Endovascular Treatment of Various Aortic Pathologies: Review of the Latest Data and Technologies

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Abstract

The technologies and innovations applicable to endovascular treatment for complex aortic pathologies have progressed rapidly over the last two decades. Although the initial outcomes of an endovascular aortic repair have been excellent, as long-term data became available, complications including endoleaks, endograft migration, and endograft infection have become apparent and are of concern. Previously, the indication for endovascular therapy was restricted to descending thoracic aortic aneurysms and abdominal aortic aneurysms. However, its indication has expanded along with the improvement of techniques and devices, and currently, it has become possible to treat pararenal aortic aneurysms and Crawford type 4 thoracoabdominal aortic aneurysm (TAAA) using the off-the-shelf devices. Additionally, custom-made devices allow for the treatment of arch or more extensive TAAAs. Endovascular treatment is applied not only to aneurysms but also to acute/chronic dissections. However, long-term outcomes are still unclear. This article provides an overview of available devices and the results of endovascular treatment for various aortic pathologies.

Keywords
- aortic aneurysm
- endovascular aortic repair
- endograft
- abdominal aortic aneurysm
- thoracic aortic aneurysm
- thoracoabdominal aortic aneurysm
- rupture

The dawn of endovascular treatment was a report on the treatment for arteriosclerotic obstruction using a stainless steel spring coil in 1964 by Dotter and Judkins,[1] who invented the concept of a dilating a vessel using a catheter. The origin of endograft was derived from a report using a nitinol coil in 1983.[2,3] Although the concept of a stent graft for aortic aneurysms was proposed previously, the first report of implantation involved an animal experiment by Balko et al in 1986.[4] At the same time, Volodos et al[5] succeeded in implanting an endograft for a traumatic descending aortic aneurysm. Parodi et al[6] reported the first endovascular treatment of abdominal aortic aneurysms (AAAs). This report attracted widespread attention as a less invasive treatment for an aortic aneurysm, and the endograft was considered as an epoch-making development. Subsequent paradigm shifts were not limited to descending thoracic aortic aneurysms (DTAAs) and AAAs but also branched endografts have enabled endovascular repair for aortic arch aneurysms and thoracoabdominal aortic aneurysms (TAAAs), and various technological innovations are still ongoing. The initial outcomes of endovascular aneurysm repair were excellent, but late complications including endoleaks, migration, or infection have become apparent and are increasingly becoming a clinical issue. The aim of this article is to provide an overview of current available endografts and to review the outcomes of endovascular treatment for various aortic pathologies.

Thoracic Aortic Aneurysm

In 1994, Dake et al[7] reported the outcome of thoracic endovascular aortic repair (TEVAR) for 13 patients with traumatic DTAAs or chronic dissection aneurysms. The stent graft was a homemade device composed of stainless

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steel self-expanding Z stent covered with a Dacron woven graft. The initial outcome was satisfactory with no 30-day mortality, a much lower rate of postoperative complications, and a shorter length of stay compared with conventional open repair. TEVAR, including the concept of a landing zone, has also been performed with a homemade endograft or branched endograft for thoracic aortic aneurysm in Japan.[8–10]

The development of an endograft for thoracic aortic aneurysm has improved since the TAG endograft (W.L. Gore & Associates, Flagstaff, AZ) was approved by the Food and Drug Administration (FDA) in 2005. Five-year outcomes of TEVAR using TAG for DTAA were excellent, including a lower aneurysm-related death (ARD) rate in the TAG group (TAG: 2.8% vs. open surgery: 11.7%, $p = 0.008$).[11] No statistical difference was observed in overall survival, but postoperative complications were significantly lower in the TAG group compared with the open repair group ($p = 0.001$). Initial outcomes of TX2 (Cook Medical, Bloomington, IN) and Talent (Medtronic, Minneapolis, MN) also reported satisfactory results, as did Gore-TAG.[12,13] Furthermore, the 5-year outcomes of TX2 for DTAA were reported in 2014.[14] The 30-day mortality in the TX2 group was lower than in the open surgery group (1.9 vs. 5.7%). Although long-term survival and rate of freedom from ARD were not significantly different between the two groups, the postoperative incidence of complications was lower in the TEVAR group than in open surgery group consistent with the TAG study ($p < 0.001$).

The thoracic endografts are divided into two configurations: those with or without a proximal bare stent. The TAG, TX2, and Relay plus NBS (Bolton Medical, Sunrise, FL) are devices that do not have a proximal bare stent, whereas Valiant (Medtronic, Minneapolis, MN), Relay (Bolton), Zenith α (Cook Medical), E-vita (Jotec GmbH, Hechingen, Germany), and C-TAG (W.L. Gore) have a proximal bare stent. The proximal bare stent is believed to improve endograft alignment in the aortic arch and strengthen the sealing to the proximal neck. Although previous devices caused retrograde type A dissection due to an extremely strong radial force of the proximal bare stent, recent devices are more conformable in terms of improving alignment and focused more on sealing rather than fixation.

Descending Thoracic Aortic Aneurysm

Endovascular treatment for DTAAs has been more frequently performed due to the positive results of two clinical trials of involving the TAG and the TX2 as described earlier. Shortcomings of open repair for DTAA are not only higher mortality but also postoperative wound pain, and one report indicated that TEVAR patients were four times more likely to have a routine discharge to home compared with open repair.[15] The less invasiveness of TEVAR is also highlighted by other studies that indicate a lower 30-day mortality and shorter length of hospitalization compared with open surgery.[11,14,16] Additionally, TEVAR was superior to open repair in terms of a shorter length of intensive care unit stay or low incidences of postoperative complications. The occurrence rate of spinal cord ischemia (SCI), which is related to occlusion of the intercostal artery and Adamkiewicz artery for the treatment of an extended aneurysm, is lower after TEVAR compared with open surgery.[17] According to recent reports, the 30-day mortality rate following TEVAR was 4 to 4.7%, occurrence rate of stroke was 0.6 to 2.7%, and occurrence rate of SCI was 0.5 to 3.2%.[18–20] Although endoleaks, which are the most common cause of reintervention, occurred in 6.4 to 10.5% of cases, the long-term survival and freedom rate from ARD seem to be acceptable.

Based on the guidelines established by the European Society of Vascular Surgery (ESVS) in 2017,[21] TEVAR is evaluated as class IIb, level B in the DTAA with an aneurysm size of 5.6 to 5.9 cm, TEVAR for DTAA with an aneurysm size exceeding 6.0 cm is class IIa, level B, and open surgery for DTAA is class IIa–b, level C. Furthermore, TEVAR for ruptured DTAA with its appropriate anatomy is listed as class I, level B. Therefore, TEVAR is the first-line treatment of DTAA with appropriate anatomy.[20–22] In contrast, some cases with poor access, an absence of a landing zone, young patients with connective tissue disorder including Marfan's syndrome, presence of metal or contrast agent allergy, and large symptomatic DTAA with dysphagia or dyspnea secondary to recurrent nerve injury are candidates for open repair.

Distal Arch and Aortic Arch Aneurysm

Although most current devices can be used up to zones 2 to 4 based on the instruction for use (IFU), the initial outcomes of zone 2 TEVAR is acceptable as well as TEVAR for DTAA.[23] In a zone 2 landing, the management of the left subclavian artery (LSA) is an important consideration. LSA coverage is one of the risk factors for perioperative stroke during TEVAR. In fact, the frequency of stroke during TEVAR with LSA coverage is 6.3%, whereas without LSA coverage, it is 3.2%.[24] Since some reviews of a comparison between LSA simple coverage and LSA reconstruction have reported that LSA reconstruction reduces the risk of perioperative stroke,[24–26] LSA reconstruction may be desirable, although there is no level I evidence and further study is warranted. LSA reconstruction is not always necessary when there is a communication between the left and right vertebral arteries. However, in the absence of this communication, or in the presence of coronary bypass using left internal thoracic artery and of blood access for dialysis on the left hand, LSA reconstruction are required during TEVAR. Recently, a single branched device has been developed to preserve to the cervical branches. Valiant Mona LSA device aimed at preserving the LSA consists of a fenestrated endograft and a small diameter endograft. In a preliminary report involving a single-center study, LSA reconstruction could be performed in all cases, and the 30-day mortality was 0%.[27] A multicenter clinical trial using Gore Thoracic Branch Endoprosthesis (TBE, W.L. Gore & Associates) evaluated 22 patients undergoing TEVAR to preserve LSA in zone 2.[28] The primary end point of device delivery and branch vessel patency was achieved in 100% of the cases with no 30-day mortality. Although type 1 endoleaks were identified intraoperatively in four patients (18%), all were resolved by 1 month without reintervention.

TEVAR for aortic arch aneurysm involving distal arch aneurysm that requires landing for zones 0 to 1 is still a

challenging treatment option due to the difficulty of landing within the complex anatomy of the aortic arch and the necessity of reconstructing the neck vessels including the brachiocephalic artery (BCA) and left common carotid artery (LCCA). The procedures of complex TEVAR for aortic arch aneurysms involve totally endovascular therapy including branched, fenestrated endograft, or in situ fenestration, hybrid therapy with debranching, and staged TEVAR using frozen elephant trunk following total arch replacement (TAR). The 30-day mortality of debranching TEVAR is inconsistent and ranges between 0 and 25%.[29–31] The perioperative stroke also varies and is reported between 0.8 and 18%, which appears to be worse in comparison to TAR.[32,33] Branched endograft for aortic arch aneurysm has been utilized since the development of the Inoue stent graft.[8,9] Available industry-made fenestrated or branched endografts include the Najuta (Kawasumi Laboratories, Tokyo, Japan), a-Branch (Cook Medical), and dual-branch aortic arch graft (Bolton Medical). Initial outcomes using the Najuta endograft system (►**Fig. 1**) reported low 30-day mortality (0%) and stroke rates (3–5%). However, the reintervention rate was relatively high at 10%.[34,35] The devices of both a-Branch and Bolton dual-branch aortic arch endografts have two inner sleeves for reconstructing the BCA and LCCA. The preliminary results of 26 patients undergoing branched TEVAR with Bolton dual-branch graft revealed a 30-day mortality of 7.7% and postoperative stroke in 3.8% of cases.[36] The inner sleeves of the a-Branch attached to the outside diamond marker on the main device are independent and allow to cannulate to the cervical branches from each sleeve. There were no cases of 30-day mortality in the initial results of 27 patients using the a-Branch in a multicenter trial, and a major stroke rate of 7.4% and a minor stroke rate of 3.7% were reported.[37] Additionally, since a stiff wire has to be inserted into the left ventricle at the time of inserting the delivery system of both devices, attention must be paid to prevent left ventricle perforation.

Other totally endovascular treatments include physician-modified fenestration endograft (PMEG), in situ fenestration, and the chimney method. PMEG TEVAR is a method in which a fenestration is created to an off-the-shelf approved endograft by a physician. However, large fenestrations seem to be the major cause of endoleaks and along with medicolegal risk, PMEG is suboptimal. Thus, in situ fenestration TEVAR is a method that makes it possible to provide appropriate fenestration by puncturing the graft following endograft deployment. One of the advantages of a PMEG or in situ fenestration is that they can be performed for emergency cases because it can be performed using off-the-shelf devices as opposed to custom-made endografts. The results of 22 cases using an excimer laser to fenestrate LSA demonstrated a 100% branch vessel patency and a 4.5% in-hospital death rate.[38] Other methods include radiofrequency catheter and a simple needle puncture method for fenestration, and best technique is yet to be determined.[39–41] The chimney method is a procedure in which retrograde stents via neck vessels are inserted into the ascending aorta to maintain the blood flow of the great vessels while the main endograft is inserted deeply into the ascending aorta covering the orifices of these branches. Gutter endoleak is an endoleak caused by the space between the chimney stent and the main endograft and is classified as a type 1a endoleak and its frequency seems to increase with higher number of chimney endografts. A single-center experience of 122 patients showed that chimney repair had an excellent 30-day mortality (0.8%). However, gutter endoleak was reported in 13 patients (10.7%).[42] Although a

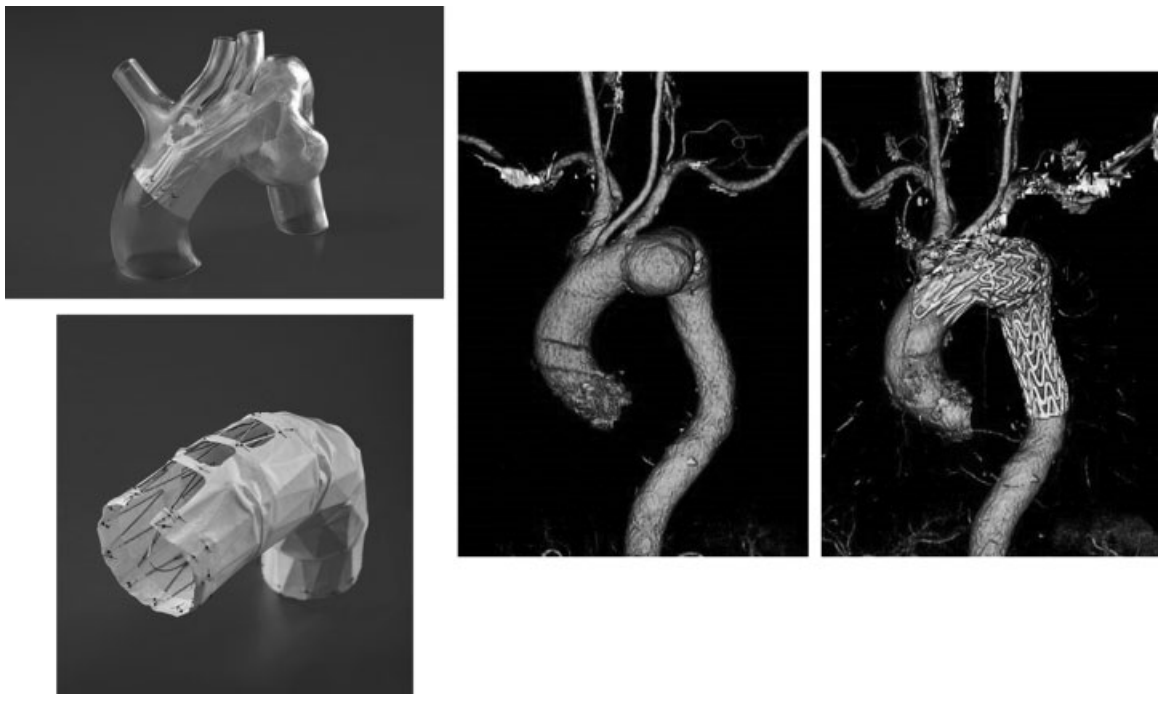

Fig. 1 Najuta endograft. Thoracic endovascular aortic repair for aortic arch aneurysm using custom-made fenestrated endograft.

recent systematic review also showed excellent chimney graft patency (97%) and 30-day mortality (4%), the occurrence rate of gutter endoleak was 11% and occurred higher with increasing number of chimneys.[43]

The most important complication after TEVAR is stroke and type 1a endoleak. Our study, which enrolled 439 patients undergoing TEVAR, demonstrated that stroke occurred in 17 patients (3.9%), and multivariate analyses revealed the presence of coronary artery disease, history of stroke, shaggy aorta, and pull-through wire technique to be independent predictors of stroke.[40] Lack of landing zone is well known as a cause of type 1a endoleak. While TEVAR for zones 3 and 4 landing showed a low incidence of type 1a endoleak, TEVAR for zones 0 to 2 landing had a higher incidence of type 1a endoleak (13.1%). Additionally, risk factors affecting type 1a endoleak included zones 0 to 2 landing TEVAR, chimney TEVAR, proximal neck diameter $>$ 38 mm, and excessive oversizing of the endograft ($>$ 114%).[41]

TEVAR for Ascending Arch Aneurysm and Type A Dissection

Indication of TEVAR for ascending arch aneurysm is more restrictive than for aortic arch aneurysm. The most common reason TEVAR is not possible is the absence of an adequate landing zone. The proximal ascending aorta involves the sinotubular junction, the coronary sinus, and the aortic valve, and the distal ascending aorta involves BCA. For these reasons, TEVAR for ascending aortic pathologies is a very challenging procedure, and only select high-risk patients with pseudoaneurysm or localized type A dissection have been treated with TEVAR. A recent systematic review from 1995 to 2017 reported that TEVAR for the ascending aorta was performed in 118 patients.[44] The aortic pathologies treated involved type A dissection (50%), pseudoaneurysm (30%), and others (20%), including penetrating ulcer, and true aneurysm. The overall survival rate was 15.2%, and ARD rate was 5%. Type 1 endoleak was identified in 18.6% and most half required reintervention underscoring the difficulty of TEVAR in this region.

Acute and Chronic Type B Dissection

The first-line treatment option for acute type B aortic dissection (TBAD) has long considered to be best medical treatment (BMT) mainly consisting of antihypertensive therapy. Only complicated TBAD with organ ischemia or rupture were candidates for surgical intervention. However, since the outcomes of surgical intervention were not satisfactory, TEVAR has been sought for such condition. The initial prognosis of the patients undergoing TEVAR was excellent, and it revealed an enlargement of the true lumen accompanied with shrinkage of the false lumen and the overall aorta diameter which is termed positive remodeling.[45] The INSTEAD trial, a randomized controlled trial (RCT) enrolled 140 patients and aimed at comparing BMT with BMT + TEVAR (Talent, Medtronic), was designed to evaluate the safety and efficacy of the treatment of uncomplicated TBAD.[46,47] Both overall survival and ARD for 2-year follow-up were comparable in the two groups, but TEVAR had a higher incidence of aortic remodeling compared with BMT ($p < 0.001$). Additionally, TEVAR was superior to BMT in terms of survival and thrombosis of the false lumen at 5-year follow-up. The results of the ADSORB trial, a prospective and RCT aimed at comparing BMT and BMT + TAG (W.L. Gore & Associates) for uncomplicated TBAD, were reported in 2014.[48] Although mortality rate was equivalent in the two groups, the BMT + TEVAR group was superior to BMT alone in terms of aortic remodeling. A recent review concluded that the long-term results of BMT alone for the treatment of uncomplicated type B dissection were inferior to those of the complicated type and showed a high frequency of surgical intervention.[49] Based on these evidences, TEVAR for acute TBAD is listed as the first-line treatment option in the ESVS guidelines.[21]

Chronic TBAD, including a residual dissection after repair of an acute type A dissection, is defined as "chronic" when 2 weeks have elapsed from the onset. There are some reports that patients with a maximum diameter of $>$ 40 mm after TBAD showed expansion of the false lumen in ~20 to 40% of cases, whereas in cases of $<$ 40 mm at the time of onset, ~80 to 95% experienced spontaneous thrombosis of the false lumen.[50,51] Other factors influencing the expansion of the false lumen were entry tear size ($>$ 10 mm), location of the primary tear (proximal descending aorta), and Marfan's syndrome.[52] There is no study comparing for open surgery versus TEVAR for chronic TBAD; however, since the results of an open repair for TBAD have improved, open repair is the standard option for low-risk patients including young patients.[53] Although there are few reports comparing open repair with TEVAR, a study enrolled 24 patients showed the 30-day mortality was 8% in open repair and 0% in TEVAR, and the subsequent survival rates within 1 year, following open repair and TEVAR, were 33 and 0%, respectively.[54] A recent review of TEVAR for chronic TBAD reported that mid-term mortality was 9 to 10% and reintervention commonly caused by endoleak from the re-entry was identified in 0 to 60% of cases.[55,56] Evidence level is low and further development of devices and techniques as well as clinical investigation is warranted for chronic TBAD.

Thoracoabdominal Aortic Aneurysm

There are no commercially available branched endografts for TAAA involving the visceral branches, and therefore, open repair is the standard treatment for TAAA. However, it is highly invasive because the surgery involves opening of both the thoracic and abdominal cavities. Cardiac dysfunction, respiratory failure, renal failure, or redo aortic surgery predicts poor postoperative survival.[57,58] Therefore, TAAA patients with severe comorbidity are not candidates for open repair and are ideally treated endovascularly. Endovascular treatments for TAAA, including fenestrated endovascular abdominal aortic repair (EVAR) (FEVAR), branched EVAR (b-EVAR), and PMEG, are required not only to exclude the aneurysm but also to maintain the visceral branches. While PMEG and other procedures such as snorkel (chimney) methods or debranching TEVAR can be performed in

emergency cases, industry-made fenestrated endografts and branched endografts take considerable time to procure. In a high-volume center experience, the 30-day mortality was 5 to 19%, and postoperative complications, of which paraplegia is the most common, occurred in 10 to 16% of cases. Severe perioperative complications were encountered most frequency following treatment of Crawford type II TAAAs.[58–61]

Totally Endovascular Repair for TAAA

The most common type of FEVAR is composed of a Zenith platform (Cook Medical). The number of fenestrations is determined by the number of reconstructed branches, and iCAST (ATRIUM Corp, Hudson, NH) has often been used for reconstructing the visceral branches. Since the main device is commonly inserted via the common femoral artery (CFA) and the required number of sheaths for branched reconstruction is inserted from the contralateral CFA, common complications include limb ischemia due to prolonged sheath insertion and the occurrence of endoleaks from the junctions between the main endograft and the branch stents. Industry-made branched endograft is also consisted of Zenith (t-Branch, Cook Medical). This device has sleeves for the visceral branches, and the main device is inserted via the CFA, but unlike with FEVAR, the sheath for reconstruction of the visceral branches is inserted via the brachial or axillary arteries (►**Fig. 2**). Thus, there seems to be a lower incidence of limb ischemia compared with FEVAR. However, the cerebral infarction rate following b-EVAR is higher than for FEVAR because of the need to pass devices through the aortic arch region.[62]

The outcomes of FEVAR and b-EVAR have been reported from various institutions.[62–72] Technical success was achieved in 90 to 97% of elective cases. The 30-day mortality was 0 to 9%, the occurrence rate of SCI was 4 to 12%, and the visceral vessel patency rate was 90 to 100%. Endoleak was identified in 3 to 15% of cases, and the reintervention free rate at 3 years ranged between 80 and 90%. The outcomes of Crawford type II TAAA was accompanied with higher mortality and longer hospitalization compared with Crawford type III TAAA. The risk factors for poor long-term survival following TAAA treatment were old age, chronic pulmonary obstructive disease, and Crawford type II TAAA.[65] In a comparison between FEVAR/b-EVAR and open surgery for the treatment of TAAA including suprarenal and pararenal AAA, the mortality rates were 6.7 and 5.4%, respectively, with no statistical difference, but the cost-effectiveness of endovascular repair was overwhelmingly inferior to that of open surgery.[71]

Other techniques include the sandwich technique and TEVAR with celiac coverage. Although the first report of the sandwich technique was initially performed for iliac aneurysm, this technique can to be applied to TAAA, especially in emergency cases.[72] Recent reports showed that the technical success and 30-day mortality rates were 88 and 6.3%, respectively, and endoleaks and risk of visceral stent occlusion were more frequent as the number of chimney grafts increased.[73] TEVAR with CA coverage indicated for Crawford type I TAAA cases is safe and effective when the CA-SMA collateral circulation is present. Technical success was acceptable, but the 30-day mortality was 9.7% in a recent review, and the most common cause of death was visceral ischemia, which accounted for 30% of such cases.[74,75]

Hybrid Repair of TAAA

Hybrid therapy usually termed as abdominal debranching TEVAR, which consists of endograft deployment across the visceral branches followed by extra-anatomical visceral artery bypass is an acceptable option for high-risk patients with TAAA. Both the iliac artery and aortic bifurcation are

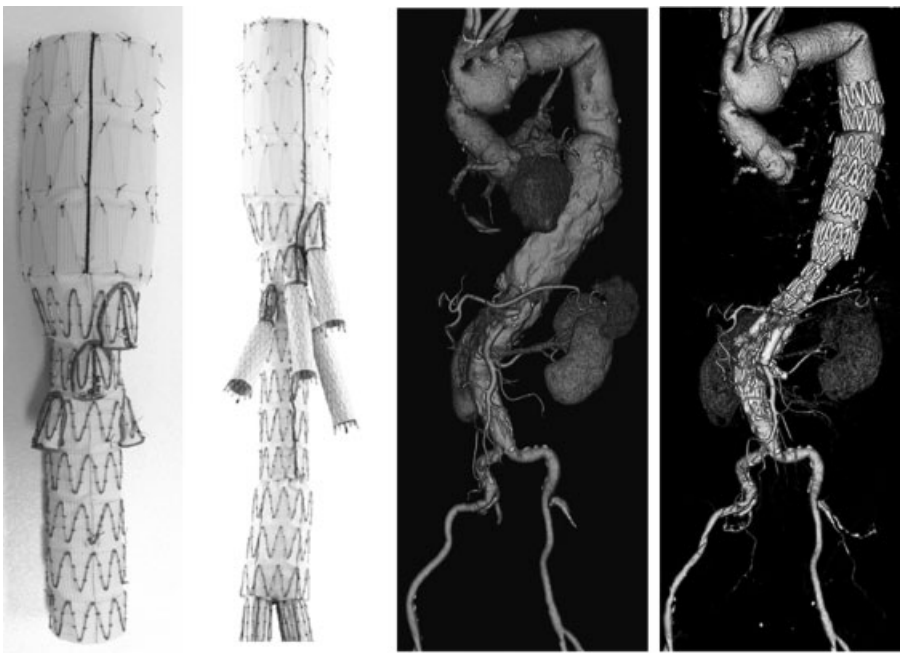

Fig. 2 t-Branch endograft. Endovascular treatment for thoracoabdominal aortic aneurysm using custom-made device.

generally used as a bypass inflow. Recent results were ~2 to 13% in terms of 30-day mortality, and the incidence of major complications was 7 to 29%, and endoleaks occurred in 5 to 17% of cases.[76–80]

Abdominal Aortic Aneurysm

Parodi et al[6] were the first to report the use of an endograft for AAAs. At the time, only straight type endografts were available, but a modular graft was subsequently developed, and a clinical study was reported.[81] The endograft for AAA differed from that for TAA in the industry developed and launched them during the early phase. Although a clinical trial using an industry-made device started mainly in Europe in 1995, the effectiveness of the treatment itself was threatened due to various complications following EVAR. However, second-generation endografts with improved performance was developed. Two randomized controlled clinical trials (EVAR trial 1 and DREAM trial) using second-generation endografts were undertaken in Europe.[82,83] Both showed a remarkable 60 to 70% reduction in 30-day mortality with EVAR compared with open repair, and the EVAR was superior to the open repair in freedom from ARD at 4 years following surgical intervention. These favorable outcomes helped early adoption and penetration of EVAR as well as further development of next-generation endografts. These trials have recently reported their 15-year follow-up in results. According to these results, the advantage of EVAR was gradually lost after 8 years following treatment. Moreover, both ARD and cancer death were significantly higher following EVAR in the long-term period.[84] However, since the newer devices have largely resolved the short comings of prior generation endografts used in these trials, and also since both trials had poor imaging follow-up that led to missing the opportunity to detect and treat endoleaks, the long-term results of these trials need to be interpreted with great caution.

Infrarenal Abdominal Aortic Aneurysm

RCTs comparing EVAR and open repair along with the trials stated previously showed that the early outcomes including mortality were superior for EVAR, but the advantages of EVAR were gradually lost in the long term.[85–87] The most common long-term complications of EVAR include endoleak, migration, infection, and late rupture. Even though there are such concerns of EVAR in the long term, more than half of the AAA cases worldwide are currently treated with EVAR.[88] Recent reports described that the 30-day mortality of EVAR was 0.5 to 1.7%, and that for open repair was 0.6 to 4.7%. Additionally, reintervention of EVAR was 5 to 9%, while that for open repair was 2 to 5%.[82–87] The endografts can be classified into two types: those with a suprarenal stent and those without. Endografts with a suprarenal top stent are Endurant (Medtronic), Talent (Medtronic), Zenith (Cook Medical), Zenith LP, Ovation (Endologix, Santa Rosa, CA), InCraft (Cordis Corp, Bridgewater, NJ), and Treovance (Bolton), whereas those without a suprarenal stent are AneuRx (Medtronic), Excluder (Gore), Anaconda (Vascutek, Scotland, UK), Aorfix (Lombard Medical, Irvine, CA), and AFX (Endologix).

Based on the IFU, the length of the proximal neck is required to be more than 10 to 15 mm and absence of severe angulation when performing EVAR. However, even in cases outside the IFU, including short proximal neck or severely angulated neck, EVAR can be performed by modifying the technique. However, it has been pointed out there is a difference in long-term outcomes between inside IFU (on label) and outside IFU (off label) cases.[89] Early type 1 endoleak and early reintervention rates were 7 and 10% for inside IFU versus 18 and 24% for outside IFU, respectively. In a multivariate analysis, a neck angle >60 degrees carried a risk of death, sac expansion, and early reintervention, a neck length <10 mm carried a risk of early/late reintervention and late death. The internal iliac artery (IIA) should not be occluded according to the IFU and to preservation of at least one IIA is also recommended by the SVS guidelines.[90] A systematic review of 2,671 patients was undertaken.[91] IIA coverage was required in 15% of EVARs, and the overall incidence of buttock claudication was identified in 28% of cases. The occurrence rates of buttock claudication between unilateral and bilateral IIAs killed were comparable (unilateral 29.2 vs. 30.3% bilateral). Meta-analysis of 15 studies comprising 931 patients revealed that unilateral IIA killed was associated with a reduced incidence of buttock claudication compared with bilateral killed. In another study, buttock claudication was reduced when coils were placed in the proximal IIA ($p = 0.003$). Erectile dysfunction occurred in 10.2% of cases, with higher rates after coil embolization of the IIA. However, ischemic complications were very rare. Recently, new devices, such as Zenith IBD (Cook Medical) or Excluder IBE (Gore, ►**Fig. 3**), for preserving IIA have become commercially available and have shown excellent outcomes.[92,93]

As mentioned previously, postoperative complications following EVAR include endoleaks, migration, and infection. Initially, types 1 and 3 endoleaks attracted much attention and were treated, but recently, problems related to sac enlargement with or without type 2 endoleak have been recognized as a weakness of EVAR. Although types 1 and 3 endoleaks should be resolved, the treatment of type 2 endoleaks remains controversial. The incidence of type 2 endoleaks within 6 months is 10 to 15%.[94] Factors affecting persistent type 2 endoleak include a patent inferior mesenteric artery, number and diameter of patent lumber arteries, and anticoagulation therapy.[95,96] Since a delayed type 2 endoleak may be associated with sac enlargement,[97] various treatments including laparoscopic ligation of the side branch vessels, coil embolization, and glue embolization are performed to resolve these type 2 endoleaks. However, more than 50% of the aneurysm sac treated for type 2 endoleaks continue to expand.[98,99] Therefore, type 2 endoleaks remain difficult to treat. As such problems, an endograft capable of occluding side branches at the time of EVAR have been developed and have been termed as endovascular aneurysm sealing. With this system, side branches are occluded by injecting polymers into the aneurysm sac during EVAR to prevent type 2 endoleaks. Early results appear to be promising but the ultimate role and value of this system are yet to be proven.[100,101]

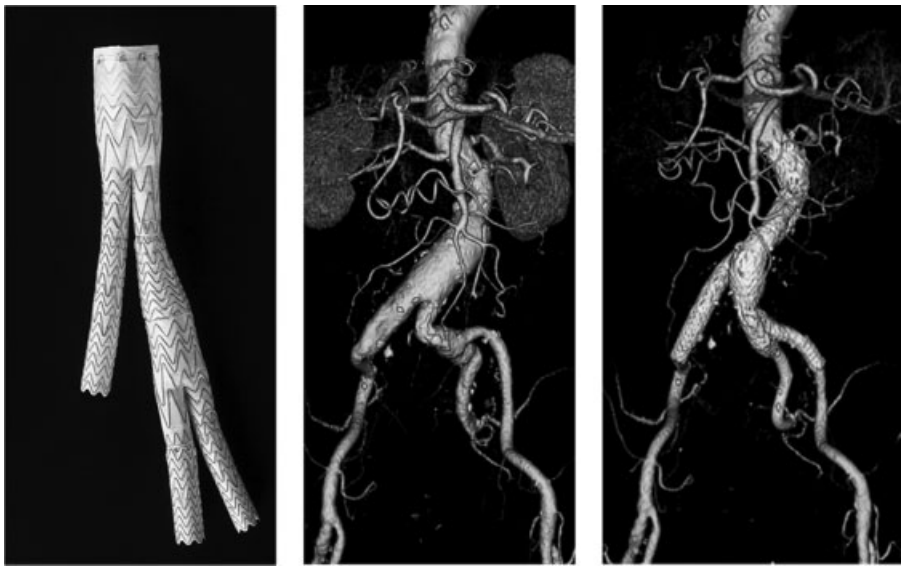

Fig. 3 Excluder IBE endograft. This is an off-the-shelf device allowing for the preservation of the internal iliac artery.

While a cut down is commonly required for the insertion of an endograft via the CFA, the feasibility of percutaneous EVAR has been reported with acceptable outcomes.[102] However, wound complication is a rare occurrence during EVAR.[103] Endograft infection after EVAR is also rare (0.6%). Most patients underwent with endograft infection have undergone surgical treatment with a prosthetic graft or an allograft. The estimated 30-day/in-hospital mortality was 26.6% for all cases, and for the patients receiving conservative treatment, the mortality rate was alarmingly high (63.3%).[104] Therefore, late endograft infection is an unsolved and a difficult problem.

Ruptured AAA and Pararenal AAA

EVAR was expected to be a useful treatment option for ruptured AAA because it is less invasive.[105] However, the IMPROVE RCT trial,[106] which compared open repair and EVAR for ruptured AAA, failed to demonstrate the superiority of EVAR in terms of 30-day mortality and cost-effectiveness. However, EVAR was superior to open repair in length of stay and the possibility of home discharge. In addition, EVAR performed at high-volume centers showed improved mortality and outcomes.[107] The aorto-uni-iliac or Nellix devices are useful even in anatomically unsuitable cases. Since the outcomes of EVAR for ruptured AAA that follow a protocol are better than those without a protocol,[108] EVAR for ruptured AAA following a protocol at a high-volume center is considered desirable.

Since the treatment of pararenal AAA is not possible with a standard EVAR, a fenestrated graft or snorkel technique is required. The Zenith fenestrated graft (Cook Medical) has been approved by the FDA and has obtained CE mark.[a] In a multicenter trial, there were no 30-day mortality and no ARD.[109] Recent studies have confirmed this excellent outcome with a 0 to 7% 30-day mortality and 95 to 98% visceral vessel patency.[110–112] On the contrary, the 30-day mortality and target vessel patency were 1 to 4% and 92 to 96%, respectively, with the snorkel EVAR.[113–115]

Conclusion

Endografts have revolutionized the treatment of aortic aneurysms and have enabled treatment of otherwise inoperable patients. Although short comings of EVAR exist, its contribution is significant and EVAR is here to stay. Miniaturization and improving long-term outcome are remaining issues for endovascular repair of TAAs and AAAs, while much more development and accumulation of data are required for the treatment of ascending, aortic arch, thoracoabdominal aneurysm, as well as acute and chronic dissections. Conversely, the role and volume of surgical repair will most likely continue to diminish.

[a] CE mark is a standard conformity mark that products are attached to those that meet the criteria of all EU member states.

References

1 Dotter CT, Judkins MP. Transluminal treatment of arteriosclerotic obstruction: description of a new technique and a preliminary report of its application. Circulation 1964;30: 654–670

2 Dotter CT. Transluminally-placed coilspring endarterial tube grafts. Long-term patency in canine popliteal artery. Invest Radiol 1969;4(05):329–332

3 Dotter CT, Buschmann RW, McKinney MK, Rösch J. Transluminal expandable nitinol coil stent grafting: preliminary report. Radiology 1983;147(01):259–260

4 Balko A, Piasecki GJ, Shah DM, Carney WI, Hopkins RW, Jackson BT. Transfemoral placement of intraluminal polyurethane prosthesis for abdominal aortic aneurysm. J Surg Res 1986;40(04): 305–309

5 Volodos' NL, Karpovich IP, Shekhanin VE, Troian VI, Iakovenko LF. [A case of distant transfemoral endoprosthesis of the thoracic artery using a self-fixing synthetic prosthesis in traumatic aneurysm]. Grudn Khir 1988;6(06):84–86

6 Parodi JC, Palmaz JC, Barone HD. Transfemoral intraluminal graft implantation for abdominal aortic aneurysms. Ann Vasc Surg 1991;5(06):491–499
7 Dake MD, Miller DC, Semba CP, Mitchell RS, Walker PJ, Liddell RP. Transluminal placement of endovascular stent-grafts for the treatment of descending thoracic aortic aneurysms. N Engl J Med 1994;331(26):1729–1734
8 Kato M, Ohnishi K, Kaneko M, et al. New graft-implanting method for thoracic aortic aneurysm or dissection with a stented graft. Circulation 1996;94(9, Suppl):II188–II193
9 Inoue K, Hosokawa H, Iwase T, et al. Aortic arch reconstruction by transluminally placed endovascular branched stent graft. Circulation 1999;100(19, Suppl):II316–II321
10 Mitchell RS, Ishimaru S, Criado FJ, et al. Third International Summit on Thoracic Aortic Endografting: lessons from long-term results of thoracic stent-graft repairs. J Endovasc Ther 2005;12(01):89–97
11 Makaroun MS, Dillavou ED, Wheatley GH, Cambria RP; Gore TAG Investigators. Five-year results of endovascular treatment with the Gore TAG device compared with open repair of thoracic aortic aneurysms. J Vasc Surg 2008;47(05):912–918
12 Fairman RM, Criado F, Farber M, et al; VALOR Investigators. Pivotal results of the Medtronic Vascular Talent Thoracic Stent Graft System: the VALOR trial. J Vasc Surg 2008;48(03):546–554
13 Matsumura JS, Cambria RP, Dake MD, Moore RD, Svensson LG, Snyder S; TX2 Clinical Trial Investigators. International controlled clinical trial of thoracic endovascular aneurysm repair with the Zenith TX2 endovascular graft: 1-year results. J Vasc Surg 2008;47(02):247–257, discussion 257
14 Matsumura JS, Melissano G, Cambria RP, et al; Zenith TX2 Clinical Trial Investigators. Five-year results of thoracic endovascular aortic repair with the Zenith TX2. J Vasc Surg 2014;60(01):1–10
15 Gopaldas RR, Huh J, Dao TK, et al. Superior nationwide outcomes of endovascular versus open repair for isolated descending thoracic aortic aneurysm in 11,669 patients. J Thorac Cardiovasc Surg 2010;140(05):1001–1010
16 Bavaria JE, Appoo JJ, Makaroun MS, Verter J, Yu ZF, Mitchell RS; Gore TAG Investigators. Endovascular stent grafting versus open surgical repair of descending thoracic aortic aneurysms in low-risk patients: a multicenter comparative trial. J Thorac Cardiovasc Surg 2007;133(02):369–377
17 Cheng D, Martin J, Shennib H, et al. Endovascular aortic repair versus open surgical repair for descending thoracic aortic disease a systematic review and meta-analysis of comparative studies. J Am Coll Cardiol 2010;55(10):986–1001
18 Zipfel B, Zaefferer P, Riambau V, et al; RESTORE II Study Group. Worldwide results from the RESTORE II on elective endografting of thoracic aneurysms and dissections. J Vasc Surg 2016;63(06):1466–1475
19 Ranney DN, Cox ML, Yerokun BA, Benrashid E, McCann RL, Hughes GC. Long-term results of endovascular repair for descending thoracic aortic aneurysms. J Vasc Surg 2018;67(02):363–368
20 Biancari F, Mariscalco G, Mariani S, Saari P, Satta J, Juvonen T. Endovascular treatment of degenerative aneurysms involving only the descending thoracic aorta: systematic review and meta-analysis. J Endovasc Ther 2016;23(02):387–392
21 Riambau V, Böckler D, Brunkwall J, et al; Writing Committee; Esvs Guidelines Committee. Editor's choice- Management of descending thoracic aorta disease: clinical practice guidelines of European society for vascular surgery (ESVS). Eur J Vasc Endovasc Surg 2017;53(01):4–52
22 Alsawas M, Zaiem F, Larrea-Mantilla L, et al. Effectiveness of surgical interventions for thoracic aortic aneurysms: a systematic review and meta-analysis. J Vasc Surg 2017;66(04):1258–1268.e8
23 Baba T, Ohki T, Kanaoka Y, Maeda K. Clinical outcomes of left subclavian artery coverage on morbidity and motality during thoracic endovascular aortic repair for distal arch aneurysms. World J Surg 2015;39(11):2812–2822
24 Hajibandeh S, Hajibandeh S, Antoniou SA, Torella F, Antoniou GA. Meta-analysis of left subclavian artery coverage with and without revascularization in thoracic endovascular aortic aneurysm repair. J Endovasc Ther 2016;23:631–641
25 Waterford SD, Chou D, Bombien R, Uzun I, Shah A, Khoynezhad A. Left subclavian arterial coverage and stroke during thoracic aortic endografting: a systematic review. Ann Thorac Surg 2016;101(01):381–389
26 von Allmen RS, Gahl B, Powell JT. Editor's choice- Incidence of stroke following thoracic endovascular aortic repair for descending aortic aneurysm: a sustematic review of the literature with meta-analysis. Eur J Vasc Endovasc Surg 2017;53(02):176–184
27 Roselli EE, Arko FR III, Thompson MM; Valiant Mona LSA Trial Investigators. Results of the Valiant Mona LSA early feasibility study for descending thoracic aneurysms. J Vasc Surg 2015;62(06):1465–71.e3
28 Patel HJ, Dake MD, Bavaria JE, et al. Branched endovascular therapy of the distal aortic arch: preliminary results of the feasibility multicenter trial of the Gore Thoracic Branch Endoprosthesis. Ann Thorac Surg 2016;102(04):1190–1198
29 Sood V, Patel HJ, Williams DM, Dasika NL, Yang B, Deeb GM. Open and endovascular repair of the nontraumatic isolated aortic arch aneurysm. J Vasc Surg 2014;60(01):57–63
30 Antoniou GA, El Sakka K, Hamady M, Wolfe JH. Hybrid treatment of complex aortic arch disease with supra-aortic debranching and endovascular stent graft repair. Eur J Vasc Endovasc Surg 2010;39(06):683–690
31 Cao P, De Rango P, Czerny M, et al. Systematic review of clinical outcomes in hybrid procedures for aortic arch dissections and other arch diseases. J Thorac Cardiovasc Surg 2012;144(06):1286–1300, 1300.e1–1300.e2
32 Ferrero E, Ferri M, Viazzo A, et al. Is total debranching a safe procedure for extensive aortic-arch disease? A single experience of 27 cases. Eur J Cardiothorac Surg 2012;41(01):177–182
33 Yoshitake A, Okamoto K, Yamazaki M, et al. Comparison of aortic arch repair using the endovascular technique, total arch replacement and staged surgery†. Eur J Cardiothorac Surg 2017;51(06):1142–1148
34 Kurimoto Y, Maruyama R, Ujihira K, et al. Thoracic endovascular aortic repair for challenging aortic arch diseases using fenestrated stent grafts from zone 0. Ann Thorac Surg 2015;100(01):24–32, discussion 32–33
35 Iwakoshi S, Ichihashi S, Itoh H, et al. Clinical outcomes of thoracic endovascular aneurysm repair using commercially available fenestrated stent graft (Najuta endograft). J Vasc Surg 2015;62(06):1473–1478
36 Riambau V. Application of the Bolton Relay device for thoracic endografting in or near the aortic arch. Aorta (Stamford) 2015;3(01):16–24
37 Spear R, Haulon S, Ohki T, et al. Editor's choice - subsequent results for arch aneurysm repair with inner branched endografts. Eur J Vasc Endovasc Surg 2016;51(03):380–385
38 Redlinger RE Jr, Ahanchi SS, Panneton JM. In situ laser fenestration during emergent thoracic endovascular aortic repair is an effective method for left subclavian artery revascularization. J Vasc Surg 2013;58(05):1171–1177
39 Tse LW, Lindsay TF, Roche-Nagle G, Oreopoulos GD, Ouzounian M, Tan KT. Radiofrequency in situ fenestration for aortic arch vessels during thoracic endovascular repair. J Endovasc Ther 2015;22(01):116–121
40 Kanaoka Y, Ohki T, Maeda K, Baba T, Fujita T. Multivariate analysis of risk factors of cerebral infarction in 439 patients undergoing thoracic endovascular aneurysm repair. Medicine (Baltimore) 2016;95(15):e3335
41 Kanaoka Y, Ohki T, Maeda K, Baba T. Analysis of risk factors for early type I endoleaks after thoracic endovascular aneurysm repair. J Endovasc Ther 2017;24(01):89–96

42 Wang T, Shu C, Li M, et al. Thoracic endovascular aortic repair with single/double chimney technique for aortic arch pathologies. J Endovasc Ther 2017;24(03):383–393
43 Lindblad B, Bin Jabr A, Holst J, Malina M. Chimney grafts in aortic stent grafting: Hazardous or useful technique? Systematic review of current data. Eur J Vasc Endovasc Surg 2015;50(06): 722–731
44 Muetterties CE, Menon R, Wheatley GH III. A systematic review of primary endovascular repair of the ascending aorta. J Vasc Surg 2018;67(01):332–342
45 Huptas S, Mehta RH, Kühl H, et al. Aortic remodeling in type B aortic dissection: effects of endovascular stent-graft repair and medical treatment on true and false lumen volumes. J Endovasc Ther 2009;16(01):28–38
46 Nienaber CA, Rousseau H, Eggebrecht H, et al; INSTEAD Trial. Randomized comparison of strategies for type B aortic dissection: the INvestigation of STEnt Grafts in Aortic Dissection (INSTEAD) trial. Circulation 2009;120(25):2519–2528
47 Nienaber CA, Kische S, Rousseau H, et al; INSTEAD-XL trial. Endovascular repair of type B aortic dissection: long-term results of the randomized investigation of stent grafts in aortic dissection trial. Circ Cardiovasc Interv 2013;6(04):407–416
48 Brunkwall J, Kasprzak P, Verhoeven E, et al; ADSORB Trialists. Endovascular repair of acute uncomplicated aortic type B dissection promotes aortic remodelling: 1 year results of the ADSORB trial. Eur J Vasc Endovasc Surg 2014;48(03):285–291
49 Lou X, Chen EP, Duwayri YM, et al. Impact of thoracic endovascular aortic repair on long-term survival in type B aortic dissection. Ann Thorac Surg 2018;105(01):31–38
50 Marui A, Mochizuki T, Mitsui N, Koyama T, Kimura F, Horibe M. Toward the best treatment for uncomplicated patients with type B acute aortic dissection: A consideration for sound surgical indication. Circulation 1999;100(19, Suppl):II275–II280
51 Winnerkvist A, Lockowandt U, Rasmussen E, Rådegran K. A prospective study of medically treated acute type B aortic dissection. Eur J Vasc Endovasc Surg 2006;32(04):349–355
52 Evangelista A, Salas A, Ribera A, et al. Long-term outcome of aortic dissection with patent false lumen: predictive role of entry tear size and location. Circulation 2012;125(25): 3133–3141
53 Zoli S, Etz CD, Roder F, et al. Long-term survival after open repair of chronic distal aortic dissection. Ann Thorac Surg 2010;89(05): 1458–1466
54 Nienaber CA, Fattori R, Lund G, et al. Nonsurgical reconstruction of thoracic aortic dissection by stent-graft placement. N Engl J Med 1999;340(20):1539–1545
55 Boufi M, Patterson BO, Grima MJ, et al. Systematic review of reintervention after thoracic endovascular repair for chronic type B dissection. Ann Thorac Surg 2017;103(06):1992–2004
56 Thrumurthy SG, Karthikesalingam A, Patterson BO, et al. A systematic review of mid-term outcomes of thoracic endovascular repair (TEVAR) of chronic type B aortic dissection. Eur J Vasc Endovasc Surg 2011;42(05):632–647
57 Suzuki S, Davis CA III, Miller CC III, et al. Cardiac function predicts mortality following thoracoabdominal and descending thoracic aortic aneurysm repair. Eur J Cardiothorac Surg 2003;24(01): 119–124, discussion 124
58 Coselli JS, LeMaire SA, Conklin LD, Köksoy C, Schmittling ZC. Morbidity and mortality after extent II thoracoabdominal aortic aneurysm repair. Ann Thorac Surg 2002;73(04):1107–1115, discussion 1115–1116
59 LeMaire SA, Price MD, Green SY, Zarda S, Coselli JS. Results of open thoracoabdominal aortic aneurysm repair. Ann Cardiothorac Surg 2012;1(03):286–292
60 Coselli JS, Conklin LD, LeMaire SA. Thoracoabdominal aortic aneurysm repair: review and update of current strategies. Ann Thorac Surg 2002;74(05):S1881–S1884, discussion S1892–S1898
61 Coselli JS, LeMaire SA, Preventza O, et al. Outcomes of 3309 thoracoabdominal aortic aneurysm repairs. J Thorac Cardiovasc Surg 2016;151(05):1323–1337
62 Baba T, Ohki T, Kanaoka Y, et al. Clinical outcomes of spinal ischemia after fenestrated and branched endovascular stent grafting during total endovascular aortic repair for thoracoabdominal aortic aneurysms. Ann Vasc Surg 2017;44:146–157
63 Rigberg DA, McGory ML, Zingmond DS, et al. Thirty-day mortality statistics underestimate the risk of repair of thoracoabdominal aortic aneurysms: a statewide experience. J Vasc Surg 2006;43(02):217–222, discussion 223
64 Verhoeven EL, Katsargyris A, Bekkema F, et al. Editor's choice-Ten-year experience with endovascular repair of thoracoabdominal aortic aneurysms: results from 166 consecutive patients. Eur J Vasc Endovasc Surg 2015;49(05):524–531
65 Eagleton MJ, Follansbee M, Wolski K, Mastracci T, Kuramochi Y. Fenestrated and branched endovascular aneurysm repair outcomes for type II and III thoracoabdominal aortic aneurysms. J Vasc Surg 2016;63(04):930–942
66 Schanzer A, Simons JP, Flahive J, et al. Outcomes of fenestrated and branched endovascular repair of complex abdominal and thoracoabdominal aortic aneurysms. J Vasc Surg 2017;66(03):687–694
67 Budtz-Lilly J, Wanhainen A, Eriksson J, Mani K. Adapting to a total endovascular approach for complex aortic aneurysm repair: outcomes after fenestrated and branched endovascular aortic repair. J Vasc Surg 2017;66(05):1349–1356
68 Amiot S, Haulon S, Becquemin JP, et al; Association Universitaire de Recherche en Chirurgie Vasculaire. Fenestrated endovascular grafting: the French multicentre experience. Eur J Vasc Endovasc Surg 2010;39(05):537–544
69 Silingardi R, Gennai S, Leone N, et al; Italian mbEVAR study group. Standard "off-the-shelf" multibranched thoracoabdominal endograft in urgent and elective patients with single and staged procedures in a multicenter experience. J Vasc Surg 2018; 67:1005–1016
70 Gallitto E, Gargiulo M, Freyrie A, et al. Off-the-shelf multibranched endograft for urgent endovascular repair of thoracoabdominal aortic aneurysms. J Vasc Surg 2017;66(03):696–704.e5
71 Michel M, Becquemin JP, Clément MC, Marzelle J, Quelen C, Durand-Zaleski I; WINDOW Trial Participants. Editor's choice - thirty day outcomes and costs of fenestrated and branched stent grafts versus open repair for complex aortic aneurysms. Eur J Vasc Endovasc Surg 2015;50(02):189–196
72 Lobato AC. Sandwich technique for aortoiliac aneurysms extending to the internal iliac artery or isolated common/internal iliac artery aneurysms: a new endovascular approach to preserve pelvic circulation. J Endovasc Ther 2011;18(01):106–111
73 Schwierz E, Kolvenbach RR, Yoshida R, Yoshida W, Alpaslan A, Karmeli R. Experience with the sandwich technique in endovascular thoracoabdominal aortic aneurysm repair. J Vasc Surg 2014;59(06):1562–1569
74 Vaddineni SK, Taylor SM, Patterson MA, Jordan WD Jr. Outcome after celiac artery coverage during endovascular thoracic aortic aneurysm repair: preliminary results. J Vasc Surg 2007;45(03): 467–471
75 Mehta M, Darling RC III, Taggert JB, et al. Outcomes of planned celiac artery coverage during TEVAR. J Vasc Surg 2010;52(05): 1153–1158
76 Hughes GC, Barfield ME, Shah AA, et al. Staged total abdominal debranching and thoracic endovascular aortic repair for thoracoabdominal aneurysm. J Vasc Surg 2012;56(03):621–629
77 Kuratani T, Kato M, Shirakawa Y, Shimamura K, Sawa Y. Long-term results of hybrid endovascular repair for thoraco-abdominal aortic aneurysms. Eur J Cardiothorac Surg 2010;38(03): 299–304
78 Hawkins RB, Mehaffey JH, Narahari AK, et al. Improved outcomes and value in staged hybrid extent II thoracoabdominal aortic aneurysm repair. J Vasc Surg 2017;66(05):1357–1363

79 Tshomba Y, Melissano G, Logaldo D, et al. Clinical outcomes of hybrid repair for thoracoabdominal aortic aneurysms. Ann Cardiothorac Surg 2012;1(03):293–303

80 Donas KP, Lachat M, Rancic Z, et al. Early and midterm outcome of a novel technique to simplify the hybrid procedures in the treatment of thoracoabdominal and pararenal aortic aneurysms. J Vasc Surg 2009;50(06):1280–1284

81 Chuter TA, Green RM, Ouriel K, Fiore WM, DeWeese JA. Transfemoral endovascular aortic graft placement. J Vasc Surg 1993;18 (02):185–195, discussion 195–197

82 Greenhalgh RM, Brown LC, Kwong GP, Powell JT, Thompson SG; EVAR trial participants. Comparison of endovascular aneurysm repair with open repair in patients with abdominal aortic aneurysm (EVAR trial 1), 30-day operative mortality results: randomised controlled trial. Lancet 2004;364(9437):843–848

83 Prinssen M, Verhoeven EL, Buth J, et al; Dutch Randomized Endovascular Aneurysm Management (DREAM)Trial Group. A randomized trial comparing conventional and endovascular repair of abdominal aortic aneurysms. N Engl J Med 2004;351 (16):1607–1618

84 Patel R, Sweeting MJ, Powell JT, Greenhalgh RM; EVAR trial investigators. Endovascular versus open repair of abdominal aortic aneurysm in 15-years' follow-up of the UK endovascular aneurysm repair trial 1 (EVAR trial 1): a randomised controlled trial. Lancet 2016;388(10058):2366–2374

85 Becquemin JP, Pillet JC, Lescalie F, et al; ACE trialists. A randomized controlled trial of endovascular aneurysm repair versus open surgery for abdominal aortic aneurysms in low- to moderate-risk patients. J Vasc Surg 2011;53(05):1167–1173.e1

86 Lederle FA, Freischlag JA, Kyriakides TC, et al; Open Versus Endovascular Repair (OVER) Veterans Affairs Cooperative Study Group. Outcomes following endovascular vs open repair of abdominal aortic aneurysm: a randomized trial. JAMA 2009; 302(14):1535–1542

87 Powell JT, Sweeting MJ, Ulug P, et al; EVAR-1, DREAM, OVER and ACE Trialists. Meta-analysis of individual-patient data from EVAR-1, DREAM, OVER and ACE trials comparing outcomes of endovascular or open repair for abdominal aortic aneurysm over 5 years. Br J Surg 2017;104(03):166–178

88 Dua A, Kuy S, Lee CJ, Upchurch GR Jr, Desai SS. Epidemiology of aortic aneurysm repair in the United States from 2000 to 2010. J Vasc Surg 2014;59(06):1512–1517

89 AbuRahma AF, Yacoub M, Mousa AY, et al. Aortic neck anatomic features and predictors of outcomes in endovascular repair of abdominal aortic aneurysms following vs not following instruction for use. J Am Coll Surg 2016;222(04):579–589

90 Chaikof EL, Dalman RL, Eskandari MK, et al. The Society for Vascular Surgery practice guidelines on the care of patients with an abdominal aortic aneurysm. J Vasc Surg 2018;67(01):2–77.e2

91 Bosanquet DC, Wilcox C, Whitehurst L, Cox A, Williams IM, Twine CP; British Society of Endovascular therapy (BSET). Systematic review and meta-analysis of the effect of internal iliac artery exclusion for patients undergoing EVAR. Eur J Vasc Endovasc Surg 2017;53(04):534–548

92 Jongsma H, Bekken JA, Bekkers WJ, et al. Endovascular treatment of common iliac artery aneurysms with an iliac branch device: multicenter experience of 140 patients. J Endovasc Ther 2017;24 (02):239–245

93 van Sterkenburg SM, Heyligers JM, van Bladel M, et al; Dutch IBE Collaboration. Experience with the GORE EXCLUDER iliac branch endoprosthesis for common iliac artery aneurysms. J Vasc Surg 2016;63(06):1451–1457

94 van Marrewijk C, Buth J, Harris PL, Norgren L, Nevelsteen A, Wyatt MG. Significance of endoleaks after endovascular repair of abdominal aortic aneurysms: The EUROSTAR experience. J Vasc Surg 2002;35(03):461–473

95 Ward TJ, Cohen S, Patel RS, et al. Anatomic risk factors for type-2 endoleak following EVAR: a retrospective review of preoperative CT angiography in 326 patients. Cardiovasc Intervent Radiol 2014;37(02):324–328

96 Bobadilla JL, Hoch JR, Leverson GE, Tefera G. The effect of warfarin therapy on endoleak development after endovascular aneurysm repair (EVAR) of the abdominal aorta. J Vasc Surg 2010;52(02):267–271

97 Okada M, Handa N, Onohara T, et al; National Hospital Organization Network Study Group for Abdominal Aortic Aneurysm in Japan. Late sac behavior after endovascular aneurysm repair for abdominal aortic aneurysm. Ann Vasc Dis 2016;9(02):102–107

98 Sarac TP, Gibbons C, Vargas L, et al. Long-term follow-up of type II endoleak embolization reveals the need for close surveillance. J Vasc Surg 2012;55(01):33–40

99 Jouhannet C, Alsac JM, Julia P, et al. Reinterventions for type 2 endoleaks with enlargement of the aneurismal sac after endovascular treatment of abdominal aortic aneurysms. Ann Vasc Surg 2014;28(01):192–200

100 Gossetti B, Martinelli O, Ferri M, Silingardi R, Verzini F; IRENE Group Investigators. Preliminary results of endovascular aneurysm sealing from the multicenter Italian Research on Nellix Endoprosthesis (IRENE) study. J Vasc Surg 2017:S0741-5214(17) 32384-4

101 van den Ham LH, Holden A, Savlovskis J, Witterbottom A, Ouriel K, Reijnen MMPJ; EVAS Type IA Endoleak Study Group. Editor's choice- Occurrence and classification of proximal type I endoleaks after endovascular aneurysm sealing using the Nellix™ device. Eur J Vasc Endovasc Surg 2017;54(06):729–736

102 Nelson PR, Kracjer Z, Kansal N, et al. A multicenter, randomized, controlled trial of totally percutaneous access versus open femoral exposure for endovascular aortic aneurysm repair (the PEVAR trial). J Vasc Surg 2014;59(05):1181–1193

103 Maeda K, Kanaoka Y, Ohki T, Sumi M, Toya N, Fujita T. Better clinical practice could overcome patient-related risk factors of vascular surgical site infections. J Endovasc Ther 2015;22(04):640–646

104 Argyriou C, Georgiadis GS, Lazarides MK, Georgakarakos E, Antoniou GA. Endograft infection after endovascular abdominal aortic aneurysm repair: a systematic review and meta-analysis. J Endovasc Ther 2017;24(05):688–697

105 Ohki T, Veith FJ. Endovascular grafts and other image-guided catheter-based adjuncts to improve the treatment of ruptured aortoiliac aneurysms. Ann Surg 2000;232(04):466–479

106 Powell JT, Sweeting MJ, Thompson MM, et al; IMPROVE Trial Investigators. Endovascular or open repair strategy for ruptured abdominal aortic aneurysm: 30 day outcomes from IMPROVE randomised trial. BMJ 2014;348:f7661

107 Lesperance K, Andersen C, Singh N, Starnes B, Martin MJ. Expanding use of emergency endovascular repair for ruptured abdominal aortic aneurysms: disparities in outcomes from a nationwide perspective. J Vasc Surg 2008;47(06):1165–1170, discussion 1170–1171

108 Moore R, Nutley M, Cina CS, Motamedi M, Faris P, Abuznadah W. Improved survival after introduction of an emergency endovascular therapy protocol for ruptured abdominal aortic aneurysms. J Vasc Surg 2007;45(03):443–450

109 Greenberg RK, Sternbergh WC III, Makaroun M, et al; Fenestrated Investigators. Intermediate results of a United States multicenter trial of fenestrated endograft repair for juxtarenal abdominal aortic aneurysms. J Vasc Surg 2009;50(04):730–737.e1

110 Midy D, Becquemin JP, Mialhe C, Frisch N, Martinez R, Caradu C; EFEFA Research Group. Results of the French multicentric study of ANACONDA™ fenestrated endografts in the treatment of complex aortic pathologies (EFEFA Registery). Ann Vasc Surg 2017;43:151–165

111 Blankensteijn LL, Dijkstra ML, Tielliu IF, Reijnen MM, Zeebregts CJ; Dutch Fenestrated Anaconda Research Group. Midterm results of the fenestrated Anaconda endograft for short-neck infrarenal and juxtarenal abdominal aortic aneurysm repair. J Vasc Surg 2017;65(02):303–310

112 Quiñones-Baldrich WJ, Holden A, Mertens R, et al. Prospective, multicenter experience with the Ventana Fenestrated System for juxtarenal and pararenal aortic aneurysm endovascular repair. J Vasc Surg 2013;58(01):1–9

113 Donas KP, Lee JT, Lachat M, Torsello G, Veith FJ; PERICLES investigators. Collected world experience about the performance of the snorkel/chimney endovascular technique in the treatment of complex aortic pathologies: the PERICLES registry. Ann Surg 2015;262(03):546–553, discussion 552–553

114 Li Y, Zhang T, Guo W, et al. Endovascular chimney technique for juxtarenal abdominal aortic aneurysm: a systematic review using pooled analysis and meta-analysis. Ann Vasc Surg 2015; 29(06):1141–1150

115 Maeda K, Ohki T, Kanaoka Y, Baba T, Kaneko K, Shukuzawa K. Comparison between open and endovascular repair for the treatment of juxtarenal abdominal aortic aneruysms: a single-center experience with midterm results. Ann Vasc Surg 2017; 41:96–104