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ABSTRACT

Acute type A aortic dissection (ATAAD) is a life-threatening condition that requires emergency surgery to avert fatal outcome. Conventional surgical procedures comprise excision of the entry tear and replacement of the proximal aorta with a synthetic vascular graft. In patients with DeBakey type I dissection, this approach leaves a chronically dissected distal aorta, putting them at risk for progressive dilatation, dissection propagation and aortic rupture. Therefore, ATAAD survivors should undergo serial imaging for evaluation of the aortic valve, proximal and distal anastomoses, and the aortic segments beyond the distal anastomosis. The current narrative review aims to describe potential complications in the early and late phases after ATAAD surgery, with focus on their specific imaging findings.

INTRODUCTION

Patients with acute type A dissection (ATAAD) are prone to devastating complications (such as pericardial tamponade, aortic valve regurgitation and aortic rupture) and require emergency surgery to avert fatal outcome.[1] The cornerstone of surgical treatment comprises resection of the primary entry tear and replacement of the ascending aorta with a synthetic vascular graft ('tear-oriented' strategy). If the primary entry tear is encountered in the arch, this segment should also be replaced. Of note, the dissection extends beyond the arch in 80% of ATAAD patients.[2] Whether replacement of these adjacent segments with residual dissection or some forms of aneurysmal formation (but without entry tear) should already be performed during the primary procedure, remains widely debated.[3 4] In such cases, the conventional tear-oriented surgical approach leaves a distally dissected aorta with a potentially patent false lumen. These segments are prone to progressive aneurysm formation and dissection propagation, and serial imaging is indicated to guide future reinterventions. Surprisingly, an overview of postsurgical ATAAD complications and imaging recommendations was not yet provided in the literature. The current narrative review describes potential aortic events in the early and late phases after ATAAD surgery, with focus on their specific imaging findings. In addition, suggestions for preferred imaging modalities and intervals during postoperative surveillance are provided.

DISEASE CLASSIFICATION AND SURGICAL PROCEDURES

The Stanford system divides dissections by their most proximal involvement, with type A involving the aorta proximal to the left subclavian artery and type B involving the segments distal to this vessel. The DeBakey system also acknowledges the extent of dissection and distinguishes between type I (involvement of both the ascending and descending aorta), type II (ascending aorta only) and type III (descending aorta only).

The extent of primary surgical treatment of ATAAD is multifactorial and depends on: (1) the origin of the entry tear, (2) involvement of the aortic valve, (3) signs of end-organ malperfusion (including coronary occlusion), (4) presence of aneurysmal disease of the root and/or arch, (5) patient comorbidities and clinical presentation and (5) the expertise of the surgical team.

Current standard is a root-sparing supracoronary aortic replacement with aortic valve resuspension, aimed at obliteration of the false lumen and restoration of valve function (class I, level of evidence (LoE) B; figure 1A).[5] Concomitant aortic root replacement requires reimplantation of the coronary arteries but is indicated when the root is dilated or contains the primary entry tear (class I, LoE B; figure 1B).[5] On the distal extent, most procedures involve replacement of the aorta to the base of the brachiocephalic trunk using an open anastomosis technique, allowing inspection of the aortic arch (class I, LoE B).[5] This approach provides the option of hemiarch replacement using a bevelled anastomosis, stabilising the inner arch curvature but leaving the branch vessels untouched. The additional perioperative risk of total arch replacement is justified in patients in whom the primary entry tear is encountered in the arch and in those with cerebral or distal malperfusion syndromes (class IIa, LoE B; figure 1C).[5]

IMAGING FOLLOW-UP: GENERAL APPROACH

Imaging within days after surgery is recommended for detection of early complications (class I, LoE C).[6 7] Moreover, this approach provides a baseline reference for all imaging performed during follow-up. Transthoracic echocardiography (TTE) is the first-line modality in the general cardiology population and has logistic advantages in the acute and direct postoperative setting. Transoesophageal echocardiography (TOE) plays an important role in guiding surgical procedures and evaluating postoperative results directly after a patient comes off cardiopulmonary bypass. However, both TTE and TOE primarily provide a focused evaluation of the aortic valve and proximal aorta. The distal ascending aorta, arch and descending aorta (ie, segments that are prone to late complications after ATAAD surgery) demand assessment by CT or

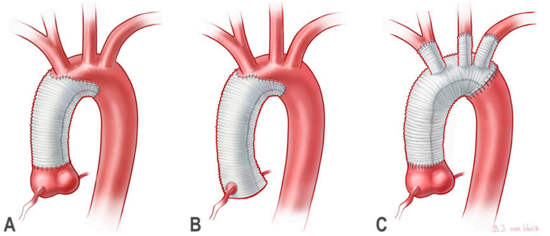

Figure 1 Frequently applied techniques for surgical correction of ATAAD. (A) Supracoronary ascending aortic and hemiarch replacement. (B) Root, supracoronary ascending aortic and hemiarch replacement. (C) Supracoronary ascending aortic and total arch replacement. Illustration by Barry van Varik (pulse medical art). ATAAD, acute type A aortic dissection.

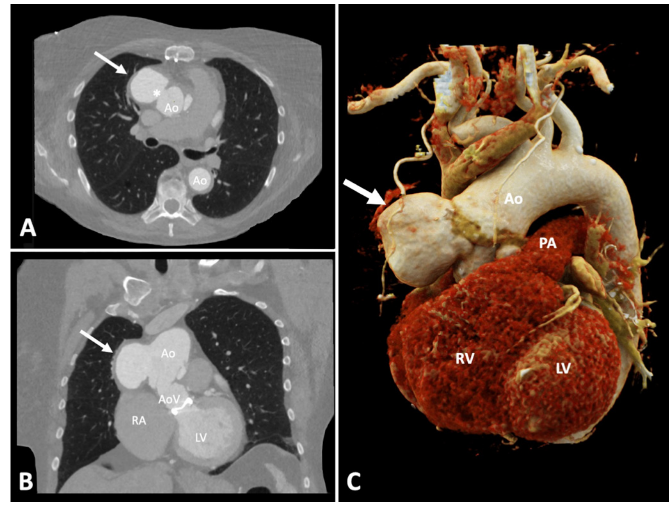

Figure 2 (A–C) Large pseudoaneurysm (arrow) at the level of the distal suture line in an ATAAD patient who was treated with root and ascending aortic replacement and underwent implantation of a composite graft with mechanical aortic valve (Bentall). *Pseudoaneurysm neck. ATAAD, acute type A aortic dissection; AO, aorta; AoV, aortic valve; LV, left ventricle; PA, pulmonary artery; RA, right atrium; RV, right ventricle.

MRI. In the direct postoperative evaluation of surgical results, CT is the modality of choice due to its fast acquisition times. In contrast, MRI is contraindicated in patients with unsecured metal requisites (such as temporary epicardial pacemaker leads). CT remains the preferred diagnostic modality during long-term follow-up in many centres, given its widespread availability, rapid procedural times and high spatial resolution (class I, LoE C).[6] However, its cumulative radiation exposure may be substantial. Therefore, MRI is a reasonable alternative in younger patients in whom repeat examination is indicated (class IIa, LoE C).[6] Whether CT or MRI is used, in case of repetitive imaging over time it is recommended that the same modality be used to allow for an adequate comparison (class I, LoE C).[6] Of note, while imaging modalities and intervals for follow-up are relatively well described in current guidelines, the level of expertise of the imager is not discussed. In our opinion, imaging of the post-surgical aorta with residual dissection is complex and requires interpretation by dedicated cardiovascular imagers.

There is paucity of data regarding the intervals at which imaging surveillance after ATAAD should be performed. Based on expert opinion, prevailing guidelines recommend follow-up at 3, 6 and 12 months after hospital discharge (class 1, LoE C).[6] Thereafter, follow-up is advised yearly or more frequently when complications develop.

EARLY POSTOPERATIVE COMPLICATIONS

Anastomotic leakage and pseudoaneurysm

Significant anastomotic leakage directly postoperatively is usually an indication for surgical re-exploration. Persisting, more gradual leakage resulting in pseudoaneurysm complicates 5%–8% of cases after proximal aortic replacement.[8] Pseudoaneurysm mostly occurs due to suture line dehiscence at proximal or distal anastomoses or at the site of coronary reimplantation and is more frequently observed after ATAAD surgery compared with elective aortic procedures.[9] Other risk factors include underlying connective tissue disease, the choice of surgical procedure and the use of synthetic surgical adhesives to achieve hemostasis.[10] In commonly performed procedures where pseudoaneurysm formation is more frequently encountered, such as coronary angiography and peripheral interventions, anticoagulant therapy has also been established as an important risk factor.[11] For post-ATAAD pseudoaneurysm formation, this is yet to be confirmed, and chronic anticoagulant use was not associated with late mortality or reoperation.[12] Pseudoaneurysms are mostly asymptomatic but carry a high risk of rupture due to diminished wall support. Although no specific recommendations exist, surgical repair is often indicated.[13] Of note, when the formation of a pseudoaneurysm is observed in the late phase after primary surgery, this should raise suspicion of graft infection.[14]

It is recommended that CT protocols for evaluation of the postsurgical aorta comprise both native and contrast-enhanced acquisitions (ie, CT angiography (CTA)).[15] ECG-gating is essential to avoid motion artefacts at the level of the proximal aorta. Pseudoaneurysms typically present on CTA as hyperattenuating and smooth-walled sacs with a narrow neck that communicate with the aortic lumen (figure 2A–C).[16] The non-enhanced scan serves to recognise postoperative material (such as anastomotic felt and staples) that may have a hyperattenuating appearance mimicking pseudoaneurysm. MRI is also a reliable technique for pseudoaneurysm detection but less convenient in the early postoperative setting. Moreover, MRI is less useful in patients who underwent implantation of a valved graft due to metallic artefacts that may project in the area of interest. TOE is more sensitive than TTE for detection of pseudoaneurysms at the level of the aortic root, while both echocardiographic techniques are limited in their ability to visualise the distal ascending aorta. On ultrasound, pseudoaneurysms are characterised by a pulsatile echo-free space with turbulent flow on colour Doppler. A 'to-and-fro' pattern may be observed on pulsed wave tracings at the pseudoaneurysm neck.[17]

Distal malperfusion

End-organ malperfusion at first presentation is observed in 25%–30% of ATAAD patients and adversely affects survival.[18] Some studies suggested a beneficial effect of delayed aortic repair after first restoring compromised end-organ perfusion.[19] However, later studies have demonstrated that approximately 80% of malperfusion syndromes resolute by immediate ascending aortic repair with exclusion of the entry-tear.[20] Severe persisting end-organ malperfusion directly after primary surgery can be detected by clinical and biochemical examination and usually requires prompt reintervention. In more subtle cases or dynamic obstruction, postoperative CTA is useful to assess the topographic relationship between the true and false lumen and

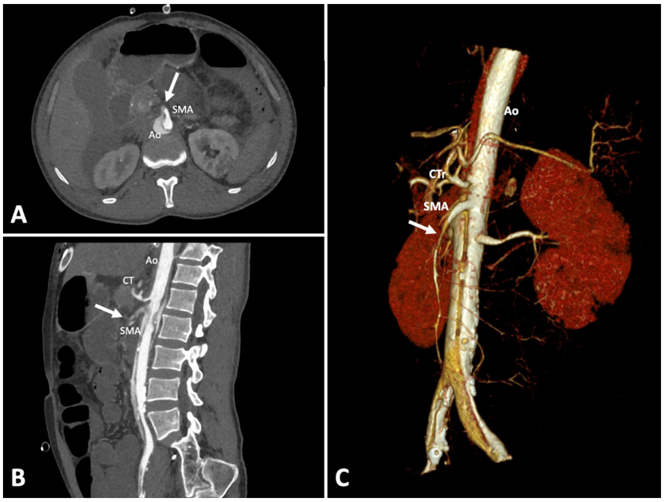

Figure 3 (A–C) CT angiography of an ATAAD patient who was treated with ascending aortic and hemiarch replacement and presented with clinical signs of mesenteric ischaemia and hyperlactataemia in the direct postoperative phase. Notice the false lumen compressing the true lumen of the SMA. AO, aorta; ATAAD, acute type A aortic dissection; CTr, coeliac trunk; SMA, superior mesenteric artery.

to detect true lumen compression (figure 3A–C). Furthermore, CT can be used to obtain evidence of end-organ ischaemia, such as asymmetric kidney enhancement (renal ischaemia) or pneumatosis intestinalis and pneumoperitoneum (visceral ischaemia). Combined with clinical and biochemical findings, CTA can confirm the definitive indication for endovascular revascularisation (or peripheral bypass surgery, in case of lower extremity ischaemia).

LATE PROXIMAL COMPLICATIONS

Aortic root related events

Since more extensive ATAAD surgery—either on the proximal or distal extent—is associated with higher perioperative mortality, the choice of surgical strategy must be a balance between short-term risks and long-term durability of aortic repair. Replacement of the aortic root is only performed during initial surgery in 5%–10% of cases in which this segment is severely diseased.[21] In the majority of patients, the root is left in situ, predisposing them to late complications. Common indications for late root reoperation include progressive dilatation (figure 4A–E, 13% of patients), pseudoaneurysm (5%) and recurrent dissection (3%).[22 23] In general, root replacement during follow-up is recommended when the diameter exceeds 55 mm in patients without elastopathy (class IIa, LoE C).[6] In most cases, if asymptomatic, reintervention can be performed electively. The diameter of the preserved aortic root may grow faster compared with patients without previous dissections, potentially due to altered local haemodynamics in the adjacency of a rigid supracoronary graft prosthesis.[24] Therefore, annual imaging for evaluation of the root diameter seems reasonable in the first years after supracoronary aortic replacement. Emerging techniques (such as four-dimensional (4D) phase-contrast MRI) have demonstrated an association between disturbed haemodynamics and aortic dilatation in aneurysm patients,[25] but their value in prediction of complications after ATAAD has not yet been investigated.

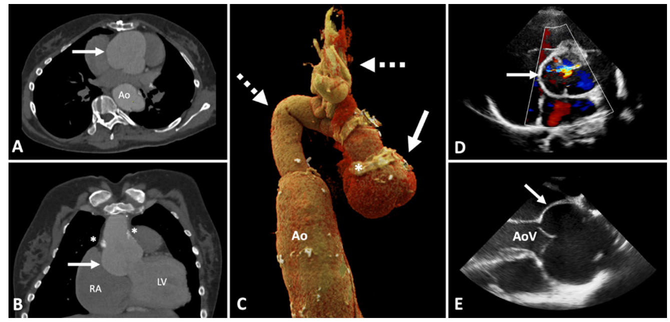

Figure 4 (A–C) CTA of a patient with Marfan syndrome and previous ATAAD, initially treated with supracoronary ascending replacement. During a later (elective) procedure, the arch and descending aorta were replaced, with reimplantation of the supra-aortic vessels (dashed arrows). Now the patient presented with progressive dilatation of the aortic root and concomitant aortic valve regurgitation (arrows). (D–E) Short-axis (D) and long-axis (E) TOE views showing the dilated root with central regurgitation jet on colour Doppler. AO, aorta; AoV, aortic valve; ATAAD, acute type A aortic dissection; CTA, CT angiography; LV, left ventricle; RA, right atrium; TOE, transoesophageal echocardiography.

Aortic valve regurgitation

Haemodynamically significant aortic regurgitation (AR) is present in up to 50% of patients before ATAAD repair.[26] This can occur secondary to (acute or chronic) root and annular dilatation, when the intimal tear extends proximally into the sinuses of Valsalva detaching the aortic valve, or when a dissection flap prolapses through the aortic valve into the left ventricular outflow tract during diastole.[27] In most cases of secondary AR, valve resuspension sufficiently restores valve function. Still, up to 4.6% of patients develop severe AR within 10 years after primary ATAAD repair, and this risk is higher in individuals with persisting moderate valve regurgitation after initial surgery (figure 4D).[28] Therefore, frequent surveillance is indicated in the latter group, while imaging intervals can be prolonged to once every 3 years in those with only trivial or mild AR.[29] TTE—using an integrative approach considering qualitative, semiquantitative, and quantitative parameters—is the key diagnostic tool to evaluate regurgitation mechanism and severity (recommended, but no specific class or LoE).[29] Regurgitation fraction derived from phase-contrast MRI strongly correlates with echocardiographic assessment, rendering MRI a useful technique when TTE results are equivocal.[30] Generally, surgical reintervention is indicated when recurrent AR is severe and symptomatic or in case of decreased left ventricular function and can be performed electively (class I, LoE B)[31]

LATE DISTAL COMPLICATIONS

Arch and descending aortic aneurysm progression or dissection

The extent to which the aorta should be replaced beyond the proximal arch remains an important matter of debate. The incentive for a more aggressive strategy is to improve long-term survival by reducing late distal events and reinterventions. Moreover, extended repair (ie, that includes the aortic arch and beyond) facilitates a landing zone for eventual future endovascular procedures. The most frequent indication for elective reoperation after ATAAD surgery is distal aneurysm progression, which may result either from expansion of the false lumen (figure 5A–E, in DeBakey type I) or progression of an aneurysm of the non-dissected descending aorta. Progressive

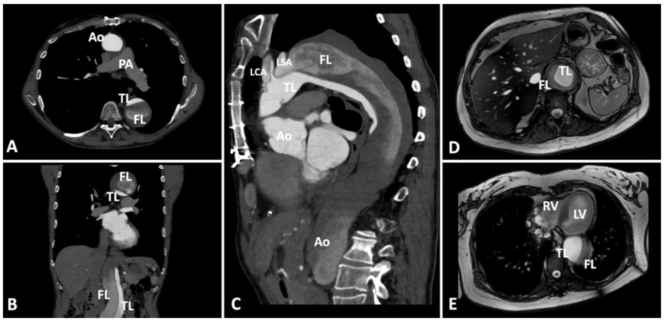

Figure 5 (A–C) CTA of a patient with prior ATAAD treated by supracoronary and hemi-arch replacement, now presenting with progressive dilatation of the distal arch and proximal descending aorta and a patent distal false lumen. The supra-aortic vessels arise from the true lumen. (D–E) Axial BTFE MRI-acquisitions of a different patient with chronic type B dissection with thrombosed false lumen. AO, aorta; ATAAD, acute type A aortic dissection; BTFE, balanced turbo field echo; CTA, CT angiography; LCA, left carotid artery; LSA, left subclavian artery; FL, false lumen; PA, pulmonary artery; TL, true lumen.

false lumen expansion is associated with the number of false lumina, number of true–false lumen fenestrations, retrograde false lumen flow pattern and an increased false:true lumen ratio, among others.[32–34] Especially false lumen patency predisposes to growth and is observed in 43%–67% of patients after primary ATAAD repair and related to increased 10 year mortality.[35] Diameter increase has shown to be 3.7 mm/year in patients with patent false lumina, as compared with 1.1 mm/year in those in whom the distal false lumen is thrombosed.[36] Of note, persistent distal re-entry tears (additional true–false lumen fenestrations that can be difficult to assess during primary ATAAD repair) are usually the cause of false lumen patency. Although still under investigation, false lumen instability can be assessed using different novel techniques or other markers of local inflammation. Among others, these include pleural effusions, alterations in wall shear stress and increased ^{18}F-fluorodeoxyglucose (^{18}F-FDG) uptake on positron emission tomography (PET)/CT scan.[37–39] Apart from diameter increases, aortic length is also associated with adverse outcome and should be taken into account as well.[40]

A differentiation in indication for intervention on the aortic arch and descending aorta are provided in current guidelines, stating a cut-off diameter of 55 mm for the arch and 60 mm for the descending aorta (both class IIa, LoE C, preferably performed electively).[6] Of note, contemporary techniques (such as the frozen elephant trunk, facilitating a surgical total arch replacement and descending aortic stentgraft placement) have emerged to combine conventional surgical and endovascular techniques, promoting false lumen thrombosis and favourable downstream aortic wall remodeling.[41] Although conflicting evidence exists on the effect of blood pressure control on aneurysm progression, this might be an important modifiable factor in this context, with the potential to prevent future complications or interventions.[42]

Although the ascending and descending aorta also differ significantly in terms of embryological origin, 28% of ATAAD patients present with coinciding descending thoracic or abdominal aortic aneurysms, even when the distal aorta is not dissected.[43] Therefore, in ATAAD survivors with and without connective tissue diseases and regardless of dissection extent, serial imaging of the entire aorta is indicated during follow-up.

Rupture of distal aortic segments

Late rupture of distal aortic segments, which occurs in 4% of patients, is a devastating and often lethal complication after ATAAD repair.[44] Its occurrence is related to false lumen patency, although patients with thrombosed false lumina can also suffer distal rupture. However, it should be noted that incidence is probably underestimated, as many patients die before arrival at the hospital. The sensitivity of echocardiography in suspected aortic rupture is limited.[45] Therefore, CTA should be the imaging modality of choice given its time-effectiveness and superior diagnostic accuracy (class I, LoE C).[6] Following confirmation of the diagnosis of rupture, patients should be treated immediately (emergency intervention, class I, LoE C),[6] preferably by endovascular intervention (class I, LoE C).[6]

To prevent the lethal complication of rupture, specific signs of impending rupture can be noted on CTA, which can aid physicians to identify patients at risk. Many of these patients present with classical symptoms of acute aortic syndrome. Findings on CTA suggesting impending rupture include increased aneurysmal size with rapid enlargement, periaortic fat stranding, focal wall discontinuation, a high-attenuation crescent sign of the aortic wall, pleural effusion, thrombus fissuration and a 'draped' aorta sign (suggesting contained rupture).[46] If impending rupture is objectified, urgent intervention is indicated (class I, LoE C)[6]

GRAFT INFECTIONS

Infections of aortic grafts are a relatively rare form of endocarditis that occur at an incidence of 0.2% per year. Diagnosis can be challenging, especially in the subacute postoperative phase. Late pseudoaneurysm formation should raise suspicion of infection, as this can be the first presenting sign.[14] Surgery for explantation of infected graft material is indicated in cases with persistent signs of infection or recurrent septic emboli under appropriate antibiotic treatment. The key concept of reoperation for graft infection is removal of all potentially infected material. However, surgery for graft infection is technically challenging, as reflected by high perioperative mortality rates. In general, both surgically and conservatively treated graft infections carry a poor prognosis with approximately 30% risk of mortality.[47] As such, no specific recommendations are provided in literature, but surgical re-intervention might be considered in younger and low-risk patients with refractory bacteraemia.

Transoesophageal echocardiography has a sensitivity and specificity of 92% and 90% for detection of prosthetic valve endocarditis and is recommended as first-line imaging technique.[48] However, detection of supracoronary graft infection mostly requires a multimodality imaging approach, as TEE can only detect endocarditis in 57% of such cases.[47] ^{18}F-FDG PET/CT has evolved as an important supplementary technique with 88.9% sensitivity for detection of aortic graft infection (figure 6A–C).[49] As a result, a positive PET/CT has become a major criterion for diagnosis of endocarditis in latest cardiovascular guidelines.[48] Still, in the early postoperative phase, nuclear imaging should be interpreted with caution, as the normal postsurgical inflammatory response may result in non-specific tracer uptake in the first 3–6 months after surgery.[7] CT has a lower sensitivity and specificity than PET/CT for diagnosing graft infections but may reveal perigraft complications (such as abscess formation and infective pseudoaneurysm) and septic emboli affecting different organs and tissues and could therefore often used prior to PET in daily clinical routine. Table 1 summarises early and late complications and utility of different imaging modalities for their diagnosis.

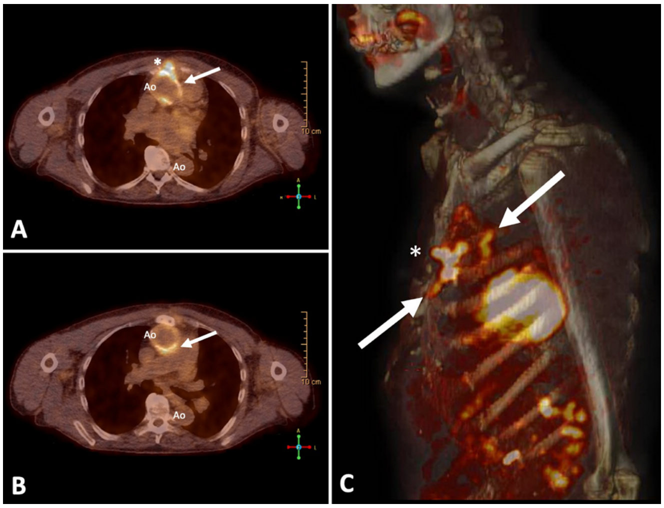

Figure 6 (A–C) ^{18}F-FDG PET/CT of a patient who underwent supracoronary and hemi-arch replacement for ATAAD, demonstrating significant uptake in and around the vascular prosthesis (arrows) and sternal fistulation (*). ^{18}FDG, ^{18}F-fluorodeoxyglucose; AO, aorta; ATAAD, acute type A aortic dissection; PET, positron emission tomography.

GAPS IN EVIDENCE AND FUTURE DIRECTIONS

Imaging follow-up after ATAAD carries a class I recommendation in prevailing guidelines, which seems justified given the high incidence of early and late postsurgical complications. However, adherence to these recommendations is low, as only 14% of patients undergo regular imaging in the first years following surgery.[50] This poor adherence may be explained by important gaps in evidence, which could be addressed in future prospective studies. Most importantly, a differentiation in follow-up intervals between patients with patent and thrombosed false lumina should be determined, as well as for patients at different aortic sizes. Whether yearly follow-up of patients with long-term 'stable' disease is indicated is still undefined.

Although the role of 4D flow MRI in postsurgical patients is still under investigation, this emerging technique enables quantification of a wide range of haemodynamic parameters and has potential to predict aortic growth. The advent of such new techniques paves the path for tailored imaging follow-up, accounting for age, false lumen patency, current aortic size and presence of haemodynamically significant disease progression.

Table 1 Summary of early and late complications and utility of different imaging modalities for their diagnosis

	5-year incidence	Imaging modality				
		TTE	TOE	CTA	MRI	PET/CT
Pseudoaneurysm	5%	+	++	+++	+++	–
Persisting malperfusion (subacute)	20%–25%	–	–	+++	–	–
Severe aortic valve regurgitation	2.5%	+++	+++	–	++	–
Root aneurysm progression	15%	++	++	+++	++	–
Distal aneurysm progression	17.5%	–	–	+++	++	–
Distal aortic rupture	3%	–	–	+++	–	–
Graft infection	1%	–	+	++	–	+++

CMR, cardiac MRI; CTA, CT angiography; PET, positron emission tomography; TOE, transoesophageal echocardiography; TTE, transthoracic echocardiography.

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