identified Alb<40 g/L (P=0.004), Cre≥1.5 mg/dL (P=0.007), urea nitrogen ≥25 mg/dL (P=0.001), ALT≥40 U/L (P=0.002), and OSR (P=0.024) as independent risk factors for poor postoperative prognosis (**Table 4**).

Discussion

Ruptured abdominal aortic aneurysm (rAAA) is one of the most critical conditions in vascular surgery, with advanced age, aneurysm asymmetry, coexisting renal insufficiency, and chronic obstructive pulmonary disease being key risk factors for rupture [11]. The rupture of an abdominal aortic aneurysm leads to rapid hemorrhage into the abdominal cavity, causing hemorrhagic shock, organ failure, and increased infection risk [12, 13]. Consequently, the mortality rate rAAA is high, with many patients dying within 2 hours of admission and diagnosis [14].

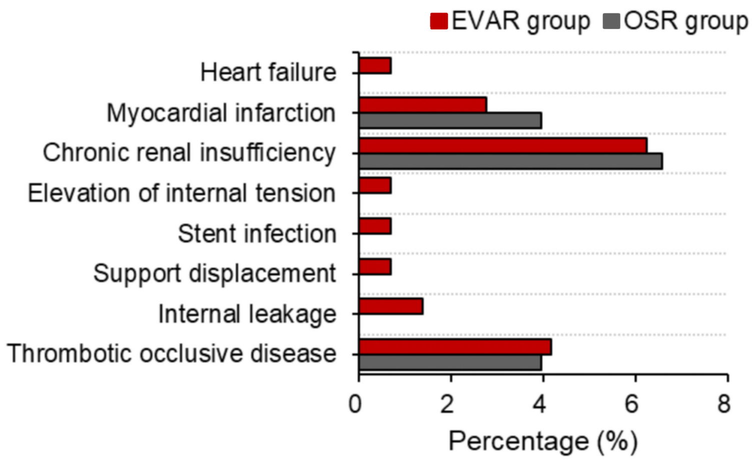

Figure 8. Comparison of post-discharge complications between the two groups. Notes: OSR, open surgical repair; EVAR, endovascular aortic repair.

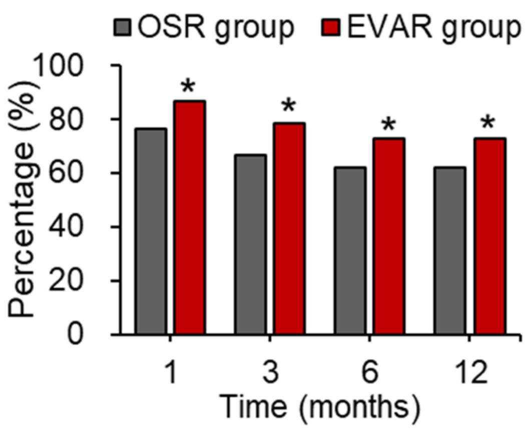

Figure 9. Comparison of 1-year survival rates between the two groups. *$P<0.05$, vs. OSR. Notes: OSR, open surgical repair; EVAR, endovascular aortic repair.

Open surgical repair (OSR) has long been the standard treatment for rAAA. It facilitates thorough hematoma removal and improves gastrointestinal recovery, while also preventing abdominal compartment syndrome [15]. OSR is applicable for the aneurysms in challenging locations, such as those extending from the celiac trunk to the suprarenal abdominal aorta. However, OSR is associated with large incision, prolonged recovery times, high complication rates, and elevated mortality. Previous studies have shown a mortality rate of 50% with OSR due to extended operation times, increased blood loss, and significant transfusion needs [16]. This study observed slightly lower mortality rates, which may be attributed to the smaller sample size. EVAR is a minimally invasive procedure, performed under imaging guidance, where a stent graft is placed through small incisions in the femoral arteries to redirect blood flow into the aneurysm [17, 18]. EVAR has been shown to be especially beneficial for high-risk patients, offering quicker recovery, reduced intraoperative blood loss, and lower mortality rates. Studies have reported 30-day and one-year mortality rates of 9.6% and 14.5%, respectively, for EVAR in rAAA patients, highlighting its effectiveness in improving survival [19].

This study found that patients with rAAA treated with EVAR had significantly lower IOB, blood transfusion volume, and fluid infusion volume compared to those treated with OSR. EVAR's ability to seal the ruptured aneurysm orifice quickly effectively reduces the need for extensive exposure and incision, minimizing blood loss. This is crucial for preventing insufficient perfusion of vital organs due to decreased blood pressure and volume [20]. Additionally, the fasting time, time to first ambulation, ICU stay, and hospital stay were all significantly shorter for EVAR group compared to OSR group. This may be due to the rapid balloon occlusion technique used in EVAR, which can effectively reduce bleeding and help correct shock and maintain visceral perfusion.

EVAR also resulted in lower mortality rates compared to OSR. A retrospective review of the National Health Insurance Service (NHIS) database found that the perioperative mortality rate for EVAR was lower than for OSR (29.8% vs. 35.0%), although no significant differences in complications or all-cause mortality were observed [21]. A meta-analysis of six studies comparing EVAR and OSR for rAAA confirmed that EVAR had lower perioperative mortality, overall mortality during follow-up, rates of acute kidney injury, early postoperative reinterventions, and shorter hospital stays [22]. EVAR achieves this by deploying a stent graft throu-

Table 3. Univariate logistic regression analysis of postoperative prognosis of study subjects

Factors	Survival group (n=160)	Death group (n=72)	X^2/t	P
Diabetes mellitus	20 (12.50)	8 (11.11)	0.090	0.831
Hypertension	93 (58.13)	39 (54.17)	0.317	0.573
Coronary artery disease	11 (6.88)	57 (79.17)	125.246	<0.001
Cerebral infarction (or Stroke)	16 (10.00)	13 (18.06)	2.256	0.133
Hyperlipidemia	33 (20.63)	23 (31.94)	3.474	0.062
Peripheral vascular disease	30 (18.75)	46 (63.89)	45.931	<0.001
COPD	79 (65.83)	45 (62.50)	3.438	0.064
Chronic renal insufficiency	6 (3.75)	22 (30.56)	33.620	<0.001
Smoking	84 (52.50)	63 (87.50)	26.202	<0.001
Admitted until operation	15.27±5.33	16.24±4.73	-1.327	0.186
Examination until operation	11.62±3.38	12.08±2.48	-1.036	0.301
Admission until examination	4.76±0.28	4.80±0.31	-0.973	0.331
Surgical time	276.53±36.55	269.54±34.78	1.368	0.173
IOB	1567.53±256.76	1588.64±258.74	-0.578	0.564
Intraoperative blood transfusion volume	672.57±112.57	691.67±109.67	-1.205	0.229
Intraoperative blood transfusion volume	3128.88±347.97	3098.55±299.86	-0.640	0.523
Fasting time	6.89±1.23	6.92±1.35	-0.167	0.868
First time getting out of bed	9.37±1.55	9.42±1.26	-0.240	0.810
ICU length of stay	5.93±0.48	5.85±0.36	1.263	0.208
Length of hospital stay	18.33±3.92	17.65±2.22	1.375	0.170
Postoperative Alb (g/L)			27.522	<0.001
<40	48 (30.0)	48 (66.7)		
≥40	112 (70.0)	24 (33.3)		
Postoperative Cre (mg/dL)			41.171	<0.001
<1.5	139 (86.9)	34 (47.2)		
≥1.5	21 (13.1)	38 (52.8)		
Postoperative BUN (mg/dL)			38.771	<0.001
<25	104 (65.0)	15 (20.8)		
≥25	56 (35.0)	57 (79.2)		
Postoperative ALT (U/L)			21.526	<0.001
≤40	78 (48.7)	12 (16.7)		
>40	82 (51.3)	60 (83.3)		
Postoperative AST (U/L)			2.335	0.126
<40	95 (59.4)	35 (48.61)		
≥40	65 (40.6)	37 (51.39)		
Therapeutic method			8.840	0.003
OSR	68 (42.5)	16 (22.2)		
EVAR	92 (57.5)	56 (77.8)		

Notes: OSR, open surgical repair; EVAR, endovascular aortic repair; COPD, chronic obstructive pulmonary disease; IOB, intraoperative bleeding; ICU, intensive care unit; Alb, albumin; Cre, creatinine; BUN, blood urea nitrogen; ALT, alanine aminotransferase; AST, aspartate aminotransferase.

gh the femoral artery, isolating high-pressure blood flow from the aneurysm and reducing surgical trauma [23, 24]. In contrast, OSR involves larger incisions to expose and repair the aneurysm, resulting in more trauma, greater blood loss, and longer recovery times [25]. Further analysis of perioperative outcomes for patients undergoing EVAR alone for rAAA revealed a 30-day mortality rate of 27% and a one-year mortality rate of 39%. Independent risk factors for increased 30-day mortality included unstable preoperative hemodynamics

Table 4. Multivariate logistic regression analysis of postoperative prognosis of study subjects

Factors	*β*	*SE*	*Wald*	*OR*	*95% CI*	*P*
Coronary artery disease	0.799	0.196	5.426	1.900	0.782-3.233	0.065
Peripheral vascular disease	1.230	0.996	1.513	3.421	0.481-8.031	0.684
Chronic renal insufficiency	0.009	0.067	0.027	1.017	0.125-1.286	0.232
Smoking	0.596	0.091	40.295	1.845	0.693-1.103	0.076
Alb<40 g/L	0.678	0.257	6.590	1.956	1.188-3.259	0.004
Cre≥1.5 mg/dL	0.256	0.053	13.227	1.287	1.156-1.557	0.007
BUN≥25 mg/dL	0.304	0.041	14.467	1.362	1.252-1.658	0.001
ALT≥40 U/L	0.416	0.267	8.443	1.526	1.251-1.933	0.002
Therapeutic method (OSR)	0.511	0.288	7.446	1.535	1.212-1.828	0.024

Notes: OSR, open surgical repair; Alb, albumin; Cre, creatinine; BUN, blood urea nitrogen; ALT, alanine aminotransferase; AST, aspartate aminotransferase.

and ABO blood type mismatches [26]. This highlights the importance of evaluating preoperative hemodynamics to improve postoperative survival rates in rAAA patients.

Complications following surgery for rAAA are diverse and can affect multiple organ systems, including the circulatory, respiratory, digestive, and urinary systems [27]. MODS is a leading cause of postoperative death in patients with rAAA [28, 29]. In this study, the incidence of MODS during the perioperative period was 4.8% for OSR and 5.4% for EVAR. This may be due to factors such as hemorrhagic shock and hemodynamic instability. Prompt control of aortic bleeding and early restoration of circulating blood volume are critical for maintaining vital organ perfusion in rAAA patients. Abdominal compartment syndrome is another severe complication following EVAR, and is associated with higher mortality [30]. This study found a higher complication rate with OSR compared to EVAR. As a minimally invasive procedure, EVAR avoids extensive dissection and organ exposure, thus reducing the risk of bleeding and infection during surgery. It is particularly advantageous for elderly patients, those with poor physical condition, and those with comorbidities, as EVAR minimizes physiological stress, accelerates postoperative recovery, and reduces complication rates.

Multivariate logistic regression analysis revealed Alb, Cre, urea nitrogen, ALT, and treatment method as independent risk factors affecting postoperative prognosis of rAAA patients. In rAAA patients, low albumin levels typically reflect malnutrition, liver dysfunction, or chronic inflammatory states, leading to reduced plasma colloid osmotic pressure, increased tissue edema, and impaired wound healing and immune function. In addition, low albumin levels are also associated with higher rates of postoperative complications, including infections, pulmonary complications, and MODS, contributing to poorer prognosis. Elevated creatinine levels indicate impaired renal function, commonly observed in rAAA patients due to shock, hypotension, or inadequate renal perfusion. High creatinine levels are closely associated with postoperative renal failure, MODS, and increased mortality. Patients with renal insufficiency are more prone to electrolyte imbalances, acid-base imbalances, and abnormal drug metabolism, which heightens surgical risks and complications. Urea nitrogen, a byproduct of protein metabolism excreted by the kidneys, is elevated in rAAA patients with renal dysfunction. High levels are associated with worsening kidney function and increased mortality risk, likely compounded by systemic inflammation and metabolic disorders, further elevating surgical risks. High ALT levels suggest liver dysfunction or injury, which can lead to coagulation dysfunction, impaired drug metabolism, and weakened immune function. These factors increase the risk of bleeding, medication issues, and infections, all contributing to a poorer prognosis.

However, EVAR requires certain conditions to be effective, including thick access vessels, good anchoring conditions at both ends of the aneurysm (i.e., a diameter less than 3 cm), and a proximal aneurysm neck length exceeding 1 cm. A study [31] comparing rAAA repair outcomes by gender found that in-hospital mortality was higher in female patients (34.4% vs.

26.6%), and the 8-year survival rate was lower (36.7% vs. 49.5%). This may be due to factors such as older age and higher rates of chronic kidney disease in women. Additionally, risk factors for immediate postoperative death in rAAA patients included preoperative systolic blood pressure below 70 mmHg, estimated blood loss greater than 40%, pulmonary disease, and elevated creatinine levels [32]. Therefore, future development of advanced endovascular devices is needed to broaden the applicability of EVAR, and careful monitoring of patient physiology prior to surgery is essential to reduce postoperative mortality.

Regarding postoperative pain and recovery, the study found that the VAS, VPS, and PPI scores were all significantly lower in the EVAR group compared to the OSR group. This suggests that EVAR is superior in reducing postoperative pain and promoting venous function recovery [33]. The minimally invasive nature of EVAR results in less surgical trauma, leading to a reduced pain response and faster venous function recovery. The lower PPI scores in the EVAR group further support the idea that EVAR enhances pain management, likely due to quicker recovery and less pain post-surgery.

In this study, the EVAR group demonstrated significantly lower levels of postoperative inflammatory markers compared to the OSR group, including CRP, WBC, IL-1α, IL-6, IL-8, and TNF-α. These results indicate that EVAR offers a clear advantage in reducing postoperative inflammation and tissue damage. Unlike OSR, EVAR is minimally invasive with smaller incisions that cause less damage to surrounding tissues, thereby decreasing the trauma response and postoperative inflammation [34]. The minimally invasive nature of EVAR not only reduces local tissue damage but also alleviates the stress on the body's hemodynamics and tissue repair processes, leading to a significant reduction in inflammatory markers like IL-1α, IL-6, IL-8, and TNF-α. As a result, EVAR is associated with shorter postoperative recovery times, fewer postoperative infections and complications, enabling faster patient recovery. Additionally, the reduced burden on the body results in a less intense inflammatory response, as evidenced by studies showing lower inflammatory markers in the EVAR group compared to the OSR group [35]. This aligns with findings from other research, which suggest that EVAR may enhance postoperative recovery by minimizing immune system activation [36]. Overall, EVAR significantly reduces postoperative inflammation and tissue damage, offering substantial benefits in terms of inflammation control, recovery speed, and immune response.

The primary limitations of this study include its retrospective design and single-center data, which may introduce selection bias and information bias, thereby limiting the generalizability of the conclusions. Additionally, the postoperative follow-up period was relatively short, lasting only one year, which prevents a comprehensive assessment of long-term outcomes and complications. Future research should consider conducting prospective, multi-center, large-sample randomized controlled trials to validate the differences in efficacy between EVAR and OSR across diverse regions and patient populations. Extending the follow-up period would provide valuable insights into long-term survival rates and postoperative complications. Furthermore, future studies should explore individualized treatment plans for patients and evaluate the effects of alternative therapeutic approaches to optimize the management of rAAA.

Conclusion

Compared to OSR, EVAR offers significant advantages in reducing surgical trauma, minimizing postoperative complications, alleviating pain and inflammation, and improving survival rates. Consequently, EVAR is an effective and safe treatment for rAAA and should be considered for broader application in clinical practice.

Disclosure of conflict of interest

None.

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