



Endovascular Aortic Aneurysm Repair: A Narrative Review

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Abstract

Endovascular aortic aneurysm repair (EVAR) has evolved as minimally invasive method of treating infrarenal abdominal aortic aneurysms (AAA) with perioperatively mortality of less than 1% compared with 5% with open AAA repair as suggested by many randomized control trials. Computed tomography angiography is the imaging of choice for appropriate selection of a patient with EVAR. For patients with unsuitable anatomy, advanced EVARs techniques, such as fenestrated, branch, and chimney EVARs, are also increasingly being offered to patients with equal success. Patients with ruptured AAA are treated with this minimally invasive procedure. Percutaneous EVAR emerged with less of wound-related complications. Endoleaks are the most common complications peculiar to this procedure, and most are preventable by preoperative planning. They are detected on completion angiogram or on the surveillance imaging. This review discusses indications of EVAR, its selection criteria, procedural steps, and common complications associated with this procedure and advanced EVARs.

Keywords

- ▶ abdominal aortic aneurysm
- ▶ stent-graft
- ▶ complex aortic aneurysms
- ▶ EVAR
- ▶ endovascular aneurysm repair

Introduction

Abdominal aortic aneurysm (AAA) is defined as abnormal progressive dilatation of abdominal aorta.¹ The objective of this review article is to understand current concept of risk factors for developing AAA, level-1 evidence for endovascular aortic aneurysm repair (EVAR), selection criteria for a patient for EVAR, currently used grafts, principles of EVAR procedure, descriptions of advance technique with AAA for poor access routes and hostile neck, evidence for endovascular AAA for ruptured abdominal aortic aneurysm (rAAA), and common complications associated with this procedure.

Risk Factors for Abdominal Aortic Aneurysm

Among the various variable risk factors (hypertension, inherited diseases, and connective tissue disorders), smoking and increasing age appears to be the most important for devel-

opment of AAA. In a population-based study of 6,386 men and women aged 25 to 80 years in Tromsø, Norway, an aneurysm was present in 263 (8.9%) men and 7 (2.2%) women ($p < 0.001$). The prevalence increases with increase in age. Person who had smoked for more than 40 years has an odd ratio of 8.0 of having AAA (Ullery et al).² AAA has life-threatening complication of rupture. Fifty percent of patients with ruptured AAA are not able to reach hospital and 30 to 50% have in-hospital mortality even after an emergency repair. Mortality rate is much less if the aneurysm is repaired electively before aneurysm rupture.

EVAR is a minimally invasive method of treating AAA. This was first described by Parodi in 1991 and involves placement of a stent-graft across the aneurysm to exclude it from arterial circulation. It obviates the need for laparotomy and aortic cross-clamping, as needed in open repair. EVAR has revolutionized aortic aneurysm management. Currently, in

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most vascular centers across the world, majority of AAAs are treated by EVAR.

Repair of AAA is taken when its diameter reaches to 5.5 cm or more. It is also indicated if the size of aneurysm increases to greater than 0.5 cm within 6 months.³

Randomized Controlled Trials for Endovascular Aortic Aneurysm Repair

Many randomized controlled trials (EVAR-I, Dutch Randomized Endovascular Aneurysm Management [DREAM] trial, open versus endovascular repair of abdominal aortic aneurysm [OVER] trial, and ACE [Aneurysme de L aorte abdominale: Chirurgie versus Endoprothese] trial) had shown that EVAR is associated with significant reduced perioperative mortality compared with open repair,⁴ and it is also associated with shorter operating time, reduced in-hospital stay, and decreased blood loss as compared with open repair.⁵

In EVAR trial, men and women aged ≥ 60 years with an aneurysm of ≥ 5.5 cm (as identified by computed tomography [CT] scanning), anatomically suitable and fit for operating room (OR) were randomly assigned 1:1 to either EVAR ($n = 626$) or OR ($n = 626$). At 0 to 6 months after randomization, patients in the EVAR group have a lower mortality (adjusted hazard ratio [HR] = 0.61, 95% confidence interval [CI]: 0.37–1.02 for total mortality; HR = 0.47, 95% CI: 0.23–0.93 for aneurysm related mortality, $p = 0.036$). Over a mean of 12.7 years (standard deviation = 1.5 years, maximum = 15.8 years), 9.3 deaths per 100 person-years recorded in the EVAR group and 8.9 death per 100 persons.

The ACE trial compared mortality and major adverse events after EVAR and open surgical repair (OSR) in patients with AAA anatomically suitable for EVAR and at low or intermediate risk for open surgery. A total of 316 patients of >5 cm aneurysms were randomized in institutions with proven expertise for both treatments. A total of 316 patients of >5 cm aneurysms were randomized in institutions with proven expertise for both treatment: 219 were available for analysis and 149 were assigned to OSR and 150 to EVAR. Patients were monitored for 5 years after treatment. Statistical analysis was by intention to treat. With median follow-up of 3 years (range: 0–4.8 years), there was no difference in the cumulative survival free of death, or major events rates between OSR and EVAR of 95.9 ± 1.6 versus $93.2 \pm 2.1\%$.

Patel et al assessed term efficiency of EVAR against open repair in patients deemed fit and suitable for both procedure (EVAR trial 1; EVAR) against no intervention in patients unfit for OR (EVAR trial 2; EVAR 2). EVAR has an early survival benefit but an inferior late survival benefit compared with OR which needs to address by life-long surveillance of EVAR and reintervention if necessary. EVAR does not prolong life in patients unfit for OR (Patel et al). They highlighted limitations that devised used were implanted between 1999 and 2004. New devices might have better results.

Selection Criteria for Standard Endovascular Aortic Aneurysm Repair

CT angiography (CTA) is the main imaging modality for preoperative planning.⁶ Certain anatomical standards must

be fulfilled for successful EVAR deployment. To achieve adequate image quality, standard slice thickness of ≤ 1 mm is taken. Workstation image processing provides accurate diameter, angle, and curvilinear length measurements. Four anatomical areas are assessed when considering for suitability for EVAR: proximal fixation site, distal fixation sites, aneurysmal morphology, and distal vessel evaluation.

Proximal Aortic Neck

It is the proximal fixation site for stent-graft.⁷ Its length, angle, diameter, shape, presence of calcification, or thrombus in it, all have effect on the EVAR outcome. Aortic neck is measured from lowest renal artery to the start of aneurysm. Aortic neck less than 10 mm is associated with greater risk of type-1 endoleak and stent-graft migration.

Aortic angle is the angle between the flow axis of supra- and infrarenal aortas (aneurysmal neck), if greater than 60 degrees, this can interfere with the ability of stent-graft to achieve adequate proximal control.

Aneurysmal neck shape is defined by the difference of the diameter between the proximal and distal aneurysmal neck. It can be straight, tapered, or reverse tapered. Usually reverse tapered neck have greater distal aortic neck diameter than proximal one and a complicated outcome. It also requires more meticulous imaging. Diameters at several locations should be obtained to assess the extent of tapering within the neck.

For standard EVAR, cylindrical neck of at least 15 mm in length, with a diameter of 33 mm or less and with no or minimal thrombus and calcification is preferred. Excessive thrombus and extensive calcification may interfere stent-graft apposition against the aortic luminal surface.

Aneurysm Morphology

Aneurysmal morphology refers to aneurysmal angle, presence of intraluminal thrombus, and branching vessels from the aneurysm.

Distal Vessel Fixation

Patent, nontortuous, and nonstenotic iliac arteries with distal landing zone of >30 mm are preferred. Patency of both internal iliac arteries is also important to prevent pelvic ischemia. The diameters of iliac arteries should be measured at several points before iliac bifurcation, with special focus on the intended landing zone. The distance between the aortic bifurcations and iliac bifurcation was recorded on both sides. Iliac bifurcation and aortic bifurcation diameter should be measured as narrower diameter can lead to stent-graft occlusion due to unexpected stent-graft kinking. Diameters of landing zones are measured using the minor axis from the outer to outer (from adventitia to adventitia) margin, even in the presence of mural thrombus within the arterial lumen.

Distal Vessel Evaluation

Normal looking, noncalcified common femoral arteries are preferred for smooth stent-graft delivery.

Table 1 Current infrarenal abdominal aneurysms available in the market

Device name	Company	Configuration	Maximum device diameter	Minimum device diameter	Active fixation	Anatomical fixation
Zenith	Cook	Trimodular	36	22	Suprarenal stent with barbs	
Talent	Medtronic	Bimodular	36	22	Suprarenal stent	
Aneurx	Medtronic	Bimodular	28	20		
Endurant	Medtronic	Bimodular	36	23	Suprarenal stent with barbs	
Excluder	Gore	Bimodular	31	23	Barbs	
Powerlink	Endologix	Unibody	34 (Cuff)	22	Suprarenal stent on aortic cuff	Deployment at aortic bifurcation

Current Grafts Used

There are currently six endografts approved by the U.S. Food and Drug Administration (FDA) for the treatment of infrarenal AAA which are available in the market as given in ►Table 1.

Device Selection

Currently, most used grafts are modular bifurcated grafts. A bifurcated graft has two components that are inserted separately and then joined. The primary component consists of an aortic and iliac stent-graft with and an attachment site for the secondary component which is placed in the contralateral iliac artery (Blim). For challenging iliac and distal aortic anatomy, tapered aortoiliac devices can be used. According to the instruction for use (IFU), abdominal stent-grafts, such as Zenith (Cook Medical) and Talent (Medtronic), have bare-metal struts that extend over the fabric of the graft to provide suprarenal fixation. These struts provide active fixation in shorter aortic necks and in reverse taper necks to prevent slippage. They can cause laminar thrombus disruption in suprarenal aorta and can inhibit access to renal, mesenteric artery orifices for further procedures. Despite these concerns, they are used safely with no major adverse effects.

The stent-graft devices must be oversized, 10 to 20%, with respect to proximal aortic neck diameter to achieve optimal seal. Aortouni-iliac devices are used along with femorofemoral bypass surgery typically for patients with ipsilateral iliac artery occlusion or with narrower aortic bifurcation.

Branch Vessel Embolization

Although the effectiveness of preemptive embolization of aortic branches is controversial, patients with inferior mesenteric artery diameter >3.0 mm or lumbar artery diameter >2.0 mm can be candidates for this prophylactic embolization to prevent retrograde aneurysmal sac filling and enlargement.⁸

Endovascular Aortic Aneurysm Repair Procedure

EVAR can be performed in interventional/catheterization suite, conventional OR or in a hybrid OR. Interventional suite has quality imaging that greatly facilitates the procedure but may lack the optimum sterilization and lighting facilities

available in a standard operating room.⁹ There is a higher risk of wound infection.¹⁰ Whereas in many centers, EVAR is being performed in operation theaters under mobile C-arm with safety. OR provides better sterile environment, although imaging quality may be suboptimal to that of an intervention suite.

The hybrid OR with fixed C-arm positioning affords greater flexibility and safety. Hybrid OR provides both the facilities of excellent imaging and sterile environment. Preoperative planning is the most important aspect of the procedure, as major part of the procedure is performed before entering the operating room. Mostly it is done by specially designed soft wares.

EVAR can either be performed under local, regional, or general anesthesia. For most operators, general anesthesia provides a more controlled environment.

Although the steps may vary with different devices but following are the common steps for a standard EVAR in most cases:

After obtaining access of both common femoral arteries (CFAs) either by open or percutaneous means, sheaths are placed. A full digital subtraction angiogram is obtained to confirm aneurysmal configuration, aortic neck, and location of the orifices of both renal arteries. Main body of stent-graft system is deployed from one of the CFA. Through the other CFA, cannulation of stent-graft limb is done. After successful cannulation, contralateral limb stent-graft is deployed after confirming internal iliac artery (IIA) orifice. Ipsilateral limb extension is completed after confirming IIA orifice. Ballooning with compliant balloon is performed to expand and attach the stent-graft to the native vessel at both the proximal and distal sites and at the points of graft overlap. And in the end, completion angiogram is done to find any post-EVAR endoleak and to confirm the patency of all graft components.

Precise angiographic imaging is necessary throughout the procedure. The C-arm should be oriented orthogonal to the branch vessel of interest to avoid parallax error. For example, cranial angulation should be used for the aortic neck, and caudal angulation to be used to image iliac arteries. Right and left oblique projections should be used to visualize the renal arteries ostia and the iliac artery bifurcation.

Endovascular Aortic Aneurysm Repair for Poor Access Routes

Selection of primary access route is influenced by vessel diameter, tortuosity, and atherosclerotic plaque. Unsuitable iliofemoral arterial anatomy predisposes to access site complications and represent “poor access route” and a relative contraindication to EVAR. Small, calcified, heavily diseased and tortuous vessels can present a challenge and potentially preclude EVAR. With better devices and improved experience, EVAR is now being offered to patients even with poor access. Techniques, such as guidewire placement, balloon predilation, and pull-through, can be effective in passing stent-graft through difficult access arteries.

Endovascular Aortic Aneurysm Repair for Ruptured AAA

EVAR is increasingly being offered for patients with rAAA. The potential advantages include avoidance from consequences of large abdominal incisions, longer operative time, and consequences of aortic cross-clamping/reperfusion injury.

In 2000, Ohki and Veith reported 10% (2/10) operative mortality for rAAA treated with EVAR.¹¹ A meta-analysis in 2008, reported 21% mortality for patients treated with EVAR.¹² The IMPROVE, a randomized control trial, in 2014 did not show superiority of EVAR in terms of 30-day mortality over OSR. The perioperative mortality was 35% for EVAR compared with 37% for OSR.¹³ This trial did suggest significant reductions in mortality in EVAR performed use of local anesthesia.¹⁴

Endovascular Aortic Aneurysm Repair for Juxtarenal Abdominal Aortic Aneurysms

Juxtarenal/pararenal aortic aneurysm involve the visceral segment and these terms are used to refer to AAA with infrarenal neck less than or equal to 1 cm in length. When treating patients with inadequate proximal neck and distal zones, it is necessary to improve the sealing zone of the stent-graft and move it to a healthier portion of the aorta or the iliac vessels. There is risk of comprising mesenteric and renal arteries orifices with use of standard EVAR stent-grafts. Approximately, one-third of patients with AAA are deemed unsuitable for conventional EVAR due to unfavorable proximal neck anatomy.¹⁵ Advanced EVAR techniques extend the stent-graft proximally while maintaining perfusion to vital aortic branches. They are divided into fenestrated EVAR (F-EVAR) or snorkel or chimney EVAR (C-EVAR).¹⁶ In chimney technique, a suprarenal fixation—in a healthy portion of the aorta—can be achieved by placing two stent-grafts into the renal arteries and landing into the aortic lumen in parallel with the aortic main body. In snorkel technique, a parallel graft is placed alongside the main aortic endoprosthesis to maintain flow in a covered branch vessel. Initially snorkel was done in emergency situations¹⁷ and more of a rescue procedure, since it needs frequent reinterventions. Early success with the snorkel technique for juxta renal aneurysms has rapidly made it the procedure of choice for complex EVAR. The flexibility of the technique and lack of requirement

for custom build devices may make this approach more attractive than branched and fenestrated stent-grafts. This technique is still open to several discussions regarding long-term durability and the increased risk of type-1 endoleak. Lee et al have reported results of using “snorkel technique” for juxtarenal aneurysms in 56 patients. Technical success of snorkel placements was 98.2%. Thirty-day mortality was 7.1%. Postoperative imaging revealed one renal snorkel graft occlusion at 3 months (98.2% overall patency rate). Seven (25%) early endoleaks were noted in the first follow-up CT. The secondary intervention rate was 3.6%.¹⁸ In F-EVAR, aneurysmal sac is excluded by keeping patent all abdominal branches, such as superior mesenteric artery, the renal arteries, and the accessory renal arteries. By using F-EVAR, a better seal is achieved because the landing zone is secured in a straight and healthy portion of the aorta.

The Performance of the Chimney Technique for the Treatment of Complex Aortic Pathologies (PERICLES) registry evaluated 517 patients treated with 898 total stents during chimney EVAR. The reported technical success was 97.1%. Overall 30-day mortality was 4.9% and at 3 years was 25.1%. Patency of the chimney grafts was 94.1%. A total of 119 patients in U.S. centers and 398 in European centers were treated during the study period. U.S. centers preferentially used Zenith (54%) and European centers the Endurant (62%) as the main body endograft component.¹⁹ F-EVAR needs customized stent-grafts which takes months before use, as they are specially manufactured from the company based on the individualized patient anatomy. With proper planning, late failures are becoming rare.²⁰ Shahverdyan et al have reported experience of 48 F-EVAR procedures using the Anaconda custom-made device (Vascutek). The primary technical success rate was 94% with three unsuccessful cannulations of the renovisceral arteries. The 30-day mortality was 4%. Two occlusions of the right renal stent/artery were detected.²¹

Percutaneous Endovascular Aortic Aneurysm Repair

Conventionally, common femoral arteries (CFAs) are surgically exposed for stent-graft delivery. Although it is safe and effective approach but can be associated with increased wound related complications. Percutaneous EVAR (P-EVAR) is an alternative which is becoming popular as associated with less of these complications.²² In PEVAR, CFA is punctured under ultrasound guidance and CFAs are closed with suture-mediated vascular closure devices mostly used in pair.

A large retrospective study showed that PEVAR was associated with shorter operative time, shorter hospital stays, and fewer wound complications compared with patients undergoing surgical cut down for exposing CFAs.²³ A randomized controlled trial (RCT) has also showed feasibility of percutaneous EVAR with acceptable outcomes.²⁴ CFAs with extensive calcification are associated with more of access-related complications and avoided. Percutaneous closure is also contraindicated in stenotic or small caliber femoral artery and in high femoral artery bifurcation.

Complications following Endovascular Aortic Aneurysm Repair

These can be divided into early and late. Early complications (at the time procedure) of EVAR may include access vessel injury, improper endograft placement, early endoleaks, ischemic, or systemic complications (such as the postimplantation syndrome). Late complications include endoleaks, femoral pseudoaneurysm formation, endograft migration, graft kinking, or occlusion and endograft infection. Meticulous patient selection and preprocedural workup can reduce the incidence of these complications.²⁵

- Access vessel injury: rarely iliac artery rupture can happen. It needs placement of a new stent-graft or open repair.
- Improper stent-graft placement: this can happen if the stent-graft is used outside of IFU. Its incidence is higher in patients with hostile neck.
- Postimplantation syndrome: it is defined when there is $>38^{\circ}\text{C}$ temperature, lasting for more than 1 day along with leukocytosis ($\text{WBC} >12,000/\mu\text{L}$), and a negative blood culture.
- Stent-graft migration: it is defined when there is displacement of stent-graft $>5\text{--}10\text{ mm}$ from its original fixation site. It is treated by proximal extension with aortic cuffs, large expandable stents to augment and endoanchors (for short aortic neck $<10\text{ mm}$).
- Endoleaks are the most common complication after EVAR.²⁶ They are detected in 10 to 45% of treated patients. There are of five different types. Type-I endoleaks are of implantation type. They occur due to improper apposition of endograft against the aortic wall and occur either at proximal or at distal implantation sites. They occur either at proximal (type Ia) or distal (type Ib) sites. Type-II endoleaks form due to retrograde filling of aneurysmal sac from patent inferior mesenteric artery (IMA) or from lumbar arteries. Type-III endoleaks form due to defects in the stent-graft or leakage at the junction points of stent-grafts due to separation of modular graft components. Type-IV endoleaks are porosity endoleaks. In Type-V endoleaks, there is gradual increase in aneurysmal sac without evidence of contrast leak. They are also known as "Endotension." Types I and III are also known as direct endoleaks, as there is direct leakage of blood into aneurysmal sac. They can rapidly increase pressure in the aneurysmal sac and increase risk of aneurysmal growth and rupture. They need immediate intervention. Types II and IV are known as indirect endoleaks. Most of them resolve with time. They have more benign course than the direct endoleaks. Only those patients with increase in aneurysmal size are candidates for intervention.

Endoleaks are also classified as early and late. Early endoleaks can be detected at the completion angiogram, while late endoleaks are detected on the follow-up visits either on contrast enhanced or plain CT scan in combination with ultrasound. Contrast-enhanced CT scan is used because it is more objective. It is very sensitive and specific in detection of endograft migration, kinking beside the endo-

leaks. Abdominal duplex ultrasound (DUS), although operator based, is an alternative in patients with renal dysfunction who are not candidates for contrast-enhanced CT scan. In experienced hands, DUS can detect endoleak along with flow direction which are of three different types. The bidirectional flow is a risk factor for increase in aneurysm diameter.

Type 1a endoleaks can be treated by additional stent-graft placements, use of balloon-expandable metallic stent/aortic cuffs, use of endoanchors, or by embolization with liquid embolic agents.

Type 1b are treated by extension of stent-graft.

Type II: only patients with increase in aneurysmal size on serial images needs intervention. Most can be dealt by angioembolization. Compared with direct endoleaks, type-II endoleaks are relatively benign. As many as 80% of type-II endoleaks resolve spontaneously within 6 months of the stent-graft implantation. Those that persist are unlikely to cause aneurysm pressurization, dilatation, or rupture. There is approximately 1% of aneurysm rupture reported at 2 years in such cases.

Type III by placement of additional stent-graft at disconnection or ballooning at overlap zones to secure modular connection.

Type IV are self-limiting and do not need treatment.

Endovascular Aneurysm Sealing

EVAS is a novel technology in which bilateral stents are deployed to create blood flow lumen to distal anatomy. Endobags filled with biostable polymer create seal. It is a simple predictable procedure. It reduces type-2 endoleak and secondary procedures. It can be offered to patients with shorter necks. Studies are required to document the clinical performance for EVAR and its long-term outcomes.²⁷

Post-Endovascular Aortic Aneurysm Repair Rupture

Life-long surveillance and meticulous attention are needed to any possible endograft malfunction, leading to possible rupture. This has been reported to 1.5% at mean of 29 months.²⁸

Disadvantages of Endovascular Aortic Aneurysm Repair

They include life-long surveillance, exposure to radiation, and a higher rate of reintervention and a higher rate of aneurysmal-related death after 6 months.

Conclusion

EVAR is the preferred treatment of AAA. With increasing experience and rapid technological improvement, it is being offered to patients with complex anatomy and in emergency situations. Preoperative planning is the key to the success of this procedure.

Conflict of Interest

None declared.

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