Endovascular Treatment of Ruptured Abdominal Aortic Aneurysms

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Abstract

Keywords

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- endovascular aortic repair
- endovascular repair of rAAA
- interventional radiology

Since its inception in the 1990s, endovascular aortic repair has quickly replaced traditional open aortic repair (OAR) as the most common method for elective treatment of abdominal aortic aneurysms (AAA). After numerous iterations and failures of different endografts, the technology has undergone dramatic improvements with evidence pointing to this technology serving as a safe and durable modality, albeit with the requirement of routine surveillance. Not surprisingly, the ability to treat patients with AAAs with minimally invasive technology that could theoretically mitigate some of the risks associated with OAR, such as aortic cross clamping and significant blood loss, was also adopted in patients with ruptured AAAs and is now the preferred treatment method if anatomically feasible.

Despite recent evidence suggesting that the incidence of ruptured abdominal aortic aneurysms (rAAA) is on the decline, rAAAs remain associated with significant mortality (30–50%) and health care spending, as many of these patients have prolonged and complex hospital courses.^{1–4} The first successful elective reconstruction was performed in 1953 with an open approach using a homograft, and the traditional open technique using either a transabdominal or retroperitoneal approach was later popularized by Drs. Cooley and DeBakey with mortality after rupture ranging from 50 to 70%.^{5,6} These approaches require large exposures, aortic cross clamping, and the potential for significant blood loss, as well as pulmonary, renal, or cardiac postoperative complications.

As providers became more comfortable with endovascular aortic repair (EVAR) for elective treatment of AAA since its introduction in the 1990s, it was only a matter of time before this therapy was utilized for rAAAs. The first endovascular repair for rAAA was performed in 1994, and over the last decade there has been a rapid adoption of endovascular repair of rAAA (rEVAR)—a study involving the Vascular Quality Initiative database showed that in 2003, 0% of rAAA were performed endovascularly by reporting centers, while in 2013 58% of cases were performed with EVAR.⁷ More recent studies

have shown that as of 2018 close to 70% of rAAAs are repaired with EVAR.⁸ ►**Fig. 1** represents an example of a typical rAAA patient and the endovascular repair.

Candidacy Criteria—Anatomic, Institutional for Treating Ruptured AAA with EVAR

Preparing for a rEVAR presents unique challenges compared with that of an elective EVAR. In the elective setting, there is ample time to plan for anatomic challenges and to select an endograft that best fits the patient's needs based most commonly on three-dimensional reconstructions from computed tomographic (CT) scans. In general, there are particular anatomic criteria that are important to focus on the elective setting including aortic neck diameter (>10–15 mm), aortic neck length (>10–15 mm), aortic neck angulation (<45–60 degrees), and the specific type of neck geometry such as conical versus reverse tapered. ►**Fig. 2** gives a general representation of the key measurements needed in planning. In addition, preexisting celiac and/or superior mesenteric artery (SMA) occlusive disease can preclude candidacy for EVAR, due to coverage of the inferior mesenteric artery. Despite these criteria, practitioners routinely challenge the limits of the instructions for use (IFU) for each device to allow the use of

Fig. 1 (a and b) Pre- and postdeployment of ruptured endovascular aortic repair. (a) Top arrow demonstrates proximal aortic occlusive balloon control and the bottom arrow shows contrast extravasation associated with rupture. (b) Postdeployment angiography. Of note, there was a small type IV endoleak on completion.

endovascular technology in a wider patient population, in particular, patients who may not be ideal candidates for open aortic repair (OAR).⁹

The proportion of rEVARS that fall within typical IFU ranges from 47 to 67% based on meta-analyses.¹⁰ Furthermore, these same studies have demonstrated that rAAAs tend to have more challenging anatomy compared with elective AAA, including shorter aortic neck lengths and larger infrarenal aortic neck diameters. Several groups have studied aortic neck anatomy and outcomes in the setting of rAAA. They found that only 30 to 40% of rAAA patients undergoing EVAR met typical IFU criteria, and more importantly, patients with hostile aortic necks had an inferior 30-day mortality compared with those having favorable aortic neck anatomy. Additionally, patients with hostile neck anatomy had higher rates of abdominal compartment syndrome (ACS) and secondary interventions.^{11,12} Despite this, a growing body of literature exists in favor of rEVAR even when offered outside of strict IFU. It is ultimately left to the discretion of the surgeon weighing the risks and benefits of the choice of repair technique.

In the setting of a rAAA, if a patient is hemodynamically stable or can be stabilized, a CT scan is invaluable for planning for rEVAR, as it can lend insight into the anatomic challenges prior to the case. Single-center studies have shown that up to

88% of patients diagnosed with rAAA survive at least 2 hours after hospital admission and that patients obtaining CT imaging did not have adverse effects on mortality.^{13,14} Moreover, data from the IMPROVE trial (Immediate Management of the Patient with Rupture: Open Versus Endovascular Repair) demonstrated that up to 97% of patients underwent CT imaging prior to rAAA repair and the mean time to the operating room was 25 minutes shorter in the endovascular group.¹⁵ These data suggest that a short delay to the operating room for a CT scan is safe and provides the necessary information in planning for the case if the patient's hemodynamics permit. Our institutional stance is to move forward with a CT scan for all patients suspected of rupture, hemodynamics permitting.

Technical Details

Depending on the hemodynamic status of the patient, the procedure can either be performed awake under monitored anesthesia care (MAC) or with general anesthesia but avoiding induction until the patient is prepped from chest to thighs and the interventionalist is ready to access the femoral artery. A Foley catheter and arterial line are used to monitor urine output and blood pressure. Bilateral femoral arteries are accessed under ultrasound guidance and aortic wire access is achieved so that an aortogram can be quickly performed and

Fig. 2 Schematic of abdominal aortic aneurysm measurements for stent graft sizing (Image previously published by our group in *Vascular and Endovascular Surgery: A Comprehensive Review*, Chapter 40: Endovascular Repair of Juxtarenal (Chimney), Infraarenal, and Iliac Artery Aneurysms). (a) Aortic neck length; (b) aneurysm length; (c) length of common iliac artery; $a + b + c$ = distance from lowest renal artery to ipsilateral internal iliac artery. 1, Aortic neck diameter; 2, maximum aneurysm diameter; 3, diameter at aortic bifurcation; 4, diameter of common iliac artery.

a supraceliac aortic occlusive balloon can be utilized in particularly unstable patients, but attention should be paid to the amount of visceral ischemia time over the course of the procedure. Each femoral artery is “preclosed” using ProGlide (Abbott Vascular, Santa Clara, CA) percutaneous closure devices. Alternatively, the femoral arteries can be accessed using traditional open surgical technique.

Once the interventionalist is comfortable analyzing the aortogram findings, the patient is systemically heparinized usually with a dose of 50 U/kg. If a patient is particularly coagulopathic, the heparin can be “under-dosed” or avoided entirely. The main body of the device is placed up the iliac artery with the most straightforward anatomy leading to the infrarenal aorta. After deployment of the main body and contralateral gate, the latter is cannulated most commonly using a Kumpe or KMP catheter (Cook Medical Inc., Bloomington, IN) and a glide wire. After selecting the contralateral gate, the pigtail catheter is maneuvered within the endograft to ensure that we actually cannulated within the device. The distance of the contralateral gate to the hypogastric artery is measured and the appropriate limb overlap is calculated, and the limb is advanced and deployed. The ipsilateral limb is then addressed, ensuring sparing of the ipsilateral hypogastric artery. For patients with concomitant iliac artery aneurysm, an iliac branch device can be utilized (depending on the device), or more commonly an iliac extension can be placed with coil embolization/sacrifice of that side’s iliac artery.

Once the device is fully deployed, balloon inflation proceeds at the proximal end, graft-to-graft junctions, and then distal end. A completion angiography is performed looking for endoleak, in particular, types I and III. If a type I endoleak is noted, proximal extension, re-ballooning, or further extension with renal stenting may be required to achieve a seal. If a type III endoleak is noted, relining of the junctions may be needed. If neither is present, protamine should be given to assist with hemostasis. Femoral and pedal pulses should be checked after sheaths are removed. If the abdomen is tense, or peak inspiratory pressures rise, bladder pressures can be checked. In the setting of a worrisome abdominal exam, elevated bladder pressures, and hemodynamic compromise, a low threshold should be given toward releasing the abdominal compartment (this is discussed in detail later).

Access: Percutaneous versus Cutdown

As device delivery profiles have decreased in diameter over the years, percutaneous deployment of EVAR (pEVAR) has become the favored access technique over open femoral artery cutdown.

Nonetheless, pEVAR can be performed with larger profile devices up to 26 Fr. pEVAR is appealing during ruptures as it can be performed on an awake patient, and is generally quicker than an open cutdown which commonly requires general anesthesia.

The first randomized control trial to assess the safety and efficacy of pEVAR was performed by Nelson and colleagues and all patients underwent percutaneous closure using a Perclose ProGlide or Prostar XL (Abbott Vascular, Inc, Redwood City, CA) with a 21-Fr profile introducer system. Their findings demonstrated a high initial technical success with pEVAR and non-inferior failure rates with traditional open femoral artery cutdown. Moreover, pEVAR was associated with shorter times to hemostasis and procedure completion and more favorable trends in blood loss, groin pain, and quality of life (QOL).¹⁶ Similarly, Buck et al utilizing the American College of Surgeons National Surgical Quality Improvement Program database compared pEVAR with traditional open femoral artery cutdown and demonstrated decreased operative times, shorter length of stay (LOS), and less wound complications.¹⁷

Relative contraindications to pEVAR include morbidly obese patients with a large pannus, high femoral bifurcation behind or above the inguinal ligament, severe groin scarring, small femoral artery size, and circumferential or significant anterior femoral artery calcification. Initial failure rates have been documented ranging from 1 to 6% and midterm failure rates of less than 2% (pseudoaneurysm, dissection).^{18,19} pEVAR can be safely utilized in the setting of a previously percutaneously closed femoral artery but can be associated with increased access failure.¹⁷

Devices

The stent graft best suited for rAAA truly comes down to the experience of the interventionalist with a specific device from the elective setting. Unfortunately, there are no randomized

Table 1 Most commonly used FDA-approved abdominal aortic stent grafts in the United States

Device	Company	Configuration	Fixation	Max device diameter	Access
AFX	Endologix	Unibody	Anatomic at aortic bifurcation	34 (cuff)	Ipsilateral: 17 Fr (ID) Contralateral: 7 Fr (ID)
Ovation	Endologix	Trimodular	Suprarenal with barbs and infrarenal sealing rings	34	Ipsilateral: 14 Fr (OD) Contralateral: limb dependent
Endurant	Medtronic	Bimodular ^a	Suprarenal with barbs	36	Ipsilateral: 18–20 Fr (OD) ^b Contralateral: 14–16 Fr (OD)
Zenith	Cook	Trimodular	Suprarenal with barbs	36	Ipsilateral: 18–22 Fr (ID) Contralateral: 14–16 Fr (ID)
Excluder ^c	Gore	Bimodular	Infrarenal barbs	35	Ipsilateral: 16–18 Fr (OD) Contralateral: 12–15 Fr (OD)

Abbreviations: FDA, Food and Drug Administration; ID, inner diameter; OD, outer diameter.
^aCan be trimodular especially if you have to coil or cover the internal iliac artery to treat a concomitant iliac artery aneurysm.
^bSheathless system.
^cCan be used in conjunction with Gore’s iliac branched endoprosthesis.

studies comparing specific devices utilized for rAAA. However, understanding some of the nuances of each device can help an interventionalist choose one appropriately based on their comfort level with the device and the patient’s anatomy.

Specific considerations include fixation at the proximal aspect of the device (i.e., suprarenal vs. infrarenal; active vs. anatomic), modularity (docking limbs), and placement of

contralateral limbs. All these have important implications in managing different types of aortoiliac anatomy. ►**Table 1** and ►**Fig. 3** depict the details of each endograft.

Endologix (Endologix, Irvine, CA): Ovation and AFX2 AFX—Conceptually their engineers designed a device to try to best preserve the native bifurcation and therefore created a

Fig. 3 Most commonly used FDA-approved aortic stent grafts. (a) Endologix AFX Endurant. (b) Endologix Ovation. (c) Medtronic. (d) Cook Zenith. (e) Gore Excluder with iliac branched endoprosthesis.

unibody component that allows for anatomic fixation on the aortic bifurcation and thereby obviates active proximal fixation. Proximal seal involves initially an infrarenal landing zone with the capability of building up with an aortic cuff; the proximal seal is achieved via radial force and properties of the device's DuraPly material that creates apposition to the aortic wall. The device is approved for aortic neck lengths ≥ 15 mm. The device offers a unique contralateral gate cannulation through an up-and-over approach integrated within the ipsilateral introducer that obviates the need for contralateral cannulation. However, traditional limb cannulation from the contralateral femoral artery can still be utilized if desired. Access involves a 17-Fr (inner diameter [ID]) ipsilateral introducer and 7-Fr (ID) contralateral introducer.

Ovation ix/Alto—Modular device with active, proximal suprarenal fixation barbs and infrarenal sealing rings. The most unique aspect of this device is the infrarenal sealing rings that are “activated” with a polymer that requires 14 minutes after filling to mature (the sealing rings take ~ 45 seconds to fill). While the polymer matures, the interventionalist can cannulate the contralateral lumen using the same crossover technique described previously with the AFX device or traditional contralateral side cannulation. The device is approved to treat aortic neck lengths ≥ 10 mm. An important detail pertaining to considering use of this device for ruptures is that the ipsilateral limb cannot be deployed until after the 14 minutes of polymer cure time, seemingly making this a less popular alternative during rAAA than other devices when quick deployment is necessary. The Ovation Alto, approved on March 16, 2020, by the Food and Drug Administration (FDA), was developed in part to combat this limitation by allowing for ballooning of the infrarenal segment prior to polymer deployment to allow for a seal initially. Access for the Ovation involves a 14-Fr ipsilateral introducer (outer diameter [OD]) and 15-Fr (OD) for the Alto. Sizing for the contralateral limb sheath is limb dependent.

Medtronic Endurant (Medtronic, Santa Rosa, CA)

This is a modular system (can be trimodular if you are required to extend the iliac limb and coil the internal iliac artery) with active suprarenal fixation and barbs. The contralateral gate is cannulated in standard fashion. The device is approved to treat aortic neck lengths ≥ 10 mm, but in conjunction with their Heli-FX Endoanchor system, it can be utilized in neck lengths less than 10 mm down to 4 mm. Access involves a sheathless delivery system with an 18 to 20 Fr (OD, 6 or 6.7 mm crossing profile) and 14 to 16 Fr (OD, 4.7 or 5.3 mm crossing profile) for contralateral limbs.

Cook Zenith (Cook Medical, Bloomington, IN)

This is a modular system with active suprarenal fixation with barbs. The contralateral gate is cannulated in standard fashion from the contralateral femoral artery. The device is approved to treat aortic necks ≥ 15 mm. Endoanchors have been approved with this device but have only been trialed in secondary interventions, as this company offers a fenestrated device for juxtarenal aneurysms. Access involves 18- to 22-Fr (ID) ipsilateral introducer and 14- to 16-Fr contralateral introducer (ID).

GORE Excluder (W. L. Gore & Associates, Flagstaff, AZ)

This is a modular system with active infrarenal fixation barbs. The contralateral gate is cannulated in standard fashion from the contralateral femoral artery. The device allows for the ability to reconstrain the proximal end of the endograft for ideal placement, and to facilitate gate cannulation. The device has been approved to treat aortic neck lengths ≥ 15 mm. GORE has the unique option of an iliac branch endoprosthesis for iliac artery aneurysms and preservation of flow to the internal iliac artery. Access involves 16- to 18-Fr (OD) ipsilateral introducer and 12- to 15-Fr (OD) contralateral introducer.

Standard Grafts versus AUI-Fem-Fem

The use of an aorto-uni-iliac (AUI) stent graft in a rAAA was first described in 1994 by Yusuf et al.²⁰ The adoption of this technique was not surprising, given its prior success in the elective setting, especially in patients with severe unilateral iliac artery occlusive disease and poor physiologic status.²¹ The benefits of AUI include the ability to rapidly gain hemostasis with aortic and single limb deployment obviating the need for contralateral gate cannulation. After hemodynamic control has been demonstrated, the contralateral common iliac artery is occluded or plugged and a crossover graft is placed, thereby restoring pelvic and lower extremity perfusion. Several devices and plugs have been utilized in the literature, including Medtronic ENDURANT II AUI, Cook Zenith AUI and iliac plug, and AMPLATZER plugs (St. Jude Medical, Fridley, MN). As improved EVAR technology has allowed for smaller delivery profiles and therefore the ability to navigate through more challenging iliac artery anatomy, the AUI has become a less popular option in the treatment of rAAAs and truly has become a bailout option in cases of severe unilateral occlusive iliac artery disease.

Physician-Modified Endografts

One of the main criteria that make patients poor candidates for rEVAR (and in elective cases in general) are short, infrarenal aortic necks. Cook Medical has transformed the elective treatment of juxtarenal AAAs through the development of their fenestrated device (fenestrated endovascular aortic repair (FEVAR)) that allows for fenestrations for the renal arteries and SMA to create a more proximal seal zone. The translation of this technology to the rupture setting is problematic for these reasons; first, the device takes approximately 1 month to design and be shipped to a center, and second, the amount of time to deploy the device with visceral cannulation can exceed that needed to safely complete the case during a rupture. Nonetheless, several groups have experienced with back table modification of traditional bifurcated devices, otherwise known as physician-modified endografts, to allow for treatment of ruptured juxtarenal AAAs using endovascular means.²² In short, the bifurcated graft is unsheathed on a separate table sterilely and a marker is used to note the locations of the visceral vessels based on reconstructive imaging. Bovie cautery is then used to make individual fenestrations, which are then reinforced with Amplatz Gooseneck Snares (EV3 Endovascular Inc., Plymouth, MN). The device is then reconstrained and reloaded into its original sheath. For a

patient who is particularly unstable, this approach may not be preferred due to time limitations, and furthermore this requires a high degree of comfort level and skill with endovascular technology that is not present across all centers. Moreover, it is noteworthy that these procedures are considered off-label by nature and require investigational device exemptions (IDEs) to be reimbursed.

Special Postoperative Considerations—Abdominal Compartment Syndrome and Management

There are certain complications after rEVAR that are not associated or are less common with traditional OAR, including endoleak, late graft failure with aneurysm sac expansion and the need for explant, and ACS. ACS is one of the most acutely devastating complications after rEVAR and the incidence has been demonstrated in up to 20% of patients in single-center studies.²³ Because retroperitoneal blood products are not evacuated during rEVAR, a hematoma can lead to increased intra-abdominal pressure, and a severe inflammatory response in that space resulting in multiorgan system failure with high morbidity and mortality. Therefore, a high index of suspicion needs to be maintained to prevent complete hemodynamic collapse. An elevated bladder pressure, classically a pressure >20 mm Hg in conjunction with worsening respiratory and hemodynamic status is considered pathognomonic for ACS.^{23,24} A patient with a distended abdomen with worsening renal, pulmonary, or cardiac function after rEVAR should be taken back to the operating room for an exploratory laparotomy to alleviate hemodynamic collapse and renal and mesenteric compromise. A thorough exploration of the retroperitoneal space is not necessarily indicated and may result in more bleeding. If patients respond well following exploratory laparotomy, they usually return to the operating room in 36 to 48 hours for formal abdominal closure. Risk factors for ACS include surrogates for patients presenting in severe extremis such as the need for an aortic balloon occlusion, higher transfusion requirement, coagulopathy, and conversion to AUI.²³

Perioperative and Long-Term Outcomes

To date there are three randomized trials comparing outcomes of EVAR to OAR for the treatment of rAAAs: AJAX (Amsterdam Acute Aneurysm Trial),²⁵ ECAR (Ruptured Aortoiliac Aneurysm: Endo versus Surgery),²⁶ and IMPROVE (Immediate Management of Patients with Ruptured Aneurysm: Open versus Endovascular Repair).⁷ All three concluded that 30-day and 1-year mortality outcomes were no better for EVAR compared with OAR, although secondary outcomes such as hospital LOS and QOL favored EVAR. However, all trials have significant flaws most notably related to patient selection. For example, both AJAX and ECAR excluded unstable rAAA patients who were treated with OAR or not offered any therapy at all. Moreover, both had a disappointing randomization rate of less than 25%. In the IMPROVE trial, only 154 out of 316 patients randomized to EVAR actually underwent rEVAR;

112 underwent OAR and 17 received no therapy. Of the patients randomized to the OAR group ($n = 297$), 36 underwent EVAR and 19 received no therapy. Analyses of patients according to the therapy they actually received resulted in a 30-day mortality favoring EVAR (25 vs. 38%; $p < 0.002$).²⁷ These latter conclusions have led most interventionalists to pursue an EVAR-first approach to rAAAs if feasible.

More recent retrospective studies have further confirmed this approach. A study from the Vascular Quality Initiative (VQI) from January 2020 by D'Oria and colleagues⁸ analyzed both perioperative and long-term outcomes of EVAR versus open aortic repair (OAR) from 2004 to 2018 for rAAAs and demonstrated that within VQI submitting centers, EVAR has favorable perioperative and long-term outcomes compared with OAR. Specifically, OAR was associated with a higher odds of in-hospital mortality (odds ratio [OR], 1.76; confidence interval [CI], 1.54–2.01; $p < 0.001$) and increased overall postdischarge mortality (OR, 1.36; CI, 1.23–1.51; $p < 0.001$). Moreover, OAR showed a significantly higher risk of 1-year postdischarge reinterventions (OR, 2.10; CI, 1.52–2.89; $p < 0.001$) and mortality trends at 5 years continued to favor EVAR (45 vs. 54%, $p < 0.001$). Another retrospective VQI study²⁸ published in February 2020 compared the evolution of 5-year survival after EVAR versus OAR for rAAA between two time periods (2004–2012 vs. 2012–2018). Survival improved within the propensity-matched EVAR cohort when comparing the two time periods (mortality: 63 vs. 49%, hazard ratio [HR]: 0.77; CI: 0.61–0.97; $p = 0.03$), while survival for the matched OAR cohort did not show a significant difference comparing the two time frames (mortality: 52 vs. 59%; HR: 0.88; CI: 0.69–1.11; $p = 0.28$). When comparing EVAR to OAR within each time frame, there was no survival difference in the early cohort; however, the late cohort favored EVAR (63 vs. 54%; HR: 0.69; 95% CI: 0.60–0.79; $p < 0.001$). These data suggest that as interventionalists became more comfortable treating ruptures with EVAR, as device companies improved their technologies, and as institutions invested in developing algorithms to treat ruptures with EVAR, patients benefited from this approach.

Conclusions

rEVAR has revolutionized the treatment of rAAAs, particularly in patients who were once ruled out for repair due to underlying comorbidities making them poor candidates for OAR. There are multiple devices on the market that have excellent results in the elective setting and each have unique characteristics that can make them successful in treating rAAAs despite the lack of randomized trials comparing each to the other; ultimately, it is left to the discretion of the interventionalist based on their familiarity with a device and the patient's anatomy. ACS is a highly morbid complication after rEVAR that should be considered if a patient's hemodynamic status is worrisome after endovascular repair. Although three randomized trials comparing EVAR to OAR for rAAA did not show short-term benefit for each approach, follow-up analyses and studies favor rEVAR if anatomically feasible.

Conflict of Interest

None declared.

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