Complications of endovascular aneurysm repair of the thoracic and abdominal aorta: evaluation and management

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Abstract: In recent decades, endovascular aneurysm repair or endovascular aortic repair (EVAR) has become an acceptable alternative to open surgery for the treatment of thoracic and abdominal aortic aneurysms and other aortic pathologies such as the acute aortic syndromes (e.g., penetrating aortic ulcer, intramural hematoma, dissection). Available data suggest that endovascular repair is associated with lower perioperative 30-day all-cause mortality as well as a significant reduction in perioperative morbidity when compared to open surgery. Additionally, EVAR leads to decreased blood loss, eliminates the need for cross-clamping the aorta and has shorter recovery periods than traditional surgery. It is currently the preferred mode of treatment of thoracic and abdominal aortic aneurysms in a subset of patients who meet certain anatomic criteria conducive to endovascular repair. The main disadvantage of EVAR procedures is the high rate of post-procedural complications that often require secondary re-intervention. As a result, most authorities recommend lifelong imaging surveillance following repair. Available surveillance modalities include conventional radiography, computed tomography, magnetic resonance angiography, ultrasonography, nuclear imaging and conventional angiography, with computed tomography currently considered to be the gold standard for surveillance by most experts. Following endovascular abdominal aortic aneurysm (AAA) repair, the rate of complications is estimated to range between 16% and 30%. The complication rate is higher following thoracic EVAR (TEVAR) and is estimated to be as high as 38%. Common complications include both those related to the endograft device and systemic complications. Device-related complications include endoleaks, endograft migration or collapse, kinking and/or stenosis of an endograft limb and graft infection. Post-procedural systemic complications include end-organ ischemia, cerebrovascular and cardiovascular events and post-implantation syndrome. Secondary re-interventions are required in approximately 19% to 24% of cases following endovascular abdominal and thoracic aortic aneurysm repair respectively. Typically, most secondary reinterventions involve the use of percutaneous techniques such as placement of cuff extension devices, additional endograft components or stents, enhancement of endograft fixation, treatment of certain endoleaks using various embolization techniques and embolic agents and thrombolysis of occluded endograft components. Less commonly, surgical conversion and/or open surgical modification are required. In this article, we provide an overview of the most common complications that may occur following endovascular repair of thoracic and AAAs. We also summarize the current surveillance recommendations for detecting and evaluating these complications and discuss various current secondary re-intervention approaches that may typically be employed for treatment.

Keywords: Endovascular aneurysm (or aortic) repair (EVAR); thoracic endovascular aneurysm repair (TEVAR); abdominal aortic aneurysm (AAA); imaging surveillance; endograft; secondary endovascular interventions

Introduction

Endovascular repair of the thoracic and abdominal aorta is an important advance in the treatment of aortic aneurysms and other aortic pathologies. Since the U.S. Food and Drug Administration (FDA) approved the use of endograft devices, there has been a 600 percent increase in the annual number of endovascular aneurysm (or aortic) repair (EVAR) procedures performed (1). Endovascular abdominal aortic aneurysm (AAA) repair and thoracic endovascular aneurysm repair (TEVAR) currently account for nearly 50% of all aortic aneurysm repairs that are performed in the U.S. (1). In recent years, there has been an overall decrease in the incidence of ruptured aneurysms, likely due a combination of improved AAA screening, and increased rates of elective endovascular repairs in patients who would not otherwise be surgical candidates (1). While these techniques were initially used for the treatment of patients who were deemed high-risk surgical candidates, emerging data in recent years proving their safety profile have made EVAR the preferred treatment techniques for many patients with aortic aneurysms due to the decreased perioperative morbidity and the comparable to improved outcomes of these procedures relative to open surgical repair (2-9).

EVAR involves the placement of a prosthetic endograft within the thoracic or abdominal aorta at the site of an aneurysm or other pathologic process that threatens the integrity of the aorta. The various endograft components are typically compressed within a delivery sheath and are introduced into the vascular system through the lumen of an access vessel, to be subsequently deployed at the site of the aneurysm. Once deployed at the target site of treatment, the endograft self-expands to contact the aortic wall thereby excluding the weakened aortic wall or aneurysm sac from the pathologic increased flow and pressure that might otherwise lead to aortic/aneurysm rupture. Among the most important determinants for the success of an endovascular repair are the anatomic suitability of the patient's vasculature for device placement, and the choice of an endograft that is of appropriate size and configuration for the patient's anatomy and aortic morphology. The device must provide adequate seals or fixation proximally and distally at the endograft landing zones in order to successfully exclude the aneurysm sac. To be a suitable candidate for EVAR, certain general anatomic criteria must be fulfilled including an aortic aneurysm proximal neck size that measures 18–32 mm in diameter and is greater than 10 mm in length, a neck angulation that is typically less than 45–60 degrees (depending on the device used), a common iliac artery diameter between 8–22 mm and an external iliac diameter greater than 7 mm (10). If the planned positioning of the endograft is expected to cover important aortic side branch vessels, debranching procedures may be needed prior to graft placement or fenestrated endografts may be required.

AAA repair is indicated in patients with symptomatic aneurysms, in those who have an aneurysm diameter greater than 5.5 cm, or in those whose aneurysm has expanded by more than 0.5 cm in a 6-month interval (2). Similarly, repair is indicated for thoracic aortic aneurysms in symptomatic patients, patients with an aortic size index equal to or greater than 2.75 cm/m^2, patients with aortic diameters of 6 to 7 cm, patients with genetically-mediated conditions that are associated with aortic pathology or patients with aneurysm diameter expansion of greater than 10 mm per year (11-13). In patients whose anatomic criteria are suitable, EVAR is typically the preferred means of treatment. Absolute contraindications to EVAR include various unfavorable anatomic features such as excessive aortic tortuosity and angulation, a hostile proximal neck with circumferential calcification, excessive mural thrombus or an extremely conical configuration, and extremely small-caliber access vessels. There are also certain relative contraindications such as the inability or unwillingness to comply with post-procedural surveillance imaging.

EVAR of the abdominal aorta conveys a number of advantages when compared to open aneurysm repair. Available data show perioperative survival benefit as compared to open surgery. In a systematic review of 1,532 patients, endovascular repair was associated with a significantly lower 30-day mortality (1.6%) than open surgery (4.8%) (14). The survival advantage conveyed by endovascular repair is even greater in high-risk surgical candidates where the 30-day post-procedure mortality rate was found to be 4.7% compared to 19.2% in those who underwent open repair (15). To our knowledge, no randomized studies are available comparing open and endovascular repair in the thoracic aorta. However, observational studies suggest equivalent or better overall outcomes (16). EVAR of the abdominal aorta is also associated with a significant reduction in perioperative morbidity when compared to open surgery, with decreased blood loss, elimination of the need for cross-clamping the aorta intraprocedurally and shorter recovery periods (1,17-20). Specific to thoracic aneurysm repair, TEVAR provides the advantage of avoidance of sternotomy and thoracotomy, both of which carry high patient morbidity (20).

While EVAR is associated with improved short-term survival in patients with aortic aneurysms, it is important to note that available data do not show long-term improvement in survival benefit when compared to open repair. In a review of 22,830 matched Medicare patients who underwent endovascular and open repair, lower perioperative mortality was again demonstrated (21). However, the overall mortality was similar between the two groups at 3 to 4 years post-procedure (21). Because endograft imaging surveillance is mandatory for the remainder of a patient's life after EVAR, the risk of the long-term radiation exposure associated with imaging makes the use of this technique somewhat controversial in young patients who are otherwise good surgical candidates, given the equivalent long-term survival outcomes of the two techniques. The decision to pursue endovascular or open repair should be personalized to each patient and should be based on the patient's age, surgical risk and vascular anatomy.

With EVAR, the preferred intervention for the majority of patients with aortic aneurysms, an increasing number of complications are being reported as a result of the marked increase in the number of these procedures that are being performed (22). Emerging data show that endograft-related complications are relatively common. Following EVAR for AAA, the rate of complications has been reported to range between 16% and 30% with secondary interventions needed in up to 19% of patients (23-28). For TEVAR, late complications have been shown to occur in up to 38% of patients with secondary intervention required in approximately 24% of cases (9,29-32). In this article, we summarize the current surveillance recommendations for detecting and evaluating complications following EVAR of the thoracic and abdominal aorta. We also provide an overview of commonly reported complications and discuss the secondary interventions typically performed for treatment.

Endograft surveillance and evaluation

Current surveillance recommendations

Lifelong post procedure imaging surveillance is currently recommended in all patients following endovascular repair of the thoracic and abdominal aorta so as to evaluate the long-term performance of the endoprosthesis. Imaging is essential for assessment of the integrity of the endograft and for confirmation of the stability of or a decrease in the size of the excluded aneurysm sac. If a post-procedural complication or abnormality is detected by clinical or imaging surveillance, the latter can also be used to further evaluate and characterize the abnormal finding; commonly occurring post-procedural problems include endoleaks, endograft migration or collapse, limb kinking and/or stenosis and endograft infection. Imaging techniques that are used for surveillance include conventional radiography, computed tomography (CT), ultrasonography, nuclear imaging, magnetic resonance angiography (MRA) and conventional angiography, with CT considered as the gold standard modality. These techniques are summarized in *Table 1*. Current guidelines for surveillance imaging post-endovascular repair recommend imaging at 30 days, 6 and 12 months following the procedure and yearly thereafter, if no complications are detected (11,33).

Conventional radiography

Conventional radiography can provide an overview of graft positioning and integrity and conveys the advantage of low surveillance cost and low radiation exposure (34). Anteroposterior (AP) radiographs can be helpful in detecting endograft migration and separation of modular endograft components (35). Supplemental oblique views can be used to detect wire fractures (35). However, conventional radiography is rarely used alone for post-procedural surveillance but may instead be used as a complement to other imaging modalities. There are multiple disadvantages of using conventional radiography for surveillance, such as the inability to evaluate the size of the residual aneurysm sac or to detect soft tissue and flow-related complications such as endoleaks and graft infections, many operators and institutions no longer routinely use this imaging technique for endograft evaluation.

CT and CT angiography (CTA)

CT is considered the gold standard technique for surveillance imaging in patients who have undergone EVAR. Typical CT imaging protocols include a non-contrast phase, an arterial imaging phase and a delayed imaging phase at 120–300 seconds. Non-contrast imaging is necessary so as to differentiate high density material such as calcification that may be present in the aneurysm sac from abnormalities such as endoleaks that may be seen on subsequent later phase imaging. Arterial and delayed-phase imaging are used to assess endograft integrity, to detect

Table 1 Applications of existing imaging modalities in patient surveillance following endovascular aortic repair

Modality	Best use	Advantages	Disadvantages
Radiography	Adjunct to other modalities	Low cost	Inability to evaluate aneurysm sac
		Low radiation exposure	Inability to detect endoleaks
Computed tomography (CT)	Gold standard for surveillance	High sensitivity for detection of complications	Radiation exposure
		Better spatial resolution than ultrasound and MRI	Requires iodinated contrast administration
		Widespread accessibility	
		Low cost	
Magnetic resonance angiography (MRA)	Standard for surveillance in patients with iodinated contrast allergy	No radiation exposure	Limited availability
		No need for iodinated contrast in cases of contrast allergy	High cost
		No need for gadolinium if poor renal function (TOF-MRA)	Long scan times
Ultrasonography	Adjunct to other modalities; can be used in patients with contraindication to CT and MRA	Low cost imaging	High inter-operator variability
		Widespread availability	Image quality dependent on patient's body habitus
		Lack of ionizing radiation	
		Avoidance of iodinated contrast	
Nuclear imaging	Detection of endograft infection	Helps distinguish infection from postoperative changes in immediate postoperative period	Limited applications
			Long scan times
			Requires nuclear tracer administration
Conventional angiography	Pre-procedural planning	Can detect directionality of endoleaks	Invasive procedure
		Can detect culprit inflow vessels in type II endoleaks	Non-negligible risks of complications secondary to vascular access
		Can be combined with endovascular re-intervention	

TOF-MRA, time-of-flight MRA.

and characterize endoleaks and to assess for the presence of other abnormalities such as limb occlusion or endograft infection. The diameter or volume of the residual aneurysm sac should be measured on each surveillance scan in order to ensure stability or to demonstrate a decrease in the size of the excluded sac. We typically measure the largest diameter of the aneurysm sac using a double-oblique short-axis orientation, so as to improve measurement accuracy and increase inter-reader reproducibility. Many operators advocate calculation of the residual aneurysm sac volume as the most accurate measurement, if appropriate post-processing software is available.

CTA provides 92% sensitivity for the detection of endoleaks and offers better spatial resolution for the assessment of the endograft relative to ultrasonography and MRA (36,37). In addition, CT conveys the advantage of widespread accessibility and relatively low cost when compared to other imaging modalities. Despite these advantages, significant concerns remain about the cumulative radiation exposure and the need for the repetitive administration of iodinated contrast (34,38). Cumulative radiation exposure is of particular concern in younger patients undergoing yearly surveillance CT scans. Similarly, administration of iodinated contrast

is problematic in patients who are at risk for contrast-induced nephropathy. Recent advances in dual-source dual-energy CT and other image reconstruction approaches are promising for radiation dose reduction (39,40). Reduced contrast-dose techniques are also being actively explored so as to reduce the risk of contrast-induced nephropathy (41).

MRA

MRA is considered an alternative to CTA for post-EVAR surveillance imaging (42). Typical imaging protocols include an axial T1-weighted gradient echo sequence, a single-shot fast spin echo sequence and pre- and post-contrast sequences. Non-contrast time-of-flight MRA (TOF-MRA) imaging can also be performed and is especially useful in patients with poor renal function or those who have a contraindication to gadolinium use. Unlike CT, TOF-MRA also allows the detection of the directionality of blood flow. Recent data suggest that MRA is superior for the imaging of nitinol endografts as compared to CT (43). Otherwise, gadolinium-enhanced MRA is equivalent to CTA in sensitivity for the detection of endoleaks. When TOF-MRA imaging is used alone in patients with a low estimated glomerular filtration rate (eGFR), its sensitivity for endoleak detection can be as low as 54% (44). However, when TOF is used in conjunction with gadolinium-enhanced MRA, it has 97% concordance with angiography for the detection of endoleaks (45).

MRA conveys several advantages when compared to CTA including the use of non-ionizing radiation for imaging and the avoidance of the administration of iodinated IV contrast. MRA is especially useful in patients who have an iodinated contrast allergy or who have other contraindications to receiving these contrast media. Potential drawbacks to MRA use include the more limited availability of MR as compared to CT, the higher imaging costs, longer scan acquisition times, use in claustrophobic patients and the inability to clear all patients for imaging by magnetic resonance. In patients undergoing contrast-enhanced magnetic resonance imaging (MRI), emerging evidence also suggests that there is gadolinium deposition and accumulation in the central nervous system even in patients with normal renal function (46,47). Although the clinical significance of gadolinium deposition in the brain remains unclear, care should be taken when using MRI for patient surveillance until further data is available about the long-term safety of gadolinium-based agents.

Ultrasonography

Ultrasound can be quite useful for the surveillance of a patient following EVAR. A typical post-procedure ultrasound protocol includes B-mode imaging of the abdominal aorta, iliac arteries and femoral arteries in transverse and longitudinal orientations in order to assess the endograft, the landing zones and the size of the residual aneurysm sac. The examination should also include the use of color and power Doppler so as to confirm endograft patency and to assess for flow directionality and the presence or absence of endoleaks. Emerging data suggest that contrast-enhanced ultrasound (CEUS) with non-targeted microbubbles can be used to enhance the sensitivity of ultrasound in endoleak detection (48). A recent systematic review also suggested that CEUS has high sensitivity for detecting endoleaks and can be introduced as a routine diagnostic modality to be followed by CTA only when the ultrasound is positive to further characterize an endoleak (49). Ultrasound is reported to have a specificity of 93–94% and a sensitivity of 70–82% for the detection of endoleaks (49-51).

Ultrasound imaging for surveillance following EVAR offers the advantage of low-cost imaging, widespread availability, a lack of ionizing radiation and the avoidance of iodinated contrast use. However, ultrasound suffers from high inter-operator variability and the quality of the collected images is highly dependent on the patient's body habitus. Evaluation of endograft integrity and positioning is also limited with ultrasound. Accordingly, ultrasound remains an adjunctive technique in surveillance and is rarely used as the sole surveillance tool unless the patient has contraindications to both CT and MRA.

Nuclear imaging

Nuclear imaging techniques have been found to mostly be useful for the detection and characterization of an endograft infection, with labeled white blood cell (WBC) imaging, gallium scanning and FDG-PET imaging all having demonstrated roles (52,53). The sensitivity of these techniques for the detection of endograft infection has been reported to range between 60% and 100% (52,54). Nuclear imaging is especially useful in the immediate post-operative period when endograft infection is suspected. It has been shown that nuclear imaging during that period is more sensitive than CT for the detection of graft infection (52,55).

Table 2 Common device-related and systemic complications post endovascular aortic repair and recommended management approaches

Complications	Management
Device-related complications	
Endoleaks	
Type I	Use of touch-up balloon; endograft extension(s); endostaples
Type II	Transarterial, translumbar or transcaval embolization; ligation of inflow vessel(s)
Type III	Use of additional endograft or additional iliac limb grafts
Type IV	No specific treatment; if symptomatic, endovascular relining of graft
Type V	No specific treatment; if symptomatic, endovascular relining of graft
Stent migration	Use of large balloon-expandable stents; endostaples
Endograft infection	Antibiotics; resection of infected graft with placement of antibiotic-soaked graft
Limb kinking or occlusion	Endovascular conversion; angioplasty; stent placement; thrombolysis; femoro-femoral bypass
Endograft collapse	Relining of collapsed graft; axillo-bifemoral bypass
Systemic complications	
Ischemia	
Limb ischemia	Same as management options for graft limb occlusion mentioned above
Renal ischemia	Repositioning the graft inferiorly or stenting of involved renal arteries
Bowel ischemia	Bowel resection
Pelvic ischemia	No intervention typically needed; symptoms improve with time
Spinal cord ischemia	Staged repairs or spinal drainage
Cerebrovascular accidents	Standard stroke management guidelines
Post-implantation syndrome	Patient surveillance and aspirin; no antibiotics needed

The use of ^{99m}Tc-labeled red blood cells and technetium-99m sulfur colloid has been proposed for the detection of endoleaks in post-endovascular repair surveillance imaging. However, available data show that these techniques exhibit significantly lower sensitivity when compared to CT (56,57).

Conventional angiography

CTA and MRA are more sensitive than digital subtraction angiography (DSA) for the detection of complications following EVAR (34,36). DSA is currently used for pre-procedural planning or intraprocedural guidance prior to or during secondary interventions. Post-procedural DSA also allows one to bypass immediate follow-up post-procedural imaging in patients who have clinically apparent post-EVAR complications. DSA is especially useful for the detection of the directionality of an endoleak and for identifying the culprit inflow vessel in type II endoleaks.

DSA, however, is an invasive procedure and carries non-negligible risks including access site complications such as hematoma or pseudoaneurysm formation, and other adverse events like arterial dissection or thrombosis, retroperitoneal hemorrhage, and vessel rupture.

Endovascular repair complications and their management

Device-related complications

Endoleak

Endoleaks are the most commonly occurring complication following EVAR. The most common complications are summarized in *Table 2*. Endoleaks represent persistent blood flow perfusing the residual aneurysm sac thus indicating failure to completely exclude the aneurysm. There are five types of endoleaks that have been extensively
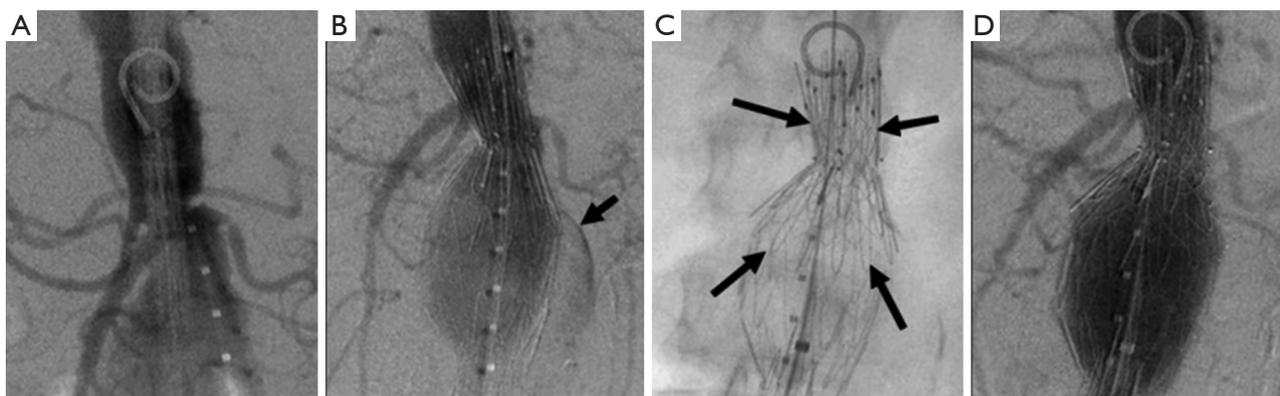
Figure 1 Treatment of a type IA endoleak. Intraprocedural DSA images show (A) a short and conical proximal neck in a patient undergoing EVAR. This is a known predisposing factor for a type IA endoleak; (B) following deployment of the endograft, contrast can be seen coursing outside of the confines of the device (arrow) filling the aneurysm sac, a finding that is typical of a type I endoleak; (C) in order to maximally distend the endograft device at the proximal attachment site, a high radial force balloon-mounted bare-metal Palmaz® stent (arrows) was deployed; (D) after placement of the additional stent, the endoleak has been eliminated, with only the endograft filling. DSA, digital subtraction angiography; EVAR, endovascular aneurysm (or aortic) repair.

described (58-61). Type I endoleaks occur because of an incompetent seal at the proximal (type IA) or distal (type IB) endograft attachment site. Type II endoleaks are characterized by persistent flow into and out of the residual aneurysm sac via patent aortic side branch vessels such as the inferior mesenteric artery, lumbar arteries, accessory renal arteries or the left subclavian artery. Type III endoleaks are caused by structural failure of the endograft itself. Examples include tears in the endograft fabric and separation or dehiscence of modular graft components. Type IV endoleaks are caused by graft porosity, while type V endoleaks are characterized by continued residual aneurysm sac expansion despite the lack of any evidence of an endoleak by imaging, which is a phenomenon that is known as endotension. The most commonly occurring types of endoleaks following both thoracic and abdominal EVAR are types I and II. Endoleaks are more commonly seen following endovascular repair of the abdominal aorta and occur in 15–30% of patients in the first 30 days after the procedure (34,62). They are seen less commonly with TEVAR, occurring in 4–15% of the cases (9,30,63). When present, endoleaks carry an increased risk for continued aneurysm expansion and eventual rupture.

Because endoleaks are the most commonly occurring complication following EVAR, secondary interventions for their treatment, when necessary, represent the most frequently performed post-repair procedure. Techniques for treating type I endoleaks are aimed at securing the involved

proximal or distal endograft attachment site or seal zone (*Figures 1,2*). Potential techniques include using a large caliber compliant balloon to more optimally distend the endograft at the attachment site or to extend the endograft proximally or distally with an endograft aortic extension cuff or limb (64). Other operators advocate using a high radial-force stent at the proximal attachment site to more securely seal the graft, while others have favored peri-graft embolization using a liquid embolic agent such as n-butyl cyanoacrylate (65,66). More recent techniques include the use of endostaples to secure the position of the primary aortic endograft or of an aortic extension cuff to the native aorta (67,68). The most commonly used strategy for treatment of a proximal type I endoleak involves placement of an aortic cuff extension.

Secondary interventions for type II endoleaks almost always involve some type of embolization (*Figures 3,4*). Embolic occlusion of the patent aortic side branches that continue to perfuse the residual aneurysm sac or embolization of the nidus within the residual sac are the commonly employed techniques, with the latter favored. Routes of access for performing type II endoleak embolization include transarterial (69), percutaneous translumbar aortic (70), and transcaval approaches (71). Various embolic agents have been used including intravascular coils, liquid embolic agents such as n-butyl cyanoacrylate, thrombin and ethylene vinyl alcohol copolymer (Onyx®, Covidien-Medtronic, Minneapolis,
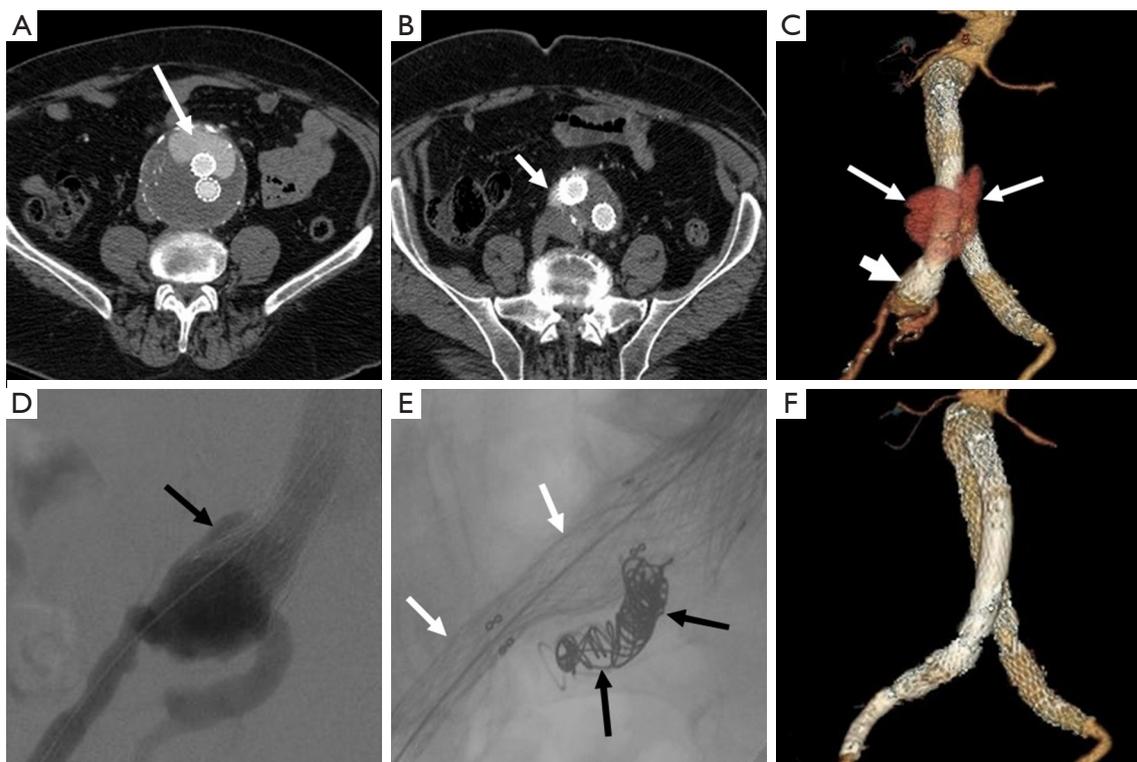
Figure 2 Treatment of a type IB endoleak. Axial contrast-enhanced post-EVAR surveillance CT images show (A) a large collection of contrast (arrow) anteriorly within the residual AAA sac external to the endograft limbs that (B) courses inferiorly (arrow) adjacent to the right iliac limb of the graft; (C) 3D image again shows the endoleak (arrows) and also demonstrates that the distal aspect of the right iliac limb is flared (short arrow); (D) intraoperative DSA shows contrast tracking outside of the flared end of the right iliac limb (black arrow), a finding that is typical of a type IB endoleak; (E) intravascular coils (black arrows) were placed in the right internal iliac artery so as to prevent retrograde perfusion of the area of endoleak and an additional modular graft limb (white arrows) was extended into the external iliac artery to achieve a satisfactory distal seal; (F) 3D image following endoleak repair shows the final configuration of the right iliac limb as well as resolution of the endoleak. EVAR, endovascular aneurysm (or aortic) repair; AAA, abdominal aortic aneurysm; DSA, digital subtraction angiography; CT, computed tomography.

MN, USA) (72). Other described techniques include surgical ligation of the culprit inflow vessel (73,74). These embolization procedures carry a risk for the development of ischemic colitis when the inferior mesenteric artery (IMA) is involved.

Management of type III endoleaks usually requires placement of additional modular endograft components to seal and re-establish the integrity of the affected portion(s) of the endograft (64) (*Figures 5,6*). No specific treatment is recommended for type IV and type V endoleaks. However, if treatment becomes necessary because of continued expansion of the residual aneurysm sac, endovascular re-lining of the original endograft or open surgical conversion may be necessary.

Endograft migration

Device migration is a common complication that requires secondary intervention following EVAR (75). It is defined as displacement of the endograft by more than 5–10 mm from its original position (*Figure 7*). It is often due to progressive dilatation of the aneurysm neck but can also be related to aortic tortuosity, aortic wall degeneration after endograft placement or may be secondary to graft over- or under-sizing. Device migration is associated with endoleaks, aneurysm sac expansion and possible rupture. Device migration has been reported to occur following 1.0–2.8% of TEVAR procedures and 1–10% of endovascular repair of the abdominal aorta at 1 year post-intervention (6,9,30,76). In cases of aortic endograft migration, treatment is very similar
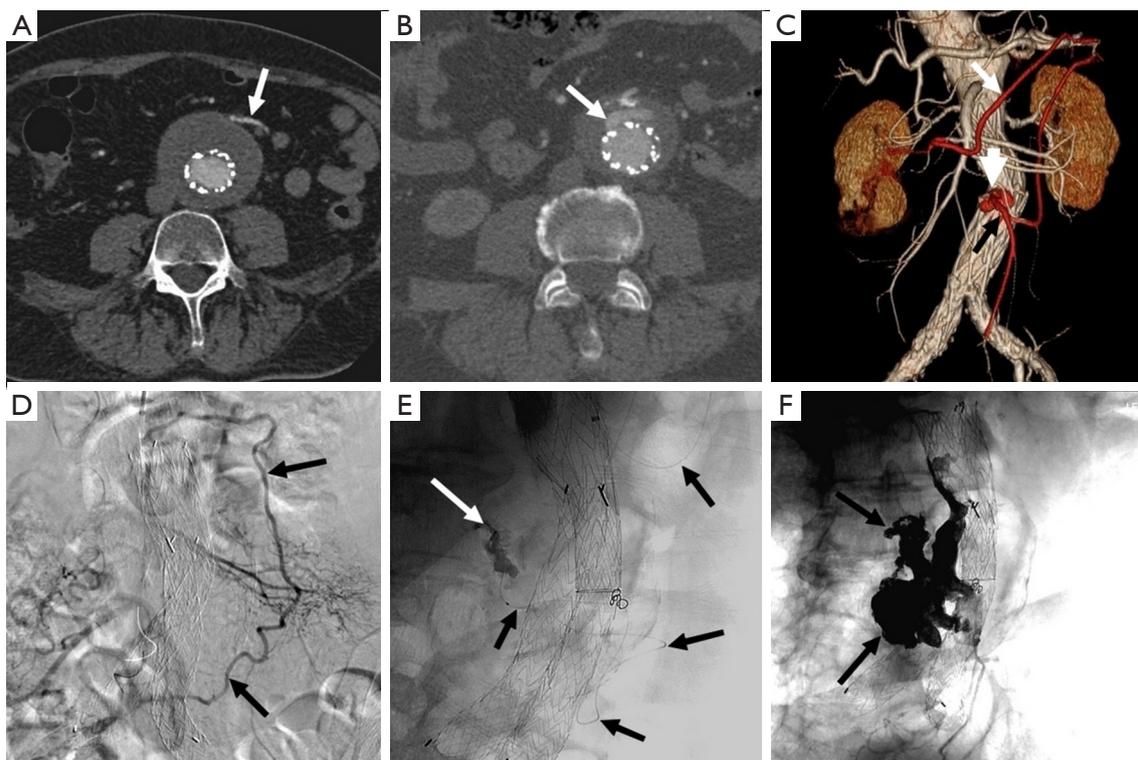
Figure 3 Treatment of a type II endoleak. Axial contrast-enhanced post-EVAR surveillance CT images show (A) a contrast-filled patent inferior mesenteric artery (IMA) (arrow) emanating from the residual AAA sac; (B) a contrast collection anterior (arrow) to the endograft fills via retrograde flow within the IMA, which is typical of a type II endoleak; (C) a 3D image shows that the middle colic artery (white arrow), arising from the superior mesenteric artery (SMA) fills the left colic artery of the IMA (black arrow) in retrograde fashion, thereby perfusing the endoleak nidus (short arrow). This course is highlighted in red; (D) intraoperative DSA shows the same vascular arcade (arrows) that fills the type II endoleak nidus; (E) a microcatheter (black arrows) has been passed through this SMA to IMA route and contrast has been injected opacifying the nidus (white arrow); (F) the endoleak has been embolized using Onyx®, with the large cast (black arrows) evident in the AAA sac. EVAR, endovascular aneurysm (or aortic) repair; AAA, abdominal aortic aneurysm; CT, computed tomography.

to management of a type I endoleak. Endovascular treatment options include the use of aortic extension cuffs or placement of large balloon-expandable stents to augment the fixation of the endograft to the native aortic wall and thus extend the fixation zone. Another option is that of using endostaples to secure the graft to the aortic wall (77,78).

Endograft infection

Endograft infection has been reported to occur in 0.4–3.0% of cases following EVAR of the abdominal aorta (60,61,79,80). It is associated with high mortality rates that range from 25% to 50% and that are usually secondary to septic shock (60,80,81). Endograft infection may be caused by intraprocedural contamination, in which case the infection occurs early after the procedure. If the

infection occurs at a later time after repair, it may be the result of a remote site of infection leading to colonization of the endograft. Rarely, endograft infection may lead to aortoenteric fistula formation (80). Patients typically present with fever, leukocytosis and back pain. Endograft infections may be managed conservatively with antibiotics or may be treated aggressively with endograft explantation and placement of an antibiotic-coated graft (37,82,83). The clinical approach is highly dependent on the clinical scenario and the patient's comorbidities.

Limb kinking or occlusion

Kinking and/or occlusion of endograft limbs have been reported in 2–4% of patients following EVAR of the abdominal aorta (84,85) (*Figure 8*). Causes for these
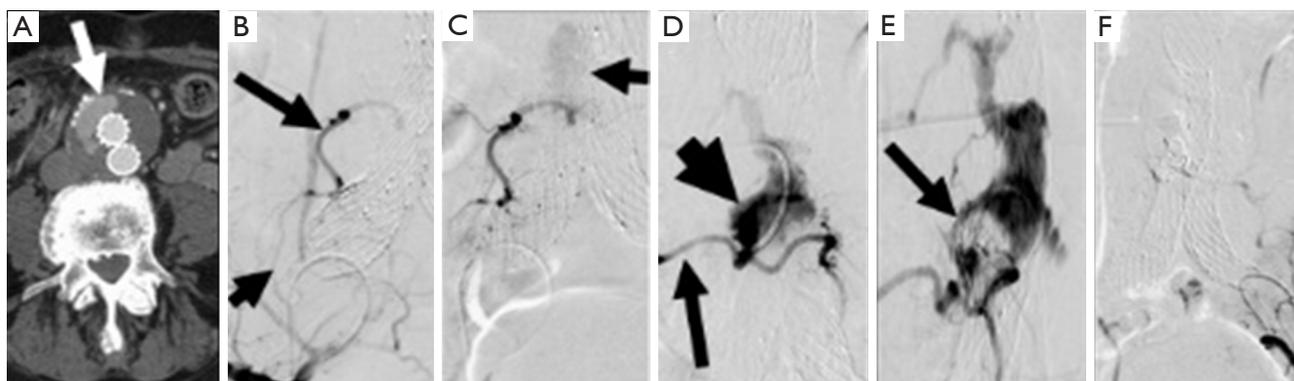
Figure 4 Translumbar treatment of a type II endoleak. Axial contrast-enhanced post-EVAR surveillance CT image shows (A) a contrast (arrow) anteriorly within the residual AAA sac external to the endograft limbs; (B) intraoperative right internal iliac DSA shows filling of the iliolumbar artery (short arrow) with retrograde perfusion of a lower lumbar artery (arrow); (C) a more delayed image shows faint opacification of the endoleak nidus (arrow) within the aneurysm sac; (D) via percutaneous translumbar access, a catheter (arrow) has been introduced directly into the residual AAA sac and contrast has been injected, opacifying the nidus (short arrow) and additional lumbar arteries; (E) a combination of intravascular coils and liquid thrombin were used to embolize the nidus. A filling defect (arrow) in the base of the nidus is seen where the initial embolic agents have been introduced; (F) final image after translumbar embolization shows elimination of the type II endoleak. DSA, digital subtraction angiography; EVAR, endovascular aneurysm (or aortic) repair; AAA, abdominal aortic aneurysm; CT, computed tomography.

complications include progressive decrease of the size of the residual aneurysm sac over time, excessive aortic neck angulation and a narrow diameter to the distal aortic neck (86). Limb kinking can lead to type I and/or type III endoleaks as well as to endograft migration. It can also result in endograft limb thrombosis and occlusion which may in turn cause acute lower extremity ischemia. A number of treatment options are available for the treatment of limb kinking, stenosis or occlusion. Severe limb kinking can be treated by placement of reinforcing stents or additional endograft limbs within the original graft. Percutaneous angioplasty can be performed with or without additional endograft placement to treat limb stenosis or occlusion. Additionally, occluded endografts may sometimes be treated with thrombolysis or thrombectomy and new limb placement. With thrombectomy, care has to be taken to avoid distal embolization into outflow runoff vessels. Other options include a cross-femoral surgical bypass, which may often be the preferred procedure. Timely management of this complication is especially important so as to decrease the likelihood of distal limb ischemia and to improve patient outcomes.

Endograft collapse

Device infolding or collapse has been reported following TEVAR. It is thought to be related to a small proximal aortic curvature or may be associated with oversizing of the endograft relative to the native aorta (87,88). A bird-beak configuration of the endograft is significantly correlated with the risk of type IA endoleak formation, and is a potential risk factor for proximal endograft collapse or infolding (*Figure 9*). Endograft collapse is most commonly seen after endovascular repair of traumatic aortic injuries (89). Endograft collapse typically occurs within the first 30 days after the procedure, with a median time to collapse of 15 days, as reported in a review of 60 cases of endograft collapse following TEVAR (87). A high level of suspicion is needed for the diagnosis of endograft collapse in the first 30 days after the procedure. Patients typically present with symptoms of acute aortic occlusion.

The majority of patients undergo endovascular re-intervention with the repair achieved by relining the collapsed endograft (87). Relining is the preferred mode of re-intervention and provides for a more definitive solution. Available data shows that dilation of the collapsed endograft without stent placement is associated with early recurrence of the collapse (90,91). A small percentage of patients may require surgical intervention for repair by endograft removal and open aortic repair or by axillo-bifemoral bypass.
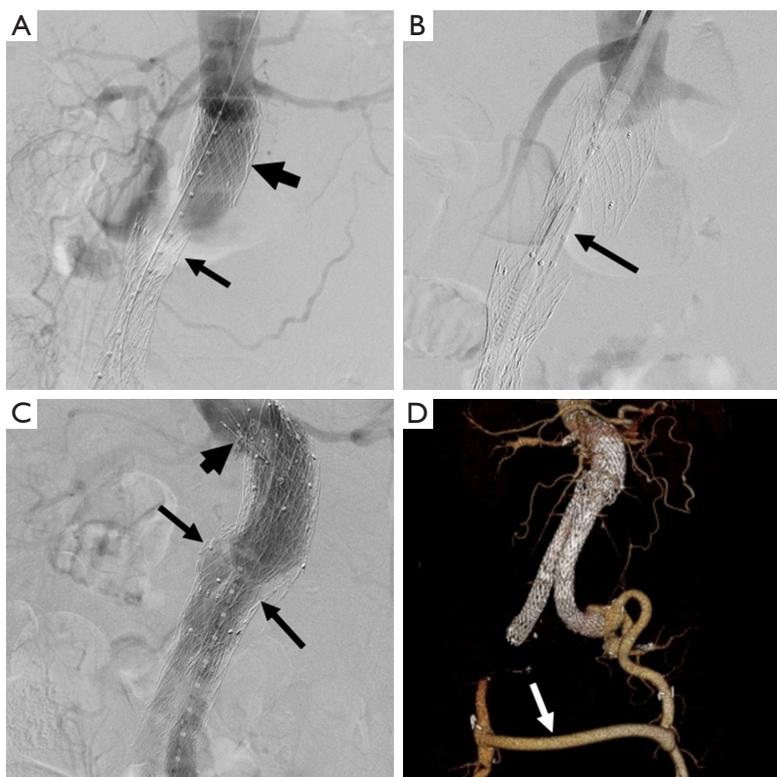
Figure 5 Type III endoleak repair. (A) Intraoperative DSA shows complete separation of components of a modular endograft, with the proximal aortic cuff (short arrow) remaining in the original position but with detachment of the endograft body (arrow), with an intervening segment in which there is no endograft, so that the AAA sac is no longer excluded; (B) a new endograft component (arrow) has been introduced and will be used to bridge the separated endograft components; (C) after placement of the new component the integrity is restored (arrows). The new component extends proximally (short arrow) above the original aortic cuff; (D) the type III repair required extension of the new component via only one limb of the bifurcated body of the original endograft. Thus, in order to perfuse the contralateral lower extremity, placement of a cross femoral bypass graft (arrow) was necessary, as seen in this 3D CT image. DSA, digital subtraction angiography; AAA, abdominal aortic aneurysm; CT, computed tomography.

Systemic complications

Ischemia

Ischemic complications following EVAR have been reported in approximately 9% of cases, an incidence that is higher than is seen following open surgical repair (92). Ischemia may be caused by arterial thrombosis, embolism, arterial dissection or arterial obstruction occurring as a result of endograft malpositioning. Organs and vascular territories that may be affected by ischemia following EVAR of the abdominal aorta include the kidneys, bowel, pelvic organs/muscles and the lower extremities. Spinal cord ischemia is more commonly associated with TEVAR (93). A number of cases of left upper limb ischemia, left upper extremity claudication and subclavian steal syndrome have also been

reported following TEVAR (94,95).

Lower limb ischemia is among the most common forms of ischemia seen following EVAR of the abdominal aorta with the majority occurring as a result of endograft limb occlusion (92), the management of which is addressed in the previous section. Limb ischemia can occur following TEVAR in the setting of inadvertent coverage of the left subclavian artery by the endograft (94-96). This is usually an infrequent complication and is rarely symptomatic (97). More often, based upon the individual patient anatomy, left subclavian artery coverage is a planned component of the procedure, for which carotid-subclavian bypass or transposition is performed prior to TEVAR.

Postprocedural renal ischemia may result from arterial thrombosis embolus or dissection, may be due to
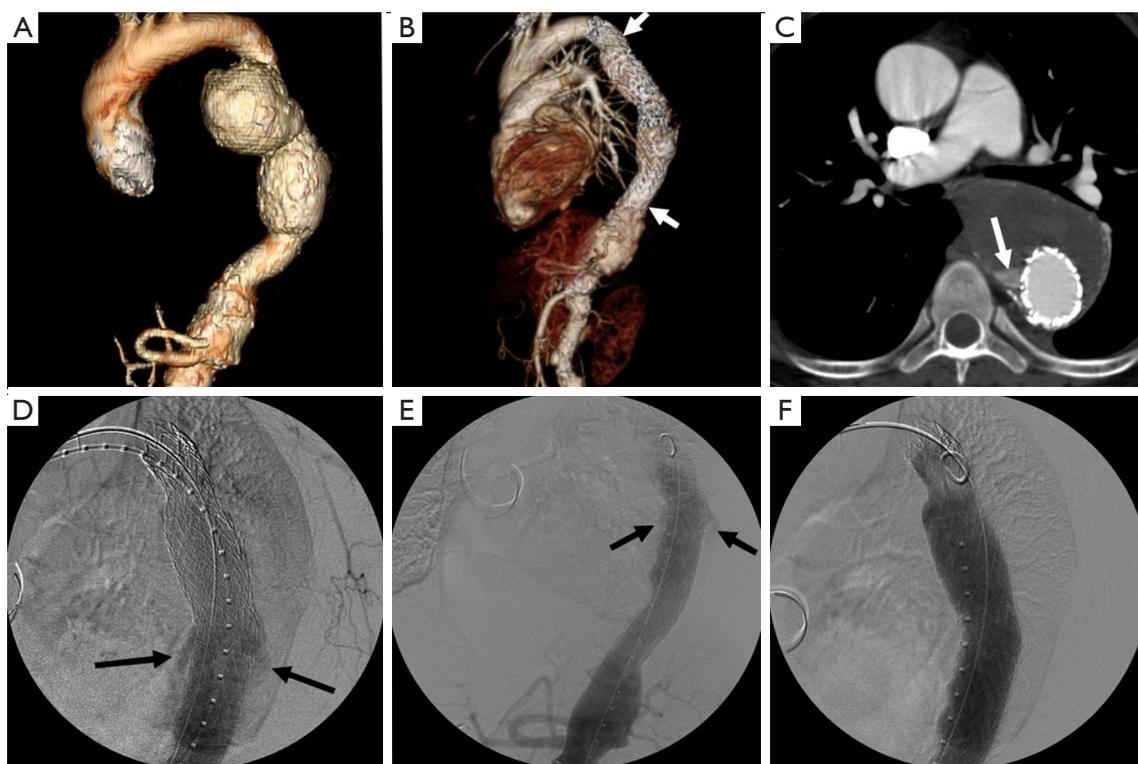
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Figure 6 Endoleak following TEVAR. (A) 3D CTA image of the thoracoabdominal aorta prior to TEVAR shows a large bilobed descending thoracic aortic aneurysm; (B) the aneurysm was treated with placement of a thoracic endograft (arrows); (C) axial image from a surveillance CT shows a contrast collection (arrow) adjacent to the endograft, c/w an endoleak; (D) intraoperative DSA shows that the endoleak (arrows) is adjacent to overlapping modular components of the TEVAR endograft, indicating that this is a type III endoleak; (E) an additional endograft component was placed bridging the area from which the endoleak originates: prior to balloon distension of the new component the endoleak is still evident (arrows); (F) after distending the newly placed device component with a compliant balloon, the endoleak is eliminated. CTA, CT angiography; TEVAR, thoracic endovascular aneurysm repair; DSA, digital subtraction angiography; CT, computed tomography.

inadvertent intraprocedural coverage of the origin(s) of the renal arteries by the endograft or can result from endograft migration (98,99). A short aortic neck carries an increased risk of inadvertent coverage of the renal arteries by the endograft. If the kidneys are not visualized on completion arteriography, stenting of the involved renal artery(ies) may be attempted. If renal function continues to deteriorate, surgical bypass may be needed in order to revascularize the involved kidney.

Intestinal ischemia may occur following EVAR and, when present, most commonly involves the colon, where it is reported to occur in 1–3% of patients (100,101). Colonic ischemia is thought to result from endograft coverage of the inferior mesenteric artery origin, a phenomenon that occurs in all cases of EVAR of the abdominal aorta. If there

are poorly developed mesenteric collateral arcades, left colonic ischemia may ensue. Small bowel or right colonic ischemia in the distribution of the superior mesenteric artery (SMA) is much less common and may be secondary to thromboembolism from catheter and/or guidewire manipulation, especially in a long procedure or by inadvertent coverage of the SMA origin by the endograft. Bowel ischemia is far less commonly seen with TEVAR and has been reported when there was inadvertent coverage of the celiac artery by the distal aspect of the endograft; these may often be less symptomatic if there is significant mesenteric collateralization. If there is inadvertent coverage of both the celiac trunk and SMA by the endograft, patients will likely present with ischemic colitis. Patients with ischemic colitis secondary to endovascular repair typically
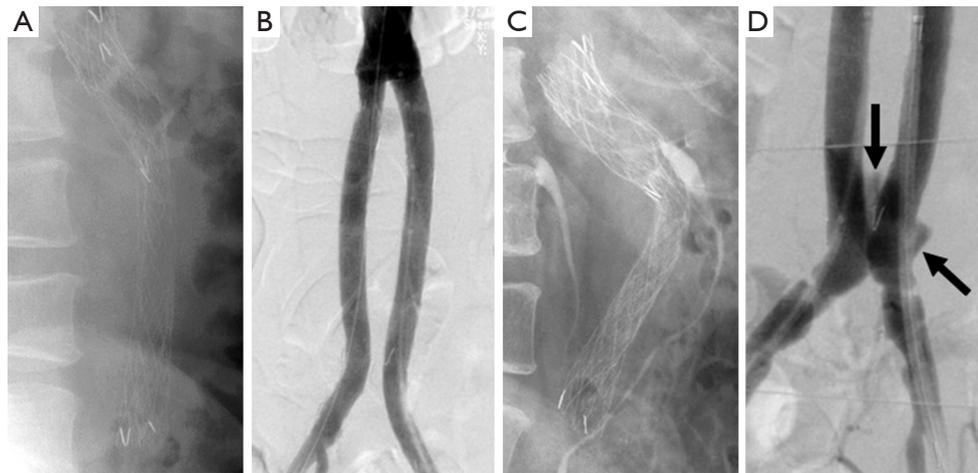
Figure 7 Endograft migration. (A) Lateral radiograph 1 month after EVAR shows the expected configuration of the endograft post-placement; (B) the intraoperative DSA at the time of endograft placement shows a typical endograft configuration; (C) a lateral radiograph obtained 2 years after EVAR shows that the endograft limbs are now bowed anteriorly. This change in the endograft configuration occurred as a result of remodeling of the residual aneurysm sac; (D) the distal ends of the iliac limbs have now migrated cephalad, resulting in type IB endoleak (arrows). EVAR, endovascular aneurysm (or aortic) repair; DSA, digital subtraction angiography.
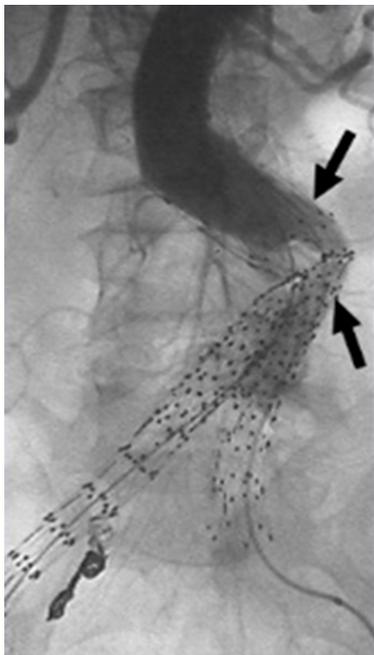

Figure 8 Kinked endograft limbs. DSA shows kinked endograft limbs (arrows), a phenomenon that may occur in association with remodeling of the AAA sac following EVAR, and may lead to limb occlusion and thrombosis. DSA, digital subtraction angiography; AAA, abdominal aortic aneurysm; EVAR, endovascular aneurysm (or aortic) repair.

Figure 9 Bird-beak configuration of TEVAR endograft. There is imperfect apposition at proximal end of the thoracic endograft to the lesser curve of the thoracic aortic arch. This lack of apposition results in a wedge-shaped gap between the undersurface of the endograft (white arrow) and the aortic wall (black arrow). The bird-beak configuration is significantly correlated with the risk of type IA endoleak formation, and it is a potential risk factor for proximal endograft collapse or infolding. TEVAR, thoracic endovascular aneurysm repair.

present with abdominal pain and bloody diarrhea less than 30 days post procedure. A history of prior embolization of one or both internal iliac arteries significantly increases the risk of this complication (101).

Pelvic ischemia has also been reported following EVAR of the abdominal aorta in the setting of internal iliac artery embolization. Intentional embolization of one or both internal iliac arteries has been used in patients with complex iliac arterial anatomy so as to allow extension of endograft limbs into the external iliac arteries or to exclude internal iliac artery aneurysms. Patient symptoms following internal iliac artery embolization include buttock claudication, rectal ischemia, erectile dysfunction and skin malperfusion and necrosis. Buttock claudication has been reported in 31–35% of cases and erectile dysfunction in 17–24% of patients. Symptoms tend to improve with time with no intervention needed. However, there is a higher risk of symptoms persisting in cases in which there has been bilateral internal iliac artery embolization. Intraoperative strategies to preserve perfusion of the internal iliac arterial territories in order to prevent these complications include investigational iliac branched devices (not currently approved by the FDA), surgical revascularization of the internal iliac artery, operator modification of currently existing endografts, and other techniques such as placement of parallel endografts.

Spinal cord ischemia occurs very rarely in association with EVAR of the abdominal aorta , with approximately 14 cases reported to date (92,102,103). Unfortunately, however, the incidence of spinal ischemia is much higher with TEVAR where it is estimated to occur in up to 12% of cases (93). Symptoms of spinal cord ischemia typically develop within 12 hours following repair and may lead to paraplegia (72). Risk factors include the extent of aortic coverage by the device, perioperative hypotension, long procedural durations, coverage of the left subclavian artery, previous open infrarenal aortic repair and renal insufficiency (16,104). Spinal drainage can be used in cases in which there is planned extensive coverage of the thoracic aorta to reduce the risk for spinal cord ischemia.

Cerebrovascular events

Embolic strokes have been reported to occur in 4% to 8% of the cases following TEVAR, an incidence rate that is comparable to open surgery (16,29,105). The relatively high risk is a result of the proximity of the proximal seal zone of the endovascular graft to the origins of the vertebral and carotid arteries. Risk factors for strokes complicating TEVAR include the presence of mobile atheromata in the aortic arch, a history of prior strokes, and the need for proximal graft deployment (105). Middle cerebral circulation strokes are most common, although posterior circulation strokes have been reported as a result of embolization of debris through the vertebral arteries.

Postimplantation syndrome

Postimplantation syndrome may occur after EVAR and has a reported incidence ranging between 13–60% (106,107). It is thought to represent an inflammatory immune-mediated response, with the release of inflammatory cytokines that occurs as a result of endothelial activation through a reaction to the endograft material (107). Symptoms are flu-like in nature and manifest clinically as a systemic inflammatory response that is characterized by fever, leukocytosis, and elevated inflammatory markers, including C-reactive protein (CRP), tumor necrosis factor (TNF)-alpha and interleukin (IL)-6 levels (92-94). Pleural effusions may occur with postimplantation syndrome and are seen in 37–73% of cases after TEVAR (108). Treatment consists of surveillance and aspirin administration to reduce inflammation, with no antibiotics indicated.

Open surgical conversion

Open surgical conversion involves surgical modification of an existing endovascular graft. Open conversion rates range from 0.6% to 4.5%. Surgical intervention is reserved to select cases where repair by endovascular means is not possible (16,109,110). Open surgical conversion is typically needed in select cases of symptomatic type V endoleaks, or in cases involving extensive endograft migration. Aneurysm rupture typically requires removal of the endograft and repair with synthetic grafts or homografts. Open surgical repair is usually of last resort especially with many patients treated with EVAR not being good surgical candidates.

Conclusions

EVAR is increasingly being used for the treatment for thoracic and AAAs and certain other aortic pathologies. It is minimally-invasive, is associated with decreased perioperative morbidity and conveys a short-term survival advantage when compared to open surgical repair. One of the disadvantages of EVAR is the relatively high incidence of post-procedural complications that thus necessitates lifelong imaging surveillance of patients. CT is the preferred method for post-procedural imaging surveillance. A number of patients require secondary re-interventions to

address post-procedural endograft-related complications. Most re-interventions are pursued using an endovascular approach. With the increasing number of endovascular repair procedures performed, it is important for clinicians to gain familiarity with common complications and treatment strategies following this procedure.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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