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The Importance of Imaging Assessment Before Endovascular Repair

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Abstract  Indications for and experience with placement of endovascular stent grafts in the thoracic aorta are still evolving. Recent advances in imaging technologies have drastically boosted the role of pre-procedural imaging. The accepted diagnostic gold standard, digital subtraction angiography, is now being challenged by the state-of-the-art computed tomography angiography (CTA), magnetic resonance angiography (MRA) and trans-oesophageal echocardiography (TEE). Among these, technological advancements of multidetector computed tomography (MDCT) have propelled it to being the default modality used, optimising the balance between spatial and temporal resolutions and invasiveness. MDCT angiography allows the comprehensive evaluation of thoracic lesions in terms of morphological features and extent, presence of thrombus, relationship with adjacent structures and branches as well as signs of impending or acute rupture, and is routinely used in these settings.

In this article, we review the current state-of-the-art radiological imaging for thoracic endovascular aneurysm repair (TEVAR), especially focusing on the role of MDCT angiography. After analysing the technical aspects for optimised imaging protocols for thoracic aortic diseases, we discuss pre-procedural determinants of candidacy, and how to formulate interventional plans based on cross-sectional imaging.

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Since the first thoracic endovascular aortic repair (TEVAR), using homemade devices, published by the Stanford University in July 1992, significant improvements were made in the following generations, which are widely manufactured commercially. However, delivery systems remain large (22F to 24F), relatively rigid and difficult to deploy smoothly and accurately, owing to extensive frictional resistance. Furthermore, hybrid procedures, which combine surgical and endovascular techniques, have expanded the potential applications of stent-grafting to...
more complex situations, such as stent-graft placement anchored to an elephant trunk or TEVAR of the arch. For these reasons, imaging is crucial for patient enrollment, device selection in correlation with the anatomy of the lesion, as well as formulation of a plan for the intervention.

Recent advances in imaging technologies, in part inspired by advancements in stent-graft technology, have drastically changed the character and role of pre-procedural imaging. The accepted diagnostic gold standard, digital subtraction angiography, is now being challenged by the state-of-the-art computed tomography angiography (CTA), magnetic resonance angiography (MRA) and transoesophageal echocardiography (TEE). These techniques provide information not only on the aortic lumen but also on the wall and surrounding mediastinal structures. Of these, technological advancements of multidetector computed tomography (MDCT) have propelled it to being the default modality used, optimising the balance between spatial and temporal resolution and invasiveness. In this article, we review the current state-of-the-art radiological imaging for TEVAR, especially focusing on the role of MDCT angiography.

Imaging Techniques

Chapter 1

CT angiography
Computed tomography (CT) currently is the most widely used modality in the evaluation of the thoracic aorta due to its high diagnostic accuracy for detection of aortic pathology. MDCT can simultaneously acquire up to submillimetric sections with gantry rotation time of approximately 0.5–0.33 s. Respiratory motion artefacts are no longer a problem, since high-resolution imaging of the entire aorta can be obtained in a single breath hold. Imaging of all phases of contrast enhancement has also become possible using a single-contrast agent bolus. Thinner section allows isotropic voxels, essential to obtain high-resolution three-dimensional (3-D) reconstructions in any selected plane. Despite ionising radiation hazards and the nephrotoxicity of contrast agents, the technique is widely available, fast, cost-effective and efficient.

Optimising CT parameters
MDCT scanning requires an understanding of the basic principles for optimum results. Pitch and collimation are two important parameters of image acquisition. The slice thickness is dependent on the detector collimation. The smaller the collimation, the thinner is the available slice thickness. The quality of the 3-D reconstructions is directly related to the thickness of the obtained axial slices. A CT arteriogram should be acquired with the thinnest available collimation (0.625–0.75 mm). Pre-contrast or delayed images can be acquired with thicker collimations (1.5 mm or greater) to reduce irradiation, as they are not used in post-processing. Currently, the standard tube voltage for CTA is 120 kV. The tube current should be approximately 120 mAs, and automated dose modulation should be used. A tube voltage of 100 kV increases the contrast-to-noise ratio because of a more effective X-ray absorption by iodine at lower tube voltages, which improves image quality and reduces patient radiation exposure by 35% in comparison with 120 kV at a constant tube current. Consequently, lowering the voltage during CTA can reduce the volume of required iodinated contrast medium.

Electrocardiographic gating

Although less-frequent with MDCT, the motion caused by transmitted cardiac pulsation to the major arteries may create problems. These pulsation artefacts are particularly pronounced in the proximal ascending aorta and may frequently mimic an intimal flap resulting in a false-positive diagnosis of aortic dissection. Electrocardiographic (ECG) gating can avoid this problem; it is available in new CT scanners and may be applied prospectively or retrospectively. A decision should be made as to the need for ECG gating. As a general rule, if the heart, coronary arteries, aortic root or ascending aorta are to be evaluated, ECG leads should be placed for gating to minimise cardiac pulsation artefacts. Moreover, it has been shown that diameters of the thoracic aorta can change by up to 17.8% through the cardiac cycle. Considering that most clinicians oversize endografts by only 10%, inadequate estimation of the fluctuations in aortic diameters may lead to serious errors of undersizing, hence contributing to the various means of graft failure. For these reasons, the use of ECG gating has been proposed when endograft choice is to be made so that the optimal sizing can be ascertained.

On the other hand, in emergency imaging for chest pain, some authors push the benefits of exploiting a single CT acquisition with the so-called triple rule-out technique to simultaneously explore pulmonary arteries, coronaries as well as thoracic aorta. ([Johnson, 2008 #155], [Urbania, 2009 #156]). We are reticent to embrace this approach as we believe that scans should be tailored for individual clinical questions, given that contrast timing and scanning parameters are much different if only one clinical question needs to be answered, that is, a pulmonary embolism CT is much different from a coronary CTA, where artefacts may limit the study for certain structures while other structures may be better visualised. Moreover, in acute aortic syndromes, we need to have a complete exploration of the aorta at an arterial phase, from the thoracic inlet down to the bifurcation of the femoral arteries for complete assessment, which is not achievable with ECG gating. The coverage suffices to both detect disease extension and assess the delivery route for endovascular devices that might be the preferred therapeutic modality to treat the abnormality.

Contrast-enhancement methods
CT angiography requires intravenous injection of iodinated contrast agents to display the vessel lumen. The use of additional iodinated contrast media in TEVAR candidates can be a problematic clinical issue, especially in patients presenting with multiple co-morbidities where the risk of contrast-induced nephropathy is greatly accentuated. Faster scanners have resulted in shorter scan duration and contrast bolus duration, allowing the use of less contrast agent. This advantage can be used to inject the same...
amount of contrast at a higher flow rate to achieve a greater luminal enhancement. Right ante-cubital veins are the preferred injection sites because dense contrast in the left brachio-cephalic vein may cause artefacts, which can limit the evaluation of the aortic arch and the proximal segments of the great vessels. The type of contrast is also important, with most centres now using low osmolar and high iodine concentrations (350–370 mg ml⁻¹). The patient should be advised to take a medium-sized breath during image acquisition, as too much of a breath hold or a bearing down may cause a Valsalva effect which can alter contrast delivery to the vessel in question.

Optimum intra-luminal enhancement during peak aortic opacification is of utmost importance for a good CTA study. Automated bolus tracking is used more often than the test-bolus technique, because it is easier to use, more efficient and reduces the total contrast medium dose. Another important consideration with regard to synchronisation of the contrast bolus and the scan is the table feed. We can recommend using a fixed table feed of 40–48 mm s⁻¹, combined with bolus tracking to perform aortic CTA.

Post-processing methods

Once CTA acquisition is complete, the raw data are reconstructed at the thinnest slice thickness available for that acquisition, so that small structures can be adequately visualised and optimum 3-D reconstructions can be obtained from these axial source images. Although axial sections are still the mainstay of interpretation, 2-D and 3-D reformatting techniques such as maximum intensity projection (MIP), multiplanar reformation (MPR), curved planar reformation (curved MPR) and volume rendering (VR) may facilitate interpretation and improve communication with referring physicians (Figs. 1 and 2).

Study protocol

As a rule, oral contrast agent is not given before CTA. An initial non-enhanced scan of the whole thoracic aorta is obtained (collimation: 1.5–0.6 mm; slice thickness: 5 mm; and reconstruction interval: 5 mm). This non-enhanced scan is important for proper planning of the contrast-enhanced scan and also useful in the evaluation of certain entities, such as intramural haematoma (Fig. 3). ECG-gated contrast-enhanced scanning is useful only for the ascending aorta. For the other cases, a CT without ECG gating could be sufficient, allowing a complete examination of the thoracic and abdominal aorta in one step (collimation: 0.75 mm; slice thickness: 0.75 mm; reconstruction interval: 0.4 mm) (Fig. 4). In case of dissection, a delayed scan is routinely obtained at 60-s delay with acquisition parameters similar to the non-enhanced scan to visualise the parenchyma and the late opacification of false lumen.

MR angiography

Magnetic resonance (MR) is an important alternative technology for pre-procedural imaging of TEVAR patients when MDCT angiography is contraindicated. MR of the thoracic aorta usually requires a combination of several available MR imaging methods, each of which has certain advantages and contributes to the diagnostic versatility of the technique. Dynamic Contrast-Enhanced MR angiography (CE-MRA) is the most widely used method because of its speed and robustness, providing projection images of the aorta similar to conventional invasive angiography (Fig. 5). CE-MRA uses the T1 shortening effects of gadolinium-based contrast agent, so that the blood appears bright regardless of flow patterns or velocity. Contrast amount at a rate of 40 ml/2.5 ml, and saline amount 20 ml/2.5 ml are used. As for CT, the synchronisation of image acquisition and arrival of the bolus of contrast agent in the region of interest is crucial to obtain high image quality. As for CT scanner, several methods are used for determining the correct contrast injection timing, especially in patients with low cardiac output. A timing-bolus scan, automatic detection of contrast bolus passage, and, more frequently, MR imaging...
in case of dissection, as for CT, a routine use of a second scan also is helpful to evaluate late-enhancing vascular structures, and parenchymal perfusion. Both mask and contrast-enhanced images are obtained with breath-holding and the mask image is subtracted from the contrast-enhanced sequence before MIP reconstructions. Most commonly, post-processing involves the use of an MIP algorithm to create a projection image, but axial reformatting is also very helpful.

The usage of gadolinium chelate contrast agents in patients with chronic renal insufficiency was long considered to be safe. However, there have been recent reports that gadolinium-based contrast agents increase the risk for developing a serious medical condition called nephrogenic systemic fibrosis (NSF) in patients with severe renal insufficiency. NSF may result in a fatal or severe form of systemic fibrosis affecting the skin, muscle and internal organs. In patients with severe renal insufficiency...
Figure 4  Axial CTA and 3D images of an 81-year-old man with a large aneurysm of the descending aorta revealing a contained rupture with a left hemothorax. Note marked dilation of the aortic root at the level of the sinus of Valsalva resulting in a "pear-shaped" aortic root.
(glomerular filtration rate <30 ml min\(^{-1}\) 1.73 m\(^{-2}\)), only unenhanced MR angiography should be performed, but this does not allow an accurate evaluation of a potential candidate for a stent-graft implantation. In fact, risks of contrast injection must be individually evaluated in patients with renal insufficiency in terms of risk/benefit ratio, in particular if a stent graft is recommended.

**Black-blood vascular imaging**

In conventional spin echo MR imaging, blood usually is low in signal intensity because of movement of spins between a pair of (90° and 180°) slice-selective radiofrequency pulses. If blood flows out of the plane of the section in the time interval between successive radiofrequency pulses, the result is absence of signal, called a signal flow void. For better depiction of intra-luminal or mural abnormality dedicated black-blood technique is preferred because it provides better suppression of the signal from flowing blood.

**Phase-contrast imaging**

Phase-contrast imaging is a unique MR imaging technique that measures blood flow and can be used in many clinical applications to evaluate physiologic properties of blood flow. Two scans are acquired (flow-sensitive scan and a flow-compensated reference scan), which are automatically subtracted from each other. By knowing the cross-sectional areas of a vessel (measured from anatomic images), blood flow volume and velocity can be calculated quantitatively.

**Echocardiography**

TEE is a semi-invasive procedure that provides optimal imaging of the ascending and descending aorta and can sometimes visualise the upper part of the abdominal aorta. TEE can be performed quickly, at bedside and without using nephrotoxic contrast agents, providing accurate measurements of different aortic segments, and is an important determinant for diagnosis, management and follow-up. The use of multiplane probes allows reduction of the classical blind zone, caused by the trachea at the junction of ascending aorta and proximal part of the arch. Colour Doppler enhances detection of the entry tear and can reveal the presence of additional multiple small communications between the true and false lumens in case of aortic dissection, especially those involving the descending aorta. Intravenous infusion of an echographic contrast

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**Figure 5** A 55-year-old male patient treated for coarctation with a post stenting pseudoaneurysm. 1/ CTA with 3D reconstructions. A large partially thrombosed pseudoaneurysm is seen with the bare stent placed at the level of the isthmus. 2/ T1-weighted axial image, and contrast-enhanced MRA of the aorta with sagittal oblique source and MIP images showing the false aneurysm. The subtracted image, obtained by subtracting the unenhanced mask image from the contrast-enhanced source image, demonstrates better suppression of the background signal. Mild artefacts are seen related to the stent.
agent can enhance the performance of TEE to detect small re-entry tears of dissection and to demonstrate turbulence in the false lumen (Fig. 6). Screening of contraindications and preparation (local anaesthesia, intravenous access, material and structures for resuscitation) are especially important in cases of aortic pathologies.

Catheter Angiography

During the early years of TEVAR, diagnostic catheter angiography was routinely performed as a mandatory pre-procedural examination. However, catheter angiography is an invasive, expensive and time-consuming examination. Moreover, the projectional nature of fluoroscopic and catheter angiographic imaging does not adequately portray the 3-D configuration of the vessels, so that pre-procedural planning based on these images is subject to increased error. Today, CT and MR angiography with 3-D reconstruction abilities have replaced catheter angiography and has been established as the gold standards for pre-procedural evaluation (Fig. 7).

Pre-interventional Planning

Chapter 2

Pre-procedural imaging combines three main tasks: to determine the patient’s eligibility for TEVAR, to choose the appropriate stent-graft devices and to simulate a plan for the intervention. For peri-procedural planning, various anatomical factors need to be assessed, including the location and morphology of the neck in relation to the major branches in order to determine the stent-graft landing zones, the diameters of the neck to decide the appropriate size of the stent-graft device and the condition of femoral and iliac arteries to choose vascular access pathways (Fig. 8).

To ensure an adequate stent-graft placement, the following conditions must be evaluated:

Vascular Access

Many major adverse events during TEVAR are related to difficulties with access arteries. To ensure that large-profile...
devices can safely navigate the selected vascular route to the thoracic aorta, preoperative imaging must include high-resolution characterisation of the femoral arteries, iliac arteries and infra-renal aorta. Diameters, tortuosity, degree of atherosclerosis and calcifications of potential access vessels all need to be evaluated. The presence of previous stenting of the iliac arteries or small aorto-iliac bypass could be another contraindication for a femoral approach as they are inextensible, and therefore may not allow the introduction of stiff devices. In such situations, alternative routes such as the abdominal aorta, thoracic aorta or supra-aortic branches could be used.9 Recently, in selected patients, entirely percutaneous stent-graft procedures have been performed with the puncture sites closed by commercially available suture-mediated access-closure devices. In comparison to routine surgical exposures, this approach has the advantages of a shortened time to recovery and possible reduced risk of access site complications, namely infection, lymphocele, seroma and postoperative scars. The major limitations are clearly small femoral arteries and calcification that must be checked first before shifting to entirely percutaneous procedures.

Length and morphology of landing zones

Identification and designation of appropriate proximal and distal landing zones is crucial to the clinical success of TEVAR.

The length of the proximal landing zone along the lesser curvature of the aorta is only half that along the greater curvature in the strongly angulated distal arch. The expected length of the device should be predicted in consideration of its asymmetric redundancy in the proximal landing zone. In addition, a proximal landing zone in the strongly angulated distal arch could be problematic with poor device apposition and risk of type I endoleak.

Figure 7 Angiography with a calibrated catheter, of a post-traumatic pseudoaneurysm located in the descending aorta. The length of the proximal landing zone along the lesser curvature of the aorta is only half that along the greater curvature in the strongly angulated distal arch. The expected length of the device should be predicted in consideration of its asymmetric redundancy in the proximal landing zone. In addition, a proximal landing zone in the strongly angulated distal arch could be problematic with poor device apposition and risk of type I endoleak.

Figure 8 Prestent-graft measurement: Identification and designation of appropriate proximal and distal landing zones is crucial for TEVAR planning. A central line (red line) must be drawn to obtain strict perpendicular measurements to the aortic axis (double arrows). Proximally, the distance from the origin of the left subclavian artery or the left common carotid artery to the beginning of the aneurysm defines the landing zone. The distance from distal end to the coeliac artery must be also measured. The length of aortic segment to be treated can be estimated using 3D reconstructions (blue line), measuring the length of the lumen from the beginning of the proximal landing zone to the end of the distal landing zone. The angulations of the aorta (yellow lines) and the planned position of the stent graft after deployment must be well estimated. The degrees of accordion and bow redundancy may be difficult to predict and are frequently underestimated. For the choice of an aortic stent-graft diameter, we use the maximum diameter from adventitia to adventitia. If the cross-sectional shape of the lumen at the landing zones is elliptical or even crescentic rather than circular, mathematical modelling is done (maximum + minimum diameter/2) to obtain correct device sizing.

The length of the proximal landing zone is usually measured along the greater curvature of the aorta, but the actual length along the lesser curvature may be significantly shorter when the distal arch is involved (Fig. 7). Proximally, the distance from the origin of the left subclavian artery (LSCA) or the left common carotid artery (LCCA) to the beginning of the aneurysm defines the landing zone. When the neck is shorter than 15 mm, the stent graft can be deployed to intentionally cover the LSCA. It remains controversial whether re-vascularisation of a covered LSCA is necessary to reduce the risk of stroke, paraplegia, vertebro-basilar insufficiency and/or left upper extremity claudication.10 Nevertheless, if intentional exclusion of the ostium of the LSCA is unavoidable, complete imaging of the
vertebral arteries and collaterals must be performed before implantation to avoid major neurological complications.

The length of the distal neck defined as the distance from the lower end of the lesion to the coeliac axis is a less-frequent limiting issue. Coverage of the coeliac axis can also be performed intentionally, and is usually well tolerated as long as there is no occlusive disease of the superior mesenteric artery.11 Again, pre-stent-graft placement imaging of the mesenteric vasculature to identify the pathways between the coeliac trunk and mesenteric artery through the gastro-duodenal artery is mandatory.

The extension of the disease to the visceral arteries could also be resolved by the use of fenestrated or branched stent grafts.12 The size, patency and angulations of each visceral artery must be taken in consideration to select the stent graft accordingly.

The radiculo-medullary artery of Adamkiewicz may sometimes be preoperatively identified by CT or catheter angiography. Ischemia involving this artery is the most commonly accepted mechanism of postoperative paraplegia. Coverage of an inter-costal artery supplying the artery of Adamkiewicz should be avoided if possible, requiring additional tailoring of the landing zone. Meanwhile, the risk of this complication seems to be directly related to the number of excluded collaterals. In other words, paraplegia is observed in less than 4% of cases and the associated risk factors are the combination of abdominal and thoracic treatment, exclusion of the LSCA, long stent grafts and the situation at the level of the diaphragm (Greenberg, 2000 #1317).13,14

Diameter of the stent graft

Stent-graft diameter is oversized by 10–15% to provide a good apposition to the aortic wall. The reference diameter is the external diameter of the aorta at the systolic phase if gated MDCT is used.3 Furthermore, the cross-sectional shape of the lumen at the landing zones may not be circular, but elliptical or even crescentic, requiring additional mathematical modelling (maximum + minimum diameter/2) to obtain correct device sizing. Since the maximum diameter of commercially available stent grafts is 46 mm, a maximum aortic landing zone diameter of 40–42 mm must be selected. Diameters of proximal and distal landing zones may differ widely enough to require a tapered or flared device or combination of devices.

Device length

Most device manufacturers only have standardised lengths available, although some will also accommodate custom lengths. The length of aortic segment to be treated can be estimated using 3-D reconstructions, measuring the length of the lumen from the beginning of the proximal landing zone to the end of the distal landing zone (Fig. 8). The degrees of accordion and bow redundancy may be difficult to predict and are frequently underestimated. Being prepared with longer devices and extension components must be always warranted at the time of treatment.

Arteriosclerotic aneurysms of the descending thoracic aorta typically occur in elderly patients and often manifest in a diffusely diseased and tortuous aorta, relatively normal-looking segments of which may dilate over time. Meanwhile, the aneurysms tend to elongate, producing vector forces that may eventually cause the stent graft to migrate. Therefore, it is advisable that the landing zones of the stent graft be at least 2 cm long. Moreover, when multiple stent grafts are deployed, generous overlapping (>5 cm) should be considered to avoid late disconnection.

The angulations of the aorta and the predictable position of the stent graft after deployment must be well estimated. Sharp angulations and/or high tortuosities may entail shifting the landing zone proximally or distally. Different designs of devices have different capabilities of conforming to angulations and tortuosities, and newer generations of devices are being designed with this feature in mind.

Specificity according to clinical applications

Chapter 3

Aortic dissection

Recently introduced interventional techniques, such as aortic fenestration and stent graft implantation, have opened new therapeutic options, which can be performed before or after surgery.15 Multidetector contrast-enhanced CT is the best imaging tool in the emergency setting to evaluate a clinically suspected dissection. The extent of the dissection, true and false lumen sizes, false lumen patency, proximal and distal tear sites as well as branch vessel involvement must be evaluated by CT, which should extend from the neck base to the femoral arteries. Peri-aortic fluid, pericardial effusion and pleural effusion are important additional signs.

In order to obliterate the primary tear, an adequate seal zone is required. We recommend placing the device, as often as possible, in disease-free landing zones. In other words, in the setting of a classic entry tear located just distal to the LSCA origin, the segment between the LCCA and LSCA should be used as a safer landing zone. Nevertheless, in cases of aortic dissection, the distal true lumen is usually tapered and compressed by the false lumen; as a result, the distal end of the device is deployed in a lumen much narrower than that of the proximal landing zone. In acute dissection, expansion of the true lumen is not hard to achieve if the false lumen is adequately excluded by the stent graft, and the true lumen will expand gradually to the nominal diameter of the stent graft. Inversely, in chronic dissection, the intimal flap is fibrotic and cannot expand. This reduction of the true lumen diameter may pose a challenge when using cylindrical stent grafts, with a possible risk of collapse or incomplete expansion of the graft. In these situations, a tapered stent-graft device may be a better option.

The length of the stent graft is another issue to discuss. Whereas false-lumen thrombosis is consistently seen at the level of the implanted stent graft, thrombosis distal to the implant, particularly in the distal descending aorta, is less common. This may be related to the to-and-fro movement of the intimal flap along uncovered segments of the aorta with retrograde flow through secondary distal tears. This
has implications for the selection of device length. In fact, most investigators use longer stent grafts than required to simply cover the primary tear. The additional distal coverage provides a more normal anatomic configuration by placing the distal margin of the device within the mid-thoracic segment, where the aorta is usually less curved. Further distal extension may also expedite the rate of false-lumen thrombosis. In light of this, some investigators have advocated the placement of bare stents into the distal thoracic aorta to provide structural stability without risking occlusion of additional inter-costal arteries.16

Ischaemic complications are encountered in 30–50% of the patients and represent one of the major indications for surgical intervention.17 The most commonly affected arteries are the iliac vessels; however, the most serious complications are encountered with renal and/or mesenteric ischemia. Occlusion of aortic side branches can be caused by two different mechanisms, which in fact may

Figure 9 Drawing of the different mechanisms of visceral ischemia. A. Static dissection. The aortic branch is involved at its orifice. Ischemia does not develop in a since there is a large natural fenestration. Ischemia could develop in b as the branch is occluded. B. Dynamic dissection. In this pattern, the aortic branch itself is not involved by dissection. However, blood supply is compromised owing to true lumen compression by the false lumen. C. During dynamic dissection intimal stretching of a branch could be observed. If no re-entry within the branch is observed, ischemia could develop due to compression of the true lumen. D. Complete rupture could be observed also. Ischemia does not develop if the intima of the collateral is retracted in the aorta. E. In e ischemia could develop because the intimal flap is retracted thus occluding the branch. In such a case, stenting of the branch could be proposed. TL = True lumen; FL = False lumen.
occur simultaneously as well (Figs. 9 and 10). The first mechanism is static vascular obstruction, where the dissection involves the affected side branch. Additional outflow obstruction may be caused by thrombosis of the false lumen at the level of the side branch, thus compressing the true lumen. Fortunately, in some cases the aortic side branches are perfused through a re-entry tear, thereby re-perfusing the true lumen with subsequent outflow. The second mechanism, dynamic obstruction is secondary to compression of one of the two aortic channels, (usually the true lumen) without extension of the intimal flap in the occluded side branches. A prolapse of the intimal layer into the ostium of the non-dissected side branch can accompany compression of the true lumen. (Fig. 11).

Alternatively to stent-graft insertion, fenestration and bare stent insertion could be proposed separately or combined.

Fenestration continues to be a valuable option in cases in which stent-graft treatment is not feasible owing to anatomic or organisational constraints. The use of uncovered stents in the aorta and side branches may improve flow in aortic dissection. The most common indications include (1) inadequate relief of dynamic obstruction after surgery, stent-graft treatment or fenestration, and (2) static obstruction of abdominal aortic branch vessels. Similarly, uncovered aortic stents may be a useful adjunct to dissection fenestration.

Nevertheless, before the fenestration or stenting, a complete exploration of the mechanism of the dissection by MDCT is crucial.

**Traumatic aortic injuries**

Because of its non-invasiveness and availability in most emergency departments, CT has become the main imaging modality in the evaluation of traumatic aortic injuries. It allows rapid assessment of the entire thorax, abdomen as

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**Figure 10**  A 60-year-old male patient with a history of hypertension and family history of aortic dissection presenting with sharp epigastric pain radiating to the chest. CTA revealed type B dissection. Axial image at the isthmus level shows intimal flap and tear site. Axial image at the level of the right pulmonary artery clearly shows the intimal flap separating the false lumen from the true lumen. However, blood supply is compromised at the distal end of the descending aorta, owing to true lumen compression by the false lumen. Axial image at a more cranial level reveals involvement of major arch arteries. The intimal flap was seen involving the ostia of the coeliac trunk and the superior mesenteric artery (Static dissection). Dynamic compression of the right renal artery and intimal flap retraction of the left renal artery can also be noted.
well as the brain, while patients are being monitored. Intramural haematoma, intimal tear, pseudoaneurysm and extravasation of the contrast material from the aorta are typical CT findings of acute traumatic aortic injuries (Fig. 12). The aortic isthmus is the most commonly injured aortic site.²⁰ In this case, the reference diameter is the segment of the arch between the LCCA and LSCA. In spite of attractive aspects of stent-grafting, some technical difficulties have to be overcome such as small and spastic arteries, short proximal neck and important curvature of the distal aortic arch. However, because aortic traumaticism occurs more often in young patients with immature (<20 mm) aorta, the main limitation is the common dilemma of selection of the correct stent-graft dimension. In the last few years, because of the lack of commercially available endovascular devices with small diameters, a device of a minimum 26 mm was used. Theoretically, by doing so, we are exposing the patient to aortic rupture, a complication that has not yet been described in the literature. On the other hand, very recently, endovascular devices with small diameters (20 mm) are becoming commercially available, raising the question of a late aorta/stent graft diameter mismatch. Theoretically, as we are treating an immature aorta, we can postulate that the aortic diameter will increase by at least 20–30% with time. Consequently, if a small stent graft is used today, after 10–20 years, the patient will be exposed to an undersized stent graft in comparison to his then normal aortic diameter, with a subsequent risk of migration, endoleak or pseudo-coarctation.

Future of imaging

Chapter 4

Computational fluid dynamics (CFD) obtained with an entirely non-invasive 4-D MRI protocol provides time-varying geometry and flow rates²¹,²² (Fig. 13). From a practical viewpoint, we start by performing a routine contrast-enhanced MR angiography using a 3-D slab covering the vessels of interest using an injection of gadolinium-diethylenetriamine penta acetic acid (Gd-DTPA). Secondly, 3-D velocity phase-contrast imaging is performed with the same orientation of contrast-enhanced acquisition. An initial computational grid is obtained by the discretisation of segmented contrast-enhanced MR angiography.²³ The flow simulations are performed using the finite volume (FV) method to solve the full Navier–Stokes equations that govern the flow.

On the whole, the importance of the implementation of quantitative evaluation strategies to assess flow rates, wall
Figure 13  Aortic coarctation causing dilation of the ascending aorta with pre- and post-stenotic dilatation. On this figures, obtained with conventional MRA (A), Q Flow measurements and CFD obtained by the finite elements (B), we can see the different parameters analysed: WSS (C), Pressure measurement (D), Flow (E) and turbulences (in red) (F). Coarctation is responsible for low WSS in the arch, ascending and descending aorta and branch arteries. At the level of the stenosis, increased WSS, pressure and turbulences can be observed.
shear stress and vorticity is therefore warranted in order to develop and apply objective diagnostic criteria for the description of vascular pathologies. Furthermore, the post-processing virtual 4-D modelling represent theoretically an important purpose for future investigations on the aortic dissection, in order to develop an imaging-based method for planning the interventional strategies that are actually being performed on an empirical basis. Finally, computing, in conjunction with suitable experimental data, can be important by helping understand the complex relationship between biomechanics and device failure and by aiding in design of better devices while shortening design cycle time.

Conclusions

TEVAR has become widely accepted as an important option for treatment of thoracic aortic diseases. Recent advances in cross-sectional imaging, particularly MDCT angiography, have helped to establish a new gold standard for pre-procedural assessment of potential TEVAR candidates. Optimisation of imaging protocols, as well as a thorough understanding of the indications, candidacy criteria, procedures and potential complications are essential to derive maximal benefits from these advances in modern imaging technology.

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