Computed Tomography Angiography in Aortic Disease: what the surgeon needs to know.

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Learning objectives

To provide the radiology resident, in peripheral hospitals with no specialized cardiothoracic units, important diagnostic skills to diagnose acute aortic syndrome.

To describe CT Angiography technique and intravenous Contrast Media optimization.

To identify the really important findings and how to translate these in a structured report.

To perform a proper differential diagnosis in order to establish an optimal therapeutic approach.
Background

The aorta is the largest artery in the human body, pumping up to 200 million liters of blood through the body in an average lifetime. Thoracic aortic disease presentation ranges from asymptomatic (as in an aneurysm incidentally detected on imaging) to severe acute chest pain (as in acute aortic dissection). The recent increased prevalence of aortic disease in Western countries is a result of increased clinical awareness and longer life spans. Multidetector-row Computed Tomography (MDCT) of the aorta can be used to diagnose various acute and chronic conditions of the aorta. Modern 64 detector-row and newer-generation CT scanners can evaluate the entire aorta, including its smaller branches, with one short breath hold. Endovascular therapies are playing an increasingly important role in the treatment of aortic diseases, while surgery remains necessary in many situations.

The Thoracic Aorta (Fig. 1 on page 7) extends proximally from the aortic annulus to the diaphragmatic crura distally. The thoracic aorta is subdivided into 3 parts: the ascending aorta, the arch, and the descending aorta. The Ascending Thoracic Aorta comprises the aortic root and the tubular ascending aorta. The Aortic Root lies between the aortic annulus and the sinotubular junction. The Sinuses of Valsalva arise from the aortic root. The tubular ascending aorta extends from the sinotubular junction to the brachiocephalic trunk. Approximately 3 cm of the proximal ascending aorta is within the pericardium. The coronary arteries are the only branches of the ascending aorta. The Aortic Arch extends from the brachiocephalic trunk to the origin of the left subclavian artery. The Isthmus extends from the left subclavian artery to the ligamentum arteriosum. Three branches usually arise from the aortic arch: the brachiocephalic trunk, the left common carotid artery, and the left subclavian artery. The brachiocephalic trunk divides into the right common carotid artery and the right subclavian artery.
Normal Anatomy

Fig. 1: Segments of the ascending and descending aorta. Three-dimensional arrangement of the aortic root, which contains 3 circular "rings" but with the leaflets suspended within the root in crown-like fashion. Green Ring: virtual ring formed by joining basal attachment of aortic valvar leaflets; Yellow Ring: anatomic ventriculo-arterial junction; Blue Ring: sinutubular junction.


Acute Aortic Syndrome is a group of aortic pathologies that are acute emergencies. Underlying aortic diseases include penetrating atherosclerotic ulcer, intramural hematoma, aortic dissection, rupturing aneurysms and traumatic aortic injury. The aortic wall consists of 3 layers (tunica intima, tunica media, and adventitia). Acute Aortic Dissection is presumed to occur when an intimal tear develops, permitting entry of blood to a diseased underlying media characterized by elastic degeneration and smooth muscle cell loss (Fig. 2 on page 7). Chronic acquired conditions, such as systemic arterial hypertension, sometimes in combination with atherosclerosis, cause thickening and fibrosis of the intimal layer and degradation and apoptosis of smooth muscle cells in the media. These processes lead to necrosis and fibrosis of the elastic components of the arterial wall, which in turn produce wall stiffness and weakness, from which dissection and rupture may arise. Chronic arterial hypertension has been widely accepted as the most common acquired condition that leads to dissection of the aorta from high shear
Nearly 75% of patients with AAD have a history of hypertension. Other acquired conditions that have been associated with AAD include direct blunt trauma, tobacco use, hyperlipidemia, cocaine (including crack cocaine) use, and pregnancy.

**Physiopathological aspects of aortic disease**

**Fig. 2:** A) Intimal Tear permits entry of blood to a diseased underlying media. B) Alternatively, the dissection may originate from the vasa vasorum rupture within the media, developing an Intramural Hematoma. C) Penetrating Atherosclerotic Ulcer consists of the ulceration of an atherosclerotic lesion, penetrating the internal elastic lamina and determining hematoma of the media; atherosclerotic penetrating ulcer leads to late formation of saccular or fusiform aneurysms.


**Aortic Dissections** can be classified according to involvement of the ascending aorta or arch. This involvement implies a worse prognosis and usually requires surgical management. The DeBakey and Stanford classification systems are the most commonly used systems to categorize aortic dissections and they are based on location (Fig. 3 on page 8).
In type I De-Bakey dissections, the intimal flap involves both the ascending and descending thoracic aorta; in type II, the intimal flap involves the ascending aorta only; and in type III, the intimal flap is isolated to the descending thoracic aorta. In Stanford type A dissections, the intimal flap involves the ascending thoracic aorta (with or without extension into the descending aorta), whereas in type B, the flap does not involve the ascending thoracic aorta or arch. An acute aortic dissection means that the dissection has been diagnosed within 2 weeks of the aortic dissection occurring. A chronic aortic dissection refers to an interval of 4 weeks or more from the time when the aortic dissection started.

**Fig. 1:** Segments of the ascending and descending aorta. Three-dimensional arrangement of the aortic root, which contains 3 circular "rings" but with the leaflets suspended within the root in crown-like fashion. Green Ring: virtual ring formed by joining basal attachment of aortic valvar leaflets; Yellow Ring: anatomic ventriculo-arterial junction; Blue Ring: sinutubular junction.

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Findings and procedure details

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Overview

- Technical issue: scan protocol, contrast media administration, post-processing

- CT radiological findings in acute aortic syndrome, structured reporting and checklist of important findings to be mentioned

- Brief outline of management options

- Possible post-operative complications and their radiological appearance

Technical Issue

Computed tomography plays a central role in the diagnosis, risk stratification, and management of aortic diseases. Its advantages over other imaging modalities include the short time required for image acquisition and processing, the ability to obtain a complete 3D dataset of the entire aorta, and its widespread availability. Electrocardiogram (ECG)-gated acquisition protocols are crucial in reducing motion artefacts of the aortic root and thoracic aorta (Fig. 4 on page 33). High-end MSCT scanners (16 detectors or higher) are preferred for their higher spatial and temporal resolution compared with lower-end devices. In suitable candidates scanned on 64-detector systems or higher-end devices, simultaneous CT coronary angiography may allow confirmation or exclusion of the presence of significant coronary artery disease before transcatheter or surgical repair.
Fig. 4: Standard Thoraco-Abdominal CT Angiography Scan Protocol. Non-enhanced CT, followed by CT contrast-enhanced angiography, is the recommended protocol, particularly when intramural hematoma or aortic dissection are suspected. Venous Phase is recommended after stent-graft repair of aortic aneurysms, to detect endoleaks. The average effective radiation dose during aortic computed tomography angiography is estimated to be within the 10-15 mSv range.

References: Radiology, UPMC Italy, ISMETT - Palermo/IT

In our Unit it is used a non-ionic, monomeric, extracellular contrast agent with an iodine concentration of 370 mg/mL, prepared at 37°C, and injected into an antecubital vein through a 20- or 18-gauge catheter using a dual-shot injector. All enhanced CT acquisitions were performed using a dedicated multiphasic injection protocol. The total amount of CM was tailored to the patient's BMI and was administered with five boluses at different flow rates (Fig. 5 on page 33).
- Non-ionic, monomeric, extracellular contrast agent with an iodine concentration of 370 mg/mL
- Multiphase Injection: maximum dose of 90 mL at an average infusion rate of 3.2 mL/s for BMI between 25 and 30 kg/m²
- Bolus Tracking: predefined threshold of 80 HU in the ascending aorta
- No Bolus Chaser

**Fig. 5:** Contrast Media injection protocol.

**References:** Radiology, UPMC Italy, ISMETT - Palermo/IT

The 3D reconstruction techniques are an important tool for the diagnosis of Acute Aortic Syndromes, particularly in patients undergoing endovascular procedures (Fig. 6 on page 34 - Fig. 7 on page 35 - Fig. 8 on page 38).
Fig. 6: Multiplanar Reconstruction (MPR) (left lateral image) allows images to be created from the original axial plane in either the coronal, sagittal, or oblique plane; Curved-MPR straights the vessel along the centerline; Maximum Intensity Projection consists of projecting the voxel with the highest attenuation value on every view throughout the volume onto a 2D image; Volume Rendering Volume not only allows display of the vascular anatomy but also provides definition of soft tissue, muscle, and bone.

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**Fig. 7**: Cine Loop Reconstructions are obtained from row data, reconstructing all phases from 0 to 90% of RR interval (increment 10%). (Video 1 - Video 2)

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Table 1: Video 1 - CineLoop Reconstruction: Calcified Bicuspid Aortic Valve.

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Fig. 8: Vantages and Disadvantages of post-processing techniques.

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CT Findings

Although echocardiography remains the principal imaging technique for assessment of the Cardiac Valves, ECG-gated CT angiography is proving to be an increasingly valuable complementary modality in this setting. CT angiography allows excellent visualization of the morphologic features and function of the normal valves, as well as of a wide range of valve diseases, including congenital and acquired diseases, infectious endocarditis, and complications of valve replacement. CT angiography also permits simultaneous assessment of the valves and coronary arteries, which may prove valuable in presurgical planning. Bicuspid Aortic Valve (BAV) is the most common congenital cardiac anomaly, with an estimated incidence of 0.9% to 2% in the general population. The "purely" BAV is composed of two cusps, morphologically and functionally (Fig. 9 on page 39). Associated with a certain proportion of BAVs is a dilatation of the ascending aorta, especially in young patients, exposing these patients to an increased risk of comorbidity owing to aneurysm formation and dissection.
Fig. 9: Upper right: Schematic presentation of the developmental phenotypes of the aortic valve and typical characteristics; Prominent line in schematic drawings represents a raphe, which is the nonseparated or conjoint segment of two underdeveloped cusps extending into the commissural area. Upper left: Multiplanar Reconstruction planes orientation for valvular anatomy assessment. Bottom left: axial view of aortic valve and diameters (average of three measurements). Bottom middle and right: examples of Bicuspid Aortic Valve with and without raphe.

References: Radiology, UPMC Italy, ISMETT - Palermo/IT

The main principle of surgery for Ascending Aortic Aneurysms is that of preventing the risk of dissection or rupture by restoring the normal dimension of the ascending aorta (Fig. 10 on page 40).
Fig. 10: Left side: Multiplanar Reconstruction planes orientation for ascending aorta assessment. Right side: guidelines for surgery and risk classification based on diameter of ascending aorta and body surface area.

**References:** Radiology, UPMC Italy, ISMETT - Palermo/IT

Presence of **Penetrating Aortic Ulcer** (PAU) represents another high risk aortic condition. Such lesions represent 2-7% of all Acute Aortic Syndrome. Propagation of the ulcerative process may either lead to **Intramural Hematoma**, **Pseudoaneurysm**, or even **Aortic Rupture**, or an acute **Aortic Dissection** (Fig. 11 on page 41). PAU is often encountered in the setting of extensive atherosclerosis of the thoracic aorta, may be multiple, and may vary greatly in size and depth within the vessel wall. The most common location of PAU is the middle and lower descending thoracic aorta (Type B PAU). Less frequently, PAUs are located in the aortic arch or abdominal aorta, while involvement of the ascending aorta is rare.
Fig. 11: Curved Multiplanar Reconstruction shows Penetrating Aortic Ulcer of the aortic arch.

References: Radiology, UPMC Italy, ISMETT - Palermo/IT

Intramural Hematoma (IMH) (Fig. 12 on page 42) is hemorrhage localized to the aortic media in the absence of a visible intimal tear. IMH is considered equivalent to aortic dissection regarding prognostic and therapeutic implications because an IMH may progress to aortic dissection and rupture. IMH may develop secondary to spontaneous rupture of vasa vasorum of the medial aortic layer, penetrating aortic ulceration, or blunt trauma. Hypertension is the most common predisposing risk factor.
Intramural Hematoma

- Circumferential or crescent-shaped high-attenuation thickening of the aortic wall on non contrast CT
- NO False Lumen
- Equivalent to Aortic Dissection: Type A or B (Stanford Classification)

Fig. 12: Unenhanced CT is extremely valuable in identifying Intramural Hematomas (Upper Left). Several findings help differentiate IMH from a thrombosed false lumen of an aortic dissection: IMHs do not enhance; no intimal tear is seen; IMHs maintain a constant circumferential relationship with the aortic wall; the false lumen of a dissection has a longitudinal spiral geometry.

References: Radiology, UPMC Italy, ISMETT - Palermo/IT

Aortic Dissection results from an intimal tear extending into the inner layer of the aortic media; an intimal flap separates the false and true lumens. The blood within the false lumen may be free flowing or thrombosed. Risk factors for aortic dissection include preexisting thoracic aortic aneurysm, chronic hypertension, Marfan syndrome, bicuspid aortic valve, infection, and prior cardiovascular surgery. The dissected aorta can be dilated or normal in caliber. Dissections involving the ascending aorta (Stanford A; DeBakey I and II) are surgical emergencies because dissections in this area are prone to rupture or other critical complications, including development of hemopericardium, pericardial tamponade, and death. Other potential complications of ascending aortic dissections include aortic valve rupture, aortic insufficiency, coronary artery dissection, stroke, and myocardial infarction. The course of Type B dissection is often uncomplicated so, in the absence of malperfusion or signs of (early) disease progression, the patient can be safely stabilized under medical therapy alone, to control pain and blood pressure.
MDCT is the most common modality to detect aortic dissections. Its high sensitivity for detecting dissection, wide availability, and ability to identify alternative diagnoses for chest pain makes MDCT an excellent first choice in evaluating suspected dissection (Fig. 13 on page 43 - Fig. 14 on page 44).

Fig. 13: Multiplanar Reconstruction planes show the right position to obtain axial view of dissected aorta, true and false lumen diameters. Differentiation of the false and true lumen is imperative in surgical repair and percutaneous treatment with endografts. Customarily, the most reliable way to identify the true lumen is by determining continuity with the undissected portion of the aorta. The cross-sectional area of the false lumen is also often larger than that of the true lumen. The beak sign is another helpful diagnostic sign: focal low-density thrombus is present in the beaked margin of the false lumen, which helps delineate the false from the true lumen.

References: Radiology, UPMC Italy, ISMETT - Palermo/IT
Fig. 14: Main MDCT findings in aortic dissection to search and report. Recommendations for treatment.

References: Radiology, UPMC Italy, ISMETT - Palermo/IT

Traumatic Aortic Injury (Fig. 15 on page 45) is a tear involving all layers of the aortic wall, usually caused by rapid deceleration (high-speed motor vehicle accident or fall from significant height). The mortality rate is high, with most patients dying in the field. Survival is highest for tears at the aortic isthmus. Proposed mechanisms for aortic injury include shearing and hydrostatic forces secondary to rapid deceleration and osseous pinching.
**Fig. 15**: Traumatic aortic pseudoaneurysm on contrast-enhanced CT. Upper left: MPR and VR images show irregular focal outpouching of the isthmic aorta, consistent with partial aortic transection and pseudoaneurysm formation in this patient who has a history of a high-speed motor vehicle collision. Bottom left and right side: control post-endovascular repair.

**References**: Radiology, UPMC Italy, ISMETT - Palermo/IT

**Reporting CT Angiography**

How to translate the evidences that we have seen in a structured report?

- Describe your findings using five "W" rules (Fig. 16 on page 46)
- Made a structured template report for CT Angiography (Fig. 17 on page 47)
- Write your impressions
Fig. 16: Tips for describe your findings in emergency conditions. 
References: Radiology, UPMC Italy, ISMETT - Palermo/IT
Fig. 17: CT Angiography structured report template.

References: Radiology, UPMC Italy, ISMETT - Palermo/IT

Treatments Options

- **Ascending Aortic Aneurysm**: if the aneurysm is proximally limited to the sinotubular junction and distally to the aortic arch, resection of the aneurysm and supra-commissural implantation of a tubular graft is performed under a short period of aortic clamping, with the distal anastomosis just below the aortic arch. If the aneurysm extends proximally below the sinotubular junction and one or more aortic sinuses are dilated, the surgical repair is guided by the extent of involvement of the aortic annulus and the aortic valve (Fig. 18 on page 48 A).

- **Type A aortic dissection**: surgery is the treatment of choice. Acute Type A aortic dissection has a mortality of 50% within the first 48 hours if not operated. It is preferable to replace the aortic root if the dissection involves at least one sinus of Valsalva, rather than perform a supracoronary ascending aorta replacement only (Fig. 18 on page 48 B).
Type B aortic dissection: patients with uncomplicated Type B dissection receive medical therapy to control pain, heart rate, and blood pressure, with close surveillance to identify signs of disease progression and/or malperfusion. Thoracic Endovascular Aortic Repair (TEVAR) aims at stabilization of the dissected aorta, to prevent late complications by inducing aortic remodelling processes (Fig. 18 on page 48 C). Obliterating the proximal intimal tear by implantation of a membrane-covered stent-graft redirects blood flow to the true lumen, thus improving distal perfusion. Thrombosis of the false lumen results in shrinkage and conceptually prevents aneurysmal degeneration and, ultimately, its rupture over time.

Fig. 18: Treatment Options.

Postoperative Complications

After surgical repair, patients require regular screening to exclude signs of impending aortic rupture or other complications, including endoleak, prosthetic graft degeneration, infection, malfunction of aortic valve prosthesis, and aneurysm formation in other portions of the aorta (Fig. 19 on page 49 - Fig. 20 on page 50 - Fig. 21 on page 51 - Fig. 27 on page 58).
Follow-up after thoracic endovascular repair is recommended at discharge, at 1, 3, and 6 months, and then yearly. Follow-up after surgical repair is recommended at discharge and then yearly but can be extended to 2 to 3 years if there is stability for the first year.

**Fig. 19:** Anastomotic Pseudoaneurysm is a form of false aneurysm, whose wall does not consist of all normal layers of arterial wall. Mechanisms implicated include infection, poor anastomotic technique, and intrinsic aortic wall disease. Surgical options vary according to pathologic features of the pseudoaneurysm, and operations can be challenging, especially in the presence of infection, previous cardiac surgery, or aortic valve regurgitation.

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Aortic Annular Abscess

Fig. 20: Aortic Annular Abscess can occur as a complication of aortic valve endocarditis and is more common on a prosthetic aortic valve. Prosthetic valve dehiscence may occur. Early and extensive surgical reconstruction of major aortic annular abscess can be essential, because antibiosis alone is usually inadequate to arrest the destructive effect of the abscess.

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Fig. 21: Aortic Root Redissection can occur in conservative approach of ascending aortic dissection. Multiple root repair techniques using prosthetic and biologic materials. The two most commonly described methods involve fortification of the aortic wall using Teflon felt and/or biologic glue. The results of using biologic glue as a stand-alone technique demonstrate acceptable operative results, but less durable long-term outcomes.

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Fig. 22: Endoleak describes perfusion of the excluded aortic pathology and occurs both in thoracic and abdominal (T)EVAR. Different types of endoleaks are illustrated in Fig. 23.

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**Endoleak Classification**

<table>
<thead>
<tr>
<th>TYPE</th>
<th>Description</th>
<th>Codes</th>
<th>Details</th>
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<tr>
<td><strong>I</strong></td>
<td>Inadequate seal at graft ends</td>
<td>1A (Proximal), 1B (Distal), 1C (Iliac)</td>
<td>Contrast extravasation in continuity with the site of the graft attachment</td>
</tr>
<tr>
<td><strong>II</strong></td>
<td>Retroleak. Aneurysm sac filling via branch vessel. 80%</td>
<td>2A (1 vessel), 2B (2 or more vessels)</td>
<td>Retrograde flow through branch vessels (lumbar arteries or inferior mesenteric artery)</td>
</tr>
<tr>
<td><strong>III</strong></td>
<td>Leak through defect in graft</td>
<td>3A (Junctional separation of the modular components), 3B (Fractures or holes involving the endograft)</td>
<td>Contrast extravasation: central or distal to the graft attachment</td>
</tr>
<tr>
<td><strong>IV</strong></td>
<td>Graft porosity</td>
<td></td>
<td>Contrast extravasation anywhere of the aneurysmal sac without evidence of clear leak origin</td>
</tr>
<tr>
<td><strong>V</strong></td>
<td>Endotension</td>
<td></td>
<td>Continued expansion of aneurysm sac without demonstrable leak on imaging</td>
</tr>
</tbody>
</table>

**Fig. 23:** Different types of endoleaks.

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## Post-Processing

<table>
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<th>Tecnique</th>
<th>Vantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPR</td>
<td>Useful for the assessment of origin and extension of intimal layer</td>
<td>Difficult evaluation of all vascular segments</td>
</tr>
<tr>
<td>CMPR</td>
<td>Useful for diameter analysis (True/False lumen)</td>
<td>No reference points. Risk of underestimating the true or false lumen</td>
</tr>
<tr>
<td>MIP</td>
<td>No</td>
<td>It is not suitable for the analysis of aortic wall or for dissection layer</td>
</tr>
<tr>
<td>VR</td>
<td>Global 3D visualization</td>
<td>Trombized false lumen is not visualized</td>
</tr>
<tr>
<td>CINE-LOOP</td>
<td>Assessment of valvular anatomy</td>
<td>No flow analysis</td>
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Aortic Dissection - Findings CT

- Extension of the intimal flap
- Entry/reentry sites identification
- Relationships between the true and false lumens
- Origin and patency of the aortic branches
- Organs perfusion
- Coronary artery involvement

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</tr>
<tr>
<td>1C (Iliac)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TYPE II</th>
<th>Retroleak. Aneurysm sac filling via branch vessel. 80 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2A (1 vessel)</td>
<td>Retrograde flow through branch vessels (lumbar arteries or inferior mesenteric artery)</td>
</tr>
<tr>
<td>2B (2 or more vessels)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TYPE III</th>
<th>Leak through defect in graft</th>
</tr>
</thead>
<tbody>
<tr>
<td>3A (Junctional separation of the modular components)</td>
<td>Contrast extravasation: central or distal to the graft attachment</td>
</tr>
<tr>
<td>3B (Fractures or holes involving the endograft)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TYPE IV</th>
<th>Graft porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Contrast extravasation anywhere of the aneurysmal sac without evidence of clear leak origin</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TYPE V</th>
<th>Endotension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Continued expansion of aneurysm sac without demonstrable leak on imaging</td>
</tr>
</tbody>
</table>

**Fig. 23:** Different types of endoleaks.

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Conclusion

In conclusion, this education exhibit outlines the pathophysiology, technical aspect of image acquisition, diagnostic patterns, management options and possible operative complications of the various pathologies in the spectrum of acute aortic syndrome. ECG-gated MDCT is poised to become the reference standard method in assessing the thoracic aorta. Clear and structured report is mandatory in Emergency Department.
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References


