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THE ABDOMINAL AORTIC ANEURYSM FROM PATHOGENESIS TO MODERN TREATMENT APPROACHES – OPEN SURGERY VERSUS EVAR

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ABSTRACT

Introduction and Purpose: Abdominal aortic aneurysm (AAA) is a serious vascular condition with a high risk of rupture and associated mortality. It most commonly affects older males with cardiovascular risk factors such as smoking, hypertension, and atherosclerosis. With the advancement of surgical techniques, two primary treatment strategies have emerged: open aneurysm repair (OAR) and endovascular aneurysm repair (EVAR). This paper aims to review and compare both approaches in terms of clinical effectiveness, safety profile, indications, complications, and long-term outcomes, while also considering molecular, biomechanical, and economic aspects.

Materials and Methods: A thorough analysis of contemporary clinical evidence was performed, emphasizing both surgical and endovascular treatment modalities' strengths, limitations, and clinical outcomes. The analysis also included pathophysiological mechanisms underlying AAA development.

State of Knowledge: OAR remains the treatment of choice in younger patients and in cases with complex aneurysm anatomy, connective tissue disorders, infection, or unfavorable vascular morphology. Despite being more invasive, OAR offers long-term durability and lower rates of secondary interventions. EVAR, in contrast, is associated with lower perioperative mortality, shorter hospitalization, and faster recovery, but requires lifelong imaging surveillance and carries a higher risk of reintervention due to complications such as endoleaks or graft migration. Long-term survival appears comparable between both methods, though some studies suggest a potential advantage of OAR in certain subgroups. Ongoing research into fenestrated and branched endografts, microRNA modulation and epigenetic enzyme targeting may pave the way for more personalized and non-surgical treatment options.

Conclusions: Both OAR and EVAR have specific indications and limitations, and the choice of therapy should be individualized based on patient characteristics, anatomy, and institutional expertise. Further multicenter, long-term studies are needed to evaluate overall survival, complication rates, cost-effectiveness, and quality of life in patients undergoing AAA repair.

KEYWORDS

Abdominal Aortic Aneurysm, EVAR, Stent-Graft, OAR, Aneurysm Rupture

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1. Introduction

An abdominal aortic aneurysm (AAA) is a serious and potentially life-threatening medical condition, defined as a permanent dilation of the abdominal aorta exceeding 50% of its original diameter or measuring more than 3.0 cm in diameter [1]. This pathology primarily affects males over the age of 65, with its prevalence increasing with age, particularly among populations with a history of smoking, hypertension, and atherosclerosis [2,3].

The diagnosis of an abdominal aortic aneurysm (AAA) is often made incidentally, typically during imaging studies conducted for unrelated medical issues. In some countries, screening programs are available for high-risk individuals, such as those over 65 years of age, active smokers, those with first-degree relatives who have a history of AAA, individuals with other peripheral aneurysms, or those with a history of organ transplantation. These programs facilitate early detection and strategic planning for intervention [4]. The risk of aneurysm rupture significantly increases once the diameter exceeds 5.5 cm, which serves as a primary criterion for surgical intervention [5].

There are currently two primary treatment options for abdominal aortic aneurysm (AAA): traditional open surgical repair (OSR) and endovascular aneurysm repair (EVAR). The OSR method, which has been in use for many years, involves making an incision in the abdomen and implanting a vascular graft at the site of the aneurysm. On the other hand, EVAR is a minimally invasive technique that involves inserting a stent graft into the vessel lumen through access via the femoral arteries [19,20]. This method does not eliminate the aneurysm; instead, it protects against rupture and other potential complications.

2. Objective of the work

The objective of this study is to examine the existing literature on the pathogenesis of abdominal aortic aneurysm (AAA), as well as to compare and outline various treatment methods, taking into account their effectiveness, safety, and influence on patients' quality of life. This analysis will also incorporate treatment outcomes across different age and risk groups, along with the economic implications of both therapeutic approaches.

3. Materials and methods

In order to prepare this article, a literature search was conducted using databases including the European Journal of Vascular and Endovascular Surgery, PubMed, ResearchGate, and Google Scholar. The search included combinations of the following terms in the context of review: AAA, abdominal aortic aneurysm, OAR, EVAR, aneurysm rupture, and pathogenesis.

4. State of knowledge

5. Pathogenesis

The progression of the disease may be prolonged and often asymptomatic, yet the risk of aneurysm rupture significantly increases as its diameter grows. The formation of abdominal aortic aneurysm (AAA) is influenced by a complex interplay of biological mechanisms, including endothelial dysfunction, inflammation, oxidative stress, epigenetic modifications, and biomechanical factors.

5.1 Anatomy of the Abdominal Aorta and Morphological Changes

The aorta's wall is composed of three distinct layers: the inner layer (intima), the middle layer (media), and the outer layer (adventitia). In the case of abdominal aortic aneurysm (AAA), degeneration occurs in all these layers, with a particular emphasis on the middle layer. A key factor in this degenerative process is the breakdown of structural proteins in the extracellular matrix—primarily elastin and collagen—by proteolytic enzymes, especially matrix metalloproteinases (MMPs). This degradation, coupled with the loss of smooth muscle cells (SMCs), significantly contributes to the weakening of the vessel wall's integrity [13].

5.2 Endothelial Dysfunction and Oxidative Stress

A key early event in the development of abdominal aortic aneurysm (AAA) is endothelial dysfunction, which disrupts the balance between vasodilatory and pro-inflammatory factors. This disruption leads to increased permeability of the endothelial layer, heightened leukocyte adhesion, and the onset of an inflammatory response. The functional differentiation of endothelial cells—their inherent heterogeneity—may account for the localized variations in the vessel wall's susceptibility to damage [11].

Furthermore, oxidative stress, characterized by the excessive generation of reactive oxygen species (ROS), plays a critical role in the activation of matrix metalloproteinases (MMPs) and the subsequent induction of pro-inflammatory cytokines such as tumor necrosis factor-alpha (TNF-α) and interleukin-6 (IL-6). This cascade of events significantly accelerates the degradation of vascular structures [13,16].

5.3 Inflammatory Cells and Their Role in the Pathogenesis of Abdominal Aortic Aneurysm (AAA)

In abdominal aortic aneurysm (AAA), there is significant infiltration of immune cells. Recent studies offer a comprehensive overview of the specific roles played by various inflammatory cells:

- Macrophages: These cells are critical sources of matrix metalloproteinases (MMPs) and pro-inflammatory cytokines, which contribute to the degradation of the vessel wall.
- T Lymphocytes: They regulate the inflammatory response by promoting the activation of other immune cells.
- B Lymphocytes: These cells are responsible for producing antibodies and cytokines, which may influence the course of inflammation.
- Mast Cells: They release histamine and proteases, further aggravating tissue degradation.

The interplay among these cells contributes to chronic inflammation and the ongoing destruction of the structural integrity of the vessel wall [16].

5.4 Molecular Mechanisms and Epigenetics

Molecular pathways play a vital role in the pathogenesis of abdominal aortic aneurysm (AAA), as they regulate the balance between the degradation and repair of extracellular matrix components. Notably, microRNAs, particularly miR-29b, serve as negative regulators of genes responsible for synthesizing extracellular matrix proteins, including type I, III, and V collagen (Col1a1, Col3a1, Col5a1) and elastin (Eln). Elevated levels of miR-29b diminish the production of these proteins, compromising the structural integrity of the vessel wall and fostering the development of AAA. Conversely, inhibiting miR-29b enhances the expression of these genes, leading to a strengthened extracellular matrix, improved vascular wall integrity, and a reduction in aneurysm progression. Research using mouse models has demonstrated that administering an inhibitor of miR-29b curtailed the advancement of AAA, highlighting its therapeutic potential [12].

Additionally, the enzyme SETDB2 in macrophages plays a crucial role in modulating the activity of metalloproteinases by inhibiting tissue inhibitors of metalloproteinases (TIMPs). This suppression results in unchecked metalloproteinase (MMP) activity and subsequent degradation of the vessel wall. Notably, the deactivation of SETDB2 in macrophages was found to reduce the risk of abdominal aortic aneurysm (AAA) in mice. These findings indicate that SETDB2 may serve as a promising therapeutic target for the treatment of AAA [14].

5.5 Biomechanical Aspects and Rupture Risk

The risk of abdominal aortic aneurysm (AAA) rupture is influenced by various geometric and biomechanical characteristics. The primary determinant of rupture risk is the maximum aneurysm diameter. Additionally, the length-to-width ratio is noteworthy, as more elongated aneurysms can create different stress distributions. The presence of thrombus within the lumen, along with its thickness and volume, impacts the hemodynamics and structural integrity of the vessel wall, contributing to its weakening. Another critical factor is the maximum wall stress, which is directly related to the likelihood of rupture. Furthermore, aneurysm shape asymmetry results in an uneven distribution of mechanical forces, and a reduced thickness of the aortic wall increases susceptibility to damage. Modern imaging techniques, such as CT angiography (CTA), combined with biomechanical analysis, enable the assessment of rupture risk independent of the aneurysm's size [15].

6. Open Surgical Repair of Abdominal Aortic Aneurysm

6.1 Indications nad contraindications

Open surgical repair (OAR) of abdominal aortic aneurysm (AAA) is a time-honored treatment method that has been practiced since the mid-20th century. While endovascular techniques (EVAR) have gained traction in recent decades, OAR remains the preferred option in situations where percutaneous interventions are not suitable.

6.1.1 The primary indications for OAR include:

- Aneurysm diameter of ≥55 mm in men and ≥50 mm in women
- A diameter increase of >10 mm per year
- Symptomatic aneurysms presenting with pain, compression, or tissue erosion
- Suspected connective tissue disorders associated with the aneurysm
- Inflammatory or infected aneurysms
- Inadequate anatomical conditions for EVAR [33]

Additionally, younger patients may benefit from OAR due to its advantages in long-term outcomes.

6.1.2 Contraindications

Absolute contraindications include:

- Advanced multi-organ failure
- Lack of patient consent
- Recent stroke or myocardial infarction occurring within the past 30 days

Relative contraindications include:

- Advanced lung disease (e.g., FEV1 < 1 L)
- Severe aortic valve stenosis
- Heart failure classified as NYHA class IV
- Coagulation disorders that cannot be corrected [4]

6.2 Surgical Technique

6.2.1 Preparation for Surgery

The patient is positioned supine and placed under general anesthesia. Central and arterial access is established, and urine output is monitored. Anticoagulation prophylaxis is provided through the administration of heparin prior to the placement of vascular clamps [4].

6.2.2 Surgical Approaches: Transperitoneal vs. Retroperitoneal

Transperitoneal Access (Midline Laparotomy):

This is the most commonly used approach as it offers excellent visualization of the aorta and its branches.

Advantages:

- Allows simultaneous exposure of both aortic aneurysms and iliac vessels.
- It is a well-established technique.

Disadvantages:

- Higher risk of paralytic ileus.
- Potential injury to abdominal organs.
- Increased postoperative complications in patients with a history of previous laparotomies.

Retroperitoneal Access (Retroperitoneal Approach):

This approach is recommended for pararenal aneurysms and patients with a history of prior laparotomies.

Advantages: It offers a lower risk of paralytic ileus, fewer respiratory complications, enhanced access to the pararenal aorta and adrenal vessels, and a shorter recovery time for peristalsis.

Disadvantages: However, it is technically more challenging and provides limited exposure of the iliac vessels [17,18].

6.2.3 Clamping and Resection of the Aneurysm

Aortic clamping is performed either suprarenally or infrarenally, contingent upon the specific anatomical location of the aneurysm. Subsequently, the aneurysmal sac is incised to facilitate the removal of any existing thrombus within the cavity.

6.2.4 Vascular Reconstruction

The choice of grafts used in vascular reconstruction depends on the extent of the aneurysm:

- Straight grafts (tube grafts) are used when the aneurysm only involves the abdominal aorta.
- Bifurcated grafts (aorto-bifemoral grafts) are used when the aneurysm extends into the iliac arteries.

Anastomoses are typically performed using continuous non-absorbable monofilament sutures. The graft is covered by the aneurysm wall to further separate it from the small intestine wall, which helps reduce the risk of infection [4].

6.3 Operative Time and Blood Loss

A typical surgery lasts between 2 and 4 hours and is associated with an average blood loss of approximately 1,000 ± 800 mL. Blood transfusions are required in 20% to 50% of patients [34].

6.4 Complications

The most common complications include:

- Myocardial infarction, particularly in patients with coronary artery disease.
- Renal failure, especially when the aorta is clamped above the renal arteries.
- Bowel obstruction, hemorrhage, wound infections, and postoperative hernia.
- Post-perfusion syndrome, which occurs in patients with acute ischemia of the lower limbs following an aneurysm rupture.

6.5 Mortality and Treatment Outcomes

The operative mortality rate for elective open abdominal repair (OAR) is currently about 2% to 5%, whereas in emergency cases of ruptured abdominal aortic aneurysm (rAAA), it can reach as high as 53% [4].

7. EVAR (Endovascular Aneurysm Repair)

EVAR (Endovascular Aneurysm Repair) is a minimally invasive procedure designed to treat abdominal aortic aneurysms (AAAs). The primary goal of this treatment is to exclude the aneurysm sac from the circulatory system by implanting a vascular graft (stent-graft). This approach reduces the risk of aneurysm rupture, shortens hospital stays, and decreases the likelihood of perioperative mortality [19,20].

7.1 Preoperative Assessment and Procedure Planning

Patients who are eligible for Endovascular Aneurysm Repair (EVAR) undergo an anatomical evaluation using computed tomography angiography (CTA). The key factors assessed during this evaluation include the length and angle of the aneurysm neck, the presence of calcifications and thrombus, as well as the diameters of the aorta and iliac vessels, and their tortuosity [19,22].

A neck length shorter than 10–15 mm, a diameter greater than 28 mm, calcifications covering more than 50% of the neck circumference, or an angle exceeding 60 degrees may hinder the secure anchoring of the stent-graft. Additionally, anatomical anomalies such as luminal narrowing, iliac artery aneurysms, or severe vessel angulation can present technical challenges during the procedure [19,23,33].

7.2 Vascular Access and Preparation of the Surgical Field

The procedure is most commonly conducted through the femoral arteries, utilizing either a surgical approach or a percutaneous one. Given the size of the delivery systems, the percutaneous method necessitates the use of closure devices, such as the Perclose ProGlide. In cases where arteries exhibit significant calcifications or have narrow lumens, a surgical access is preferred. Typically, the entire procedure is performed under local anesthesia; however, it may also require spinal or general anesthesia in some cases [22].

7.3 Stent-Graft Insertion and Implantation

After gaining access to both femoral arteries, guidewires and vascular sheaths are introduced. The main body of the stent-graft is then inserted into the aorta. This main body is self-expanding and covered with synthetic fabric that is resistant to penetration. [19,21]

Positioning of the stent-graft is performed under fluoroscopy, utilizing radiographic markers placed within the stent-graft and contrast imaging of the aorta. Once the main body is accurately positioned, typically below the takeoff of the renal artery, it is deployed. [21,23]

The next step involves the implantation of the stent-graft limbs, which are customized to fit the patient's anatomy. These limbs are generally positioned above the bifurcation of the common iliac artery. If the aneurysm affects the common iliac artery or the area of its bifurcation, it may be necessary to consider embolizing the internal iliac artery with coverage or implanting an additional bifurcated stent-graft to ensure unobstructed blood flow to both iliac arteries. [22]

7.4 Optimization of Sealing and Correction

To improve the sealing and anchoring of the stent-graft, post-dilatation ballooning is commonly performed using specialized low-pressure balloon catheters. This ballooning procedure targets the proximal portion (anchored in the neck), all contact points between the individual components, and the distal limbs.

In cases involving challenging anatomical features, such as a shortened aneurysm neck or the presence of branches at the anchoring site, additional techniques may be employed. These include fenestrated stent-grafts (FEVAR), chimney stent-grafts (ChEVAR), or branched stent-grafts (BEVAR). [21,22]

7.5 Final Assessment and Postoperative Management

Following the implantation of the stent-graft, a final angiography is conducted to verify proper blood flow through the stent-graft. This includes ensuring adequate perfusion to the renal arteries and ruling out any endoleaks within the aneurysm sac. Endoleaks pose a risk of causing the aneurysm to continue expanding or even rupture. They are categorized into several types:

- Type I: Proximal or distal leaks at the sealing site
- Type II: Retrograde blood flow through lumbar or inferior mesenteric arteries
- Type III: Leaks resulting from defects at the junctions between modules

Additionally, the Maya classification includes Type IV, which is caused by porosity in the covering material, and Type V, characterized by aneurysm enlargement without visible leakage.

In cases of Type I or Type III endoleaks, balloon angioplasty is typically performed. If a Type Ia endoleak is detected, it may be necessary to implant additional stent-graft modules to rectify the leak. [19,22]

7.6 Complications and Long-Term Surveillance

Technical complications can include stent-graft migration, endoleaks, post-implantation syndrome, acute limb ischemia, prosthetic infection, and renal artery occlusion. As a result, patients need regular follow-up and imaging assessments. This involves CT angiography at 1 month, 6 months, and then every 12 months thereafter [4, 19, 22, 23].

8. Comparison of EVAR vs OAR

Endovascular Aneurysm Repair (EVAR) is recognized as a minimally invasive technique that provides several short-term advantages. It is associated with reduced surgical trauma, the option to perform the procedure under local anesthesia, shorter hospital stays, and faster recovery times. However, EVAR necessitates regular follow-up monitoring, involves increased radiation exposure, presents nephrotoxic risks from contrast agents, and carries the possibility of requiring additional interventions to prevent aneurysm rupture. In contrast, Open Aneurysm Repair (OAR) entails a more invasive approach, utilizing general anesthesia and often resulting in longer hospital stays and slower recovery. Nevertheless, it offers certain long-term benefits, such as a decreased risk of future reoperations, lower radiation exposure, and potentially reduced adverse effects from contrast agents. OAR may also yield better long-term survival rates. On the downside, this method is associated with a higher risk of perioperative mortality compared to EVAR. Additionally, for those who are professionally active, it may impose restrictions on physical activity and increase the likelihood of developing incisional hernias.

Perioperative and Short-Term Outcomes:

EVAR (Endovascular Aneurysm Repair) exhibits significantly lower perioperative mortality rates compared to OAR (Open Aneurysm Repair) [6, 25, 30]. Numerous studies indicate that the 30-day mortality rate is markedly reduced following EVAR, with figures such as 1.2% compared to 3.3% [25], 1.6% versus 4.6% [6], and even 0.4% against 0.6% [31]. Furthermore, EVAR is associated with a decreased incidence of perioperative complications [24, 29, 31], fewer blood transfusions, shorter hospital stays, and quicker discharges to home [8, 25]. When considering the treatment of ruptured AAA (Abdominal Aortic Aneurysm), both EVAR and OAR demonstrate similar mortality rates; however, a greater proportion of patients who underwent EVAR were discharged directly to their homes [8].

Long-Term Survival and Effectiveness:

Most studies indicate that, after several years, the survival differences between endovascular aneurysm repair (EVAR) and open abdominal repair (OAR) tend to decrease [7, 9, 26, 30, 31]. After six years, the survival rates were quite comparable, with EVAR at 68.9% and OAR at 69.9% [7]. However, some long-term analyses suggest that the survival time following OAR may be longer [30]. In younger patients, EVAR may offer long-term benefits; however, in older patients, this advantage appears to diminish, despite the anticipated greater benefits associated with endovascular treatment [9].

Complications and Secondary Interventions:

EVAR is associated with a notably higher rate of secondary interventions, particularly concerning issues such as leaks and graft migration [7, 10, 26, 30]. In contrast, the most prevalent secondary intervention following OAR consists of correcting postoperative hernias [7]. Research [10] and [29] indicates that EVAR carries an increased risk of secondary ruptures and mortality during long-term follow-up. Additionally, conversion from EVAR to OAR is linked to a significant risk of complications [29]. Furthermore, some studies suggest a marginally elevated risk of cancer development, particularly in the abdominal area, following EVAR compared to traditional open surgical repair. This increased risk may be attributed to radiation exposure during the EVAR procedure and the subsequent monitoring through computed tomography. Although these differences are relatively minor, they could hold clinical significance, especially for patients with additional risk factors [35, 36].

Quality of Life, Costs, and Other Factors:

EVAR may provide an improved quality of life and a quicker recovery [8]. Although the short-term costs for EVAR and OAR are comparable, some analyses indicate that EVAR could be more cost-effective within healthcare budgets, particularly for specific patient groups [8, 27]. EVAR is especially advantageous for high-risk patients who are not suitable candidates for OAR [28]. Additionally, studies underscore the significance of patient selection in the decision-making process for therapy [28, 32].

9. Conclusions

Currently, the treatment of abdominal aortic aneurysm (AAA) primarily involves two strategies: open surgical repair (OAR) and endovascular aneurysm repair (EVAR). OAR is especially recommended for younger patients, those with complex aneurysm anatomy, connective tissue disorders, infections, or instances where anatomical factors prevent the use of EVAR. Although OAR is more invasive and requires a longer recovery period, it offers superior long-term durability and a lower incidence of secondary interventions.

On the other hand, EVAR is a minimally invasive procedure that allows for faster recovery and is associated with lower perioperative mortality rates. However, despite its short-term benefits, EVAR requires ongoing radiological monitoring and has a higher risk of subsequent procedures due to complications such as endoleaks, graft migration, or branch occlusion. Additionally, some studies have suggested an increased risk of long-term complications, including intra-abdominal malignancies, which may be linked to repeated exposure to ionizing radiation during lengthy procedures and from follow-up computed tomography (CT) imaging.

Comparative analyses suggest that endovascular aneurysm repair (EVAR) offers superior perioperative outcomes, including reduced mortality, less blood loss, shorter hospital stays, and faster discharge. However, the differences in survival rates between the two methods tend to diminish over the long term. Consequently, the selection of a therapeutic strategy should be guided by a personalized evaluation of anatomical and clinical factors, patient preferences, and the availability of institutional resources and surgical expertise.

As we look to the future, various promising directions emerge in the evolution of AAA treatment. Chief among these is the swift progress in stent-graft technology, particularly the development of fenestrated and branched devices (FEVAR, BEVAR). These advancements broaden the scope of endovascular aneurysm repair (EVAR) to include anatomically complex cases that were previously considered suitable only for open surgery.

Growing attention is being directed toward molecular and epigenetic research, which may open avenues for pharmacological therapies aimed at slowing or halting the progression of aneurysms. The modulation of microRNA expression, such as the inhibition of miR-29b, alongside the regulation of epigenetic enzymes like SETDB2, could form the basis for future causative treatment strategies.

Advanced imaging techniques and biomechanical analyses are increasingly influential in the assessment of aneurysm rupture risk. These methods enable a more precise evaluation not only of aneurysm diameter but also of wall structure, intraluminal thrombus burden, and wall stress distribution. The integration of these diagnostic modalities with clinical decision support systems holds promise for improving patient selection for interventions and enhancing overall treatment safety.

Further comparative research is crucial to thoroughly illuminate the long-term outcomes, complication profiles, and cost-effectiveness of both Open Aortic Repair (OAR) and Endovascular Aneurysm Repair (EVAR) across diverse patient populations. While current evidence offers valuable insights into perioperative results and mid-term efficacy, significant gaps persist concerning the durability of outcomes, quality of life, and the incidence of late complications, such as graft-related failures, reinterventions, and potential oncological risks associated with repeated imaging and radiation exposure. To optimize patient selection criteria, refine therapeutic decision-making, and develop evidence-based clinical guidelines for managing abdominal aortic aneurysms, well-designed, prospective, randomized studies with extended follow-up are essential.

Disclosure

Authors' contribution:

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