Surveillance Imaging following Endovascular Aneurysm Repair: State of the Art

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Abstract

Keywords

- abdominal aortic aneurysm
- endovascular aneurysm repair
- surveillance imaging
- endoleak
- interventional radiology

Endovascular aneurysmal repair (EVAR) has become a prominent modality for the treatment of abdominal aortic aneurysm. Surveillance imaging is important for the detection of device-related complications, which include endoleak, structural abnormalities, and infection. Currently used modalities include ultrasound, X-ray, computed tomography, magnetic resonance imaging, and angiography. Understanding the advantages and drawbacks of each modality, as well available guidelines, can guide selection of the appropriate technique for individual patients. We review complications following EVAR and advances in surveillance imaging modalities.

Endovascular aneurysmal repair (EVAR) is a minimally invasive technique for the treatment of abdominal aortic aneurysms (AAA) which continues to increase in prominence and prevalence. Endovascular repair of AAA was first described 1991,¹ and subsequently approved for clinical use in 1999. Multiple generations of endografts have since been developed, with expanded indications and improvements. Studies have shown lower 30-day all-cause mortality with EVAR, with this short-term advantage seen to be greatest in patients at highest risk for open surgery.² Meta-analysis of the EVAR-1, DREAM, OVER, and ACE trials demonstrated early survival with EVAR relative to open repair, though this benefit becomes equivocal over a 5-year follow-up period.³

With increased utilization of EVAR, there is an expanded role for imaging in the postoperative setting. An analysis of 22,830 Medicare beneficiaries showed that reintervention was more likely with EVAR when compared with open repair (9.0 and 1.7%, respectively) within a 4-year follow-up period.⁴ Other studies have estimated the incidence of endograft-related complications to be 11 to 30%.^{5–10} Surveillance imaging is critical to detect and treat endograft-related complications, including endoleak, device migration, kinking, occlusion, and infection. Advances in imaging technology aim to improve diagnostic sensitivity while decreasing potential harms such as exposure to contrast agents or ionizing radiation.

Endoleak

Endoleak is a unique complication to EVAR, defined by persistent flow into the excluded aneurysmal sac.¹¹ Diagnosis can occur during completion arteriography at the time of placement or at noninvasive follow-up imaging. In the initial description by White et al in 1996,¹² an endoleak was defined as incomplete exclusion of the aneurysm sac by an endograft; since then, the definition has expanded to include additional sources of flow designated as Types I to V (► **Table 1**, ► **Fig. 1**).

Type I endoleaks represent incomplete apposition of the endograft ends to the arterial wall at either the proximal end (Type Ia) or a distal end (Type Ib). The incidence of Type I endoleaks is estimated to be 12%.¹³ A review of 2,402 patients demonstrated that more Type I endoleaks are identified at or around the time of placement (3.3% of patients) than at 1 year follow-up (1% of patients).¹⁴ Factors associated with increased Type I endoleak incidence include short, angulated, or reverse tapered geometry of the neck, heavy atherosclerotic burden at the attachment sites, or metal ring breaks in the graft.^{15–17} Type Ib risk factors include oversizing of iliac limb diameters by less than 10% and extensive coverage of the common iliac artery.¹⁸

Table 1 Endoleak classification

Endoleak type	Location	Subtypes
Type I	Attachment site	Ia—Proximal
		Ib—Distal
		Ic—Iliac occluder
Type II	Collateral vessel	Ila—Single vessel
		Ilb—Multiple vessels
Type III	Graft failure	IIla—Midgraft puncture
		IIlb—Junctional
		IIlc—Other (e.g., suture hole)
Type IV	Graft wall porosity	—
Type V	Endotension	—

Source: Adapted from Shah and Stavropoulos.⁷⁵

Fig. 1 Illustration of endoleak types (I–IV). Type Ia, proximal attachment site; Type Ib, distal attachment site; Type II, collateral vessel; Type III, graft failure; Type IV, porosity of graft wall.

Type II endoleaks occur in the setting of retrograde flow into the excluded aneurysmal sac, typically from a lumbar artery or the inferior mesenteric artery (IMA). These represent the most common subtype, estimated to represent 76% of endoleaks,¹³ and affect 22% of EVAR patients.¹⁹ The rate of diagnosis is shown to be higher at 1 to 6 months, with a gradual decline over time.²⁰ The natural history of Type II endoleaks is relatively benign; most will resolve spontaneously and associated rupture is rare (~1%).²¹ Thus, intervention is warranted only in settings where endoleak persistence causes continued sac enlargement.²² Factors associated with aneurysmal size progression include greater diameter of the IMA or lumbar arteries and multiple lumbar arteries extending from the aneurysm sac.²³

Type III endoleak is characterized by leakage due to component separation or graft rupture, with an estimated 3% incidence.²⁴ Treatment is indicated, as pressurization of the aneurysmal sac increases risk of aneurysmal rupture.²⁵ Type IV endoleak results from graft porosity with exudate crossing the endograft wall, and is rarely seen with newer generation EVAR devices. Type V endoleak, known as endotension, is an increase in the excluded aneurysmal sac size without identifiable Types I to IV endoleak. Suggested etiologies have included a missed endoleak or transudation across graft fabric.²⁶

Structural Complications

Structural complications related to EVAR include device migration, component separation, limb kinking, and occlusion. Graft migration is among the most common reasons for reintervention²⁷ (→Fig. 2), due to an associated Type I endoleak or occlusion of branch vessels, such as the renal arteries or internal iliac arteries. In addition, migration places the device at greater risk for thrombosis.²⁸ Factors related to graft migration include placement, undersizing or oversizing, and tortuosity.^{29,30} Component separation may occur in the setting of inadequate overlap between components or shrinking of the aneurysm sac over time, with complications including Type III endoleak. Fortunately, with newer generation devices, separation occurs less frequently.³¹ Endograft limb kinking can occur in the setting of inferior translocation, with potential for graft occlusion or thrombosis.³² Graft occlusions typically occur within the first year of placement, with posited risk factors for limb occlusion including small aortic bifurcations and tortuous, angulated iliac arteries^{33,34} (→Fig. 3).

Graft Infection

Aortic graft infections are a relatively uncommon, but serious, complication of endovascular repair. Graft infection incidence is estimated to be between 0.5 and 2%, with up to 38% perioperative mortality.^{35,36} Findings visible on computed tomography (CT) include gas within the aneurysm sac and periaortic inflammatory stranding (→Fig. 4). Factors contributing to graft infection include procedure-related contamination, extension of local visceral infection, or bacteremia. Aortoenteric fistula is a rare but life-threatening complication that can be seen with aortic repair (→Fig. 5). CT

Fig. 2 Plain radiograph showing distal migration of the endograft with resultant 90-degree kinking of the left iliac limb (arrow).

angiography (CTA) is a first-line screening modality for aortoenteric fistula; in addition to the findings of graft infection, obliteration of fat plane between aorta and bowel, focal bowel wall thickening, and extravasation of vascular contrast into the bowel lumen may be seen.³⁷

Surveillance Imaging Modalities

Radiography

Conventional radiography is an important adjunct for assessing stent graft structure and positioning. Radiography can provide an overview of the graft as a whole, allowing for assessment of kinking, deformity, and migration.^{38,39} The high spatial resolution of radiography allows for the assessment of wire frame integrity and potential fracture. The benefits of utilizing conventional radiography include lower radiation exposure relative to CT, and a lack of metal-related artifacts seen in CT, MRI, and ultrasound. However, radiography remains a complementary technique in the assessment of endografts, as aneurysmal sac size or soft-tissue complications related to EVAR cannot be assessed.

Computed Tomography

CT is a mainstay of EVAR surveillance imaging. The 2018 Society for Vascular Surgery guidelines recommend CT imaging at 1 month, 6 months if concerning findings were seen on initial scan, and 1 year. In the absence of sac enlargement, the

Fig. 3 Chronic occlusion of the endovascular aneurysmal repair on sagittal CT.

Fig. 4 Graft infection within the aneurysmal sac, with focal gas seen anterior to the endograft (arrow).

recommendations allow for yearly CT or ultrasound surveillance. Concerning ultrasound findings would necessitate further evaluation with dedicated cross-sectional imaging. These postoperative surveillance protocols are based on the pivotal FDA-sponsored trials, noting that there is not yet sufficient evidence to recommend an optimal frequency of surveillance.⁴⁰

CT is the preferred modality for evaluating the graft and graft-associated complications. EVAR cages are constructed from metal alloys, including stainless steel, nitinol, and cobalt

Fig. 5 Aortoenteric fistula on CT. The patient has a remote history of aortobifemoral bypass. Endovascular aneurysmal repair was performed 3 years prior to presentation in the setting of a sentinel bleed. Axial CT shows adhesion of the third portion of the duodenum to the aortic wall (arrow), with adjacent soft-tissue stranding and enteric contrast extending to the level of the endograft. Surgical graft and endograft explant with duodenal resection revealed a 3.7 cm $\times$ 0.7 cm transmural defect of the duodenum.

chromium, which are readily visualized by CT. Newer endograft systems can have additional features on CT, such as hyperattenuating polymer gel-filled rings or transmural aortic fixation devices (**Fig. 6**). Mechanical complications assessable on CT include stent migration, kinking, and fracture. CT also allows for a high spatial resolution within soft tissues, thus making it ideal to interpret perigraft complications such as inflammatory stranding, fluid collections, and focal gas.

When screening for endoleak, aneurysmal sac size is the primary indicator of a clinically relevant endoleak. For those with contraindication to contrast use, unenhanced CT alone can provide accurate measurement of sac size. Some authors have advocated the use of unenhanced CT as a preferred initial screening modality.⁴¹ CTA is a highly sensitive modality for the detection of endoleak, and the preferred methodology to evaluate patients who are able to receive iodinated contrast. A study has shown that sensitivity with CTA exceeds 92%, as compared with 63% with digital subtraction angiography (DSA).⁴² On CTA, endoleak is visualized as

contrast opacification within the excluded aneurysm sac. Types I and III are typically seen adjacent to the endograft on arterial phase imaging. Optimal visualization of Type II endoleaks is variable on arterial versus venous phase imaging; some low-flow endoleaks are visible only on delayed phase imaging (**Fig. 7**).

While CT remains the modality of choice, concerns remain regarding ionizing radiation exposure in a population that requires long-term surveillance. Proposed methods for dose reduction include modulation of number of phases acquired, tube voltage, and reconstruction method. Some authors have recommended exposure reduction by utilizing unenhanced only or delayed phase only protocols for detecting an endoleak.^{43,44} Others have recommended performing enhanced arterial and delayed phases at 80 kVp depending on body habitus as opposed to usual 120 kVp⁴⁵ or attenuation-based tube voltage selection as means for radiation dose reduction.⁴⁶ Iterative reconstruction algorithms utilize modeling of various aspects of the CT acquisition to reduce image noise, improve contrast to noise ratio (CNR), or spatial resolution. Adaptive statistical iterative reconstruction has been shown to reduce radiation dose in abdominal CT by 25 to 50% when compared with filtered back projection.⁴⁷ Newer generation model-based iterative reconstruction may enable up to 73% dose reduction when compared with CTA performed with adaptive statistical iterative reconstruction.⁴⁸

Advances in CT imaging show potential for dose reduction. Dual-energy CT (DECT) utilizes acquisitions at two different X-ray energies or with a dual-layer detector. This can result in improved beam hardening artifact, and dose savings by allowing creation of “virtual” noncontrast images from contrast-enhanced images, obviating the need for dedicated precontrast imaging⁴⁹ (**Fig. 8**). Some authors have advocated for using a single-acquisition split-bolus protocol, with simultaneous acquisition of arterial and delayed phase imaging, which could reduce radiation dose by up to 43%.⁵⁰ Photon-counting detector (PCD) CT is an emerging technology, with potential application in EVAR surveillance. While dual-energy CT can provide tissue-specific images, the acquisition of CT images at greater than two energy bins allows for better tissue discrimination; thus, PCD has potential to further reduce radiation exposure, correct beam hardening, and allow concurrent usage of different contrast agents.⁵¹ Energy-selective images can create virtual noncontrast, as well as multiple material-specific overlay

Fig. 6 Endovascular aneurysmal repair variants on CT. (a) MIP showing multiple EndoAnchor fixation devices (Medtronic, Santa Rosa, CA); high attenuation polymer-filled ring of the Ovation stent graft system (Endologix, Irvine, CA) on (b) unenhanced, (c) arterial phase, and (d) venous phase imaging.

Fig. 7 Endoleaks on CTA. (a) Arterial phase CTA shows a Type Ia endoleak adjacent to the proximal end of an aortic endograft which has migrated inferiorly; (b) Type II endoleak, best seen on delayed phase images, arises from a lumbar artery; (c) Type III endoleak, seen on arterial phase, arises just proximal to endograft bifurcation.

images.⁵² A human PCD CT trial demonstrated statistically greater CNR by an average of 30% in the abdomen and pelvis.⁵³ Improved tissue and material discrimination with PCD CT has potential for both better visualization and dose reduction in the evaluation of endoleaks.

In patients with impaired renal function, there is a need to balance the benefits of diagnostic contrast-enhanced CT imaging with potential renal dysfunction. The consensus statement published by the American College of Radiology (ACR) and National Kidney Foundation posits that the risk of acute kidney injury (AKI) has previously been overstated, due to historical lack of control groups to separate contrast-induced AKI and contrast-associated AKI.^{54,55} While the true risk of contrast-induced AKI is unknown, prophylactic normal saline administration is recommended for glomerular filtration rate (GFR) less than 30 mL/min/1.73 m². A

randomized trial has shown no benefit of sodium bicarbonate or N-acetylcysteine when compared with normal saline. In addition to prophylactic hydration in high-risk patients, cessation of nonessential potentially nephrotoxic medications (e.g., nonsteroidal anti-inflammatory drugs) should be considered.⁵⁶ For patients in whom CT contrast administration is deemed too risky, noncontrast CT or ultrasound may be considered as screening modalities.

Magnetic Resonance Imaging

Magnetic resonance angiography (MRA) is an alternative to CTA for post endograft evaluation. At the authors' institution, the EVAR MRA protocol includes axial in and opposed phase T1-weighted gradient echo, axial single short fast spin echo, and pre- and post-dynamic gadolinium-enhanced three-dimensional gradient echo images. Image interpretation is performed utilizing multiplanar reformatting and maximum intensity projections. For patients in whom gadolinium administration is contraindicated, noncontrast MRA may be performed. While time-of-flight (TOF) imaging may have similar sensitivity to contrast-enhanced studies, studies have suggested specificity as low as 54% for endoleak detection.⁵⁷ Newer noncontrast MRA methods may have improved performance.⁵⁸

A meta-analysis has shown MRA to be potentially more sensitive than CTA for the detection of endoleaks, particularly for Type II endoleaks.⁵⁹ With the transition from 1.5 to 3.0 T MR systems, increased signal-to-noise ratio (SNR) and faster acquisition times may allow for improved vessel to background enhancement as well as reduced motion artifact.⁶⁰ While late gadolinium dynamic contrast phases are typically the best sequences in which to visualize endoleak (→Fig. 9), additional sequences to characterize endoleaks have been described. Time-resolved MRA can be considered an adjunct sequence to visualize and quantify flow characteristics in three dimensions over time; however, it is limited by spatial resolution and susceptibility artifact.⁶¹ Four-dimensional phase contrast MRA has the capacity to visualize flow dynamics within the aorta, and increased sensitivity for the detection of endoleaks relative to CTA.^{62,63}

Benefits of MRI over CT include the absence of ionizing radiation and iodinated contrast-induced AKI. However, additional patient, endograft, and contrast-related considerations must be assessed when determining candidacy for MRI. Patient considerations include accessibility in the community setting, cost, longer scan times, and claustrophobia. For those with implanted medical devices, including pacemakers and implantable cardioverter defibrillators (ICD), the risk of adverse events, though rare, necessitates proper assessment and precautions prior to imaging.⁶⁴ Gadolinium-based contrast agents (GBCAs) are well tolerated; however, the risk of nephrogenic systemic fibrosis (NSF) is a concern in patients with advanced renal disease. Recently, concern has been raised about gadolinium deposition in the brain, which is of unclear clinical significance and has been related to the number of contrast administrations as well as the use of linear GBCAs.⁶⁵ Although currently available aortic endografts have been individually classified as either

Fig. 8 Dual-energy CTA of endovascular aneurysmal repair. Image data are acquired at (a) 90 kVp demonstrating increased arterial opacification and streak artifact and (b) 150 kVp showing decreased arterial opacification and streak artifact. The combined data can be used to (c) subtract bone and metal-related signal, (d) create a scan with high arterial opacification and decreased artifact within the soft tissues using monoenergetic reconstruction, and (e) create a virtual noncontrast image.

Fig. 9 MRA showing Type II endoleak. Delayed phase gadolinium-enhanced images with subtraction demonstrate a patent aortic endograft (*). Enhancement is seen tracking along the excluded posterior aneurysm wall (arrows), supplied by the adjacent lumbar arteries.

conditional or safe for use in MRI, endograft material can influence study quality. MRA is more effective in the evaluation of nitinol stent grafts, as stainless steel and nickel alloys cause significantly more susceptibility artifact that may preclude optimal assessment.⁶⁶ Platinum coils related to embolization do not appear to cause significant artifact at 1.5 or 3.0 T.⁶⁷

Ultrasound

Ultrasound is a commonly used alternative to CT for imaging surveillance after EVAR (►**Fig. 10**). Sonographic imaging includes gray scale, Doppler, and contrast-enhanced techniques. For the measurement of aortic diameter, ultrasound has been shown to be comparable to CT and with measure-

Fig. 10 Duplex ultrasound of an abdominal aortic aneurysm in sagittal plane, showing an endoleak. An arterial waveform is seen in the excluded portion of the large aneurysmal sac, anterior to the aortic endograft (arrowheads). Color flow is visualized within the patent stent (*).

ments less affected by aortic angulations over 25 degrees.⁶⁸ Numerous studies on color duplex ultrasound (CDUS) and contrast-enhanced ultrasound (CEUS) have had conflicting opinions regarding their diagnostic value relative to CTA. A meta-analysis of 42 studies showed that CDUS and CEUS had high specificity for the detection of endoleaks, with CEUS superior to CDUS for ruling in endoleaks.⁶⁹ A meta-analysis of 18 studies showed that CEUS had higher sensitivity and comparable specificity to CTA for the detection of endoleaks after EVAR.⁷⁰ While the discovery of small endoleaks in

Fig. 11 Embolization of Type II endoleak. (a) CTA demonstrates an endoleak in the posterior aneurysmal sac; (b) translumbal approach digital subtraction angiography of the endoleak nidus demonstrates multiple feeding arteries; (c) successful coil embolization performed.

isolation may be of questionable clinical significance, the higher sensitivity of CEUS may help differentiate a low-flow endoleak from endotension in the setting of sac enlargement.

Ultrasound studies offer the benefit of low cost without ionizing radiation; however, modality, patient, and operator-related limitations exist. Ultrasound cannot effectively visualize endograft complications such as stent migration or fracture; further evaluation with an additional modality such as CT would be required in the setting of concern. Patient-related factors limiting sonographic evaluation include obesity, abdominal wall hernias, bowel gas, and calcification of the aortic wall,⁷¹ and patients typically must fast before sonographic examination. Ultrasound studies are also subject to interoperator technique and skill, resulting in greater heterogeneity in exam quality and performance. Subsequently, care must be taken when interpreting differences between examinations and different modalities. CEUS is not yet widely available and requires specific training and equipment to perform. Though the FDA has approved ultrasound contrast agents for specific applications in echocardiography, evaluation of focal liver lesions, and pediatric vesicoureteral reflux, application for evaluation of endoleak has not yet been approved.

Catheter Angiography

Noninvasive imaging techniques have become the mainstay in EVAR surveillance, starting as early as the 1990s. CTA and MRA have demonstrated increased sensitivity for the detection of endograft-related complications relative to angiography.^{42,72} Noninvasive imaging modalities avoid the low, but inherent, risk of direct arterial access, including hemorrhage, thrombosis, pseudoaneurysm, and arteriovenous fistula.⁷³

In the setting of an endoleak identified on noninvasive imaging, DSA is an essential modality for further diagnostic characterization and treatment.⁷⁴ While CTA has increased sensitivity to the presence of an endoleak, DSA can more accurately classify them due to visualization of flow.⁷² Accurate DSA characterization of endoleak as Type I or III versus

Type II defines management, requiring endograft revision or embolization, respectively. Type II embolization can be performed at the time of diagnosis, utilizing a transarterial or transfemoral approach. Preembolization DSA maps collaterals from the major feeding artery, typically the internal iliac artery or superior mesenteric artery, to determine approach. After selective catheterization of the aneurysm, DSA is to be performed to characterize the appearance of the nidus and major feeding vessels (►Fig. 11). Postprocedural DSA is performed to serve as immediate follow-up imaging. Postembolization, patients may return to routine screening; whenever possible, consideration should be made to choosing an imaging modality capable of coil artifact reduction, such as DECT.

Conclusion

CT remains the gold standard for EVAR evaluation for reasons including accessibility, reproducibility, and diagnostic sensitivity for different pathologies. Given the need for repeated scans, proposed methods to reduce ionizing radiation exposure include protocol and kVp modulation, the use of DECT, and upcoming technology such as PCD-CT. MRA and ultrasound are also useful modalities to evaluate EVAR in the appropriate patient and clinical setting. Conventional angiography remains an important modality for further classification, preoperative planning, and intervention on endoleaks detected on noninvasive imaging.

Conflict of Interest

None declared.

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