

Radiological follow-up after endovascular aortic repair – review of surveillance modalities

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ABSTRACT


Aim: This review aims to present diagnostic modalities suitable for monitoring patients after endovascular aortic repair.

Materials and Methods: A literature search was conducted across electronic databases from January 2024 to May 2025 using a combination of keywords and Boolean operators.

Conclusions: While computed tomography angiography remains the reference standard for monitoring after endovascular aortic repair, with 92% sensitivity for endoleak detection, magnetic resonance imaging and ultrasonography offer viable alternatives that eliminate radiation exposure and may reduce contrast agent requirements. Magnetic resonance imaging detects twice as many endoleaks as computed tomography angiography, whereas contrast-enhanced duplex ultrasonography achieves 98% sensitivity and 88% specificity.

Treatment of abdominal aorta aneurysm with endovascular aortic repair offers a significant opportunity for a carefully selected patient population. The selection of surveillance modalities should be tailored to individual patient characteristics.

KEY WORDS: computed tomography angiography, magnetic resonance imaging, ultrasonography, contrast media, endovascular aortic repair

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INTRODUCTION

Abdominal aortic aneurysm (AAA) is a chronic, potentially lethal disease characterized by a permanent and irreversible dilatation of the aorta, which may progress to a life-threatening aortic rupture with mortality rates exceeding 80%. Prevalence rates range from 1% to 8.9%, with AAA being more frequent in men [1]. Despite the steadily increasing prevalence of AAA over the past decades, recent data underline a decline in AAA incidence and mortality, particularly in high-income countries. This trend may be attributed to a decrease in tobacco — one of the most significant risk factors - and the significant impact of antihypertensive therapy in preventing AAA [2]. Conversely, in middle- and low-income countries with inefficient healthcare systems, the prevalence of AAA continues to rise [3]. Although AAA formation is complex and results from multiple risk factors, the most significant predictive risk factors remain advanced age, a history of tobacco smoking, male sex, family history of AAA, cardiovascular diseases, and hypertension [1].

Open surgical repair (OSR) and endovascular aortic repair (EVAR) with a stent graft placement are two available treatment approaches [4]. The primary goal of OSR is to replace the aneurysmal segment of the aorta with a synthetic graft, with anastomoses performed as close as possible to the renal arteries in the infrarenal aortic segment [4]. In selected cases, the reimplantation of the inferior mesenteric artery may be performed [5]. The OSR is considered a high-risk intervention, with a cardiovascular mortality rate exceeding 5% in the 30-day postoperative period [6]. Moreover, OSR may be burdened with significantly higher systemic complications compared to EVAR, including cardiac, pulmonary, and renal complications [7].

On the other hand, the primary objective of EVAR is to exclude the aneurysmal sac from the circulation by placing an endograft. The endograft is inserted over the aneurysmal sac via the common femoral artery under angiographic guidance. After proper positioning of the main endograft seal, distal endograft extensions are placed below the main body and extend

to the common iliac arteries. Finally, angiography confirms proper graft positioning and excludes early endovascular leaks [8]. Compared with OSR, EVAR is considered an intermediate-risk intervention, with a cardiovascular mortality risk of 1-5% [9], and it has a better safety profile, associated with a significant reduction in the postoperative complication rate and a shorter hospitalization duration [10]. The most common complications in the 30-day postoperative period after EVAR are graft endoleak, endograft migration, or graft limb thrombosis. [11]. Nevertheless, according to current guidelines, EVAR is considered the preferred treatment modality for AAA in selected patients [12]. However, in some cases, OSR may be beneficial, particularly in patients with aortic angulation and tortuosity, unfavorable aortic branch anatomy, or iliac artery obstruction [13].

Patients after aortic repair should be monitored closely to detect postoperative complications and initiate appropriate treatment [14]. The purpose of this narrative review is to present diagnostic modalities for monitoring patients after EVAR.

AIM

This review aims to present diagnostic modalities suitable for monitoring patients after endovascular aortic repair.

MATERIALS AND METHODS

To prepare this narrative review, a comprehensive literature search was conducted across multiple electronic databases, including PubMed, Scopus, and Google Scholar, covering the period from January 2024 to May 2025. The search strategy employed a combination of keywords, including "endovascular aortic repair," "computed tomography angiography," "magnetic resonance imaging," "ultrasonography," and "abdominal aortic aneurysm". Boolean operators (AND, OR) and Medical Subject Headings (MeSH) terms were utilized to optimize search sensitivity and specificity for each database.

Inclusion criteria encompassed peer-reviewed publications, including original research articles, systematic reviews, narrative reviews, letters to the editor, and meta-analyses with full-text availability in English. Exclusion criteria included conference abstracts, case reports, and non-peer-reviewed publications.

The authors independently conducted title and abstract screening in accordance with predetermined eligibility criteria. Subsequently, full-text articles of potentially relevant studies were comprehensively evaluated for final inclusion. Inter-reviewer discrepancies

were resolved through consensus discussion. Additional relevant publications identified through citation tracking and reference list screening were incorporated when they provided essential information pertinent to specific aspects of the review.

REVIEW AND DISCUSSION

POST-EVAR DIAGNOSTIC METHODS

During the first 5 years after EVAR, the risk of adverse events is estimated at approximately 20% [15]. These events may include endoleaks, stent graft migration, or endograft infection [13]. Current guidelines recommend assessing the stent graft at 30 days and 12 months post-procedural [13,15–17]. If any EVAR-related pathology is detected, additional imaging should be performed within six months of the initial examination [16]. Lifelong surveillance is recommended annually [13,15,16,18,19]. Typical assessment involves computed tomography angiography (CTA), but it can be continued with ultrasound (US) when no abnormality is noted in the first year of follow-up [16]. However, this management is considered financially ineffective and exposes patients to radiation and nephrotoxic contrast agents [15,18]. Moreover, approximately one-third of patients discontinue follow-up, which significantly increases the risk of mortality within three years post-EVAR [15]. Follow-up imaging modalities include conventional radiography and angiography, CTA as the gold standard, magnetic resonance imaging (MRI), and US [13,19,20]. Nevertheless, the best diagnostic outcomes are observed when different methods are combined [16].

CONVENTIONAL RADIOGRAPHY AND ANGIOGRAPHY

Currently, conventional radiography is rarely in use. When performed, it is typically acquired in an antero-posterior (AP) projection to assess stent graft position and integrity, and to detect potential fractures and tears [13, 21, 22] endovascular aneurysm repair or endovascular aortic repair (EVAR). Its main advantages are low cost and minimal radiation exposure [13].

Digital subtraction angiography is utilized preoperatively or during secondary interventions to visualize vessels feeding the aneurysm sac in type II endoleaks [13]. However, conventional angiography has limited sensitivity (63%) and specificity (77%) [23] and is associated with risks such as hematoma, pseudoaneurysm formation, retroperitoneal hemorrhage, and even vessel rupture [13].

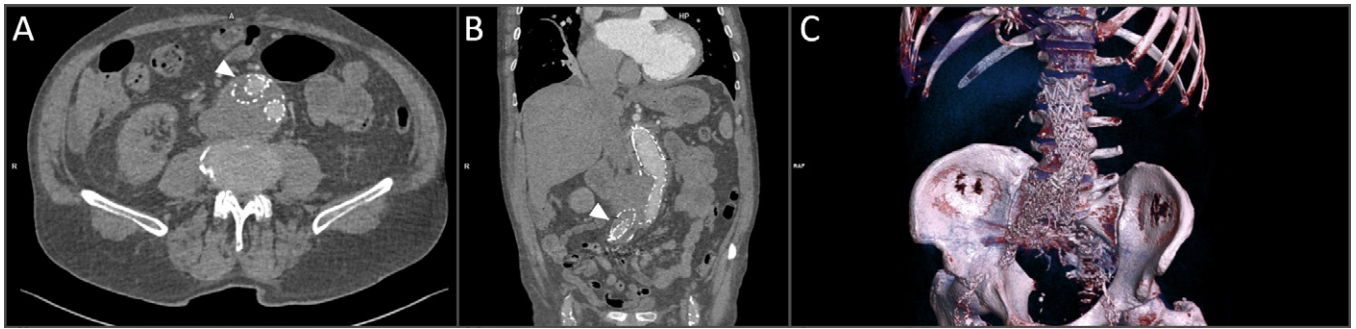


Fig. 1. Patient after endovascular aortic repair, and adding an additional stent to the right common iliac artery due to endoleak. On axial (A) and coronal (B) images, a stent graft body is visible with an additional stent inside the right stent graft extremity (arrowheads). The entire stent graft body is visible in the 3D reconstruction (C)

Source: Own materials

CTA

CTA assessment of stent grafts after EVAR is recognized as the gold standard [11,13, 19, 20, 24–26]. It enables precise visualization of the aneurysm sac, its diameter, and the anchoring of the vascular prosthesis (Fig 1) [11, 24]. Standard CT protocols comprise three phases: non-contrast, arterial (post-contrast), and delayed-phase imaging (120–300 ms post-contrast). The non-contrast phase enables the assessment of dense structures such as calcifications, while the contrast-enhanced phases allow assessment of graft integrity, detection of endoleaks, infection, or vessel occlusion. CTA has a sensitivity of 92% for endoleak detection [13].

Bley et al. [19] investigated a protocol using nonenhanced CT for follow-up after infrarenal EVAR, as the radiation dose is smaller and the contrast material may be omitted. Initial scans (0–3 months after EVAR) were performed with contrast medium to detect leakage. If no endoleak was present, the patient was asymptomatic, and the aneurysm sac expanded by less than 2%, subsequent follow-up was conducted with nonenhanced CT. If these criteria were not met, contrast-enhanced CT was introduced. This approach reduced the radiation dose by 57%–72% compared with conventional contrast CT angiography and by 69%–82% compared with protocols that included a delayed-phase post-contrast acquisition. This protocol allowed for limiting the contrast material usage, which can be beneficial for nephrologically burdened patients. Furthermore, the study demonstrated that high-pressure endoleaks (types I and III) increase aneurysm sac volume by approximately 10%, whereas low-pressure type II endoleaks are associated with a 5.4% increase. Volumetric analysis appears particularly useful for detecting type V endoleaks, in which the only indicator may be a slow, subtle sac enlargement despite the absence of contrast extravasation. Additionally, small type II endoleaks may be observed even when sac volume

decreases, and the surgical approach can be waived, as the risk of rupture is primarily associated with increased sac volume [19].

Double-energy CT (DECT) employs two different kilovoltages to acquire images of the same volume. The energy difference enables differentiation of materials based on atomic number, k-edge properties, and attenuation profiles. Various acquisition techniques exist, such as rapid-kilovoltage-switching DECT, double-source DECT, split-filter DECT, and multilayer detectors. DECT is used to generate virtual noncontrast images and iodine map reconstructions based on the iodine spectrum and its distribution in tissues. Although virtual noncontrast images are comparable to true noncontrast images, their appearance may be influenced by residual iodine. Iodine maps have been shown to be useful for detecting endoleaks. In addition, DECT can generate “noncalcium” images to assess vessels narrowed by calcified plaques [18]. Furthermore, the radiation dose with DECT is comparable to or lower than that of conventional CT, as the noncontrast phase is virtually reconstructed [13, 18, 20, 27]. This dose reduction is possible by limiting the examination to the phase following contrast agent administration and then virtually reconstructing noncontrast images. Some studies suggest that the arterial phase can be omitted, as delayed-phase images maintain high sensitivity for detecting endoleaks [18, 27]. However, the arterial phase remains essential for accurate identification of type I and III endoleaks and for a thorough assessment of the abdominal vessels and other potential pathologies [18]. Stolzmann et al. [27] reported high interobserver agreement for DECT protocols, although readers exhibited lower confidence when relying on virtual noncontrast images or omitting the arterial phase. Furthermore, DECT protocols can reduce radiation dose by 41–61% when the arterial phase is omitted, compared with single-energy CT. This is explained by the fact that

each scan in single-energy CT delivers less radiation than in DECT; more scans are required to produce the final images, which is responsible for the higher radiation dose in single-energy CT. Early imaging with DECT may be confounded by residual contrast that mimics endoleaks [27]. Javor et al. [28] described a split-bolus DECT technique, wherein two contrast boluses are administered sequentially to capture both arterial and delayed phases in a single acquisition, reducing the radiation dose by up to 42% [28].

Dynamic CT, which uses longitudinal table movement to capture the dynamic enhancement pattern, is a potential post-EVAR assessment technique. It is useful when there is no regression in sac diameter or when leakage is unclear. The method detects and differentiates endoleaks by time-to-peak attenuation [26]. Despite a higher radiation dose than other protocols [29], dynamic CT may improve the classification of endoleaks. Further prospective studies are needed to fully validate this technique [26].

IODINE-BASED CONTRAST AGENTS

Iodine-based contrast agents for CT may induce various complications, including skin reactions (rash, itching, blistering) and respiratory or gastrointestinal disturbances [30]. A significant concern is contrast-induced acute kidney injury, particularly in patients with pre-existing renal impairment, with an incidence of up to 30% in high-risk groups [11,31–33]. However, in patients with normal renal function, the probability of contrast-induced acute kidney injury is low, typically <5% [33]. Nevertheless, it is important to adequately hydrate the patient before iodine contrast use or before the use of diluted contrast agents [20]. Low-osmolar agents can reduce the incidence of contrast-induced acute kidney injury to around 2%, regardless of comorbidities. Additionally, statin use may decrease the risk of nephrotoxicity by up to 80% [34]. Notably, intra-arterial administration is associated with higher nephrotoxicity due to increased renal contrast concentration [33].

MRI

MRI is a complementary imaging modality to CT, particularly when CT is contraindicated [13,25]. It has demonstrated higher sensitivity in detecting endoleaks—especially those of unknown origin—owing to superior soft-tissue contrast [16,25,35]. Standard MRI protocols typically include T1-weighted images acquired before and after gadolinium contrast administration [13]. In a meta-analysis, Habets et al. [25] found that MRI detected nearly twice as many endoleaks as contrast-enhanced

CT, with only two type I endoleaks being missed. Many of the additional endoleaks identified are type II endoleaks, whose clinical importance remains uncertain. Only those with AAA growth require surgical treatment. MRI's ability to identify endoleaks missed by CT is a significant advantage and is recommended as an adjunct in cases of aneurysm sac expansion with no evident type II endoleak on CT [25]. However, artifacts from stent grafts composed of stainless steel or nickel alloys may compromise image quality; nitinol grafts are preferred [17,20].

The 4D-FLOW technique provides additional post-EVAR information by distinguishing endoleak types (except type V), quantifying leak volume, and assessing flow dynamics [20,36]. It can differentiate between type IIA endoleaks (bidirectional flow) and type IIB endoleaks (unidirectional flow) [36]. Katahashi et al. [36] demonstrated that higher peak flow velocity and greater amplitude of blood flow dynamics in tributary arteries are significantly associated with aneurysm sac expansion (OR 42.787, 95% CI 1.256–1463.57, $p=0.037$). The researchers established that this technique has 85.7% sensitivity and 76.2% specificity for predicting sac growth when a cutoff value of 3750 mm³/min is used. In addition, detection of tributary vessels with 4D-FLOW MRI achieved 100% sensitivity and specificity [36]. This modality enables detailed hemodynamic assessment that is challenging with contrast-enhanced CT and may help select patients with type II endoleaks who require more aggressive management [22, 36].

In patients with contraindications to contrast agents (e.g., pregnancy, renal impairment), the time-of-flight (TOF) sequence provides a useful, albeit less sensitive (approximately 54%), alternative for image acquisition [13, 37]. When combined with contrast, TOF can achieve up to 97% concordance with angiographic images [13]. Additionally, TOF allows physicians to assess the direction of blood flow within vessels, and some studies suggest that this method outperforms CT in evaluating nitinol stent grafts [13, 20].

Despite its advantages — lack of ionizing radiation and reduced contrast requirements — MRI is limited by accessibility, high cost, and longer acquisition times [13, 17]. Furthermore, despite improved detection sensitivity, the clinical relevance of additional type II endoleaks remains uncertain; only those associated with AAA enlargement warrant surgical intervention.

GADOLINIUM-BASED CONTRAST AGENTS

Adverse reactions after gadolinium contrast agents are less common than after iodine-based agents [30]. However, acute side effects, such as paresthesia, nausea,

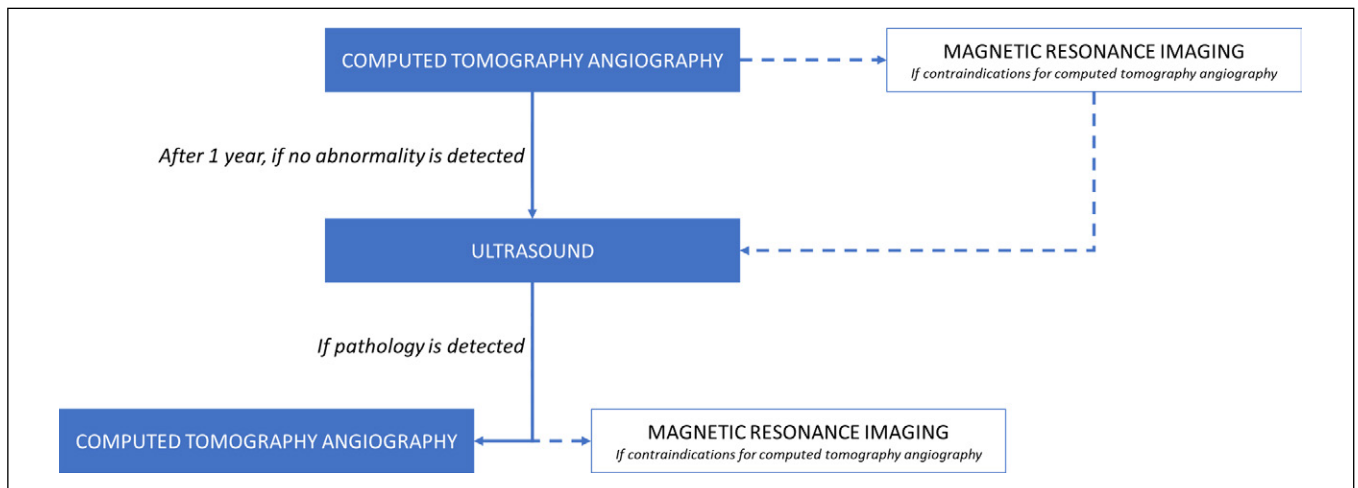


Fig. 2. Proposed diagnostic surveillance pathway following endovascular aortic repair

Picture taken by the authors

vomiting, headaches, or dizziness, may still occur [38]. There is also concern regarding gadolinium deposition in the central nervous system, even in patients with normal renal function, though the clinical implications remain uncertain [20,39]. Additionally, there is a risk of nephrogenic systemic fibrosis, primarily in patients with pre-existing renal disease [20, 32, 38, 39]. Notably, the incidence of NSF has declined in recent years, and gadolinium deposition disease is recognized as a possible, albeit rare, complication following intravenous administration [38].

US IMAGING

US is a cost-effective and widely available method for post-EVAR follow-up, particularly in patients for whom CT or MRI are contraindicated. Its primary advantages are the absence of ionizing radiation and contrast agents [13, 24]. B-mode US evaluates the abdominal aorta, iliac and femoral arteries, the aneurysm sac, and the stent graft, while Doppler US assesses blood flow direction and detects endoleaks [13]. However, its diagnostic utility is controversial. Some studies report Doppler US sensitivities of 70–82% and specificities of 93–94% [14, 27], whereas others indicate that duplex US may be inferior to CT [35]. Some authors note that, despite lower sensitivity compared to contrast-enhanced CT, Doppler US may exhibit higher specificity [16]. Differences in reported sensitivities and specificities may be attributable to the experience of both the medical center and the physicians, given that US requires expertise. On the other hand, contrast-enhanced US can match [16] or even exceed CT in endoleak detection [35]. Contrast-enhanced duplex US can reach a sensitivity of 98% and a specificity of 88% [26]. A pilot study by Esposito et al. [40] suggests that a combination of

duplex US, contrast-enhanced US, and plain CT may be sufficient for post-EVAR surveillance. Nevertheless, operator dependence and variability in image quality — owing to patient body habitus and cooperation — remain significant limitations [13, 18, 21].

PROPOSED PRACTICAL IMAGING PROTOCOL FOLLOWING EVAR

Postoperative surveillance after EVAR is crucial for post-procedural outcomes. The initial examination should be performed with CTA, which serves as the reference modality [13]. It should be the first-choice imaging modality due to its availability and reproducibility, with excellent detection of endoleaks. MRI, especially with advanced sequences such as 4D-FLOW and TOF, should be used in patients with contraindications to CTA [13, 25]. This modality offers excellent soft-tissue resolution, enabling detection and accurate classification of endoleaks. However, limited access and high cost may restrict MRI use to selected patients. For long-term follow-up, if prior examinations show no abnormalities, US can be recommended after one year [16]. It remains a viable option because of its availability and lack of radiation [13, 24]. It is noninferior to CTA and MRI, and when pathology is detected, additional examination can be performed with other modalities. Proposed diagnostic options over time are presented in Figure 2.

CONCLUSIONS

While CTA remains the reference standard for post-EVAR surveillance, MRI and US are viable alternatives. These techniques demonstrate comparable diagnostic accuracy while eliminating ionizing radiation exposure and potentially reducing contrast medium requirements.

This approach may confer particular benefit for patients with chronic kidney disease or those at risk for contrast-induced nephropathy. Clinical decision-making should incorporate a comprehensive assessment of

imaging modality selection, with careful consideration of cumulative radiation exposure and contrast agent administration in the context of individual patient risk factors and long-term surveillance requirements.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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