NON-TRAUMATIC AORTIC DISSECTION: A PRIMER

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Introduction

Few experienced emergency physicians will have escaped personal or departmental involvement in a missed case of aortic dissection (AD). A national safety campaign, emphasising the importance of CT aorta in patients with unexplained severe pain (1), has helped keep the diagnosis in clinicians' minds but cases continue to be missed.

A recent SI involving the death of a 31-year-old man from AD has led to a quality improvement project being undertaken, which aims to improve detection of AD in St George's Hospital ED. Aptly, England's Healthcare Safety Investigation Branch (HSIB) published its report *Delayed Recognition of Acute Aortic Dissection* in January 2020 (2).

The problem

The UK-wide incidence of aortic dissection is thought to be ~4000 cases per year, of whom only 1200 survive to be admitted to hospital (3). Unoperated mortality in acute type A dissection is quoted at 1-2% per *hour* (4). It is therefore imperative to identify patients with potential aortic dissection early in their ED attendance, and expedite imaging so that the diagnosis is made propitiously.

The varied clinical features of AD require that the clinician bear the diagnosis in mind when assessing a range of ED presentations, whilst simultaneously appreciating that the diagnosis is uncommon (by comparison, there are approximately 92,000 confirmed cases of MI in the UK annually (5), and approximately 25,000 admissions with pulmonary embolism (6).

Furthermore, unlike in myocardial infarction and pulmonary embolism, the role of routine ED tests (ECG, laboratory tests, chest X-ray) in ruling out the diagnosis in low-risk patients is disputed.

Finally, a gulf exists between the traditional medical school teaching on how AD presents clinically and its varied presentation in clinical practice. This may contribute to the reported misdiagnosis rate for aortic dissection of 16- 39% (7,8).

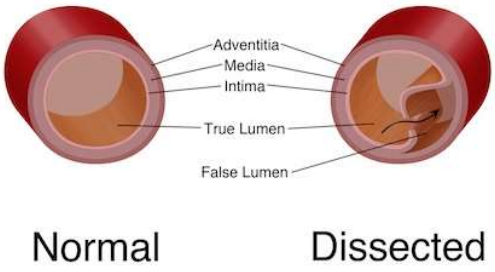
Pathophysiology

Aortic dissection

AD is the best-known of the 'acute aortic syndromes', the others being intramural haematoma (IMH) and penetrating atherosclerotic ulcer (PAU). Some authors also consider aortic aneurysm rupture (contained or not contained) within this group.

In AD, a tear occurs in the aortic intima. Blood enters the wall of the aorta and causes the muscular aortic media to separate into two layers (i.e. 'dissect'). Under pressure, the dissection then propagates distally and/or proximally along a variable length of the aorta. In cross-section, the affected aorta now has two lumens – a 'true' (original) lumen and a 'false' (due to the dissection flap) lumen:

Fig. 1: Example of aortic dissection in cross-section (image source: https://ufhealth.org/uf-health-aortic-disease-center/aortic-dissection?device=desktop) (9)



Following dissection, the true lumen collapses to a variable degree, and the false lumen dilates. Because the outer wall of the false lumen is thinned, it expands to generate the necessary wall tension to accommodate aortic pressure, thus increasing the aortic cross-sectional area (10).

Blood may exit the false lumen and re-enter the true lumen through (potentially multiple) intimal tears. The false lumen may thrombose to a variable degree but is completely patent in 51% of cases (11).

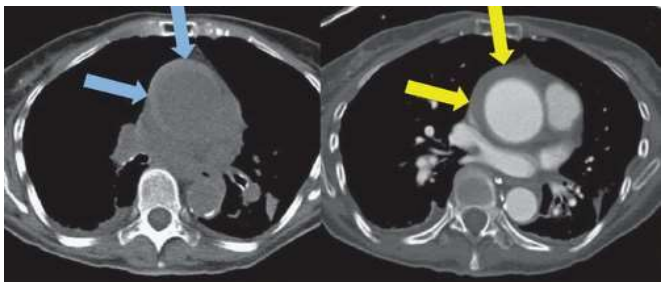
Propagation of the dissection may occur rapidly or in a stop/start fashion. This explains the single and transitory, or intermittent, nature of pain experienced by some patients with AD. Equally, patients also experience constant/colicky pain, presumably due to ischaemia/localised pressure effects.

Death results from retrograde propagation, resulting in disruption of the aortic root and acute aortic regurgitation and/or cardiac tamponade, from aortic rupture, or from other complications such as stroke/ischaemic gut/renal failure due to compromise of the relevant arteries arising from the aorta.

Intramural haematoma

IMH refers to a (typically crescentic or circumferential) haematoma in the aortic wall where no tear in the aortic intima can be found. It is best seen on the non-contrast phase of a CT aorta, where it appears as a region of high attenuation (brightness) in the aortic wall:

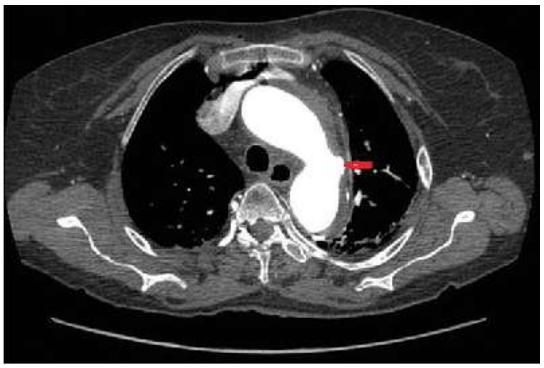
Fig. 2: Near-circumferential high attenuation (blue arrows) in the wall of a dilated ascending aorta. Note the thickened aortic wall due to distension with haematoma, seen clearly on the contrast phase image (yellow arrows) (image source: https://radiologykey.com/acute-aortic-intramural-hematoma-2 (12)



Penetrating aortic ulcer

Ulceration of an atherosclerotic plaque results in a 'crater'-like defect within the aortic wall, visible on contrast CT:

Fig. 3: Penetrating aortic ulcer (red arrow) of the distal aortic arch (image source: Simon C, Calabrese A, Canu G, *et al.* Crater-Like Ulceration of Aortic Arch. AORTA. 2014 Dec 30;2(6):289–92. (13)



The ED management of all the acute aortic syndromes is similar – immediate referral to cardiac/vascular surgery and aggressive medical management.

Classification of aortic dissection

Several classification systems exist. The most familiar and useful from an ED perspective is the Stanford classification:

- Stanford type A: Dissection involves the aorta proximal to the innominate artery
- Stanford type B: Dissection involves the aorta distal to left subclavian artery only
- Non-A-non-B: Dissection arises in the transverse arch between the innominate and left subclavian arteries

Classifying aortic dissection correctly is important:

- Stanford type A AD is a cardiac surgical emergency
- Like type A, Stanford type B AD also requires aggressive medical management and admission to critical care, but it is managed by vascular surgeons. Intervention is usual after a period of medical management for 24-48 hours. In the case of rupture, visceral or limb malperfusion, or acute dilation >4cm, however, emergency intervention is required. Further (relative) indications for emergency intervention include unremitting pain or hypertension (poor prognostic markers).
- Non-A-non-B dissections require discussion with cardiac surgery as there are no vascular procedures to manage these acutely (though there may be if these become chronic) (Peter Holt, 31/07/2020, personal communication)

Fig. 4: Anatomical divisions of the aorta (image source: http://www.aortarepair.com/anatomy.html) (14)

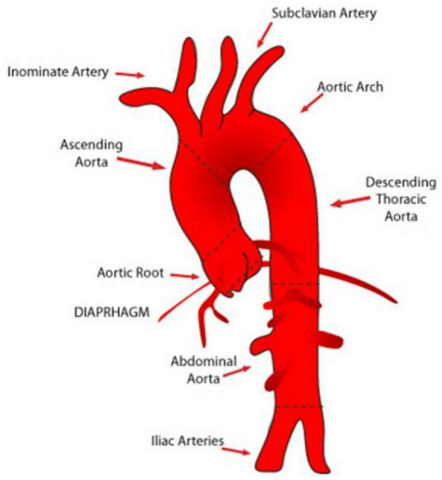
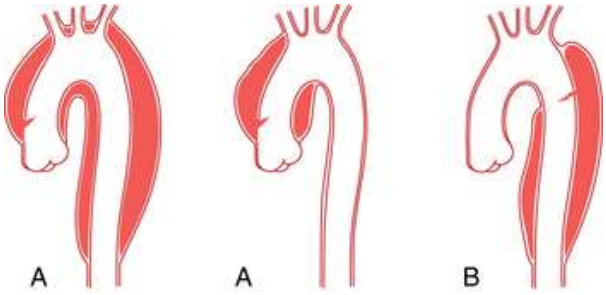


Fig. 5: Two type A dissections, the first with arch/descending thoracic/abdominal aorta involvement, and a type B dissection (image source: https://radiologykey.com/wp-content/uploads/2016/01/B9781437717198000153_f06-10-9781437717198.jpg) (15)



Type A dissection occurs more frequently than type B, comprising 67% of cases in an international registry of >4000 aortic dissections (the International Registry of Acute Aortic Dissections (IRAD)) (16).

Stanford vs. De Bakey vs. DISSECT classifications

The above-described Stanford classification has the advantages of ease of recall, and – in UK practice – it suggests which specialty should admit the patient. It is less helpful in guiding specific interventions.

Essentially, it is the site of entry which determines the treatment and not the extent of the dissection. That is, if the site of entry is in the ascending aorta or the arch, then surgical treatment by cardiac surgeons is required. If the site of entry is the descending thoracic aorta, initial management is mainly medical (given the above provisos) and the patient is referred to vascular surgery (Marjan Jahangiri, personal communication, 11/08/2020).

The De Bakey (1965) classification of AD is into 3 types, and reflects the contemporary surgical approach (17):

- Type I arises in the ascending aorta and extends into the descending thoracic aorta and beyond; repaired via a median sternotomy by transecting the ascending aorta and re-approximating the true and false lumens
- Type II is confined to the ascending aorta; repaired via a median sternotomy by resecting the entire dissection and replacing it with a Dacron graft

- Type III arises in the descending thoracic aorta; repaired via a thoracotomy by replacing the entire dissection with a Dacron graft (type IIIa) or extending repair further into the abdominal aorta (type IIIb)

The utility of the De Bakey classification system has fallen as surgical techniques have evolved, and it does not consider endovascular repair. However, it is still frequently used and has the advantage that the dissection type signals (to some extent) the method of repair to surgically correct it.

The DISSECT (2013) classification considers the specific anatomic and clinical manifestations of the disease process that are most relevant to modern decision-making (18). DISSECT is a mnemonic for duration of disease, intimal tear location, size of the dissected aorta, segmental extent of aortic involvement, clinical complications of the dissection, and thrombus within the aortic false lumen. Unlike the Stanford and De Bakey classifications, it considers endovascular, as well as surgical, treatment options. In the ED setting, however, the DISSECT classification is unduly complex.

Risk factors

These are broadly common to both type A and type B dissections. Risk factors from the IRAD data are presented below (16):

Table 1: Demographics

Category	Total AD (n = 4428)	Type A AD (n = 2952)	Type B AD (n = 1476)	p value type A vs. type B
Mean age (+/- SD)		61.5 years (+/- 14.6)	63.6 years (+/- 14.1)	<0.001
Male	66.9%	67.5%	65.8%	0.272

Table 2: Past medical/procedure history (as presented in study – selective)

Category	Total (n = 4428)	Type A AD (n = 2952)	Type B AD (n = 1476)	p value type A vs. type B
Hypertension	76.6%	74.4%	80.9%	<0.001
Atherosclerosis	26.5%	23.8%	31.7%	<0.001
Previous cardiac surgery	16.1%	14.2%	19.6%	<0.001
Known aortic aneurysm	15.5%	12.7%	20.7%	<0.001
Aortic aneurysm and/or AAD*	9.2%	6.4%	14.5%	<0.001
Diabetes mellitus	7.8%	7.7%	8.0%	0.673
Previous AAD*	5.7%	4.0%	8.9%	<0.001
Aortic valve replacement	5.1%	4.5%	6.2%	0.022
Coronary artery bypass graft surgery	4.9%	5.0%	4.8%	0.851
Marfan syndrome	4.4%	4.5%	4.0%	0.404
Iatrogenic**	2.8%	3.0%	2.3%	0.212
Mitral valve replacement	0.9%	0.9%	0.8%	0.726

*AAD = Acute aortic dissection

**e.g. secondary to cardiac catheterisation

Risk factors not listed in the above tables include the following:

Other genetic syndromes associated with thoracic aortic aneurysms and dissection (TAAD)

- Loeys-Dietz Syndrome
- Ehlers-Danlos Syndrome, vascular form
- Turner syndrome (19)
- Autosomal dominant polycystic kidney disease (20)
- Others: Noonan Syndrome, Alagille Syndrome (19), familial aneurysm-osteoarthritis syndrome (21), congenital contractural arachnodactyly (22)

Non-syndromic forms of aortic aneurysms and dissections

- Familial, non-syndromic TAAD (aka Erdheim's cystic medial necrosis of the aorta)

Other cardiovascular conditions associated with TAAD

- Bicuspid aortic valve (19). This is a very common type, since 2% of the population has bicuspid aortic valve, and (usually in the 50s-60s) can present with dissection (Marjan Jahangiri, personal communication, 11/08/2020).
- Aberrant right subclavian artery
- Coarctation of the aorta
- Right aortic arch

Inflammatory diseases associated with thoracic aortic disease

- Takayasu arteritis
- Giant cell arteritis
- Behçet disease
- Ankylosing spondylitis

Infective thoracic aortic aneurysms

- May be due to bacterial, fungal, viral, spirochaetal, or tubercular organisms (19)

Others

- Family history of aortic disease (dissection, aneurysm, aortic valve disease) was observed in >10% of patients in a study of 1130 IRAD cases in whom FH data was recorded (23). Family history may be subtle, e.g. sudden death due to a 'heart attack', not proven on autopsy, may in fact reflect death from AD (19).
- Smoking (24)
- Cocaine (25) or methamphetamine (26) use. Interestingly, there appears to be a delay in onset of AD following cocaine use. In a case series of 16 patients with cocaine-induced AD, AD occurred on average 12.8 hours after cocaine use (range 4-24 hours) (27).
- High-intensity weightlifting and other strenuous resistance training (28). In a retrospective study, strenuous activity prior to the onset of thoracic pain was reported in 27% of AD survivors (29).
- Severe physical (e.g. severe COPD exacerbation) and emotional stress. The same study reported the experience of severe emotional distress prior to the onset of dissection pain in 40% of AD survivors.
- Phaechromocytoma
- Chronic corticosteroid or other immunosuppressant administration (19)
- Pregnancy and the post-partum period: incidence ratio of 4 for aortic events in pregnant/post-partum women when compared with the same cohort 1 year later, but absolute risk still very low – 5.5 vs. 1.4 events per million patients (over each 270-day study period) (30)

AD risk factors in young patients (age <40 years)

- In a study of 951 AD patients, 68 (7%) were aged under 40 (11).
- Compared with older patients, those under 40 were *more* likely to have ($p < 0.05$):
    - Marfan syndrome (present in 50% of cases where age <40, vs. 2% if age >40)
    - Bicuspid aortic valve (9% vs. 1%)
    - Prior aortic surgery (12% vs. 5%)
- Those under 40 were *less* likely to have a prior history of hypertension (34% vs. 72%) or atherosclerosis (1% vs. 30%) (both $p < 0.001$).

Clinical features

Registry data for presenting symptoms and signs are presented below (31) (NB a 'pulse deficit' in the context of aortic dissection is a weak or absent brachial, carotid or femoral pulse resulting from the intimal flap or compression by haematoma (10)):

Table 3: Presenting symptoms and physical examination of patients with acute aortic dissection (n = 464)

Category	Present, No. Reported (%)	Type A, No. (%)	Type B, No. (%)	*P* Value, Type A vs B
Presenting symptoms				
Any pain reported	443/464 (95.5)	271 (93.8)	172 (98.3)	.02
Abrupt onset	379/447 (84.8)	234 (85.4)	145 (83.8)	.65
Chest pain	331/455 (72.7)	221 (78.9)	110 (62.9)	<.001
Anterior chest pain	262/430 (60.9)	191 (71.0)	71 (44.1)	<.001
Posterior chest pain	149/415 (35.9)	85 (32.8)	64 (41)	.09
Back pain	240/451 (53.2)	129 (46.6)	111 (63.8)	<.001
Abdominal pain	133/449 (29.6)	60 (21.6)	73 (42.7)	<.001
Severity of pain: severe or worst ever	346/382 (90.6)	211 (90.1)	135 (90)	NA
Quality of pain: sharp	174/270 (64.4)	103 (62)	71 (68.3)	NA
Quality of pain: tearing or ripping	135/267 (50.6)	78 (49.4)	57 (52.3)	NA
Radiating	127/449 (28.3)	75 (27.2)	52 (30.1)	.51
Migrating	74/446 (16.6)	41 (14.9)	33 (19.3)	.22
Syncope	42/447 (9.4)	35 (12.7)	7 (4.1)	.002
Physical examination findings				
Hemodynamics (n = 451)†				
Hypertensive (SBP ≥150 mm Hg)	221 (49.0)	99 (35.7)	122 (70.1)	<.001
Normotensive (SBP 100-149 mm Hg)	156 (34.6)	110 (39.7)	46 (26.4)	
Hypotensive (SBP <100 mm Hg)	36 (8.0)	32 (11.6)	4 (2.3)	
Shock or tamponade (SBP ≤80 mm Hg)	38 (8.4)	36 (13.0)	2 (1.5)	
Auscultated murmur of aortic insufficiency	137/434 (31.6)	117 (44)	20 (12)	<.001
Pulse deficit	69/457 (15.1)	53 (18.7)	16 (9.2)	.006
Cerebrovascular accident	21/447 (4.7)	17 (6.1)	4 (2.3)	.07
Congestive heart failure	29/440 (6.6)	24 (8.8)	5 (3.0)	.02

Pain in aortic dissection

It is worth highlighting that in only half of cases was the classic description of tearing or ripping pain reported. Radiating pain (28.3%) – which may be e.g. to the interscapular area/neck/jaw/arms (32–34) – was also far from universal.

The European Society of Cardiology (ESC) Aortic Diseases Guidelines describe (24):

> *'Acute deep, aching or throbbing chest or abdominal pain that can spread to the back, buttocks, groin or legs, suggestive of AD or other AAS, and best described as "feeling of rupture"'*

Some patients present with only mild pain, often mistaken for a symptom of musculoskeletal conditions in the thorax, groin, or back (33). Patients with acute heart failure and cardiogenic shock present less frequently with severe and abrupt chest pain (24).

The importance of taking an accurate pain history was demonstrated by Rosman *et al*. Of 83 AD patients, the diagnosis was correctly suspected 91% of the time if patients were questioned about the quality, location and onset of their pain, but only 49% of the time if one or more of these questions was omitted (35).

Painless aortic dissection

In the IRAD data, incidence of painless AD was low at 4.5%; however, a Chinese registry of 1003 patients found a painless AD incidence of 10.4% (36), and a Japanese series of 98 AD patients found a painless AD incidence of 17% (37). Painless AD is commoner in Marfan syndrome (33).

Patients with painless AD are more likely to be hypotensive, to have persistent disturbance of consciousness, syncope, and a focal neurological deficit, and are more likely to suffer complications of cerebral ischaemia and cardiac tamponade (37,38). In a review of 87 painless AD cases (39), left-sided neurological deficit was the commonest presenting symptom, followed by dyspnoea, then bilateral lower limb deficits. Pulse asymmetry was seen in 53% of patients.

Physical examination in aortic dissection

The measurement of bilateral arm blood pressures, looking for a systolic BP differential >20mmHg, rightly forms part of the examination in suspected AD, given its simplicity and the increased suspicion for AD if positive. The sensitivity of this sign is poor (30%) (40), though the same study reported a specificity of 87%. Of note, an interarm BP differential ≥20 mmHg has been reported in 14% of the general population (41).

Additional important physical examination features are described below (24,31,33):

- Hypertension (due a catecholamine surge or pre-existing hypertension), hypotension or shock (normotension also common – see *table 3*)
- Aortic regurgitation signs – e.g. bounding pulses, wide pulse pressure, diastolic murmur +/- heart failure signs
- Cardiac tamponade signs, e.g. muffled heart sounds
- Pericardial friction rub due to pericarditis
- Asymmetrical pulses (assess brachial, carotid and femoral pulses in particular); bruits may develop or progress on serial examination
- Pleural effusion signs
- Neurological deficits

Pathophysiology of symptoms/signs in aortic dissection

AD can result in symptoms and signs in any part of the body, as all of the body is supplied by the aorta. These may be persistent or transient (as malperfusion of aortic branch vessels due to obstruction may be 'static' or 'dynamic' (42) – consider vessels intersected by the dissection vs. a mobile dissection flap moving over time).

For example, renal artery involvement can cause flank pain (and AKI) (33,43); recurrent laryngeal nerve compression can cause hoarseness; cervical sympathetic chain involvement can cause Horner syndrome; iliac involvement can cause ischaemic limb/claudication symptoms (33); pulmonary artery compression, aortopulmonary fistula formation or pleural effusion can cause breathlessness/haemoptysis (19); peripheral nerve ischaemia can cause altered numbness/tingling/pain/weakness (33); visceral malperfusion may cause e.g. GI disturbance, ischaemic hepatitis (44), ischaemic pancreatitis (45). Various spinal cord syndromes, including anterior cord syndrome and incomplete Brown-Sequard syndrome, are reported (46). SIRS and DIC (47) are also described. Interestingly, fever is common in AD (48). Presence of fever was associated with the greatest delay to diagnosis in a study of the IRAD database (49).

This does *not* mean that anyone presenting with any one of these features should be scanned; what it means is that in the appropriate clinical context, AD – 'the great masquerader' – may be the unifying diagnosis (50).

Symptoms/signs of aortic dissection by system in painless aortic dissection

The following are arranged by system and reflect a review of some of the case report literature in AD. Unless stated, pain was not present in the history at the time of presentation:

<u>Neurological</u>

Transient weakness and numbness of the lower limbs (51)
Intermittent right leg numbness and weakness (52)
Rapidly recurring left hemiparesis (53)
Right upper limb weakness (+ pulse deficit, followed by collapse) (54)
Syncope followed by left arm weakness (+ elevated JVP) (55)
Left-sided hemiplegia following Heimlich manoeuvre (56)
Gait disturbance due to left homonymous hemianopsia (57)
Dysmetria, right hand numbness, left upper limb weakness, confusion (+ left upper limb coldness, bradycardia) (58)
Syncope (+ ventricular bigeminy) (59)
Dizziness and blurred vision (60)
Dizziness (+ hypotension, complete heart block, right upper limb pulse deficit) (61)
Uniocular blindness (+ headache) (62)
Seizures, syncope (+ transient asystole) (63)
Amnesia (+ borderline hypotension) (64)
Amnesia, disorientation (+ mild bradycardia and wide pulse pressure) (65)
Amnesia, dizziness, disorientation (+ pallor, hypotension, diastolic murmur) (66)

<u>Cardiovascular</u>

Cold, pulseless left leg and aortic regurgitation (+ left leg weakness and numbness) (61)
Dyspnoea and ejection systolic murmur (due to aortic outflow tract obstruction by the dissection flap) (67)
Symptoms of acute LVF, aortic diastolic murmur and severe hypertension (+ low-grade fever, pericarditic changes on ECG and impaired LV function on echo)

Symptoms of acute LVF, palpitations, pericardial friction rub, hypotension, AF (+ fatigue, pericarditic ECG changes, impaired LV function and pericardial effusion on echo) (68)
Superior vena cava obstruction (69)

Pulmonary

Dyspnoea, tachypnoea and hypoxaemia (+ tachycardia) (70)
Dyspnoea, left-sided pleural effusion (+ fever and severely elevated BNP) (71)
Haemoptysis (+ epigastric pain) (72)
Cough and shortness of breath (+ chest pain) (73)

GI

Abdominal tenderness and pain (+/- other symptoms) (74)
Burning throat pain and water brash (+ subsequent chest pain and right lower limb cramping) (75)
Progressive burning sensation in upper abdomen and burping (76)
GI bleeding, diarrhoea and abdominal pain (+ tachycardia, chest pain and jaw pain) (77)
Vomiting, PR bleeding and anorexia (+ fatigue, confusion and bilateral leg weakness) (78)
Vomiting and bloody diarrhoea (+ tachypnoea and hypotension) (79)
Mild dysphagia (+ hoarse voice and left vocal cord paralysis on laryngoscopy. Hoarseness due to recurrent laryngeal nerve palsy as a result of a cardiovascular abnormality is known as Ortner's syndrome or cardiovocal syndrome) (80)

Urological

Urinary retention (+ weak and heavy lower limbs) (81)
Haematuria (+ chest pain, back pain, vomiting and diaphoresis) (82)

ENT

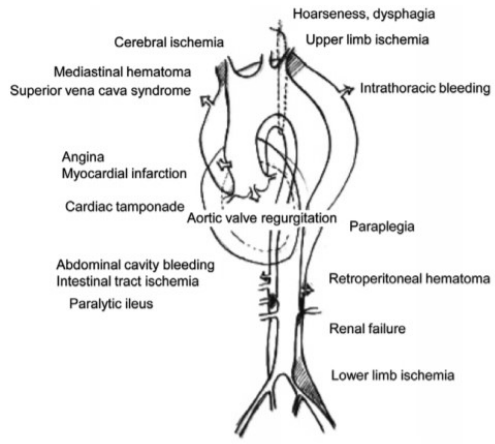
'Funny feeling in throat' (+ syncope, hypertension, bradycardia, pulse deficits, neurological deficits) (61)
Mandibular and neck pain (+ cold sweats) (83)
Hoarse voice (84)

Psychiatric

'Hysteria' and agitation (+ pulseless extremities) (85)

Below is a useful schematic of some pathological conditions seen in aortic dissection (47):

Fig. 6: Pathological conditions of aortic dissection (image source: http://jlc.jst.go.jp/DN/JST.JSTAGE/circj/CJ-66-0057?lang=en&from=CrossRef&type=abstract)



Society guidance on clinical features

The ESC aortic diseases guidelines (24) describe 'clinical data useful to assess the a priori probability of acute aortic syndrome', as follows:

Table 4: Clinical data useful to assess the a priori probability of acute aortic syndrome

High-risk conditions	High-risk pain features	High-risk examination features
• Marfan syndrome (or other connective tissue diseases) • Family history of aortic disease • Known aortic valve disease • Known thoracic aortic aneurysm • Previous aortic manipulation (including cardiac surgery)	• Chest, back, or abdominal pain described as any of the following: - abrupt onset - severe intensity - ripping or tearing	• Evidence of perfusion deficit: - pulse deficit - systolic blood pressure difference - focal neurological deficit (in conjunction with pain) • Aortic diastolic murmur (new and with pain) • Hypotension or shock

ESC's suggested diagnostic algorithm, which integrates the above, is described in the 'Diagnostic strategy' section below.

Expert commentary

Whilst clinician knowledge of the quantitative data on clinical features of AD is important, the nuances of making this diagnosis make qualitative guidance from experts particularly valuable.

Helman describes 'Five Pain Pearls of Aortic Dissection' (86):

> *'1. Ask the following three things of all patients with torso pain:*
>
> *a) What is the quality of pain? (The pain from aortic dissection is most commonly described as "sharp," but the highest positive likelihood ratio [+LR] is for "tearing.")*
> *b) What was the pain intensity at onset? (It is abrupt in aortic dissection.)*
> *c) What is the radiation of pain? (It is in the back and/or abdomen in aortic dissection.)*
>
> *2. Think of aortic dissection as the subarachnoid haemorrhage of the torso. Just like a patient who presents with a new-onset, severe, abrupt headache should be suspected of having a subarachnoid haemorrhage, if a patient describes a truly abrupt onset of severe torso pain with maximal intensity at onset, think aortic dissection.*
>
> *3. If you find yourself treating your chest pain patient with IV opioids to control severe colicky pain, think about aortic dissection.*
>
> *4. Migrating pain has a +LR of 7.6. In addition to the old adage, "Pain above and below the diaphragm should heighten your suspicion for aortic dissection," severe pain that progresses and moves in the same vector as the aorta significantly increases the likelihood of aortic dissection.*
>
> *5. The pain can be intermittent as dissection of the aortic intima* [sic] *stops and starts. The combination of severe migrating and intermittent pain should raise the suspicion for aortic dissection.'*

The same author describes the concepts of "CP + 1" and "1 + CP":

> *'The intimal tear in the aorta can devascularize any organ from head to toe, including the brain, heart, kidneys, and spinal cord. Thus, 5 percent of dissections present as strokes, and these certainly are not the kind of stroke patients who should be receiving tPA! An objective focal neurologic deficit in the setting of acute, unexplained chest pain (CP) has +LR of 33 for aortic dissection, almost diagnostic. Some of the CP +1 phenomena to think about include torso pain, cerebrovascular accident, paralysis, hoarseness (recurrent laryngeal nerve), and limb ischemia.*
>
> *In addition to thinking of CP +1, it may help to think backwards in time (1+ CP) and ask patients who present with end-organ damage if they had torso pain prior to their symptoms of end organ damage. For example, ask patients who present with stroke symptoms if they had torso pain before the stroke symptoms.'*

And on unexplained torso pain in young patients:

> *'Anyone under the age of 40 years who presents to the emergency department with unexplained torso pain should be asked if they have Marfan syndrome. In the IRAD analysis of those under 40 years, 50 percent of the aortic dissection patients had Marfan syndrome, representing 5 percent of all dissections.*
>
> - ***Look.*** *The patient doesn't always know they have Marfan syndrome, so you need to* ***look*** *for arachnodactyly (elongated fingers), pectus excavatum (sternal excavation), and lanky limbs* [60% also have lens dislocation; see Appendix (table 6) for further clues to syndromic thoracic aortic disease]
> - ***Listen.*** *A new aortic regurgitation murmur* [NB the duration of the AR murmur may be quite short in AD (10)] *has a surprisingly high +LR of 5.*
> - ***Feel.*** *Feel for a pulse deficit, which has a +LR of 2.7, much higher than that of interarm blood pressure differences.'*

Some of these 'pain pearls' are supported by guidance in the 2010 US national guidance on thoracic aortic disease (19):

- *In patients with suspected or confirmed aortic dissection who have experienced a syncopal episode, a focused examination should be performed to identify associated neurologic injury or the presence of pericardial tamponade.*
- *All patients presenting with acute neurologic complaints should be questioned about the presence of chest, back, and/or abdominal pain and checked for peripheral pulse deficits as patients with dissection-related neurologic pathology are less likely to report thoracic pain than the typical aortic dissection patient.*

On when to consider the diagnosis of AD, Helman advises (86):

- *'We need to at least* consider *the diagnosis in all patients with chest, abdominal or back pain, syncope or stroke symptoms, yet we shouldn't be working up every one of them, or else we'll bankrupt the health care system with all the CT aortograms ordered. Herein lies the difficulty.'*

A lot of the national work aimed at improving detection of aortic dissection has been driven by an EM consultant (Emma Redfern) and a radiologist (Mark Callaway) in Bristol, after 3 men in their 40s died from missed diagnoses of aortic dissection following an ED attendance there (87–89). They and a Liverpool aortic surgeon (Debbie Harrington) have made useful FOAMed contributions on AD (90). Points of note from these videos/podcast include:

- Redfern:
    - Pain can start in the neck, chest, back
    - Think of AD pain as being like 'thunderclap chest pain', reaching maximum severity within seconds of onset
    - On return of pain, it may have migrated
    - Patients can recover from pain and seem completely well, before deteriorating and dying; often diagnosed with gastritis
    - Their ED has ~75,000 annual adult attendances, does ~200 CT aortas per year, and picks up ~4-8 cases per year (they quote an incidence of 1 per 10,000 ED attendances (90). St George's ED has 127,000 adult attendances per year.
- Harrington:
    - AD affects adults of working age
    - Patients may describe severe pain unlike anything they have had before
    - Pain may be 'bursting' in character – 'something popped'
    - Often, a history of collapse is present [syncope was found in 13% of 728 international AD cases (91)]
    - Transient numbness or altered sensation common

EM/ICU physician Matthew Stull reports that almost all his patients with aortic dissection have had severe pain, with the inability to get themselves into a comfortable position. He describes a case of a man with chest pain radiating to the teeth, in whom AD was suspected over ACS due to the severity of the pain (92).

RCEM Learning recommend considering aortic dissection as a possibility when an aortic diastolic murmur is heard in the context of breathlessness (93).

Investigations

ECG

In the IRAD series, the ECG was normal in 30%, showed non-specific ST and T wave changes in 42% (commonly LVH and strain patterns associated with hypertension), ischaemic changes in 15%, and – among those with type A AD – acute MI in 5% (due to coronary artery ostia involvement. For anatomical reasons, the right coronary artery is more commonly occluded, resulting in inferior, inferior/posterior, or inferior/right ventricular MI (10,94,95).

Varying degrees of conduction block (including up to CHB and asystole) have also been described. In two missed AD cases at St George's, both in 31-year-men, subtle ECG abnormalities were seen: one patient had sinus tachycardia, partial left bundle branch block, and possible atrial enlargement; the other had borderline 1st degree heart block and sinus bradycardia (rate 50). The mechanism of AV block may be haematoma in the interatrial septum and AV junction (96).

Bradycardia may also result from disruption of arterial supply to carotid body receptors (58). Tachycardia, including SVT, and ventricular bigeminy have been reported (59).

Pericarditic changes are also described.

Unsurprisingly, an ECG associated with myocardial ischaemia is associated with significant delay to diagnosis of AD (49).

Laboratory tests

According to ESC (24):

'Laboratory testing plays a minor role in the diagnosis of acute aortic diseases but is useful for differential diagnoses. Measuring biomarkers early after onset of symptoms may result in earlier confirmation of the correct diagnosis by imaging techniques, leading to earlier institution of potentially life-saving management.'

Full blood count, coagulation studies, routine biochemistry

Various abnormalities may be seen. These may reflect pre-existing disease, an acutely 'sick' patient, or end-organ damage. Anaemia and CK elevation are reported. Leucocytosis, leucopenia, hypoalbuminaemia, CRP or fibrinogen elevation may reflect a stress response.

Troponin

Standard-sensitivity and high-sensitivity troponins were positive in 16% and 54% of acute aortic syndrome cases respectively according to one registry (97).

D-dimer

Clearly, D-dimer cannot rule in a diagnosis of AD. Controversy exists as to whether negative D-dimer result should be used for ruling out AD in low-probability patients. ESC phrase their advice on D-dimer carefully:

> 'If D-dimers are elevated, the suspicion of AD is increased. Typically, the level of D-dimers is immediately very high, compared with other disorders in which the D-dimer level increases gradually. D-dimers yielded the highest diagnostic value during the first hour. If the D-dimers are negative, IMH and PAU may still be present; however, the advantage of the test is the increased alert for the differential diagnosis.'

In the context of suspected AD, ESC recommends D-dimer testing in stable patients with acute chest pain and a low probability score for acute aortic syndrome (see 'Diagnostic strategy').

The *level* at which D-dimer is considered positive affects its sensitivity and specificity for detecting AD. At no level can D-dimer be considered usefully specific for AD. With respect to sensitivity, a prospective cohort study of 65 patients with proven AD found D-dimer levels ranging from 240 ng/mL to 138,000 ng/mL (SGH cut-off for abnormal D-dimer = 300 ng/mL). Based on these results and their own systematic review, the authors conclude, *'Current evidence supports a routine measurement of D-dimer in excluding AAD. A D-dimer <0.1 mg/mL* [100 ng/mL] *will exclude AAD in all cases.'* (98)

Other studies have found D-dimer less useful. For example, using a cut-off of 400 ng/mL, a cohort study of 61 patients with confirmed AD yielded a false-negative rate of 18% (99).

Another study of 113 AD patients, using a D-dimer cut-off of 400 ng/mL, found positive D-dimer to be 92% sensitive for detecting AD. Young age, short length of dissection, and presence of a completely thrombosed false lumen without ulcer-like projection were significantly associated with a false-negative D-dimer result (100).

D-dimer usually elevates rapidly in AD. A study of 29 AD patients found that, of those tested within 90 minutes of symptom onset, sensitivity for D-dimer in detecting AD was 93.8% (cut-off used = 800 ng/mL) (101). D-dimer elevation is prolonged in AD – one study found a sensitivity of 95.3% for D-dimer (cut-off used = 1600 ng/mL) in a cohort of 100 patients up to 10 days post-symptom onset (102).

Ultimately, the interpretation of D-dimer testing is down to the EM consultant reviewing the case. Guidelines are clear, however, that there is no role for D-dimer rule-out of AD in patients with high pre-test probability.

Chest X-ray

IRAD data are presented below (31).

Table 5: Chest radiography results for patients with acute aortic dissection

Category	Present, No. Reported (%)	Type A, No. (%)	Type B, No. (%)	*P* Value, Type A vs B
Radiography findings (n = 427)	427 (100)	256 (88.6)	171 (97.7)	
No abnormalities noted	53 (12.4)	26 (11.3)	27 (15.8)	.08
Absence of widened mediastinum or abnormal aortic contour	91 (21.3)	44 (17.2)	47 (27.5)	.01
Widened mediastinum	263 (61.6)	169 (62.6)	94 (56)	.17
Abnormal aortic contour	212 (49.6)	124 (46.6)	88 (53)	.20
Abnormal cardiac contour	110 (25.8)	69 (26.9)	41 (24.0)	.49
Displacement/calcification of aorta	60 (14.1)	29 (11.3)	31 (18.1)	.05
Pleural effusion	82 (19.2)	46 (17.3)	36 (21.8)	.24

The commonest abnormalities were widened mediastinum (61.6%) and abnormal aortic contour (49.6%), and 78.7% of patients had one or both of these. Haemothorax is also common (103). Due to poor sensitivity, chest X-ray cannot be relied upon to rule the diagnosis of AD out; equally, even if the chest X-ray is highly suggestive of AD, definitive imaging will always be required. Further information on plain chest radiography in AD is included in the Appendix. Redfern *et al* advise omitting CXR in unstable patients to avoid delays in performing more specific imaging modalities (104).

Advanced imaging

National patient safety campaigns rightly emphasise the importance of CT aorta for making the diagnosis of AD. Modern CT angiography is rapid and highly sensitive and specific. The proximity of the CT scanner to Resus and Majors means that a medical escort is easily arranged when required, and the risk of deterioration during transfer is minimised.

Common sense dictates that the usual cautions to CT angiography should be considered in the light of a life-threatening and time-critical diagnosis needing to be diagnosed. Severe contrast allergy makes CT angiography impossible. The decision to perform CT angiography in the presence of significant kidney disease should be made on a case-by-case basis, with liaison with Renal where required. Contrast CT in dialysis patients can be performed liberally.

There are significant practical drawbacks to the diagnosis of AD with transoesophageal echocardiography or MRI, the two other potentially definitive diagnostic imaging modalities for thoracic aortic dissection (invasive angiography is no longer used for diagnostic purposes in the context of AD), including the need for a specialist operator +/- sedation in the case of TOE, and remote scanning location, long image acquisition time, and additional cautions/contraindications in the case of MRI. For these reasons, CT angiography is the workhorse of diagnostic imaging in suspected AD.

Transthoracic echo is useful for diagnosis of thoracic aortic dissection, but with a sensitivity of only ~80% (24), it cannot be considered definitive. It has the advantages, however, of negligible contraindications and of 24-hour availability at St George's.

<u>CT angiography – points to note</u>

- Whilst some studies have reported sensitivity of CTA in AD of up to 100%, it is dangerous to consider *any* imaging test 100% definitive. In the SI which prompted this QIP, a CT aorta was performed in a patient with high pre-test probability for aortic dissection. Whilst no dissection flap or IMH was seen on the initial report, there were other clues to the diagnosis – a prominent ascending aorta, a trace of pericardial fluid (haemodynamically insignificant pericardial effusion is seen in ~1/3 of type A AD cases (105)), a small effusion in the pericardial recesses, and an incidental finding of polycystic kidneys. The radiologist recommended a vascular opinion but the treating clinicians did not appreciate that a diagnosis of AD had not been ruled out and discharged the patient with a plan for outpatient, not inpatient, follow-up. **Treat the patient, not the scan.**
- The risk of prematurely terminating the diagnostic work-up in patients with suspected AD after they have had a negative supposedly definitive imaging test, but where clinical suspicion remains, is highlighted in the ESC guidelines:

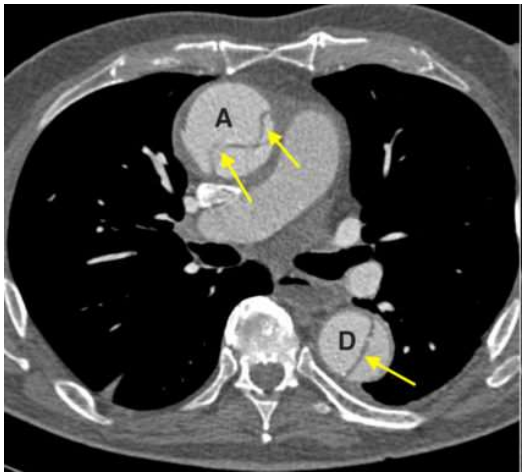
  "In case of initially negative imaging with persistence of suspicion of AAS, repetitive imaging (CT or MRI) is recommended."

  The wisdom of this is borne out by a subset of 34 patients in a cohort of 128 AD patients, for whom a combination of three clinical criteria ('aortic' pain [defined as onset over < 2 minutes and ripping in nature] + mediastinal widening, aortic widening, or both [on CXR] + pulse differential(s), blood pressure differential, or both) was 100% predictive of AD (106).
- A lot of thought has gone into the radiography protocol used for CT aortas in the emergency setting at SGH. The protocol used is dual-source high-pitch CT, rather than the traditional gold standard of ECG-gated CT. There are various

reasons for this, but both have excellent performance in eliminating motion artefact, the main problem with single-source CT.

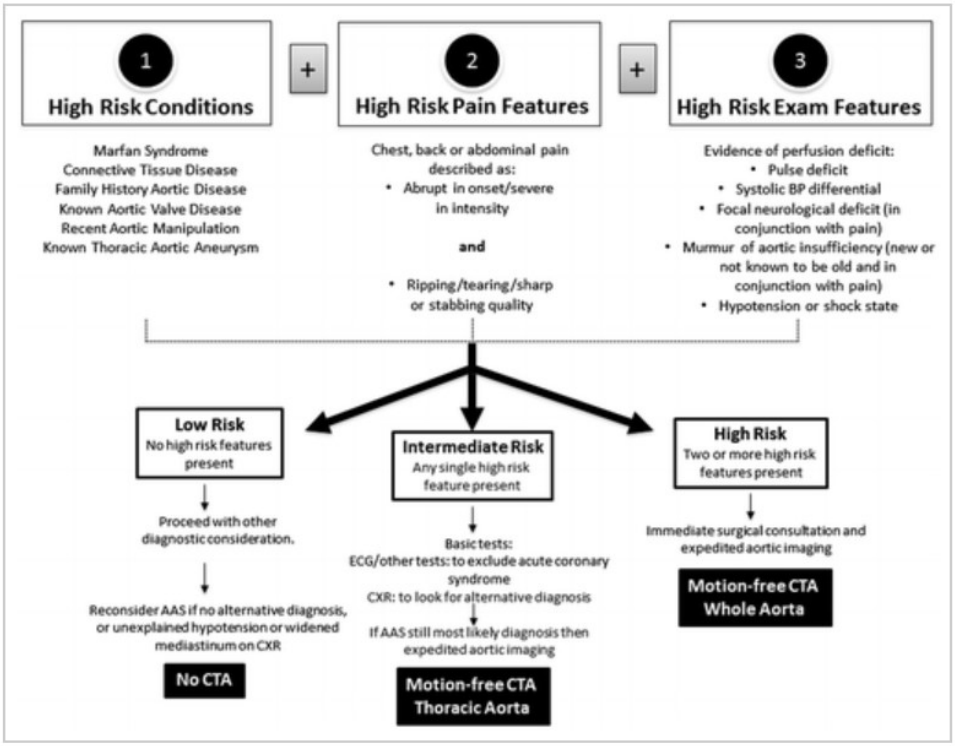
- In the rare instances where there is concern regarding the quality of a dedicated CT aorta scan, the need for repeat CT (e.g. with gating) or otherwise should be agreed with the ED consultant, radiology and/or other specialist as required.
- All the above assumes that that patient has had a *dedicated* CT aorta scan. An entirely normal CTPA doubtless lowers the pre-test probability that a patient has a thoracic AD, but it is *not* a definite scan for ruling out AD. Patients with suspected AD should have a dedicated CT aorta scan.
- Review the scan on PACS (or in the CT scanning room) with a senior EM clinician as soon as it has been performed. Radiological signs of AD can often be picked up by non-radiologists. Remember – minutes count.
- If the scan shows **aortic aneurysm with preserved integrity of the aortic wall**, and the patient has presented with **acute pain**, **contained rupture** (where perivascular haematoma is sealed off by periaortic structures) should be suspected (24). Do not discharge the patient. Refer to cardiothoracic or vascular surgery.

Fig. 7: A dissection flap is clearly visible on this contrast CT image in the ascending (A) and descending (D) aorta (image source: http://www.svuhradiology.ie/case-study/thoracic-aortic-dissection-ct) (107)



UK national radiology guidance on the imaging work-up for suspected AD is as follows (103):

Fig. 8: British Institute of Radiology 'Risk stratification for acute aortic syndrome and appropriate management strategy'



A review article by vascular surgeons from St George's advises (22):

> *'Urgent aortic imaging is needed in patients who have one or more high risk feature, but who present with no electrocardiographic changes of myocardial infarction and no history or examination findings that strongly suggest an alternative diagnosis. Although the specificity of this approach is unknown, a sensitivity of 95.7% has been reported* (108)*.'*

Redfern, Callaway and colleagues advise (104):

> *'**Proper adoption of such a scoring system*** [they reference a similar diagnostic algorithm from the US (19)] ***in the emergency department is the key to prompt and appropriate triaging of patients toward the most suitable diagnostic modality for confirmation of diagnosis.'***

Finally, US national guidelines provide some guidance on the approach to diagnosing AD in patients without any high-risk features (19):

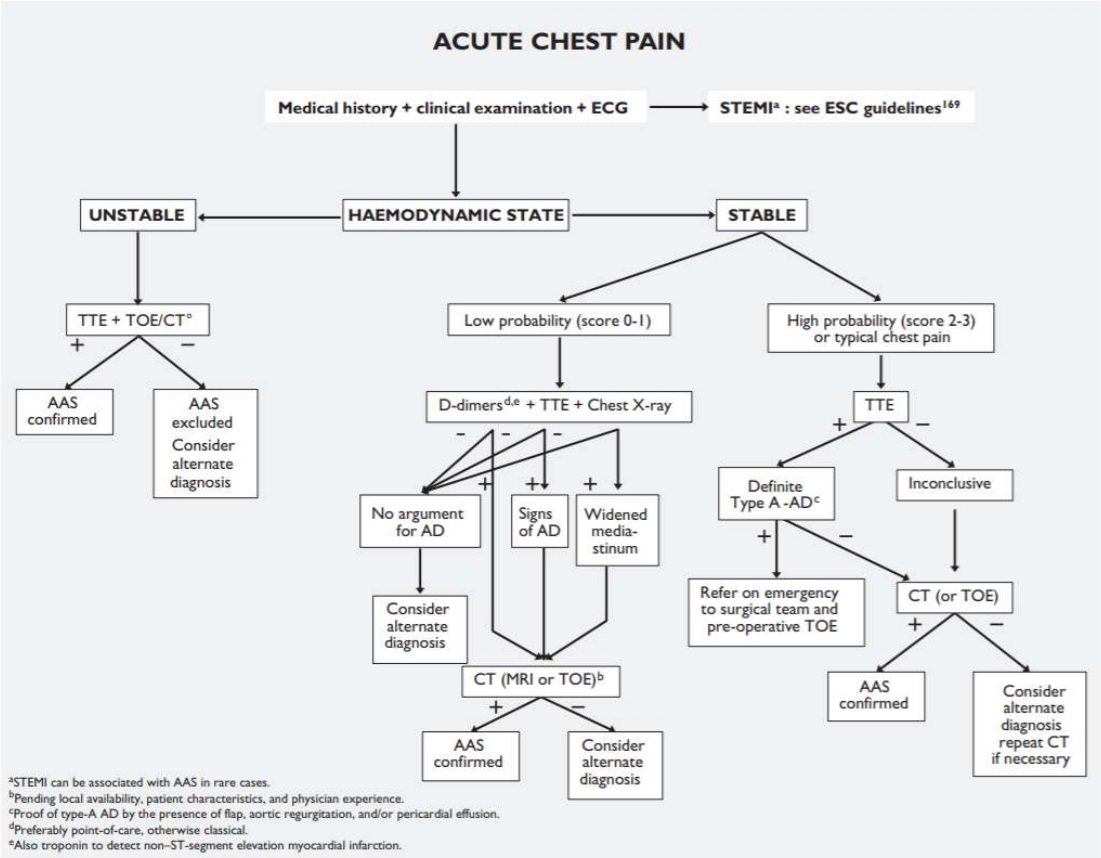
> *'Some patients with acute AoD present without any high-risk features, making early diagnosis difficult. If a clear alternative diagnosis is not established after the initial evaluation, then obtaining a diagnostic aortic imaging study, particularly in patients with advanced age (older than 70 years), syncope, focal neurologic deficit, or recent aortic manipulation (surgery or catheter based), should be considered.'*

Diagnostic strategy

No algorithm can replace a considered assessment by an experienced clinician. However, ESC's recommended decision-making flow-chart is presented below (24). In the algorithm, patients may score a **maximum of 1 point in each of the above 3 categories**, giving a probability score of 0-3 (note, however, that the presence of typical chest pain puts the patient on the 'high probability' side of the algorithm automatically). This and the above British Institute of Radiology diagnostic algorithm are both useful guides:

Fig. 9: ESC Flowchart for decision-making based on pre-test sensitivity of acute aortic syndrome

High-risk conditions	High-risk pain features	High-risk examination features
• Marfan syndrome (or other connective tissue diseases) • Family history of aortic disease • Known aortic valve disease • Known thoracic aortic aneurysm • Previous aortic manipulation (including cardiac surgery)	• Chest, back, or abdominal pain described as any of the following: - abrupt onset - severe intensity - ripping or tearing	• Evidence of perfusion deficit: - pulse deficit - systolic blood pressure difference - focal neurological deficit (in conjunction with pain) • Aortic diastolic murmur (new and with pain) • Hypotension or shock



"I'm worried that I'm organising too many CT scans – am I over-scanning?"

Redfern reports that 200 CTAs are performed in her ED per year, for ~4-8 dissections. Assuming 6 per year, this is a positivity rate of 3%. In a US cohort of 1465 patients with suspected acute aortic syndrome, only 2.7% of CTAs were positive for AAS (109).

We all have a responsibility to avoid unnecessary radiation and contrast exposure to patients, potentially harmful 'incidentaloma' findings, unnecessary work for radiology colleagues who could be reporting other scans, and unnecessary costs to the NHS. However, these numbers suggest that a significant negative scan rate is an unavoidable part of the equation in diagnosing AD.

Rational, senior-led ED decision-making on scan requests, taken in partnership with radiology colleagues, should optimise the risk/benefit in imaging for suspected AD (incidentally, a previous study calculated that the threshold probability of AAS above which the benefits of testing outweigh the risks was 3% for CTA (110)). Following the above ESC/British Institute of Radiology diagnostic algorithms helps guide rational use of CTA.

Management

See 'Treatment of Aortic Dissection' SOP.

Cardiac arrest in aortic dissection

Aortic surgeon Debbie Harrington advises attempting pericardiocentesis in young AD patients who arrest. She advises that there is no role for ED resuscitative thoracotomy in such patients (89).

Family screening

This is required in various groups. See appendix.

When things go wrong – lessons from missed cases

Salkin described 7 fatal missed diagnoses of AD which resulted in financial compensation being awarded (32):

- 58-year-old fit and well man with chest pain radiating to the back, neck and both arms, with transient episode of blindness. Normal physical exam. Non-specific ECG changes, normal cardiac enzymes and CXR. Subsequently complained of abdominal pain; underwent negative ultrasonography of the gallbladder and aorta, and had a negative CT abdomen. High morphine requirements. Arrested; type A dissection found at autopsy.
    - Comment: Classic presentation. Failure to make the unifying diagnosis. Definitive imaging of the aorta was not performed.
- 38-year-old fit and well man presented with chest pain radiating through to the back. Normal exam, ECG, cardiac enzymes, CXR. Pain migrated to the low back in the ED. Discharge diagnosis: 'acute muscle spasms, front and back'. Returned the next day but died.
    - Comment: *'The patient presented with chest pain, severe enough to come to the hospital. A diagnosis of "acute muscle spasm" is a soft and dangerous diagnosis unless you have completely eliminated the more life-threatening causes of chest pain.'* Typical history. Patient's age, good health, and initially negative work-up is falsely reassuring.
- 35-year-old man with a history of hypertension who presented with chest pain and left leg weakness, numbness and pain. Absent left femoral pulse, with leg weakness and absent reflexes. BP 98/60. Chest pain then diminished and left femoral pulse returned. Pt then began to complain of low back pain. A CT of the low back showed protrusion of the L4-5 disc. Negative work-up for myocardial ischaemia. Admitted with diagnosis of radiculopathy, discharged the next day. Died two weeks later.
    - Comment: Physician focussed on the low back pain and weakness. Failed to consider AD as a unifying diagnosis for pain, neurological and perfusion deficits. Pain above and below the diaphragm. Pulse deficit may be a transient phenomenon.
- 23-year-old six-foot woman with severe thoracic and low back pain, sharp and radiating to flanks. Recent termination of pregnancy. BP 163/120. Micrognathic, with pectus excavatum and long fingers. Multiple doses of pethidine required. Developed abdo pain in the ED. Normal labs and chest X-ray. Discharged with diagnosis of gastroenteritis. Found dead at home.
    - Comment: *'Thoracic back pain is really posterior chest pain'. 'The discharge diagnosis of gastroenteritis is another soft and dangerous diagnosis for the ED physician to make without definitely ruling out aortic dissection, especially in the presence of these symptoms and risk factors and with pain severe enough to require narcotics.'* Multiple risk factors including recent pregnancy and stigmata of Marfan syndrome. Gastroenteritis does not require pethidine. Clinical features which did not fit with the presumptive diagnosis were ignored.
- 56-year-old man with right-sided chest and shoulder pain, SoB, diaphoresis. PMH of hypertension. Pain moved to abdomen in the ED. Mild right abdominal tenderness. LVH on ECG. Chest X-ray believed normal by ED physician but reported as showing a dilated aorta. Admitted with hypertension and abdominal pain of unclear aetiology. Died later that day.
    - Comment: *'The fact that the pain in this case was right-sided is not relevant, as chest pain with aortic dissection can occur on either, or both sides of the chest, and can, in addition, be anterior or posterior or both.'* The ED physician considered AD but failed to request a definitive test.
- 81-year-old with rapid-onset chest pain, causing her to fall to the ground. Radiation to back and dull constant ache in right upper back and over right scapula. PMH of hypertension. Unremarkable examination bar patient looking 'ashen'. Non-specific T wave changes on ECG. Normal cardiac enzymes and CXR. Vomited in the ED. Pain subsequently localised to upper and lower back. Ultrasound showed gallstones but no thickening of gallbladder wall. Admitted but diagnosis of AD not considered for 36 hours. Died.
    - Comment: Notes reveal physician wasted excessive time trying to rule out MI and GI bleed. Failed to make unifying diagnosis. Pain above and below the diaphragm.

Salkin makes the following commentary on missed aortic dissection cases:

- *'An overview of missed aortic dissection cases reveals several common patterns.*
- *First, is the missed diagnosis, followed by a discharge from the ED. As you can see from the cases, the patient often receives a diagnosis of musculoskeletal pain, radiculopathy, gastroenteritis, or some other clinical entity that partially fits the patient's presentation.*
- *The second common pattern is the hospital admission with a diagnosis such as "rule out myocardial infarction," or GI bleed. Often, as with the cases discharged from the ED, the admitting diagnosis is usually not completely consistent with the patient's presentation. Again, delay in making the diagnosis with subsequent injury is typically the basis for this [law]suit.*
- *A third common fact pattern occurs when the emergency physician recognizes the underlying pathology as a dissection of the aorta and admits, or attempts to admit, the patient to the hospital. In this group of cases, the plaintiff alleges failure of the emergency physician to expedite patient evaluation and definitive management. In these cases, the patient sits waiting for admission in the ED or is admitted to the inpatient unit but decompensates or dies waiting for coordination of the OR team, cardiovascular consultation, or transfer to a tertiary care facility, etc. Obviously, this is a 'seconds to minutes' type emergency, and, once recognized, the emergency physician and the entire ED staff should use every effort to expedite management and carefully document any cause for delays, the timing and substance of communications with other physicians, and the timing of transfer of responsibility for care... Other cases involve allegations that the emergency physician did not properly manage the elevated blood pressure, causing a worsening of the dissection, rupture, and permanent injury or death.'*

Healthcare Safety Investigation Branch (HSIB) Delayed Recognition of Acute Aortic Dissection report

This draws attention to a study which found that **the foremost factor leading to diagnostic failure was perceived mildness of disease at presentation**, with acute AD being undetected in 36% of patients who *walked in* to the ED, compared to 13% of patients who arrived by ambulance (8).

The report also quotes Evangelista *et al.* (94) – *'diagnosis of this disease requires a high degree of suspicion of an aortic dissection in patients who have some risk factors*', and channels Osler ("Listen to the patient: he is telling you the diagnosis" (111)):

> *'The term 'index of suspicion' will be familiar to most doctors. More experienced clinicians will have suffered occasions when they regretted not having paid more attention to marginal items of information, as well as others when they have been almost unexpectedly rewarded for attending to 'weak signals'.'*

HSIB also considered general strategies for reducing diagnostic error. Some of these are considered in the appendix.

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Appendices

Appendix 1: Plain chest X-ray findings in aortic dissection (112)

1. Mediastinal widening
2. Abnormalities in region of aortic knob
    1. Enlargement (expansion of aortic diameter)
    2. Presence of double density (due to enlargement of false lumen)
    3. Irregular contour
    4. Blurred aortic knob (indistinct aortic margin)
3. Displacement of intimal calcium
4. Discrepancy in diameters of ascending and descending aorta
5. Displacement of trachea, left main bronchus, or esophagus
6. Pleural effusion (more common on the left)

Other findings reported include:

- Apical capping, particularly on the left
- Increased thickness of the left and/or right paratracheal stripe
- Opacification of the aorto-pulmonary window (the space between the aortic knuckle and the left pulmonary artery)

The definition of a widened mediastinum is >8.0-8.8 cm at the level of the aortic knob on portable AP chest X-ray, although this upper limit of normal varies (may be significantly larger) depending on projection, focus-to-film distance and X-ray cassette positioning (https://radiopaedia.org/articles/aortic-dissection?lang=gb).

Some examples of X-rays in aortic dissection can be found here (93).

Appendix 2: Normal adult thoracic aortic diameters (19)

Normal Adult Thoracic Aortic Diameters

Thoracic Aorta	Range of Reported Mean (cm)	Reported SD (cm)	Assessment Method
Root (female)	3.50 to 3.72	0.38	CT
Root (male)	3.63 to 3.91	0.38	CT
Ascending (female, male)	2.86	NA	CXR
Mid-descending (female)	2.45 to 2.64	0.31	CT
Mid-descending (male)	2.39 to 2.98	0.31	CT
Diaphragmatic (female)	2.40 to 2.44	0.32	CT
Diaphragmatic (male)	2.43 to 2.69	0.27 to 0.40	CT, arteriography

Notes:

- Factors influencing aortic size include age, gender, body size (height, weight, body surface area) and blood pressure. In healthy adults, aortic diameter does not usually exceed 40 mm, and tapers gradually downstream. Aortic diameters may be indexed to the body surface area, especially for the outliers in body size (24).
- Aortic size can easily be overestimated if measured obliquely.

Appendix 3: Family screening recommendations

Those with thoracic aortic aneurysm > 45mm, or dissection, require family screening in the following circumstances:

- Age at diagnosis < 50 years
- Age at diagnosis 50-60 years, no hypertension, *or*
- Positive family history (see below), *or*
- Syndromic features (see below)

See expert consensus recommendations for further details (113).

Positive family history (2)

'We suggest to define a positive family history as having at least one first- or second-degree relative with:
(1) a thoracic aortic aneurysm or dissection,
(2) an aneurysm or dissection elsewhere in the arterial tree, diagnosed below 60
(3) a left-sided congenital heart defect (e.g. congenital aortic valve stenosis or bicuspid aortic valve) or patent ductus arteriosus, or
(4) sudden death below 45 years of age.'

Syndromic features

Table 6: List of most characteristic or easily recognisable clinical features associated with syndromic forms of thoracic aortic disease (113)

Craniofacial features	Craniosynostosis
	Widely spaced eyes (hypertelorism)
	Cleft palate or bifid uvula
Ocular features	Lens subluxation/dislocation (ectopia lentis)
	Retinal detachment
	High myopia (−6.00 diopters or higher)
	Iris hypoplasia or flocculi
Cardiovascular features	Mitral valve prolapse
	Arterial tortuosity
	Multiple aneurysms or dissections
	Left-sided congenital heart defect or patent ductus arteriosus
Musculoskeletal features	Pectus excavatum or carinatum
	Joint hypermobility or contractures
	Recurrent joint subluxations/dislocations
	Severe, early-onset osteoarthritis
	Severe kyphosis or scoliosis
Cutaneous features	Thin, translucent skin with easily visible veins
	Hyperelastic skin
	Livedo reticularis
	Striae at unusual sites/not related to weight gain
	Atrophic or wide scars
Other features	Short or tall stature
	Disproportionately long limbs (dolichostenomelia)
	Abnormal long and slender fingers (arachnodactyly)
	Spontaneous pneumothorax
	Recurrent abdominal wall hernias
	Spontaneous rupture of internal organs

Appendix 4: Healthcare Safety Investigation Branch *Delayed Recognition of Acute Aortic Dissection* report: 'general strategies for reducing diagnostic error'

'In his book, How Doctors Think, Jerome Groopman describes at least three separate cases of missed AD. He discusses in particular the role of patients and families and how they can help to improve doctor's thinking and decision making by asking specific questions, which are directed at avoiding the three most common errors: anchoring (premature closure/satisficing), availability and attribution:

A. *What else could it be?*
B. *Could there be more than one thing going on to explain my problem?*
C. *Is there anything in the history, examination or test results which seems to be at odds with the working diagnosis?'*

The index case for the HSIB report was a 54-year-old man who developed chest pain whilst weightlifting. The case is well worth reading (2).

HSIB imply that 'availability' and 'anchoring' may have played a role in his delayed, and rapidly fatal, diagnosis of AD. These terms, as well as 'premature closure' and 'satisficing' are also explained below:

- *'**Availability** describes the tendency to judge an event by the ease with which similar examples can be retrieved from memory or constructed anew – or, to use a medical aphorism, 'common things are common'. Knowing that the incident occurred in the gym could increase the likelihood of a connection being made between chest pain and a musculoskeletal origin, or between chest pain and AMI, both diagnoses being much more common than acute AD. However, availability was also helpful in Richard's case, when MSpR's recent memorable encounter with a patient with acute AD led to her quickly considering this as a diagnosis.'*
- *'**Anchoring** occurs when a decision rests on, and remains too heavily influenced by, information acquired early on. Each assessment – by PM2, EDS, EDACP and FY2 - started with observations to the effect that Richard experienced chest pain while exercising in the gym, now had little pain and appeared well. An initial diagnosis of musculoskeletal pain was made by PM2 and this information was passed to the ED staff, at least in the form of a copy of the written ambulance record. In contrast, perhaps insufficient attention was given to the characteristics of the initial pain.'*
- *'**Satisficing** refers to a decision-making strategy which aims to achieve an adequate (rather than optimal) result. It may cause situations where a decision has been reached without sufficient information being sought or considered, described as **premature closure**.'*