Open vs. Endovascular Aortic Repair: Guidelines and Real-World Outcomes

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SOUHRN

Aneurysma břišní aorty (abdominal aortic aneurysm, AAA) nadále představuje kritické postižení cév s významnou morbiditou a mortalitou, vyžadující včasný zásah buď otevřenou operací (open surgical repair, OSR), nebo endovaskulární léčbou (endovascular aortic repair, EVAR). Tento přehledový článek hodnotí nejnovější doporučené postupy pro klinickou praxi a výsledky těchto dvou přístupů v reálném světě a shrnuje důkazy z randomizovaných kontrolovaných studií, údaje z velkých registrů i informace o nových, vyvíjených i v současnosti zkoušených technických prostředcích a postupech. Otevřený chirurgický přístup jako zlatý standard je sice spojen s vynikající dlouhodobou trvanlivostí, avšak s vyššími perioperačními riziky, zatímco EVAR představuje méně invazivní alternativu se sníženou krátkodobou mortalitou; vyžaduje však vzhledem k častější nutnosti reintervencí celoživotní sledování pacienta. Autoři se věnují i léčbě ruptury AAA, přičemž z hlediska přežití je EVAR výhodnější u pacientů s vhodnými anatomickými poměry, zatímco OSR zůstává jedinou možností u pacientů s nestabilními hemodynamickými poměry. V článku se věnuje pozornost i postupnému vývoji komplexní léčby aneurysmat včetně EVAR s fenestrovaným nebo větveným stentgraftem, se zdůrazněním stále většího uplatňování tohoto přístupu u vysoce rizikových pacientů. Navíc začlenění umělé inteligence a počítačového modelování vnáší do předoperačního plánování doslova revoluční prvky významně zlepšující výsledky výkonu a výběr pacientů. Přes uvedený pokrok zůstává zásadním úkolem vypracování standardizovaných protokolů pro dlouhodobé sledování pacientů po EVAR. Spojením současných důkazů s technickými inovacemi nabízí tento článek ucelený pohled na optimalizaci léčby AAA, směřování dalšího výzkumu a zlepšení výsledného stavu pacientů.

Keywords:
Aortic aneurysm complications
Branched endovascular aneurysm repair
Endovascular aortic repair
Fenestrated endovascular aneurysm repair
Open surgical aortic repair
Ruptured abdominal aortic aneurysm

ABSTRACT

Abdominal aortic aneurysm (AAA) remains a critical vascular condition with significant morbidity and mortality, necessitating timely intervention through either open surgical repair (OSR) or endovascular aortic repair (EVAR). This review evaluates the latest clinical guidelines and real-world outcomes of these two approaches, synthesizing evidence from randomized controlled trials, large-scale registry data, and emerging technological advancements. OSR, traditionally the gold standard, offers superior long-term durability but carries higher perioperative risks, whereas EVAR provides a less invasive alternative with reduced short-term mortality but requires lifelong surveillance due to its higher reintervention rates. The management of ruptured AAA is also explored, with EVAR demonstrating a survival advantage in anatomically suitable cases, though OSR remains the only option for hemodynamically unstable patients. The evolution of complex aneurysm repair, including fenestrated and branched EVAR, is discussed, highlighting its expanding role in high-risk patients. Additionally, the integration of artificial intelligence and computational modeling is revolutionizing preoperative planning, enhancing procedural outcomes and patient selection. Despite these advances, the need for standardized long-term surveillance protocols post-EVAR remains a critical challenge. By combining contemporary evidence with technological innovations, this review provides a comprehensive perspective on optimizing AAA management, guiding future research, and improving patient outcomes.

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Highlights:

- **Open vs. endovascular repair** – Open surgical repair (OSR) offers durability, while endovascular aortic repair (EVAR) reduces early mortality but requires lifelong follow-up.
- **Real-world data** – EVAR has lower short-term risk but higher reintervention and late rupture rates than OSR.
- **Complex aneurysms** – Fenestrated and branched endovascular aortic repair (fEVAR/bEVAR) expand repair options but require further study on long-term durability.
- **Technological advances** – Artificial intelligence (AI) and computational modeling enhance preoperative planning and patient selection.
- **Surveillance needs** – Standardized post-EVAR monitoring is essential to detect complications and improve outcomes.

Introduction

Abdominal aortic aneurysm (AAA) is a life-threatening vascular condition characterized by a progressive dilation of the abdominal aorta, typically defined as an aortic diameter of ≥3 cm or increasing by more than 50% compared to the normal size.[1,2] AAA predominantly affects older adults, with a higher prevalence in men compared to women. The incidence of AAA varies globally, with population-based screening programs demonstrating a declining prevalence in some regions due to improved cardiovascular risk management. Despite this, AAA remains a significant contributor to morbidity and mortality, particularly in aging populations.[3,4]

Risk factors associated with AAA development include smoking, hypertension, advanced age, male sex, genetic predisposition, and atherosclerosis. Smoking is the strongest modifiable risk factor, with a fourfold increase in AAA risk among smokers compared to non-smokers.[3] Given the often-asymptomatic nature of AAA, early detection through screening programs, particularly for high-risk individuals, is crucial in reducing aneurysm-related mortality.

AAA development involves a complex interplay of genetic, inflammatory, and biomechanical factors.[5,6] The degradation of the extracellular matrix, increased inflammatory cell infiltration, and loss of smooth muscle cells contribute to a weakening of the aortic wall.[7,8] As the aneurysm enlarges, wall tension increases, raising the risk of rupture.

The likelihood of rupture is closely associated with aneurysm diameter and growth rate. The risk of rupture significantly increases for aneurysms >5.5 cm in men and >5.0 cm in women.[9] Other predictive factors for rupture include rapid expansion (>10 mm per year), female sex, smoking, hypertension, and irregular aneurysm morphology.[10] Given the high mortality rate associated with ruptured AAA (rAAA), timely elective repair is crucial for patients meeting surgical criteria.

Surgical intervention for AAA has evolved significantly over the past century. Open surgical repair (OSR), introduced in the mid-20th century, remained the standard of care for decades. This approach involves replacing the aneurysmal segment with a synthetic graft via laparotomy, offering durable long-term results but with significant perioperative risks, including cardiac, pulmonary, and renal complications.[11,12]

The introduction of endovascular aortic repair (EVAR) in the 1990s revolutionized AAA management by providing a minimally invasive alternative. EVAR involves the deployment of an endograft via a transfemoral approach, reducing operative time, blood loss, and hospital stay. Over time, advancements in stent-graft technology and patient selection criteria have expanded EVAR indications, making it the preferred approach for many patients with suitable anatomy. The choice between OSR and EVAR remains a subject of ongoing debate.[13,14]

This article compares open surgical repair and endovascular aortic repair for abdominal aortic aneurysms, analyzing guideline recommendations and real-world outcomes. It examines perioperative and long-term results, including mortality, complications, and durability. The study also explores ruptured AAA management, complex aneurysm repair (fEVAR/bEVAR), and clinical decision-making based on randomized trials and registry data. By synthesizing current evidence, this review aims to optimize treatment selection and improve patient outcomes in modern vascular surgery.

Materials and methods

This review aims to analyze the existing literature that has explored and compared the outcomes of OSR and EVAR. A comprehensive literature search was conducted in PubMed, Scopus, Cochrane, and Web of Science using the following search query: ("Open Aortic Repair" OR "Open Surgical Aortic Repair") AND ("Endovascular Aortic Repair" OR "EVAR") AND ("Guidelines" OR "Practice Guidelines") AND ("Real-World Outcomes" OR "Clinical Outcomes"). The search was restricted to articles, reviews, and clinical trials published in English between 2020 and 2025, yielding 120 results. After screening abstracts, 108 studies were selected. Following a full-text review, 98 articles were ultimately included based on study quality. The quality appraisal framework by DiCenso et al.[15] was applied to assess the rigor of the studies, evaluating aspects such as the research problem, literature review, study design, sample selection, data collection, results, and limitations.

Results

Guidelines for elective AAA repair

Preoperative considerations

A thorough preoperative assessment is crucial in determining the best approach for elective AAA repair. One of the key factors influencing the decision between OSR and EVAR is **vascular anatomy assessment**. Key anatomical considerations include the length and angulation of the aortic neck, the presence of thrombus or calcification, and the involvement of iliac arteries. If the aneurysm exhibits complex morphology, such as severe neck angulation or an inadequate landing zone for a stent graft, OSR is typically the preferred option.[16,17]

Risk stratification plays a vital role in assessing a patient's candidacy for surgery. Cardiovascular risk is particularly important, as many AAA patients have underlying coronary artery disease. Preoperative evaluation includes ECG, echocardiography, and functional stress testing in high-risk individuals. Pulmonary assessment is also necessary, especially in patients with chronic obstructive pulmonary disease, where pulmonary function tests can predict respiratory complications. Additionally, renal function must be assessed using estimated glomerular filtration rate to prevent contrast-induced nephropathy during imaging procedures. Frailty and sarcopenia are increasingly recognized as predictors of poor surgical outcomes, making nutritional assessment and frailty scoring crucial in elderly or high-risk patients.[18,19]

Computed tomography angiography (CTA) is the gold standard for preoperative evaluation, providing detailed three-dimensional visualization of the aneurysm. Magnetic resonance angiography (MRA) serves as an alternative for patients with renal impairment or contrast allergies. Ultrasonography is commonly used for screening and monitoring small aneurysms but is insufficient for surgical planning. These imaging modalities allow for precise selection of the optimal surgical technique and help guide the decision between OSR and EVAR.[20,21]

Open surgical repair (OSR)

OSR remains a critical option for AAA management, particularly in cases where EVAR is not feasible due to anatomical constraints. OSR is preferred in younger patients with a long-life expectancy, as it provides superior long-term durability. Additionally, aneurysms with short or severely angulated necks, significant thrombus burden, or extensive iliac involvement are often unsuitable for EVAR. Infected aneurysms, mycotic AAAs, and cases where EVAR is contraindicated due to hostile anatomy also warrant OSR.[22,23]

The procedure involves a midline laparotomy or retroperitoneal approach to access the aneurysmal aorta. Once the aorta is exposed, proximal and distal clamping is performed to control blood flow, followed by aneurysm sac opening and thrombus removal. A synthetic graft is then sutured into place, replacing the diseased segment, after which circulation is restored, and the abdominal wall is closed. This method provides long-lasting structural integrity and eliminates the risk of endoleaks, which are common in EVAR.[24,25]

Graft selection in OSR is a crucial consideration. Dacron (polyester) grafts are the most commonly used due to their durability and biocompatibility. Expanded polytetrafluoroethylene grafts serve as an alternative, offering similar performance. The choice of graft material depends on surgeon preference and patient-specific factors.[26,27]

Postoperative care for OSR involves intensive monitoring in an intensive care unit (ICU) setting, focusing on hemodynamic stabilization, pain management, and early mobilization. Complications may arise, including cardiac events such as myocardial infarction and arrhythmias, pulmonary complications like atelectasis and pneumonia, renal dysfunction, and surgical site complications such as anastomotic leaks or graft infections. Despite these risks, OSR remains the gold standard for long-term durability, with lower rates of secondary interventions compared to EVAR.[28–30]

Endovascular aortic repair (EVAR)

EVAR has emerged as a less invasive alternative to OSR, particularly for elderly patients or those with significant comorbidities. The ESVS recommends EVAR for patients with favorable aortic anatomy, including a proximal neck length of at least 15 mm and a neck angulation of less than 60 degrees.[31] EVAR is also preferred in patients at a higher surgical risk, such as those with severe cardiac or pulmonary disease, who may not tolerate the stress of open surgery. Additionally, patients with rapidly expanding or symptomatic AAAs are prime candidates for EVAR, as it allows for quicker recovery and shorter hospital stays compared to OSR.[22,23,25,32]

Several types of stent grafts are available for EVAR, each designed to accommodate different anatomical challenges. Standard EVAR devices are suitable for infrarenal aneurysms with favorable neck anatomy, while fenestrated EVAR (fEVAR) and branched EVAR (bEVAR) are used for more complex cases where the aneurysm extends near the renal or visceral arteries. Fixation methods vary, with suprarenal fixation offering better stability in challenging necks, while infra-renal fixation is appropriate for less complex cases.[33,34]

The field of EVAR continues to advance, with newer stent graft technologies improving outcomes. Polymer-based sealing technology has been introduced to minimize endoleak risk and enhance graft stability.[35] Low-profile delivery systems enable the use of EVAR in patients with small iliac arteries, reducing access complications. Additionally, bioengineered grafts are being developed to improve long-term patency and reduce thrombogenicity, further refining the effectiveness of the procedure.[36]

Perioperative imaging is a key component of EVAR success. Fluoroscopy and contrast angiography are used intraoperatively to ensure proper graft placement and deployment, while intravascular ultrasound (IVUS) can provide additional real-time guidance. The success of EVAR, both initially and over the long term, relies on an accurate baseline evaluation of aortic morphology.[37,38] This includes assessing fixation and sealing landing zones, as well as obtaining precise measurements to ensure the appropriate selection of a stent graft (**Table 1**).[39]

Postoperatively, patients require lifelong surveillance, as EVAR is associated with potential long-term complications such as endoleaks, graft migration, and aneurysm sac enlargement. The recommended follow-up regimen includes CTA at 1 month, 6 months, and annually thereafter, with duplex ultrasound as an alternative for long-term monitoring in stable cases.[40]

While EVAR offers significant benefits in terms of reduced operative risk and shorter recovery time, its long-term durability remains a concern, necessitating continued imaging surveillance and possible secondary interventions. The ESVS emphasizes the importance of

Table 1 – Key imaging assessments for aortic aneurysm evaluation and repair planning

Key imaging assessments	Factors considered
Proximal neck	Suitability for cross-clamping (length, diameter, angulation, calcification, atherothrombosis)
Iliac arteries	Patency, tortuosity, aneurysm presence, pelvic circulation
Access vessels	Lower limb circulation and vessel condition
Visceral arteries	Patency and accessory renal arteries
Aneurysm presence	Identification of additional aneurysms (visceral, thoracic)
Aortic degeneration	Shaggy aorta, plaque formation, thrombi
Venous & organ anomalies	Renal and caval vein patency, kidney positioning

individualized patient selection, taking into account anatomic suitability, life expectancy, and institutional expertise to achieve optimal outcomes.[31]

A crucial but often overlooked aspect of AAA repair is its impact on cerebral perfusion and neurological outcomes. Research on adaptive cerebral perfusion strategies during aortic reconstruction, such as off-pump axillo-axillary bypass, suggests that optimizing perfusion pathways can reduce the risk of ischemic injury.[41] While OSR involves aortic cross-clamping, which can transiently reduce cerebral blood flow, EVAR may also pose risks related to embolization of atherosclerotic debris, potentially leading to perioperative strokes or cognitive decline.[42]

Although the ESVS does not yet provide definitive recommendations on neurological monitoring during AAA repair, there is growing interest in utilizing neuromonitoring techniques and tailored perfusion strategies to minimize cerebral ischemic risk. Future studies are needed to evaluate whether specific neuroprotective measures should be integrated into routine AAA management protocols.[42]

Role of AI and computational modeling in preoperative planning

Artificial intelligence (AI) and computational modeling are transforming preoperative planning by enabling precise, patient-specific simulations that predict procedural outcomes and optimize device selection. Computational models, similar to those used in heart valve research, can evaluate hemodynamic changes, graft positioning, and potential risks in both OSR and EVAR. These models allow surgeons to anticipate challenges, improve procedural efficiency, and enhance patient safety.[43,44]

AI algorithms can also assist in automating aneurysm surveillance, identifying subtle changes in aneurysm morphology that may indicate the risk of rupture or the need for reintervention. By integrating AI-driven insights with clinical expertise, surgeons can make more informed, data-driven decisions that improve both short- and long-term outcomes.[44]

Need for standardized long-term surveillance protocols post-EVAR

One of the critical challenges in EVAR management is the lack of standardized long-term surveillance protocols.[45] While regular imaging is essential to detect endoleaks, stent migration, and sac enlargement, the frequency, modality, and duration of follow-up remain variable across institutions. The ESVS emphasizes the need for lifelong surveillance, but further consensus is required to establish uniform protocols that balance efficacy, cost-effectiveness, and patient compliance.[31]

Future studies should explore the use of low-radiation imaging techniques, such as contrast-enhanced ultrasound, and evaluate the potential of wearable sensors or remote monitoring tools to streamline follow-up care. By standardizing surveillance practices, healthcare systems can reduce unnecessary imaging, improve early detection of complications, and enhance patient quality of life.[31]

Perioperative and long-term outcomes

Short-term and perioperative outcomes

The perioperative period is a critical phase in AAA repair, with significant differences in outcomes between OSR and EVAR. OSR is associated with higher operative mortality due to its invasive nature. The procedure requires a major abdominal incision, aortic cross-clamping, and prolonged anesthesia, all of which contribute to an increased risk of cardiac, pulmonary, and renal complications. Studies indicate that the perioperative mortality rate for OSR ranges between 3–5%, with higher rates observed in patients with advanced age, significant comorbidities, or prior cardiovascular disease. Additionally, OSR results in a longer hospital stay, typically exceeding 7–10 days, with many patients requiring admission to an ICU for postoperative monitoring and hemodynamic stabilization.[25,27,28]

In contrast, EVAR has significantly lower perioperative mortality, with reported rates of 1–2%, making it the preferred option for high-risk surgical candidates. The minimally invasive nature of EVAR eliminates the need for a major laparotomy and aortic clamping, thereby reducing intraoperative bleeding and stress on the cardiovascular system. Patients undergoing EVAR generally experience shorter hospital stays, averaging 2–4 days, and have a faster postoperative recovery, allowing for early ambulation and discharge. However, while the initial surgical risk is lower, EVAR is not without complications. The most notable perioperative risks include endoleaks, which occur when blood continues to flow into the aneurysm sac despite the presence of the stent graft. Endoleaks, classified into various types, may require secondary interventions if they result in continued aneurysm growth or rupture risk (**Fig. 1**). Other early complications include access site hematomas, iliac artery injuries, and renal dysfunction due to contrast exposure during endograft placement.[13,23]

Long-term outcomes

Long-term outcomes play a crucial role in determining the best approach for AAA repair, as both OSR and EVAR have distinct advantages and challenges over extended follow-up periods. OSR remains the gold standard in

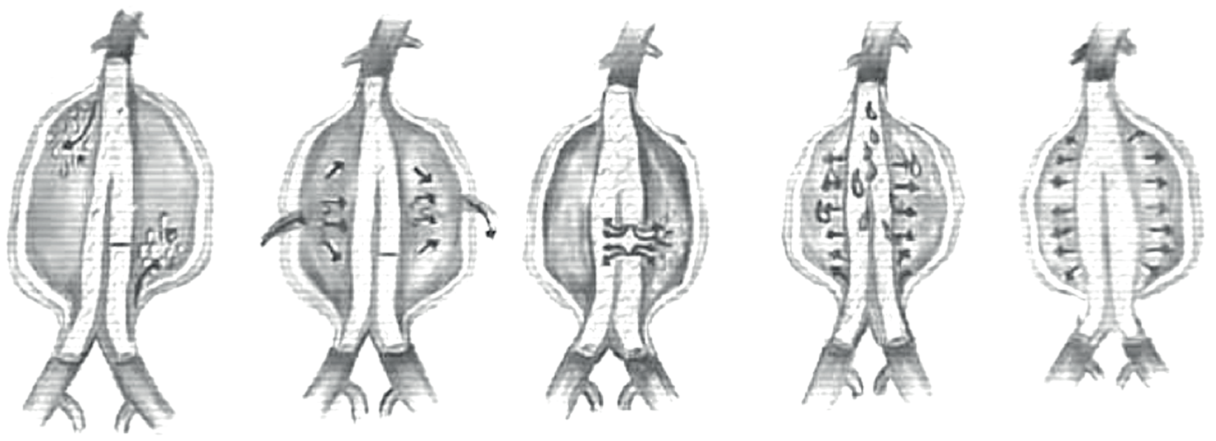

Fig. 1 – The image illustrates the five types of endoleaks associated with endovascular aneurysm repair (EVAR) for abdominal aortic aneurysms (AAA). Endoleaks after endovascular aneurysm repair (EVAR) are classified into five types. Type 1 occurs due to an inadequate graft seal, leading to direct pressurization of the aneurysm sac, requiring urgent intervention. Type 2 results from retrograde flow from aortic side branches, often monitored unless aneurysm expansion occurs. Type 3 involves graft defects or modular disconnection, necessitating immediate repair. Type 4 is due to graft wall porosity and typically resolves spontaneously. Type 5 (endotension) is aneurysm sac expansion without a detectable leak, requiring close monitoring. Management varies, with urgent repair for high-risk types and observation for others.

terms of durability, with studies demonstrating low rates of reintervention and excellent long-term aneurysm exclusion. The primary advantage of OSR is its permanent anatomical repair, as the aneurysm sac is completely removed, and the graft is sutured directly to healthy aortic tissue. This significantly reduces the risk of future complications, and most patients require minimal surveillance beyond routine clinical follow-ups. OSR is associated with lower rates of late graft complications, such as infection, occlusion, and anastomotic aneurysm formation, compared to EVAR. However, the long-term risks of OSR include incisional hernias, adhesions, and, in rare cases, graft thrombosis or pseudoaneurysm formation.[24,28,38]

Conversely, while EVAR provides a less invasive initial treatment, it is associated with higher long-term complications and reintervention rates. One of the most significant concerns is stent graft migration, which occurs when the endograft shifts from its original position due to aortic remodeling or inadequate fixation. Migration can lead to endoleaks, sac expansion, and aneurysm rupture, necessitating secondary procedures. Another notable risk is graft infection, although rare, it carries high morbidity and mortality when it occurs, often requiring complete endograft removal and OSR conversion. Additionally, continued aneurysm sac growth despite EVAR placement is a well-documented issue, leading to the necessity for lifelong imaging surveillance and potential secondary interventions.[37,39,40]

Due to the risk of complications, post-EVAR surveillance protocols are stringent, with CTA imaging recommended at 1 month, 6 months, and annually thereafter. Duplex ultrasound is an alternative for long-term monitoring in stable cases, particularly for patients with impaired renal function who may not tolerate frequent contrast-based imaging. Patients who undergo OSR, in contrast, require less intensive follow-up, often limited to clinical assessments and occasional imaging if symptoms arise.[46,47]

Studies analyzing the outcomes of elective endovascular and open surgical approaches for abdominal aortic aneurysm repair

The findings of the meta-analysis by Powell et al. (2017) indicated that EVAR resulted in lower mortality within the first six months (3.3% vs. 5.3%). However, beyond this period, there was no significant difference in mortality between the two approaches. Reintervention rates were higher in the EVAR group, although when laparotomy-based complications were factored in, as seen in the OVER trial, the difference became less significant.[48]

Giannopoulos et al. (2020) in their meta-analysis showed no substantial difference in overall mortality or aneurysm-related deaths between EVAR and open surgery after four to eight years of follow-up. However, the EVAR group exhibited a higher reintervention rate (29% vs. 15%), highlighting a key long-term drawback of the procedure.[49]

Antoniou et al. (2020) analyzed data from seven RCTs involving 2983 patients from 1999 to 2011. Their study confirmed that EVAR was associated with a lower mortality rate within 30 days (odds ratio [OR] 0.36) and six months (hazard ratio [HR] 0.62). The risk of aneurysm-related deaths was also lower in the short term (HR 0.42), but after eight years, mortality increased significantly (HR 5.12). Additionally, the EVAR group had higher rates of reintervention (HR 2.13), aneurysm rupture (OR 5.08), and death due to rupture (OR 3.57) beyond eight years.[50]

Bulder et al. (2019) conducted a large-scale study incorporating data from 189,022 patients between 1993 and 2015, including four RCTs, 20 registry-based studies, and 29 cohort studies. Their analysis found that EVAR significantly reduced 30-day mortality (1.2% vs. 3.2%) compared to open surgery. However, beyond this period, the survival advantage diminished, and long-term mortality rates were comparable between the two approaches.[51]

Li et al. (2019) included 299,784 patients in their study from 1999 to 2018, using data from three RCTs and 68 cohort studies. Their findings indicated that EVAR was associated with higher overall mortality (OR 1.19), increased reintervention rates (OR 2.12), and a higher risk of secondary aneurysm rupture (OR 2.47) within five to nine years. In follow-up beyond ten years, the need for reintervention (OR 2.47) and secondary rupture risk (OR 8.10) remained elevated, reinforcing concerns regarding long-term durability.[32]

Yokoyama et al. (2020) in an analysis of four RCTs and seven propensity score-matched studies reported that EVAR was associated with lower perioperative mortality (risk ratio [RR] 0.39). However, mortality rates varied over time, with a higher risk observed between two and six years, but no significant differences beyond ten years.[52]

Alothman et al. (2020) studied 61,379 patients recruited between 2004 and 2017, incorporating data from four RCTs and 12 cohort studies. Their findings revealed that EVAR was associated with lower perioperative mortality (1.2% vs. 4.5%), but the long-term risk of late sac rupture (1.8% vs. 0.4%) and the need for reintervention (OR 1.94) were significantly higher compared to open repair.[53]

Ruptured AAA: emergency repair considerations

Outcomes of open vs. endovascular repair in rAAA

Ruptured abdominal aortic aneurysm (rAAA) is a catastrophic vascular emergency with high mortality rates, requiring immediate surgical intervention. The choice between OSR and EVAR depends on patient stability, anatomical feasibility, and institutional expertise. EVAR has become the preferred approach in anatomically suitable patients, given its lower perioperative mortality and reduced physiological stress. However, OSR remains the standard option when EVAR is not feasible, particularly in cases with challenging anatomy, failed endovascular access, or hemodynamic instability requiring direct aortic control.[54–56]

EVAR for rAAA is associated with a significantly lower 30-day mortality rate, ranging from 20% to 35%, compared to OSR, where mortality can exceed 40–50% in some studies (**Table 2**).[31] The minimally invasive nature of EVAR eliminates the need for aortic cross-clamping and extensive surgical exposure, thereby reducing intraoperative blood loss, ischemic injury, and multi-organ failure. Additionally, EVAR allows for shorter operative times, which is crucial in critically ill patients. However, its success is highly dependent on anatomical suitability, including adequate proximal neck length and iliac artery access. In cases where EVAR is not an option due to anatomical constraints, OSR remains the only life-saving alternative.[51,53,54]

Despite its advantages, EVAR is not without complications. Endoleaks, particularly Type 1, are a major concern, as they can lead to persistent aneurysm sac pressurization and rupture, necessitating secondary intervention. Additionally, long-term durability concerns mean that patients undergoing EVAR for rAAA require lifelong surveillance to monitor for graft migration, stent fractures, or late aneurysm expansion. OSR, while more invasive, offers a definitive repair with lower rates of reintervention, making it preferable in younger patients with long life expectancy and good physiological reserves.[58–60]

Perioperative management strategies: permissive hypotension and aortic occlusion balloon

The management of rAAA extends beyond the choice of repair technique and involves critical perioperative strategies to improve survival. One of the key principles in damage control resuscitation is permissive hypotension, a strategy aimed at maintaining a systolic blood pressure of 50–70 mmHg to prevent excessive hemorrhage before definitive repair.[61,62] The ESVS recommend avoiding aggressive fluid resuscitation, as excessive volume replacement can dislodge clots, exacerbate bleeding, and worsen coagulopathy. Controlled hypotension until aortic control is achieved has been associated with better outcomes and reduced perioperative mortality.[31]

Another adjunct to rAAA management is the use of an aortic occlusion balloon, particularly in patients presenting in profound hemorrhagic shock. This technique involves temporary inflation of a balloon catheter within the aorta to control bleeding and improve perfusion to the brain and heart. Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) has emerged as a promising tool, allowing time for resuscitation and definitive repair. REBOA can be beneficial in select cases, particularly when there is delayed surgical access or need for rapid

Table 2 – Perioperative mortality rates in randomized controlled trials comparing EVAR and OSR for rAAA

RCT	Country	Study period	Number of patients (n)	30-day mortality rate (%)
Nottingham, 2006[57]	United Kingdom	2002–2004	32	53 (EVAR) vs 53 (OSR)
AJAX, 2013[58]	Netherlands	2004–2011	116	28 (EVAR) vs 29 (OSR)
IMPROVE, 2014[59]	United Kingdom	2009–2013	613	35 (EVAR) vs 37 (OSR)
ECAR, 2015[60]	France	2008–2013	107	18 (EVAR) vs 24 (OSR)
Summary			868	32.6 (EVAR) vs 34.9 (OSR)

AJAX – Amsterdam Acute Aneurysm Trial; ECAR – Endovascular or Open Surgery for Ruptured Aortoiliac Aneurysms; EVAR – endovascular aneurysm repair; IMPROVE – Immediate Management of Patients with Ruptured Aneurysm: Open vs. Endovascular Repair; OSR – open surgical repair; rAAA – ruptured abdominal aortic aneurysm; RCT – randomized controlled trial.

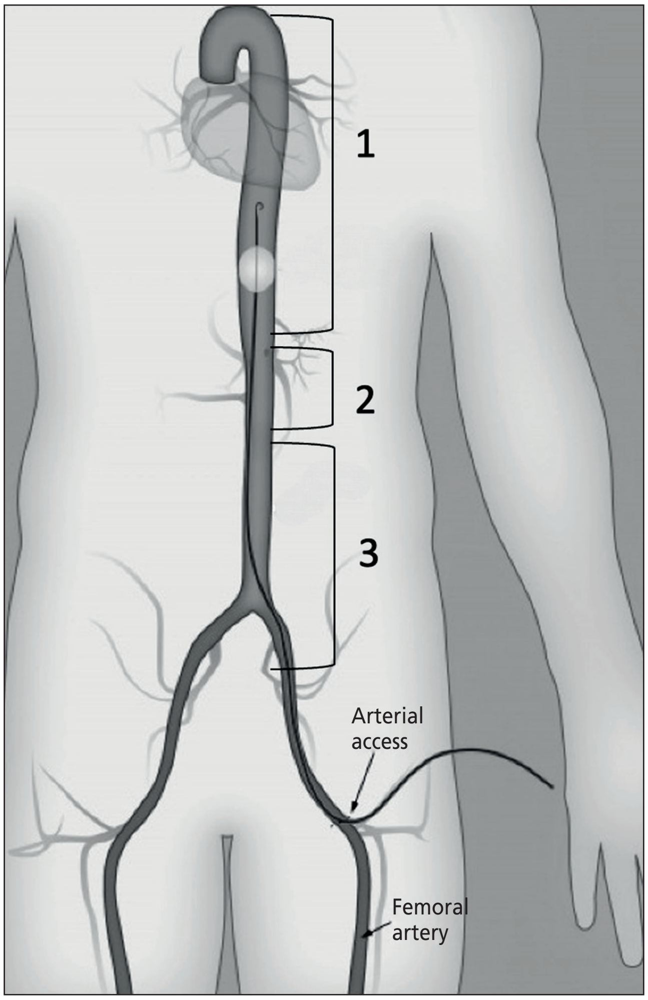

Fig. 2 – Anatomical zones of aortic occlusion for REBOA (Resuscitative Endovascular Balloon Occlusion of the Aorta). The aorta is divided into three anatomical zones to guide balloon catheter placement based on the site of hemorrhage. Zone 1: Extends from the origin of the left subclavian artery to the celiac trunk; used for intra-abdominal or uncontrolled pelvic hemorrhage. Zone 2: Located between the celiac trunk and the renal arteries; generally avoided due to the risk of mesenteric and renal ischemia. Zone 3: Spans from the lowest renal artery to the aortic bifurcation; used primarily for isolated pelvic or junctional (e.g., inguinal) bleeding. The catheter is introduced via the femoral artery, with placement confirmed by anatomical landmarks or imaging.

hemorrhage control in non-operating room settings. However, prolonged occlusion may lead to ischemic complications, including visceral and spinal cord ischemia, necessitating careful patient selection and monitoring.[63,64]

The successful placement of a REBOA balloon catheter device depends on various factors, including the clinical scenario, the expertise of the operator, and the specific characteristics of the REBOA catheter. The optimal positioning of the catheter is determined based on three anatomical aortic zones (**Fig. 2**) and is guided by the suspected source of hemorrhage.

For managing severe pelvic or junctional (i.e., noncompressible inguinal) bleeding, the catheter should ideally be positioned between the renal arteries and the aortic bifurcation, a region referred to as zone 3.[65] If bleeding persists despite occlusion in zone 3 or if there is uncontrolled abdominal or pelvic hemorrhage, the catheter should be placed within the descending aorta, specifically between the left subclavian artery and the celiac trunk, which is classified as zone 1. Zone 2, located between the celiac artery and the renal arteries, is generally not recommended for REBOA placement due to potential risks of mesenteric and renal ischemia.[63]

Hemodynamic stabilization is another crucial aspect of perioperative care. Massive transfusion protocols (MTPs) are recommended to counteract coagulopathy and minimize dilutional effects of crystalloids.[66] The use of tranexamic acid (TXA), an antifibrinolytic agent, has shown promise in reducing perioperative bleeding and improving survival.[67] Early antibiotic administration is also essential to mitigate infectious complications, particularly in patients undergoing prolonged operative times or requiring extensive surgical dissection.[68]

Real-world data on mortality and survival rates

Despite advances in surgical techniques and perioperative management, rAAA continues to have a high overall mortality rate. Even with timely intervention, mortality rates remain between 30% and 50%, with delays in diagnosis and treatment contributing significantly to poor outcomes. Pre-hospital deaths account for a substantial proportion of mortality, with studies indicating that up to 80% of patients with rAAA die before reaching the hospital. Among those who undergo repair, the 30-day mortality for OSR is approximately 40–50%, whereas EVAR has improved early survival with a 20–35% mortality rate, particularly in patients managed at high-volume centers with specialized vascular teams.[57–59]

In terms of long-term survival, studies suggest that patients who survive the perioperative period have relatively good prognosis, particularly those who undergo EVAR with minimal perioperative complications. However, late mortality remains a concern, with many patients having underlying cardiovascular disease that contributes to non-aneurysm-related deaths. Reintervention rates for EVAR-treated rAAA are higher than OSR, primarily due to endoleaks, graft migration, and aneurysm sac expansion, reinforcing the need for lifelong imaging surveillance.[57,60]

Population-based studies indicate that institutional factors, such as surgical expertise, availability of hybrid operating rooms, and adherence to modern resuscitation protocols, significantly impact survival. High-volume vascular centers with dedicated aneurysm teams tend to have better outcomes, highlighting the importance of regionalized care and centralized expertise for rAAA management. Furthermore, pre-hospital recognition and expedited transport to specialized centers can improve survival rates by reducing time to definitive treatment.[57,58]

Complex AAA Repair

Management of juxtarenal and thoracoabdominal aneurysms

Complex abdominal aortic aneurysms (AAA), including juxtarenal and thoracoabdominal aneurysms (TAAA), pose significant challenges in vascular surgery due to their involvement of critical branches supplying the renal, visceral, and spinal cord circulation. Juxtarenal aneurysms extend up to or involve the renal arteries, while TAAA involve the thoracic and abdominal aorta, often requiring extensive revascularization strategies.[69,70] Given the high morbidity and mortality associated with traditional open repair in these cases, modern endovascular and hybrid techniques have evolved to improve patient outcomes.

Patient selection for complex AAA repair should consider anatomic feasibility, comorbidities, and long-term durability. OSR remains the gold standard in younger, low-risk patients, fenestrated and branched EVAR (fEVAR/bEVAR) have emerged as less invasive alternatives, reduced perioperative risk while maintaining effective aneurysm exclusion. In high-risk patients with significant comorbidities, hybrid approaches combining open revascularization with endovascular aneurysm exclusion can provide tailored solutions for challenging anatomy.[71–73]

Fenestrated and branched EVAR (fEVAR/bEVAR) vs. OSR

For juxtarenal and thoracoabdominal aneurysms, OSR remains a durable and definitive approach, but it carries substantial risks due to extensive surgical dissection, prolonged aortic cross-clamping, and potential organ ischemia. The mortality rate for TAAA repair with OSR can reach 15–20%, with significant risks of paraplegia, renal failure, and respiratory complications. Therefore, in patients with high surgical risk, minimally invasive alternatives such as fEVAR and bEVAR have gained increasing acceptance.[72,73]

Fenestrated EVAR (fEVAR) is designed for juxtarenal AAA, incorporating customized fenestrations in the endograft to accommodate renal and visceral arteries, preserving perfusion while excluding the aneurysm. Branched EVAR (bEVAR) extends this concept to TAAA, using preloaded or in situ branch designs to maintain flow to the celiac, superior mesenteric, and renal arteries. Compared to OSR, fEVAR/bEVAR have demonstrated lower perioperative mortality (5–10%) and reduced hospital stays, but they require precise imaging planning, advanced operator skills, and lifelong surveillance to prevent endoleaks, branch occlusion, and graft migration.[69,70,73]

However, fEVAR and bEVAR have limitations, including device availability, complex procedural planning, and increased radiation exposure during implantation. Additionally, long-term durability remains a concern, with reported higher reintervention rates compared to OSR. The ESVS suggest that younger patients with long life expectancy should still be considered for OSR, while fEVAR/bEVAR should be reserved for patients at high risk for open surgery who have suitable anatomy.[72,73]

Hybrid approaches combining open and endovascular techniques

In cases where neither OSR nor full endovascular repair is feasible, hybrid repair strategies provide a valuable alternative, combining open surgical debranching with endovascular aneurysm exclusion. Hybrid repair is particularly useful for patients with extensive TAAA who are not suitable for total endovascular repair due to anatomic complexity or unsuitable access vessels.[74,75]

Hybrid techniques involve surgical revascularization of visceral or renal arteries, followed by endovascular aneurysm exclusion using a stent graft. This allows for a less invasive approach compared to traditional OSR, while maintaining durable visceral perfusion and aneurysm exclusion. The ESVS note that hybrid repair reduces operative times and minimizes the need for prolonged aortic cross-clamping, thereby decreasing the risks of spinal cord ischemia and renal failure. However, it remains a complex procedure requiring expertise in both open vascular surgery and advanced endovascular techniques.[75,76]

One of the major concerns with hybrid repair is the potential for graft complications and anastomotic stenosis at revascularized branches. Additionally, long-term outcomes are still under investigation, with some studies suggesting higher reintervention rates compared to OSR. Therefore, hybrid repair is recommended in cases where total endovascular repair is not possible but full OSR is too risky.[74–76]

Real-world outcomes and clinical decision making

Clinical trials and registry data

The comparison between OSR and endovascular aortic repair EVAR has been extensively studied through randomized controlled trials (RCTs) and national registry data. The ESVS Guidelines incorporate findings from key studies that evaluate perioperative and long-term outcomes in different patient populations.[31]

Several landmark RCTs have shaped modern AAA management. The EVAR-1 trial, a pivotal study, demonstrated that EVAR significantly reduces 30-day mortality compared to OSR (1.7% vs. 4.7%). However, it also revealed that EVAR has higher reintervention rates and no significant long-term survival advantage over OSR. Similarly, the OVER trial (Open vs. Endovascular Repair) confirmed that EVAR offers early survival benefits but requires ongoing surveillance and secondary interventions. The EVAR-2 trial, focusing on patients deemed unfit for OSR, showed that EVAR does not improve survival in patients with severe comorbidities, emphasizing the importance of careful patient selection (**Table 3**).[31]

Registry data from large-scale databases such as the Vascular Quality Initiative (VQI),[84] National Surgical Quality Improvement Program (NSQIP),[85] and European registries provide real-world insights into AAA repair outcomes. These data sets highlight that EVAR adoption has increased significantly over the past two decades, now accounting for over 70% of elective AAA repairs. However, registry studies also reinforce concerns regarding long-term durability, showing that EVAR-treated patients have higher rates of late complications, such as endoleaks, compared to OSR. Additionally, nationwide studies indicate that outcomes are significantly influenced by hospital volume and surgeon experience, with high-volume centers achieving better results for both OSR and EVAR.[84,85]

The ESVS recommend leveraging RCT data and registry findings to guide clinical decision-making, ensuring that treatment choices are aligned with evidence-based best practices and real-world outcomes.[31]

Table 3 – Clinical trials and registry data comparing OSR and EVAR for abdominal aortic repair

Study	Country	Recruitment period	Patients (n)	Main findings
EVAR-1[77–79]	UK	1999–2003	1082	Reduced perioperative mortality in EVAR (1.7% vs. 4.7%). Early survival benefit lost after two years, but long-term survival remained similar. Increased aneurysm-related mortality after eight years (7% vs. 1%), primarily due to secondary aneurysm sac rupture. Re-intervention rates were higher for EVAR.
DREAM[80,81]	The Netherlands & Belgium	2000–2003	351	Lower perioperative mortality in EVAR (1.2% vs. 4.6%). Survival advantage disappeared by the end of the first year, with comparable long-term survival (38.4% vs. 41.7% after 12–15 years). Re-intervention rate higher in EVAR (86.4% vs. 65.1%).
OVER[82]	USA	2002–2008	881	Lower perioperative mortality for EVAR (0.5% vs. 3%). Early survival benefit observed up to three years but not beyond. No significant differences in re-intervention rates, quality of life, cost, or cost-effectiveness.
ACE[8]3	France	2003–2008	316	No difference in perioperative mortality rates (1.3% vs. 0.6%). Long-term survival showed no variation up to three years. EVAR had higher re-intervention rates (16% vs. 2.4%).

Summary of randomized trials comparing EVAR and open surgery for abdominal aortic aneurysm. ACE – Aneurysms de l'aorte abdominale trial comparing open repair vs. endoprosthesis; DREAM – Dutch Randomized Endovascular Aneurysm Management trial; EVAR – endovascular aneurysm repair; OVER – Open vs. Endovascular Repair of Abdominal Aortic Aneurysms trial.

Shared decision making

Given the complexity of AAA repair, shared decision-making (SDM) is essential in selecting the optimal treatment approach. International guidelines emphasize that patients should be actively involved in discussions regarding their surgical options, balancing risks, benefits, and personal preferences to achieve the best individualized care.[86]

A major factor influencing the decision between OSR and EVAR is patient comorbidities and life expectancy. Younger patients with a long-life expectancy may benefit more from OSR due to its superior long-term durability and lower reintervention rates. In contrast, elderly patients or those with significant comorbidities may be better suited for EVAR, given its lower perioperative risk and faster recovery. Additionally, anatomic suitability plays a crucial role, as not all patients have favorable vascular anatomy for EVAR. Short or severely angulated aortic necks, extensive iliac disease, and thrombus burden may limit EVAR feasibility, necessitating consideration of OSR or hybrid approaches.[86,87]

Cost-effectiveness is another critical component of SDM. While EVAR has a higher upfront cost due to stent graft technology and frequent postoperative imaging, it often results in shorter hospital stays and reduced ICU utilization, making it more economically favorable in high-risk patients. Conversely, OSR, though more invasive, may be more cost-effective in younger patients, as it eliminates the need for lifelong surveillance and repeat interventions.[86,88] The ESVS stress the importance of healthcare resource utilization, recommending that treatment decisions consider both clinical outcomes and economic implications.[31]

Ultimately, AAA repair should be tailored to the individual, integrating patient goals, risk tolerance, anatomic suitability, and long-term prognosis. The increasing role of multidisciplinary teams, including vascular surgeons, anesthesiologists, and geriatric specialists, helps ensure that patients receive personalized, evidence-based care.[86,87]

Conclusion

The choice between open surgical repair (OSR) and endovascular aortic repair (EVAR) for abdominal aortic aneurysms (AAA) depends on patient factors, anatomy, and long-term durability. EVAR offers lower perioperative mortality, shorter hospital stays, and faster recovery, but requires lifelong surveillance due to higher reintervention rates. OSR remains the gold standard for younger patients and complex anatomies, offering superior long-term durability.

For ruptured AAA, EVAR improves early survival in suitable patients, while OSR is necessary for unstable cases. Fenestrated and branched EVAR expand treatment options for complex aneurysms but require further study on durability.

Patient-centered decision-making, guided by clinical trials and registry data, is essential for optimal outcomes. Future advancements in AI-driven planning, stent technology, and standardized surveillance protocols may improve durability and cost-effectiveness. Ongoing research is crucial to refining treatment strategies and enhancing long-term survival in AAA patients. By integrating cutting-edge advancements with clinical evidence, this article provides a forward-looking perspective on AAA management, guiding future research and improving patient outcomes.

Conflict of interest

The authors declare that they have no conflicts of interest.

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