Point of view

Thoracic and abdominal aortic aneurysms: invasive and non-invasive imaging from an endovascular perspective

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Introduction

Although many contraindications and some drawbacks do exist, thoraco-abdominal aortic aneurysmal disease is being increasingly considered as amenable to endovascular repair. At the moment endovascular repair is offered to patients with an abdominal aneurysm 50-60 mm in diameter with sufficient proximal and distal necks (≥ 1.5 cm); iliac involvement is not generally considered as a contraindication[1].

On the other hand, thoracic aneurysms with proximal neck of ≥ 1.5 cm are managed with an endovascular approach and different combined open and endovascular techniques are used to manage involvement of epiaortic vessels[2]. Advances in diagnostic equipment have led to an increase in the number of indications for aortic endografting and provide the endovascular specialist with different and complementary techniques for the imaging of all the phases of endovascular management (Table I).

Our brief review presents a picture of the main tools for the diagnosis, evaluation, intervention planning, intraoperative control and follow-up of thoraco-abdominal aortic aneurysmal pathology from an endovascular perspective.

Suspicion, screening and surveillance

The prevalence of abdominal aneurysms increases with age and ranges from 2.2 to 9%[3], while a thoracic aneurysm is present in 36% of patients with Marfan's syndrome; 20-30% of patients with a thoracic aneurysm also have an abdominal aortic aneurysm[4]. Because of the high risk of rupture, screening programs tailored to the determination of the size of the aneurysm[5-7] are essential. Clinical examination remains the primary method allowing the physician to suspect the disease: the presence of pulse asymmetry, new thoracic or abdominal aortic murmurs, and exaggerated abdominal pulsation should alarm the physician. At the same time, an abnormal thoracic X-ray showing calcifications or a tortuous or ectasic thoracic aorta may lead to a more detailed diagnostic regimen examination which together with clinical examination constitutes the first line screening process.

Conventional ultrasound of the thoracic district seems to be an effective and cost-saving second line screening and surveillance technique in patients with a positive family history, old age and a history of hypertension and/or smoking[8]. Sonography can be performed in the parasternal long-axis or suprasternal projections with transthoracic echocardiography for the delineation of the ascending aorta and arch, and in the upper esophageal or transgastric projections with transesophageal echocardiography to show almost the entire descending aorta.

Moreover, the evaluation of the abdominal aorta in the substernal projection during routine echocardiographic examination constitutes a simple and rapid screening method in patients being investigated for cardiac diseases.

Table I. Phases of the endovascular management of aortic aneurysmal disease and the usefulness of different imaging techniques compared with surgical management.

	Screening		Preoperative evaluation		Intraoperative guidance/control		Follow-up	
	Surgical repair	Endovascular repair	Surgical repair	Endovascular repair	Surgical repair	Endovascular repair	Surgical repair	Endovascular repair
X-ray	++	++	-	-	-	-	-	+
Sonography	+++	+++	+	+	++ (TAA)	++ (TAA)	++	+++
DSA	-	-	++	+	-	+++	-	++
CT	-	-	++	+++	-	-	+++	+++
MR	-	-	++	+++	-	-	+	+++
IVUS	-	-	-	-	-	++	-	+

CT = computed tomography; DSA = digital subtraction angiography; IVUS = intravascular ultrasound; MR = magnetic resonance; TAA = thoraco-abdominal aneurysm. + = only slightly useful; ++ = moderately useful; +++ = very useful; - = not useful.

Doppler capability and the introduction of the second harmonic frequency have increased the accuracy of echocardiography in detecting the presence of a thrombus or dissection within the aneurysmal vessel and in assessing an arterial wall pathology[9].

Crow et al.[10] found that a single normal ultrasonographic scan at age 65 years ruled out significant aneurysmatic disease, whereas Bailey et al.[11] demonstrated that ultrasonography performed by primary care residents is effective for the screening of abdominal aortic aneurysms. Recently, Vourvouri et al.[12] proved the usefulness of the portable hand-held echo ultrasound device for the screening of aneurysmal pathology. Depending on the size, with operative intervention limited to rapidly enlarging aneurysms ≥ 5-5.5 mm or less, small aneurysms can be safely monitored by ultrasound at 3- to 12-month intervals[13].

Sonography is performed in the sagittal and transverse projections to evaluate the aorta from the diaphragmatic hiatus to its bifurcation with sequential imaging of the common iliac arteries.

Evaluation and intervention planning

The evaluation of thoraco-abdominal aneurysms and endovascular intervention planning are routinely accomplished by computed tomography (CT) and magnetic resonance (MR) angiography[14-20].

Computed tomography. Contrast-enhanced CT angiography provides both axial and three-dimensional images which help the endovascular specialist to define the topography and anatomy of the interventional field[21-23].

Multidetector capability has improved the accuracy and rapidity of acquisition. A complete CT scan with a 1.25-3 mm slice thickness can be performed in 20 s and 70-120 ml of iodinated contrast medium.

The CT three-dimensional reconstruction is displayed using a combination of maximum intensity projection and volume rendering[24]. The length and diameters of the aneurysm as well as the length of the necks, the origin of the major branch vessels, and the extension of the aneurysm can be completely determined, providing the endovascular specialist with essential information for the determination of the size, design, and deployment sites of the endograft[25-27].

Post-processing software (AVA-advanced vessel analysis) leading to automatic centerline tracking and vessel edge detection provides real longitudinal and cross-sectional area measurements of eccentric and tortuous aneurysms[28,29].

A normal renal function and adequate intravenous access without contraindications to iodinated contrast media are prerequisites for the examination.

Magnetic resonance. Similarly, MR angiography can provide the same information but does not show mural or thrombus calcifications which are essential for iliac access during endovascular repair[28], and it has the advantage of being suitable for patients with renal insufficiency.

The technique is performed in 45-100 s, using 42-64 ml of a paramagnetic agent such as gadolinium[30-34] through a 1.5T scanner. Three-dimensional images are displayed primarily in a maximum intensity projection mode and supplemented with axial plane T1-weighted sequences to show the lining of a mural thrombus.

Stepped-table and bolus-timing strategies continue to improve the overall image quality[35,36], providing a more accurate definition of the extension of the aneurysm above the renal arteries and below the bifurcation[37].

As suggested by Neschis et al.[37], in the future MR angiography will be successfully used as the only technique for the design of the aortic endograft, with the advantages of its non-invasiveness and the absence of nephrotoxic risks.

Digital subtraction angiography. In the 70's and 80's angiography was considered the most suitable and safe technique for the evaluation of thoracic and abdominal aneurysms[38-40], but in the late 80's the technique lost its leadership and was coupled with CT and MR[41,42].

At the moment digital subtraction angiography (DSA) provides an indication for evaluating aneurysmal disease in patients with associated occlusive disease and claudication[43], in whom both the lateral and posterior-anterior projections should be routinely used[44].

Moreover, intra-arterial DSA for the evaluation of aneurysms has been shown to cost 3.2-3.7 times more than CT[45].

Intraoperative evaluation and guidance

Several techniques can help the endovascular specialist during the endovascular intervention and provide different and often complementary information at each step of the procedure.

Fluoroscopy and digital subtraction angiography. Fluoroscopy remains the gold standard and the only technique available at the moment for the intraoperative guidance of the entire endoprosthesis deployment process. During each step of the endovascular intervention, DSA checks the correct position of the endoprosthesis with respect to the main branch vessel and gives an immediate on-line control of eventual type I endoleaks.

Transesophageal echocardiography. Transesophageal echocardiographic guidance during thoracic aneurysm repair has been found to allow for a refinement of the procedure in 59% of cases, improving the immediate outcome and reducing complications[46]. It has a 100% sensitivity and specificity in detecting endoleaks and thromboexclusion[47]. The technique has some drawbacks such as a problematic acquisition in obese or bronchopneumopathic patients and necessitates specialized personnel.

Intravascular ultrasound. Many studies show a real benefit from the use of a 7F-12.5 MHz intravascular ultrasound (IVUS) probe during peripheral endovascular interventions[48,49]. It is superior to angiography in detecting incomplete stent-graft expansion[50], it provides measurements of the cross-sectional area and length of the aneurysm comparable to and more detailed than CT and DSA[51,52] and can enable final correction in the size and length of the endoprosthesis[53]. It helps to assess the correct position of the prosthesis, indirectly[54] and directly by determining an inadvertent renal artery coverage[55], can permit evaluation of an eventual arterial wall pathology following the endograft placement and it can reveal whether the endograft has expanded properly or not (Figs. 1 and 2).

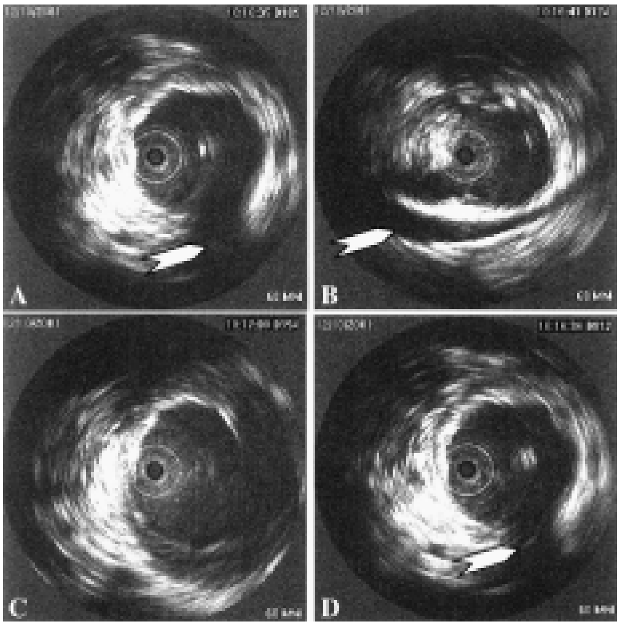

Figure 1. *Intravascular ultrasound scan before deployment of a bifurcated AneuRx endograft. Note* (arrow) *the origin of the celiac trunk* (A), *the origin of the right renal artery* (B), *the thrombus in the aneurysmatic sac* (C) *and the distal neck* (D).

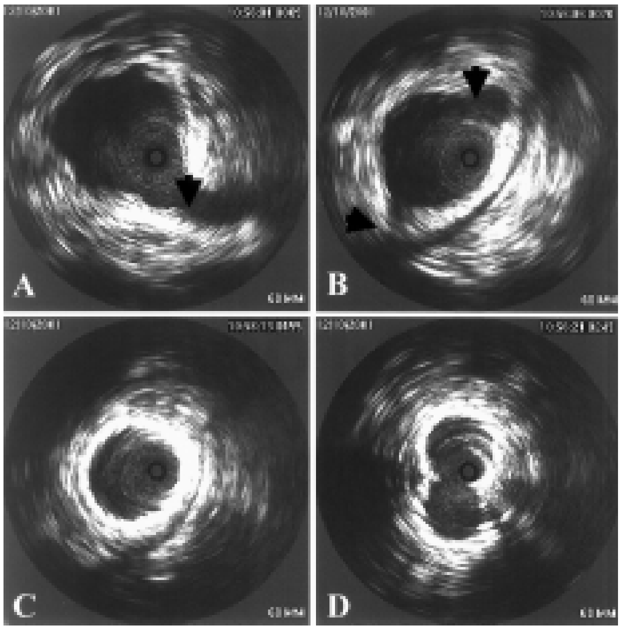

Figure 2. *Intravascular ultrasound scan after the deployment of a bifurcated AneuRx endograft. The celiac trunk* (A) *and both the renal arteries* (B) *were patent* (arrow). *Note* (arrow) *the good apposition of the graft below the renal arteries* (C) *and the clear image of the leg of the bifurcated endoprosthesis* (D).

Intravascular ultrasound by intracardiac echocardiographic probe. Recently our group showed the benefits of the use of an intracardiac echocardiographic 9F-110 cm-9 MHz probe in the endovascular repair of thoracic and complex abdominal aortic aneurysms. This technique has the advantages of a larger field of view than that obtainable with the conventional IVUS probe. Besides, it has a greater resolution and the use of its angular long sheath enables a perfect alignment to be made between the vessel and the probe in the ascending thoracic aorta, avoiding artifact and aberrance errors. It also allows for an accurate detection of the origin of the main branch vessel (Figs. 3A and 3B) and for precise measurements of the cross-sectional area and length of the aneurysm[56]. It has proved to be effective in revealing the incomplete expansion of the endoprosthesis and renal artery coverage, and in suggesting the need for further modular components (Figs. 3C and 3D) in 11/17 patients[57].

Follow-up and endograft surveillance

X-ray. Thoracic or abdominal biplane X-ray is useful for detecting an endoprosthesis kink or disruption[57,58].

Ultrasound. Sonography is used only in selected non-obese, good compliance patients, but does not provide precise enough information for sac control[58]. It is more effective in abdominal rather than in thoracic aortic aneurysm surveillance because of the technical difficulties implied in transesophageal echocardiography. Nevertheless, surveillance protocols incorporating duplex scanning are effective and may reduce overall the post-placement expenses[59]. Late endoleaks which would require further investigation using techniques such as CT or MR could be easily identified both at the thoracic and abdominal aortic levels.

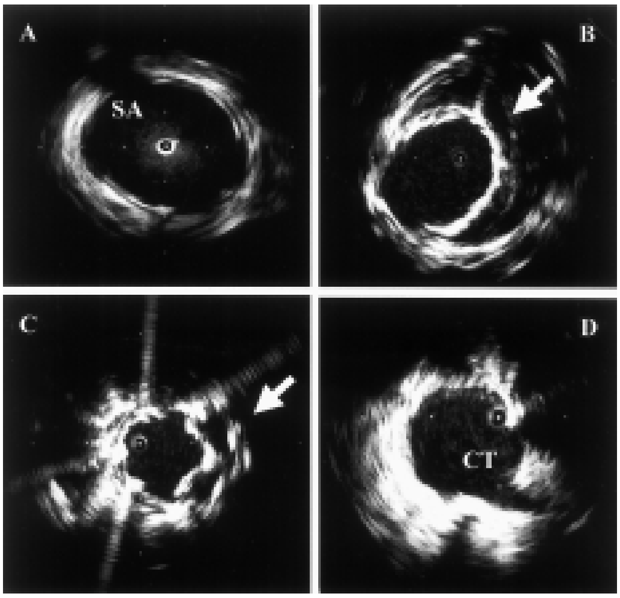

Figure 3. *Intravascular ultrasound with intracardiac echocardiographic probe in a complex thoraco-abdominal aneurysm: origin of the subclavian artery (SA)* (A), *the celiac trunk (CT)* (B), *incomplete expansion of the graft* (C) *and thrombus in the sac of the aneurysm* (D).

Helical computed tomography. Two- and three-dimensional reformatted CT is the method of choice for the follow-up of thoracic and abdominal aortic aneurysms after endografting (Fig. 4). Typical CT findings include the size of the endograft, exclusion with complete perigraft thrombosis, back-filling of the aneurysmal sac via the branch vessels (intercostal or lumbar vessels) and device dislocation, disruption and rotation and the presence of kinks and thrombosis. CT has a sensitivity of 92% and a specificity of 90% in detecting type II endoleaks[60] the biphasic acquisition being superior to the arterial phase alone[61].

Lee et al.[62] reported the utility of non-contrast CT images in distinguishing true and pseudoendoleaks (contrast entrapment during the endovascular intervention misinterpreted as an endoleak in the post-procedural CT scan).

Recently, a classification of six groups of volumetric changes of the aneurysmal sac after endografting by spiral CT has been suggested as being predictive for endoleakage: progressive reduction (Ia), transient initial increase (Ib), no change (II), late increase (IIIa), progressive increase (IIIb), and late reduction (IV) in the sac volume. Progressive reduction has been suggested as the ideal outcome, whereas group III seems to be associated with types I and III endoleaks[63].

Magnetic resonance. In young patients and in those with contraindications to iodinated contrast medium, MR is perfectly equivalent to CT. MR appears to be more sensitive in the detection of type II endoleaks[63]. Life-Path, Zenith endoprostheses cannot be suitable for MR imaging due to severe artifact production as a result of their thick metallic mesh-work[64].

Digital subtraction angiography. Angiography is inferior to CT and MR in the diagnosis of endoleaks (sensi-

Figure 4. *Computed tomographic three-dimensional reconstruction of an abdominal-iliac aneurysm before* (A) *and after* (B) *the endovascular repair using a Talent endograft and two aortic cuffs (bell-bottom technique) to seal both the abdominal and the common iliac arteries aneurysms.*

tivity 63%, specificity 77%) but it is necessary for intervention planning in patients in whom other techniques were suggestive of the presence of endoleaks[57-59].

Intravascular ultrasound. It can be useful in the assessment of suspected epiaortic or renal artery coverage not exhaustively appreciated by CT, MR and DSA[53].

During long-term follow-up, the different techniques should be selected on the basis of the availability, cost and accuracy, bearing in mind that chest or abdominal X-ray can be used as first line examinations as they are easily available and inexpensive; sonography can be scheduled in order to detect the presence of any early and late endoleaks which CT and MR could subsequently define in terms of their precise extent and location. DSA should be chosen when, on the basis of CT/MR findings, it is deemed that a further endovascular repair is needed; IVUS examination is required only in particular conditions such as the accurate definition of an eventual suspected arterial coverage or insufficient graft expansion (Table II).

Table II. Suggested techniques during follow-up after endovascular intervention.

Pre-discharge control	Long-term follow-up
Sonography CT or MR	X-ray Sonography CT or MR DSA if CT or MR are positive for endoleaks in order to plan further interventions IVUS if an incomplete expansion or inadvertent arterial coverage is detected by DSA

CT = computed tomography; DSA = digital subtraction angiography; MR = magnetic resonance; IVUS = intravascular ultrasound.

Conclusions

In the near future, a single technique for evaluating intraoperative guidance and surveillance may be developed, but at the moment only a careful combination of all these techniques provides accurate endovascular management of thoraco-abdominal aortic aneurysmal disease.

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