Percutaneous interventions for diagnostic and therapeutic approaches to the coronary and aortic branch vessels have been the mainstay of cardiovascular interventions for several decades. The development of catheter-based technologies to treat traumatic and degenerative pathology of the thoracic and abdominal aorta initially required the use of direct femoral access via open incisions because of the size of the devices and their delivery sheaths. Although the endovascular repair of infrarenal aortic aneurysms (EVAR) ushered in an entirely new concept for managing aortic pathology, there was a concomitant development of a new series of complications associated with open vascular access. Of the devices approved by the US Food and Drug Administration, the profiles of the currently available components ranges from 9F to 25F inner diameter, which correlates to 11F to 27F outer diameter. In particular, delivery systems for thoracic endografts have 22F to 27F outer diameter and are traditionally placed via femoral artery cut-down or surgically created conduits. With the evolution of devices with smaller sheaths, the development of closure devices, and noninvasive imaging studies to assess the suitability of arteries for percutaneous access, there have been major changes in the approach and timing of aortic interventions.

Closure Devices for Endovascular Interventions

Over the years, many closure devices have been marketed to decrease the need for manual compression or reversal of anticoagulation after transfemoral percutaneous diagnostic or therapeutic interventions. To date, only suture-mediated closure devices have been used to manage larger catheter-based percutaneous interventions. Two suture-mediated percutaneous closure devices currently are available for potential off-label use in the closure of endograft access sites: Perclose Prostar XL and Perclose ProGlide (Abbott Vascular, Redwood City, CA). The Perclose Prostar XL device comes in 2 different sizes. The Prostar XL 8 is designed for closure of 6.5F to 8F access sites, and Prostar XL 10 is for closure of 8.5F to 10F access sites. Compared with the Prostar XL device, the ProGlide is a lower-profile device that is relatively easier to use.

The Prostar XL device uses 2 crossing braided sutures in the artery that are then tied down for hemostasis. This device was indicated for access sites up to 10F and was designed to be used on completion of the procedure. Dosluoglu et al. showed that larger sheaths could be used if the device was placed at the beginning of the procedure, before upsizing to as large as 16F sheaths. This approach became known as the preclose technique for delivery of endografts. After the sutures are pre-deployed, they are organized and tagged with hemostats and set to the side. The subcutaneous tract is bluntly dissected to allow over-the-wire insertion of the endograft delivery system and various sheaths. A subsequent study has demonstrated that even larger sheaths could be used if a second Prostar device is deployed at 45° relative to the first device. At the end of the endograft procedure, the previously deployed sutures are used to close the arteriotomy by pushing the knots down to the level of the arteriotomy. A single Prostar XL 10 has been used to close sheaths up to 24F, but most interventionists would use 2 devices. The Perclose ProGlide device, introduced in 2004, is available for up to 8F sheaths and differs from the Prostar XL device to that it uses a monofilament polypropylene suture instead of 2 crossing braided polyester sutures. It is indicated for sheaths up to 8F. Two Perclose devices are often used to achieve the same effect as the Prostar XL device for large sheath access. To create the crossing suture pattern, the Perclose devices should be deployed with one rotated 45° clockwise and the other rotated 45° counterclockwise.

Although no risk-score modeling exists, the commonly used criteria in the selection of patients for a percutaneous approach include the following: at least a 1-cm segment of mid common femoral artery without anterior calcification, absence of severe scarring at the groin, no graft material at the access site, absence of a high common femoral bifurcation to preserve access length, and an arterial diameter that would allow insertion of the delivery device or sheath. Computed tomographic angiographic evaluation is essential in helping to determine which patients are appropriate for a percutaneous approach. Previous use of a ProGlide, a single prior femoral artery cut down, and obesity are not considered contraindications for a percutaneous approach.

Percutaneous Approach to Aortic Occlusive Disease

Percutaneous aortic stenting for aortic and iliac disease has been shown to be successful and durable. Wallstents (Boston Scientific, Natick, MA) were initially placed for primary infrarenal aortic stenosis with technical success and 91% patency at 5 years. In 1997, Sheeran and associates reported a series of midabdominal aortic stenoses that were treated with stent placement (percutaneous) in 9 patients. All
of the stenoses were atherosclerotic in nature except for one at the proximal anastomosis of an aortobifemoral graft, which may have been from fibrointimal hyperplasia. Seven of the 10 stenoses were treated with primary stent placement, whereas 3 stenoses were treated with stent placement after suboptimal angioplasty. As in the earlier reports, the technical success rate was 100%. Clinical success, defined as complete elimination of or improvement in symptoms present before stent placement, was achieved in 8 of the 9 patients with a mean duration of follow-up of 1.6 years. These results were then followed by many reports of successful aortic stenting in selected patients with focal midabdominal aortic stenoses.12–15

Recent studies have compared the myriad stent choices in the treatment of aortoiliac occlusive disease. Most suggest 1-year primary patency rates exceeding 85% regardless of stent choice.16,17 Despite this success, the published complication rate is 16%, citing both vessel wall rupture and distal embolization.18 Most surgeons, citing the Covered Versus Balloon Expandable Stent Trial (COBEST) trial, now opt for covered stents that are oversized to vessel wall diameter. This trial was a prospective, multicenter, randomized, controlled trial comparing covered and bare expandable stents.19 The investigators hypothesized that the use of covered stents would reduce intimal hyperplasia and prevent restenosis. There were no reports of atheroembolism complicating any of the procedures of patients enrolled in COBEST. There are case reports of atheroembolism after aortoiliac stenting,20 and the authors suggest that covered stents may protect against that complication. However, there are no randomized data to support this assertion. A small series from Klonaris et al21 hypothesized that the use of self-expanding stents would also trap any mural debris, thus preventing distal embolization. Additionally, the use of a covered stent would alleviate any concern about vessel wall rupture during the angioplasty process, which was seen in 2% of patients in prior studies.17,22 The results of this study showed that patients with stenoses treated with covered stents were more likely to remain free from restenosis at 18 months.19 A follow-up case series of 12 patients percutaneously treated focal infrarenal aortic occlusive disease with 100% success and zero of the aforementioned complications. Percutaneous stenting of focal aortic occlusive disease is a feasible option for many patients and is an attractive approach.

Placement of endovascular stents is the accepted therapy for iliac artery occlusive disease. The utility of selective provisional stenting to salvage iliac lesions after failed or unsatisfactory percutaneous transluminal angioplasty owing to elastic recoil, flow-limiting dissection, or residual gradient is well established. Self-expanding stents have been used in the external iliac arteries primarily because of their flexibility in tortuous system.23 In contrast, balloon-expandable stents have been used with excellent results in the common iliac vessels, where plaque burden is often more extensive and the vessels are less tortuous.19,24

**Percutaneous Abdominal and Thoracic Aneurysm Repair**

EVAR, first described by Parodi et al in 1991,1 has mostly supplanted the traditional open treatment of abdominal aortic aneurysm as a less invasive approach with decreased perioperative morbidity and mortality.25,26 In an effort to produce an even more minimally invasive option, percutaneous EVAR (PEVAR) was pioneered by Haas et al27 in 1999 using the Prostar XL and was shown at that time to be a safe and effective option for management of the femoral access site. Since that time, both the development of smaller-profile devices and the creation of another option for suture-mediated closure have allowed some centers to adopt a “percutaneous first” approach to EVAR.28 However, this approach has not been limited to high-volume or academic medical centers; the National Surgical Quality Improvement Program database revealed that, between 2005 and 2008, 44% of patients who underwent elective EVAR had a percutaneous approach.29 A few centers have even taken this a step further by attempting to perform PEVAR as an ambulatory procedure successfully in ≈30% to 40% of patients.30–32 It is conceivable that with lower-profile devices on the horizon and increased operator comfort with percutaneous closure, the prevalence of PEVAR will continue to rise.

The first EVAR devices were hand sewn on the back tables, sterilized, and then packaged into 28F to 30F sheaths for deployment. Most contemporary EVAR devices such as Zenith (Cook Medical, Indianapolis, IN), Excluder (W.L. Gore & Associates, Flagstaff, AZ), AFX (Endologix Inc, Irvine, CA), and Endurant (Medtronic, Minneapolis, MN) are deployed from 18F to 22F sheaths. Newer devices such as the Ovation Abdominal Stent Graft System (TriVascular Inc, Santa Rosa, CA) is deployed through a 14F sheath. However, the multicenter trial funded by TriVascular Inc revealed that only 43% were deployed via percutaneous access.33 This progressive decrease in profile should prove advantageous in facilitating percutaneous access. A recent meta-analysis showed a significantly decreased technical success rate when sheaths >20F were compared with sheaths <20F (88.7% versus 94.2%; P=0.001).34

Much of the literature on PEVAR points to management of the access site as the critical determinant of success. Most studies used a similar approach to percutaneous access and closure with use of the preclose technique in which 2 ProGlide 8F devices (Abbott Laboratories, Redwood City, CA) are placed into the access arteriotomy under ultrasound guidance at the 2 and 10 o’clock positions3 as detailed in the previous section. The use of ultrasound is preferable because it allows the operator to enter the vessel anteriorly and to evade calcification.35 Ultrasound-assisted femoral arterial access permits direct visualization of the blunt dissection channel down to the femoral artery. This visualization can identify tissue (ie, the inguinal ligament) that might prevent the sutures from sliding down onto the artery, leading to failure of the closure technique.35–38 There are many data to support this technique and the use of ultrasound guidance. The most compelling support for ultrasound guidance for PEVAR was published in a study by Sarmiento et al,7 who found that the use of ultrasound guidance led to a 10-fold greater likelihood of success compared with PEVAR without ultrasound guidance (P=0.03). Conflicting data suggest that reversal of anticoagulation may39,40 or may not41 influence the technical success rate of percutaneous access closure. It is also clear that there is a
learning curve associated with the use of closure devices. Two different studies revealed that operator inexperience predicts technical failure.\textsuperscript{41,42} Moreover, the learning curve for the pre-close technique is steep, with a mean 80% success rate after 15 cases and a 90% success rate after 30 cases.\textsuperscript{31} With the use of the aforementioned techniques, the overall success rates of PEVAR were excellent, with most studies quoting an incidence of 90% to 96%.\textsuperscript{7,31} One contemporary review of 22 articles that included 1087 patients revealed procedural success in 92% of patients.\textsuperscript{41} A larger meta-analysis including 36 articles and 2257 patients (3606 access sites) revealed success in 92% of patients (94% per access site). The majority (93%) were represented by a unilateral failure, and a small minority necessitated open surgery.\textsuperscript{5} Most technical failures were secondary to access site complications, with a rate of 3.6% in PEVAR. This was significantly higher (14.1%) in the open exposure group.\textsuperscript{5}

Many studies support a reduction in groin complications, including wound infection, seroma, hematoma, lymph leak, and pseudoaneurysm.\textsuperscript{43,44} When the percutaneous approach is used for endovascular repair of aneurysms, one such study quoted a >30% incidence of groin complications with EVAR compared with a <10% complication rate with PEVAR.\textsuperscript{32} The majority of access site–related complications with successful device deployment are hematomas and pseudoaneurysms, which typically do not require operative intervention.\textsuperscript{45,46} More serious access site–related complications such as thrombosis, dissection, and distal embolization are exceedingly rare and represent a minority of all complications.\textsuperscript{5,36}

Analyses examining hospital administrative data found that PEVAR led to decreased operative time.\textsuperscript{38,47} One meta-analysis averaged the operative time in 8 studies and found that PEVAR was significantly shorter by =30 minutes (106 versus 145 minutes).\textsuperscript{43} Another report examined the 2 different pre-close methods and compared them with open femoral artery exposure and found that operative time was on average 34 minutes shorter in the ProGlide group and 46 minutes shorter in the Prostar group. (\(P<0.001\)).\textsuperscript{46} Other variables that were examined and shown to be less in the PEVAR group were time to ambulation and length of stay.\textsuperscript{8,49}

Percutaneous thoracic endovascular repair (P-TEVAR) has also been performed with success rates similar to those of PEVAR using the preclose system with both the ProGlide and Prostar systems in the aforementioned fashion.\textsuperscript{46,50} The main determinant for P-TEVAR versus PEVAR is that the devices are larger (20F–26F). One study by Skagius et al\textsuperscript{46} examined 118 patients undergoing P-TEVAR and found that the incidence of technical failure was 8%, with the majority of failures requiring operative repair of the access site vessel. Another study by Ni et al\textsuperscript{10} revealed a 100% success rate with P-TEVAR and shorter operative time (96±33 versus 127±41 minutes; \(P<0.01\)) and hospital stay (15±6.8 versus 19.5±7.8 days; \(P<0.01\)). Lee et al\textsuperscript{5} published the largest single-center experience with P-TEVAR that demonstrated no significant difference in success rates of EVAR, PEVAR, and P-TEVAR, although they did show a trend toward increased success with smaller-diameter devices (12F–16F; 99.0%; versus 18F–24F, 91.4%; \(P<0.01\)). This study not only supported the feasibility of P-TEVAR but also provided more evidence that it leads to shorter operative time (80 versus 112 minutes; \(P=0.019\)) compared with TEVAR with open femoral access.\textsuperscript{9} These studies suggest that P-TEVAR is used with high success rates despite the increase in sheath size. The technical success rate of Prostar XL for closure of large (20F) femoral vascular access sites in TEVAR was investigated more recently during a 5-year period. Primary technical failure occurred in 10 of 118 access sites (8%). These cases were converted to open surgical repair, femoral fascia suturing, or external compression. Primary failure was associated with hypertension, old age, and an increased groin subcutaneous fat layer. Late access-related complications included pseudoaneurysms, hematomas, superficial groin infections, and deep venous thrombosis. None required surgical treatment.\textsuperscript{46}

**Percutaneous Management of Aortic Dissection**

The intention of therapy in patients with aortic dissection is to prevent aortic rupture (either in the acute phase or as a delayed complication of aneurysmal widening of the false lumen) and relief of branch vessel ischemia. Until approximately a decade ago, the management of aortic dissection was almost exclusively surgical. During the last 20 to 22 years, a number of minimally invasive catheter-based techniques have emerged that have significantly improved the management of patients with aortic dissection. These techniques include stent grafting for entry site closure to prevent aneurysmal widening of the false lumen\textsuperscript{51} and balloon fenestration with or without stenting of the aortic true lumen to alleviate branch vessel ischemia.\textsuperscript{52} For the stent graft implantation, a femoral arteriotomy is often necessary. Although this is carried out under general anesthesia in most centers, the procedure can also be performed under local anesthesia. In exceptional cases, surgical exposure of the iliac arteries may be necessary.\textsuperscript{53} Percutaneous management of branch vessel disease with stents has become routine.\textsuperscript{54}

Percutaneous management of thoracic aortic dissection was first reported in 2002.\textsuperscript{55} The stent graft device was composed of Gianturco stents connected with longitudinal wire struts covered with radially expanded polytetrafluoroethylene. The delivery sheath sizes were 14F to 20F. The procedures were performed with use of Perclose devices to achieve hemostasis. Successful femoral closures were achieved in 93% of patients (14 of 15) with use of the suture-mediated devices. In 7% of patients (1 of 15), surgical closure of the femoral arteries was required. The rate of pseudoaneurysm occurrence was 7% (1 of 15).

The rationale behind fenestrating the dissection flap is to equalize pressures in the 2 lumina and to improve blood flow to the ischemic vessels. Fenestration is often performed with the use of intravascular ultrasound (IVUS) guidance.\textsuperscript{56} One advantage of IVUS is that all catheter manipulations can be carried out from a single lumen without necessarily having to gain access to both lumina. Second, after perforation of the intimal flap with the needle-catheter combination, the entry of the catheter from one lumen into the other can be well visualized with IVUS by merely sweeping the IVUS catheter up and down the aorta. An angiogram is not necessarily required for this purpose.\textsuperscript{57} Third, dynamic obstructions are best visualized with IVUS; however, balloon fenestrations have also been carried out under fluoroscopy without IVUS. In such cases, angiograms in multiple projections may be necessary.
Although femoral pulses may be poorly palpable or totally absent as a consequence of the dissection, it is almost always possible to gain percutaneous femoral access. A point to bear in mind is that the flow through the needle after puncturing may not be as pulsatile as in normal vessels. For perforating the intimal flap, various combinations of catheters and guidewires or transeptal needles have been used. The improvement in flow between the 2 lumina after balloon fenestration may be a localized phenomenon. Consequently, the fenestration should be as close to the ischemic vessels as possible so that these vessels benefit maximally from the opening created in the intimal flap. Two or 3 fenestrations may be necessary to attain satisfactory results, especially in patients with ischemia involving multiple vascular territories. The result of the fenestration may be assessed by pressure measurement in the lumina, angiography, and IVUS. A decrease in the pressure gradient between the lumens signifies satisfactory fenestration.

A subset of patients who deserve mention in the discussion of aortic dissection are those with connective tissue disorders such as Ehlers-Danlos IV, Marfan, and Loeyes-Deitzi syndromes. There are very few data on the endovascular treatment of aortic pathology in these patients; available data are confined mostly to case reports and small series. There is no available literature on percutaneous treatment. A meta-analysis by Pacini et al identified 54 patients with connective tissue disorders who underwent endovascular management of their aortic dissection that resulted in a heightened rate of endoleak and reoperation and a higher mortality rate compared with historical data on open repair. The consensus opinion of Society of Thoracic Surgeons Endovascular Task Force recommends against placing stent grafts in the thoracic aorta of patients with connective tissue disorders unless there is a strong contraindication to an open procedure. Thus, by default, a percutaneous approach to placement of stent grafts would also be ill advised. One case series examining 31 family members with Ehlers-Danlos aortic disease revealed that 8 of 12 patients who underwent percutaneous diagnostic or interventional angiographic procedures had access site complications, including 2 deaths. Other literature supports open femoral artery exposure for any endovascular procedure to femoral artery exposure for any endovascular procedure to

Percutaneous Management of Coarctation

In 1944, Robert Gross and Clarence Crafoord independently performed the first successful surgical repairs of coarctation of the aorta. During the ensuing 4 decades, surgery remained the only treatment for coarctation. In the late 1970s, percutaneous balloon angioplasty was described as an alternative to surgical repair. Since then, transcatherter interventions have become increasingly popular and in many cases have emerged as the treatment of choice. A lasting result of balloon dilation typically involves a therapeutic tear of the intima and, at least partially, the media to the adventitia; such a therapeutic tear is confined to the narrowed zone. These tears predispose for possible complications such as dissection, false aneurysm, and rupture. The false lumen of such a dissection may be progressive and cause distal tearing of the vessel wall or occlusion of side vessels. A false aneurysm is a defect in the aortic wall, with contrast beyond the presumed adventitial plane with a discrete length; such a false aneurysm in time may “grow” and eventually tear. An aortic rupture is a frank disruption of the aortic wall, which appears angiographically as extravasation of contrast beyond the confinement of the aorta into the mediastinum or pleural space. A relatively high incidence of aneurysm formation of 2% to 20% has been reported after balloon dilation.

Since 1989, bare metal stents have been used to treat narrowing of the aorta. Stents neutralize many of the shortcomings of balloon dilation. Stents expand and scaffold the targeted region, thereby avoiding recoil and residual or recurrent stenosis. A good result can be obtained by simple stretching of the wall without a tear; there is no need for overdilation. Therefore, stenting results in fewer vessel wall complications: fewer aneurysms, no dissections within the stent because they are automatically contained by sealing the intimal flap, and less rupture. When intimal tears occur, the stent provides a surface for formation of neointima over the tear and reinforces the weakened areas within the aortic wall, which may later predispose to formation of a false aneurysm. The use of bare metal stents improved results, further reducing the complication rate of vessel wall trauma to 1% to 5%. Stent implantation is not without some shortcomings: The technique is technically more demanding and requires a bigger sheath.

Initially, stent implantation was used only for patients in whom surgery and balloon angioplasty had failed. However, as experience increased, stenting gradually became the treatment of choice in selected patients with aortic coarctation. This is especially the case when coarctation coexists with hypoplasia of the isthmus or transverse arch or when balloon dilation tends to have a high failure rate. The stent provides good results with stretching only. These and other morphological variations such as a tortuous coarctation, long segment coarctation, or mild discrete coarctation are now considered candidates for primary stenting. In adult patients, stenting is now being considered the treatment of choice in any variant of aortic coarctation. At the other end of the scale, in children <10 years of age, it is preferable to avoid stenting because serial redilations may be required until the child is fully grown.

The addition of covered stents has further reduced the incidence of intrastent aneurysm formation and vessel rupture to <1%; the covering will seal any tear in the vessel wall. Covered stents allow clinicians to exclude an unwanted passage to an arterial duct or an existing aneurysm and allow the creation of a new vessel segment as in aortic arch atresia.

Significant femoral vessel injury was reported in the Congenital Cardiovascular Interventional Study Consortium in a total of 15 of 588 procedures (2.6%). One patient had placement of the arterial sheath above the inguinal ligament and developed a retroperitoneal hematoma. Vessel thrombosis is more frequent in small children. In this pediatric population, if there is loss of pulse after catheterization, the recommendation is to institute heparin therapy for 24 hours. If the pulse has not returned after 24 hours or if the viability of the leg is
a concern at any point, thrombolytic therapy or surgery may be indicated.

**Percutaneous Management of Thoracic Aortic Trauma**

Thoracic aortic injury carries a mortality rate of >90%, with 80% of these individuals dying at the scene. The landmark study by Parmley and colleagues documented a mortality rate at the scene of as high as 85% and a subsequent mortality rate in nonoperated survivors of 1%/h for the first 48 hours. Aortic injuries are responsible for up to 15% of all deaths after motor vehicle accidents. Since the mid-1990s, aortic injuries have been treated with immediate surgery or endovascular stent graft placement in the operating room. This has led to a significant reduction in mortality with aortic injuries and vascular access site complications in the multiply injured patients.

In the first report of patients undergoing percutaneous repair of a traumatic thoracic aortic tear, a 10F Prostar XL device was deployed using the previously described preclose technique. The floppily wire was then exchanged for a superstiff wire. Over this wire, and depending on the stent graft used, an 18F to 22F sheath was exchanged and passed proximally into the thoracic aorta. This larger sheath was used to deliver the endovascular graft, which was placed over the area of transection and deployed without the use of chemically induced cardiac arrest or hypotension. After deployment, angiograms were performed and additional stent grafts were placed as needed. Compliant aortic occlusion balloons were selectively used to obtain stent graft apposition to the aortic wall if an endoleak was noted. The diameter of the devices used was based on previously recorded measurements of the aortic lumen diameter by computed tomography scan performed preoperatively. The devices were oversized by ≈20%. In most cases, the aorta was too small for an available thoracic stent graft. Therefore, ≈75% of the patients received an endovascular repair with multiple overlapping smaller-diameter abdominal aortic proximal extension cuffs. In a 7-year follow-up of 24 patients, there were 2 vascular access site complications (8%) that required an iliofemoral bypass in 1 patient and a thrombectomy in another. This series demonstrates that the adaptation of commercially available stent graft devices to treat blunt thoracic aortic injury is technically feasible and can be performed entirely percutaneously with low rates of morbidity and mortality.

**Percutaneous Repair of Endoleaks After EVAR**

Unlike the minimal imaging required after open repair, patients undergoing endovascular repair of the aortic and thoracic aneurysm repair require lifelong postoperative surveillance imaging to detect some of the complications unique to the endovascular approach. These include endoleak formation, endograft migration, endograft fracture, and aortic neck dilatation. The term endoleak, originally proposed by White et al., is defined as blood flow outside the endograft lumen and within the aneurysm sac. A classification system created for endoleaks after both EVAR and TEVAR according to the source of blood flow causing the leak is depicted in the Figure.

Type I endoleaks result from blood flow that originates from the proximal (type Ia) or distal (type Ib) endograft attachment sites. Separation between the endograft and the aortic wall at these locations creates direct communication with the aneurysm sac and systemic circulation. This is the most common type of endoleak associated with TEVAR and mandates intervention, as discussed subsequently.

Type II endoleaks result from retrograde blood flow into the aneurysm sac from aortic branch vessels as blood flows through branches from the nonstented segment of the aorta through the anastomotic connections and into vessels with a direct communication with the aneurysm sac. The most common branches involved in type II endoleaks are the intercostal and bronchial arteries and the left subclavian artery. These endoleaks are most often managed conservatively with close observation.

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**Figure.** Classification of endoleaks. Schematic demonstrating the different types of endoleak after endovascular aneurysm repair. Type I endoleaks occur when an inadequate graft seal results in perigraft flow and include (Ia) perigraft flow occurring proximally, (Ib) perigraft flow occurring distally, and (Ic) perigraft flow around an iliac artery occlusion device. Type II endoleaks occur when branch arteries back-bleed because of collateral flow. These endoleaks include (IIa) back-bleeding inferior mesenteric artery and (IIb) back-bleeding lumbar artery. Type III endoleaks occur when flow persists between the segments of a modular graft and include (IIa) leaks between iliac limbs or an iliac limb and main body component and (IIb) leaks between main body components. Type IV endoleaks (IV) occur when flow is present through endograft material (graft porosity). Type V endoleak, or endotension (V), occurs when persistent or recurrent pressurization of the aortic aneurysm exists in the absence of demonstrable endoleak. Reproduced from Eliason and Upchurch.
Type III endoleaks occur when there is a structural defect within the endograft such as fabric disruption or tear or when disconnection occurs between 2 endografts in modular devices. Similar to type I endoleaks, type III endoleaks require intervention.

Type IV endoleaks are caused by endograft porosity and are frequently identified at the time of graft implantation on the postimplantation angiogram when patients are fully anticoagulated. They require no specific intervention and tend to resolve spontaneously with normalization of the coagulation profile.

Type V endoleaks are also called endotension, which refers to expansion of the aneurysm sac without the presence of an identifiable endoleak. They are rare, and although the exact origin of endotension is unknown, causes may include ultrafiltration of the endograft, an undiagnosed endoleak, or thrombus providing an ineffective barrier to pressure transmission. Often, the cause is not discovered, and open surgical conversion is required if the aneurysm sac grows.

Once an endoleak has been confirmed, management has generally consisted of aggressive endovascular repair of type I and III endoleaks and observation of type II endoleaks. Type I and III endoleaks result in a direct communication between the systemic blood flow and the aneurysm sac, leading to significant pressurization of the sac and risk of rupture. It is therefore essential that these endoleaks be repaired at the time of diagnosis. The reported incidences of endoleaks vary widely, from 15% to 52%, and many patients subsequently require an endovascular or surgical reintervention.95–98 Reinterventions for type I and III endoleaks usually required endovascular placement of aortic cuffs, graft extensions, or both. In the early approach to repair type I and III endoleaks, open femoral access was used uniformly.91 Early reports of percutaneous transabdominal coil embolization of type I endoleak indicated a 50% failure rate.92 In a follow-up study, these investigators supplemented coil embolization with N-butyl cyanoacrylate embolization and achieved 100% success rate in closing type I endoleaks using a percutaneous approach.91

There is continuing uncertainty about the management of patients with type II endoleaks and endoleaks of undefined origin. Several techniques have been described to treat these endoleaks, including transarterial, transcaval, and translumbar approaches.94–96 Type II endoleaks occur in 10% to 30% of patients after EVAR and may be associated with aneurysm growth and rupture. Subdivision of type II endoleaks into transient (resolving within 6 months) and persistent (present beyond 6 months) has been found to predict EVAR-related complications. Persistent type II endoleaks have been associated with an increased incidence of adverse outcomes, including aneurysm sac growth, secondary intervention rate, the need for conversion to open repair, and rupture. Based on these observations, a strategy of selective secondary intervention for type II endoleaks in the presence of aneurysm sac expansion and persistence beyond 6 months postoperatively has been adopted. Access to the aneurysm sac can be achieved via multiple approaches and is patient specific. The location of the endoleak on computed tomography scan dictates the access that is chosen. If the inferior mesenteric artery is involved, then a superior mesenteric-to-inferior mesenteric artery access via the marginal artery of Drummond may be chosen. If the endoleak involves only the lumbar arteries, then a transfemoral or a hypogastric approach can be used. Translumbar access is frequently used for all types of persistent type II endoleaks because it gives direct access to the aneurysm sac.97

Future Challenges

Percutaneous Arch Reconstructions

Lately, a combined endovascular and open approach has been adopted as a valuable alternative, consisting of supra-aortic debranching and revascularization, followed by stent graft deployment.99 Debranching is performed to provide an appropriate landing zone for the stent graft and to preserve perfusion to the supra-aortic trunks. Although this approach provides an attractive alternative for treating aortic arch lesions, most of these adjunctive procedures remain major operations and result in not insignificant perioperative mortality. Branched stent grafts have been proposed, providing complete percutaneous aortic arch repair. However, the disadvantages of this modular approach are the required time to manufacture and deliver such custom-made stent grafts for urgent cases, the high cost of this kind of modular devices, and, most important, the high rate of embolism associated with this technique that is probably related to the complexities of multibranched unibody stent graft deployment. During endovascular treatment of aortic arch disease, difficulties of side-branch catheterization result in a high inherent risk of cerebral embolism. The use of readily available “on the shelf” endovascular materials would decrease the costs of endovascular repair and increase the accessibility to these minimally invasive techniques for a greater number of patients. Retrograde in situ fenestration seems to offer an appropriate solution to most of these issues, allowing more accurate fenestration placement with less reliance on preoperative imaging and reducing the number of catheter and guidewire manipulations in the aortic arch. The first report of successful retrograde in situ fenestration in bench and animal models was followed by clinical application in the left subclavian artery in 2003.99 This approach was used in the emergency clinical setting to treat an acute aortic arch rupture.100 These clinical reports use widely varying techniques to fashion fenestrations, but the reproducibility of this approach should be demonstrated before larger clinical application.

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Disclosures

None.

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