Ascending Aortic Dissection, Penetrating Aortic Ulcer, and Intramural Hematoma

9

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Abbreviations

AI	Aortic insufficiency
ARR	Aortic root replacement
ATAAD	Acute type A aortic dissection
AVAR	Aortic valve and aorta replacement
AVR	Aortic valve replacement
BAV	Bicuspid aortic valve
CVA	Cerebrovascular accident
DHCA	Deep hypothermic cardiac arrest
FET	Frozen elephant trunk technique
GERAADA	German Registry for Acute Aortic Dissection Type A
IRAD	Internal Registry of Acute Aortic Dissection
MHCA	Moderate hypothermic cardiac arrest
MI	Myocardial infarction
MPS	Malperfusion syndrome
ND	Neurologic deficit
PE	Pulmonary embolism
SACP	Selective antegrade cerebral perfusion
SCAR	Supracoronary ascending aorta replacement
SCI	Spinal cord injury
STEMI	ST-elevation myocardial infarction
TAR	Total arch replacement
TEE	Transesophageal echocardiogram
TTE	Transthoracic echocardiogram
VSAR	Valve-sparing aorta replacement

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Introduction

Acute aortic dissection has been among the most lethal entities in the medical literature for centuries. In 1760, King George II died suddenly of an aortic dissection. His autopsy report published by Dr. Frank Nicholls in *Philosophical Transactions* of the Royal Society described injury to the ascending aorta resulting in tamponade [1, 2]. More than two hundred years later, Jonathan Larson, creator of the musical *Rent*, died of an aortic dissection after misdiagnosis in two separate emergency departments where he presented with chest pain [3]. Despite advances in imaging and surgical technique, acute aortic dissection, especially dissection of the ascending aorta (type A in the Stanford classification), remains a challenge to recognize and treat swiftly.

Epidemiology, Pathophysiology, and Risk Factors

The incidence of acute type A aortic dissection (ATAAD) is 3.5–6 in 100,000 but increases with age [4]. There is a male predominance and the average age of presentation is 48–67 [4]. Given the rarity of dissection, much of the data and analysis comes from registries, including the Internal Registry of Acute Aortic Dissection (IRAD) and German Registry for Acute Aortic Dissection Type A (GERAADA).

The epidemiology of younger patients with ATAAD differs from that of older patients, with more individuals having genetic conditions including Marfan syndrome (*FBN1*), Loeys-Dietz syndrome (*TGFBR1 and TGFBR2*), Ehlers-Danlos (*COL3A1*), Turner syndrome (*XO* karyotype), and other mutations affecting structural proteins that are not part of known syndromes [5]. In IRAD data, Marfan patients presenting with dissection had a mean age of 35 compared to 64 in non-Marfan patients and comprised 5% of the total group [6]. They were also more likely to present with heart failure, aortic insufficiency, and have a history of aneurysm, but less likely to have hypertension [6]. Bicuspid aortic

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valves, which are associated with or independent from genetic syndromes, increase risk for dissection due to an acquired deficiency of aortic fibrillin, upregulation of matrix metalloproteinases, and death of smooth muscle [7].

Comorbidities associated with ATAAD include those common to other cardiovascular diseases, including hypertension, smoking, chronic kidney disease, chronic obstructive pulmonary disease, and stroke [4]. Less common associated factors include inflammatory conditions such as Takayasu arteritis, giant cell arteritis, Behçet disease, systemic lupus erythematous, and rheumatoid arthritis [8]. There may be an association between fluoroquinolone antibiotic use and acute aortic dissections. Calcium channel blockers have demonstrated increased aneurysm growth and rupture in Marfan mice and this observation has been observed in Marfan and other heritable aortic aneurysm diseases in humans. Furthermore, data supporting the use of angiotensin receptor blockers (ARBs, such as losartan) in Marfan patients is inconsistent.

Classification

Aortic dissection begins as a tear in the intima which is 1–5 cm in length and starts within 10 cm of the aortic valve (Fig. 9.1) [9].

Anatomic classification follows two main schemes, Stanford and DeBakey. Stanford Type A encompasses any dissection involving the ascending aorta, while Type B involves the descending aorta only. DeBakey classifications include Type I (ascending and descending), Type II (ascending only), and Type III (descending only) (Table 9.1) [4].

Limited intimal tears of the aorta (class 3 dissection) can involve either the ascending or the descending aorta. The clinical course is thought to be similar to that of traditional aortic dissections but may be more difficult to assess on imaging.

Prognostication and surgical approach require understanding the extent of dissection. The Penn classification associates mortality with extent of organ system involvement on presentation (Fig. 9.2) [10]. Dissection without branch vessel involvement or circulatory collapse has an in-hospital mortality of 3.1% (*class a*), branch vessel malperfusion with ischemia has a mortality of 25.6% (*class b*), circulatory collapse with or without cardiac involvement has a mortality of 17.6% (*class c*), and combined *b* and *c* has a mortality of 40% (Table 9.2).

Aortic dissection can also be defined temporally, into hyperacute (0–24 hours), acute (2–7 days), subacute (8–30 days), and chronic (>30 days) phases which are associated with increasing mortality from time of symptom onset to management [11].

Diagnosis

Clinical Presentation

Chest pain is present in 79–93% of patients presenting with aortic dissection (Table 9.3) [8, 12]. Hypotension is present in 46% of patients, and it is associated with adverse events including malperfusion, death, ST changes, aortic insufficiency (AI), tamponade, and neurological deficits [13]. Back pain is seen in 47% and hypertension in 36% [8].

Classical physical exam findings in acute aortic dissection include pulse deficit and either narrow or wide pulse pressure. In an examination of IRAD patients with pulse pressure divided into quartiles (narrow, normal, mildly elevated, markedly elevated), narrow pulse pressure was associated with greater hypotension, effusion, and mortality, while widened pressure was associated with a history of hypertension and mesenteric involvement [14]. Contrary to expected results, wider pulse pressure was not associated with a greater degree of AI [14].

Pulse deficit is associated with increased in-hospital mortality neurological deficit, hypotension, shock, and tamponade [15].

Neurological symptoms are seen in up to one third of presenting patients, and can include syncope, seizure, stroke, spinal cord ischemia, hypoxic encephalopathy, and neuropathy [16].

EKG Findings

EKG findings can be used for both diagnosis and prognostication in ATAAD. Coronary involvement can be secondary to actual extension of dissection to the coronaries or can be due to occlusion of ostia by the intimal flap. Classically, dissection is considered when a patient presents with STEMI (ST-elevation myocardial infarction) on EKG, however STE is found in only 4–16% of patients [17, 18]. In a study of 233 patients presenting within 6 hours of symptom onset, 51% had ST-T changes and these patients had a more adverse presentation, including shock, tamponade, severe hypertension, and AI [17].

ST elevation indicates greater likelihood of coronary involvement according to most groups [17, 19, 20]; however one group found no greater coronary involvement when there were ischemic changes [18]. STE in avR specifically is a strong predictor of in-hospital death with an odds ratio of 23.4 [19].

Biomarkers

Biomarkers can be used to favor or exclude a diagnosis of dissection. D-dimer is the degradation product of cross-

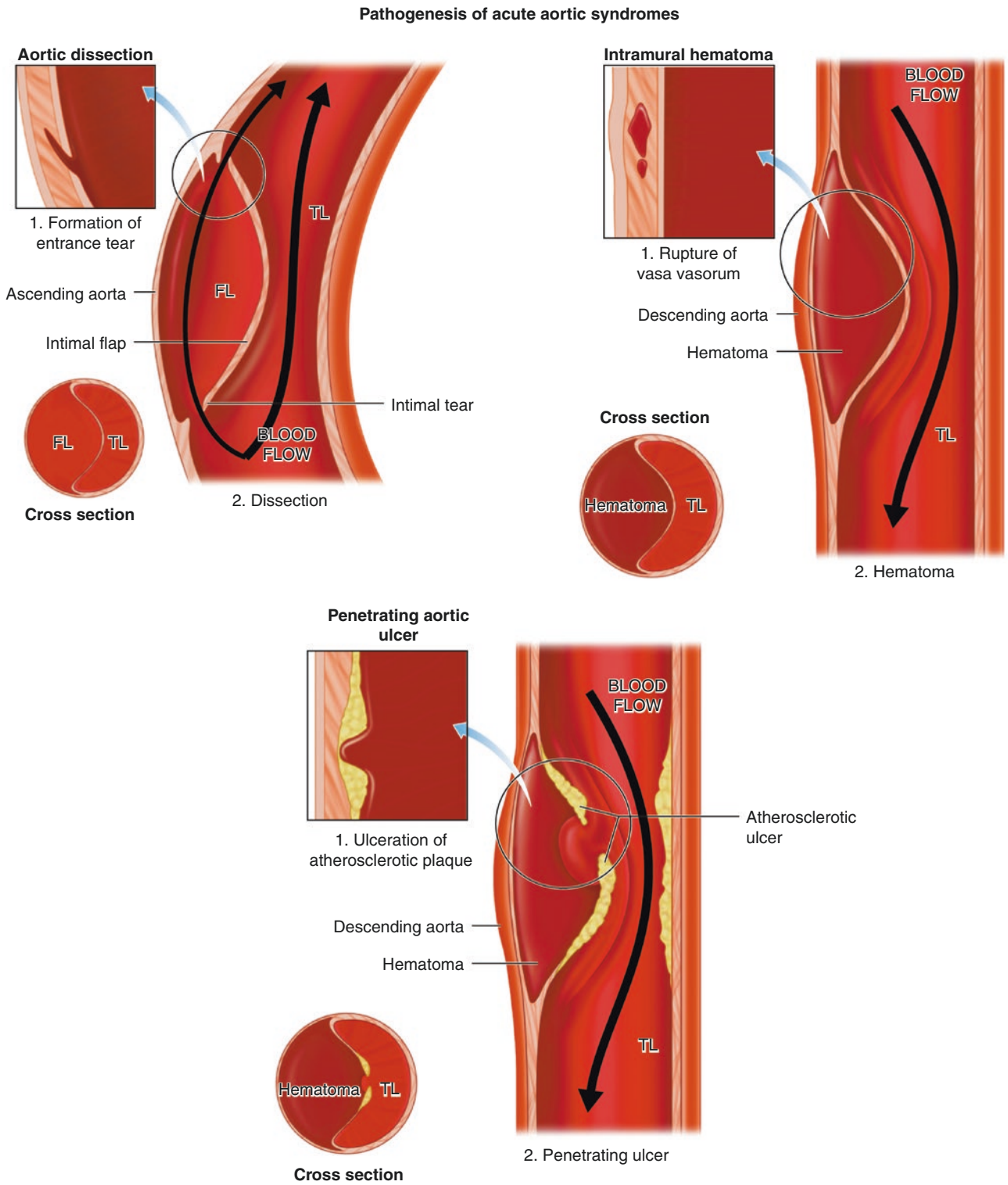

Fig. 9.1 Anatomy of the aorta and pathogenesis of acute aortic syndrome

linked fibrin and is the most widely utilized biomarker in dissection. In a meta-analysis looking at 883 AAD patients versus 1994 non-AAD patients, sensitivity was 95.2% and specificity 60.4% for a value of 500 ng/ml [21]. Short dissection, thrombosed FL, and young age are factors that may cause false negatives [21]. Elevated D-dimer is also an inde-

pendent risk factor for in-hospital mortality but not long-term mortality [22, 23]. In the IRAD Biomarkers study, ATAAD had a higher D-dimer value than other diagnoses such as myocardial infarction (MI) and pulmonary embolism (PE) [24]. Similar to PE, a level of 500 ng/mL can be used to rule out ATAAD with a NLR of 0.07 in the first day [24].

Troponin T may be an independent risk factor for in-hospital mortality, with a value greater than or equal to 0.042 ng/ml having a sensitivity of 70.8% and specificity of 76.4%. In a study of survivors versus non-survivors of ATAAD, pro-BNP had a mean value of 328 pg/ml in survivors, versus 2240 in non-survivors [25].

Other potential biomarkers which are not yet used clinically include fibrillin [5], matrix metalloproteinases [5], smooth muscle proteins [5, 8], and soluble elastin fragment [8].

Imaging

The purpose of imaging in ATAAD is not only to diagnose, but also to identify features that will be needed in downstream management – namely, site of tear, extent of rupture, and branch involvement [26]. The "classic" finding of widened mediastinum on chest x-ray was observed in only

Table 9.1 Classification of acute aortic syndromes

Stanford A (ascending +/− descending aorta)	Stanford B (descending aorta only)
DeBakey I (ascending and descending aorta)	DeBakey III (descending aorta only)
DeBakey II (ascending aorta only)	

Table 9.2 Penn classification of clinical presentation

Clinical presentation	Definition of clinical presentation class
Class a	Clinical presentation characterized by *Absence* of branch vessel malperfusion of circulatory collapse
Class b	Clinical presentation characterized by *Branch* vessel malperfusion with ischemia e.g. stroke; ischemic extremity
Class c	Clinical presentation characterized by *Circulatory* collapse with or without Cardiac involvement
Class b and c	Clinical presentation characterized by both *Branch* vessel malperfusion and *Circulatory* collapse

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Table 9.3 Acute aortic type A dissection presentation

	Frequency of occurrence
Symptoms	
Chest pain	79–93.4% [8, 12]
Back pain	47% [8]
Abrupt onset of pain	87% [13]
Neurological (syncope, seizure, stroke, spinal cord ischemia, hypoxic encephalopathy, neuropathy)	29% [16]
Syncope	16–21.6% [12]
Congestive heart failure	5% [13]
Signs	
Hypotension	29–46% [8, 13]
Hypertension	23.5–36% [8, 12]
Pulse deficit	27–32.5% [12, 13]
AI murmur	45% [8]
EKG findings	
ST-T changes	51% [18]
ST elevation	4–16% [17, 18]

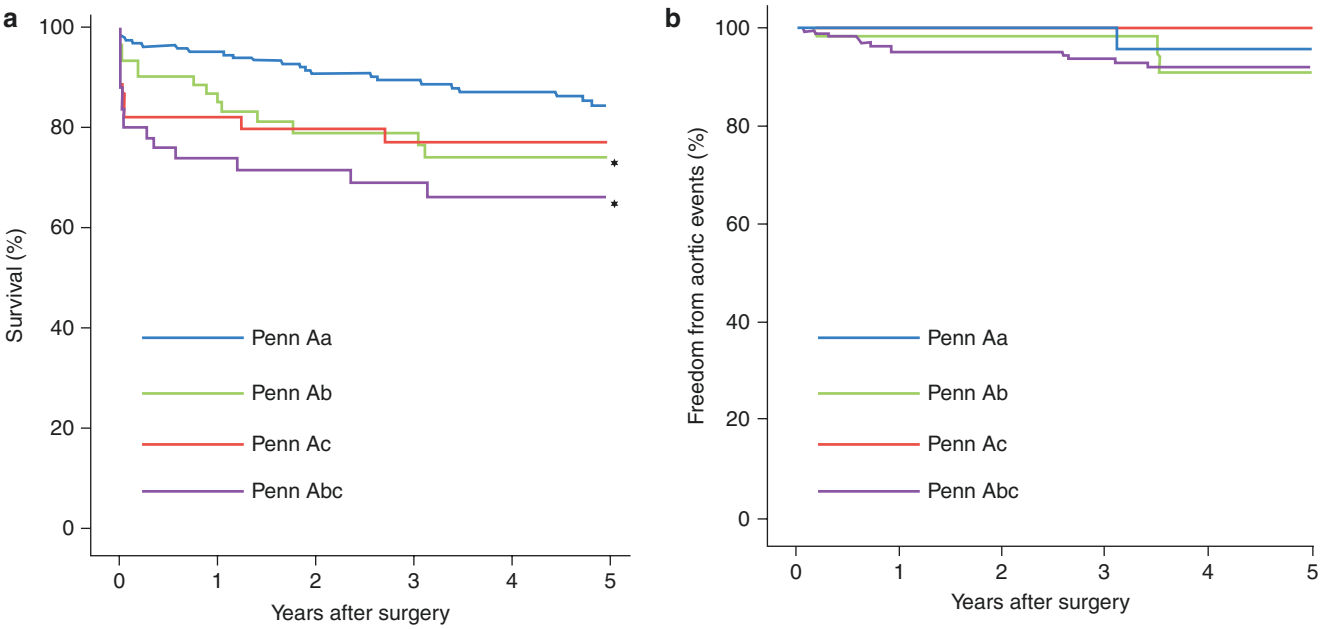

Fig. 9.2 Mortality stratified by Penn Classification (**a**) and freedom from aortic events in patients discharged with acute type A dissection (**b**). (From: Kimura [216]. Reprinted with permission from Elsevier)

37.4% of IRAD patients [27] and does not provide sufficient information for surgical planning.

CAT scan (CT) and transesophageal echocardiogram (TEE) are the most commonly used modalities, with CT having the advantage of wide availability and operator-independence [26]. During 17 years of data assessed by IRAD, CT use increased from 46% to 73% [12]. One downside to CT is that aortic flow may cause imaging artifact and be confused with a false lumen [26], but this can be minimized by using ECG-gating [28]. Features to look for include a double barrel lumen, entry tear, dilated aorta, and displaced aortic calcification [28] (Fig. 9.3). In one retrospective study, the presence of

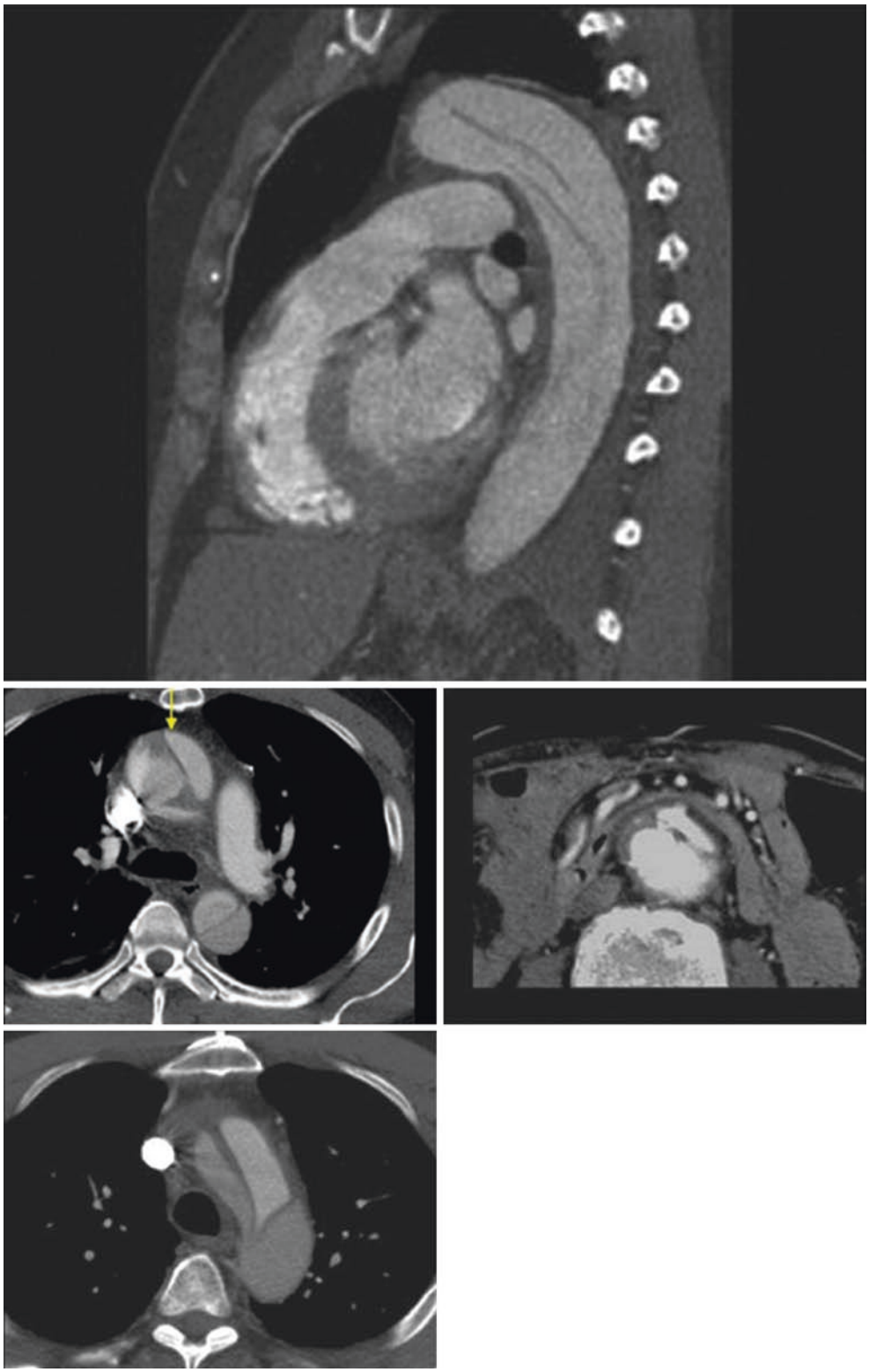

Fig. 9.3 Aortic dissection visualized on CT scan. (Images courtesy of Dr. TSA Geertsma, Ziekenhuis Gelderse Vallei, Ede, The Netherlands. Source: http://www.ultrasoundcases.info/)

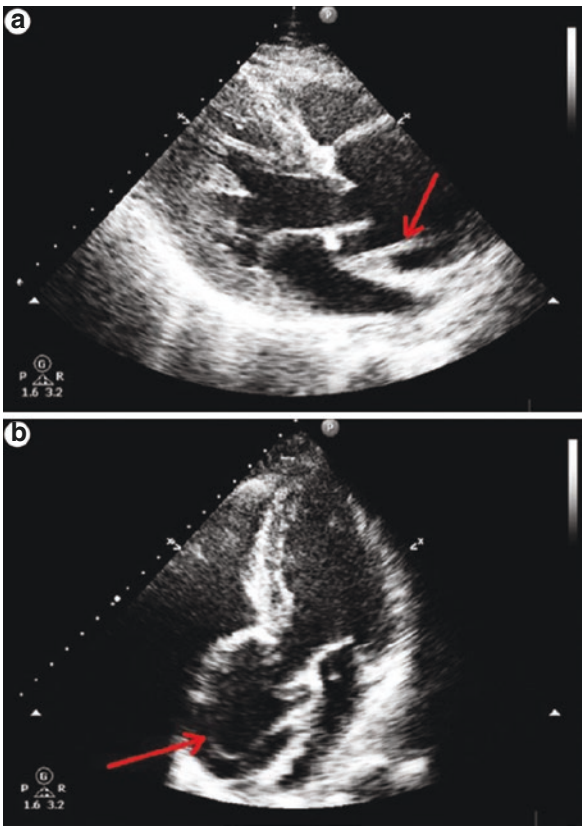

Fig. 9.4 TTE (level or aortic valve) shows tear in aortic root. (**a**) Parasternal long axis view. (**b**) Apical five-chamber view. (From Sobczyk and Nycz [217]. Open Access: © Sobczyk and Nycz; licensee BioMed Central. 2015)

a pericardial effusion and dilated ascending aorta were predictive of tear in the ascending aorta, whereas a non-thrombosed false lumen in the descending aorta predicted presence of a tear distal to the arch [29]. CT has a sensitivity and specificity of nearly 100% [30].

Transthoracic echocardiogram (TTE) (Fig. 9.4), while useful for assessing aortic insufficiency, dilatation, and effusion, has a low negative predictive value [31] and a sensitivity and specificity of 87% and 91%, respectively [28]. TEE (Fig. 9.5) is a mobile imaging modality that has strength in assessing effusion size and coronary involvement, but is less able to identify branch vessel involvement [26]. The test is operator-dependent, semi-invasive [26], and susceptible to motion artifact from reverberations off the anterior wall of the left atrium [31]. The presence of a patent false lumen on TEE is a poor prognostic factor [32]. Sensitivity for Type A dissection has been calculated at 96.8% and specificity 100% [28].

MR (Fig. 9.6) has a sensitivity of 95–100% [30] but is less widely available than other modalities, takes longer, and compromises access to patients with a life-threatening condition [33].

The responsibility of diagnosis in ATAAD typically falls on the emergency department. In a recent retrospective review of ATAAD cases, focused point-of-care cardiac ultrasound by an emergency department physician had a median diagnosis of 80 minutes versus 226 minutes in those who did not received focused ultrasound [34].

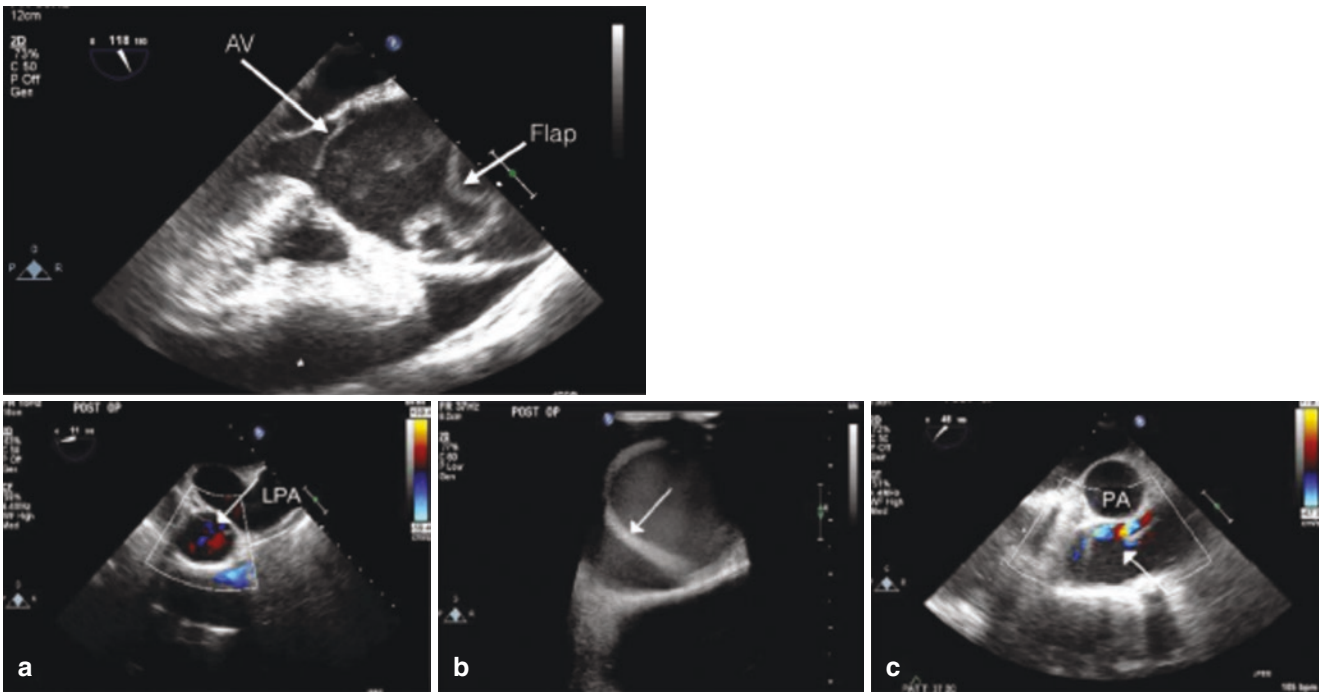

Fig. 9.5 (Row 1) Transesophageal echo long-axis view showing dissection flap (arrow) in ascending aorta. Asterisk indicates presence of hemopericadium. (Row 2) Ascending dissection shown in short-axis view (**a**), epiaortic view (**b**), and long-axis view (**c**). (Images reprinted from MacKnight et al. [26] with permission from Elsevier)

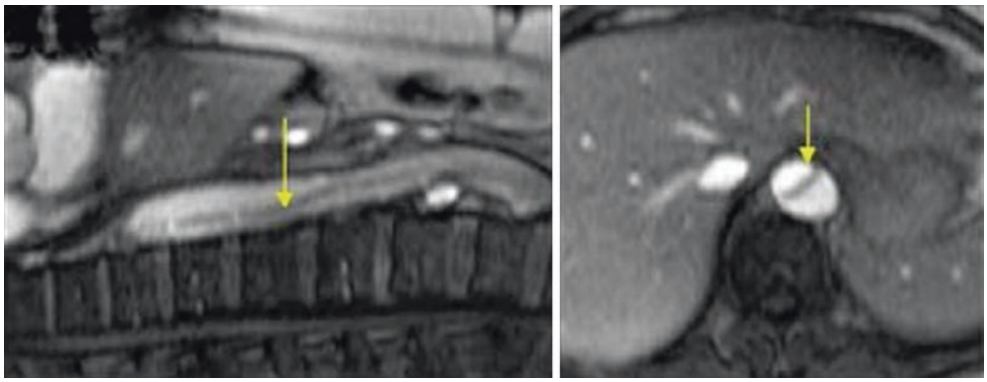

Fig. 9.6 MRI views (longitudinal, left and transverse, right) of intimal dissection. (Images courtesy of Dr. TSA Geertsma, Ziekenhuis Gelderse Vallei, Ede, The Netherlands. Source: http://www.ultrasoundcases.info/)

Diagnostic Error

Recognition of ATAAD in the face of more common chest pain syndromes is a priority in reducing mortality. Incorrect anchoring onto alternate diagnoses such as acute coronary syndrome may not only delay diagnosis, but may lead to harmful management such as use of antiplatelet or antithrombotic agents [35]. In one review of 127 patients with type A dissection, inappropriate initial diagnosis was made in 37% of cases and the median time to final diagnosis was 1.5 hours [36]. Diagnosis was further delayed in patients who had walked in and had coronary malperfusion [36].

Others have found much longer median time to diagnosis of 3–4.3 hours [37, 38]. IRAD data found that risk factors for delayed recognition include female sex, atypical pain, lack of hypotension, presentation to a non-tertiary facility, and presence of fever [37].

Diagnostic pitfalls may also be related to radiology interpretation. Chest x-ray is normal in 20–37.4% of patients [27, 39] and abnormalities on CT may be subtle, including displacement of aortic calcification or increased intimal attenuation due to thrombosis of the false lumen [39].

Management of Acute Type A Aortic Dissection

Type A aortic dissection is highly lethal, with mortality reaching 1–2% for every hour without surgical intervention [40, 41]. The guiding principles of acute type A aortic dissection management involve prompt recognition, transfer to intensive care for monitoring, and immediate impulse control – specifically reduction in heart rate, blood pressure, and LV ejection force, or *dp/dt* [40]. While patients are being evaluated for surgical intervention, or if they are deemed non-operable candidates, impulse control is achieved through the use of vasodilators, beta blockers, and calcium channel blockers. Arterial vasodilators, such as hydralazine, are relatively contraindicated as they may cause reflex tachycardia [42]. Adequate volume resuscitation and pain control should also be used to maintain a systolic blood pressure goal of 100–120 mm Hg [40].

Medical-Only Approach

Although type A aortic dissection is typically managed by immediate surgery, medical management alone is sometimes indicated. Indications for medical management alone may include stroke, severe comorbidities, prior aortic valve replacement (AVR), and late presentation more than 48–72 hours after dissection [40].

Heparinization of patients for bypass and the return of blood flow to infarcted areas of brain tissue in completed stroke are risk factors for hemorrhagic conversion [40, 43]. Therefore when stroke has been completed, risks of surgery may outweigh benefits, though the risk may be acceptable in evolving stroke [40]. A short series of four patients found that intentional delay in stroke patients before aortic surgery had beneficial outcomes [44]. On the other hand, recent data evaluating a more aggressive approach to patients with neurological injury did not show any cases of hemorrhagic conversion after anticoagulation for bypass [45].

Advanced age also increases risk for death, and outcomes in geriatric patients are described later. Age alone is not an absolute contraindication to surgery. Late presentation patients have survived the most dangerous window of dissection and can more safely undergo scheduled surgery. Previous AVR also allows delayed time until surgery, given lower likelihood that the patient will develop severe aortic insufficiency, protection of the right coronary artery from the prior graft placement, and lower risk of aortic rupture due to periaortic adhesions [40].

Centofanti et al., in a retrospective review, developed a risk equation to determine if operative benefit outweighed risk. Risk factors for mortality included age, coma, renal failure, shock, and reoperation. They found that in patients with mortality less than or equal to 58%, surgery was always beneficial [46].

Severe neurological deficit (ND), especially coma, has historically been a relative contraindication to surgery. Surgeons have become increasingly liberal when operating

on patients with neurological deficits and outcomes may be improving in this group. At one center, 8-year experience with a range of ND from comatose state to focal deficit underwent surgery, with over 50% of patients showing complete recovery. An elevated preoperative modified Rankin scale score was associated with persistent deficits [47], but even some patients with comatose state showed partial or full recovery. Notably, few comatose patients underwent surgery in this group [47]. In another recent single-center study of 24 comatose patients who underwent surgery, in-hospital mortality was similar to that of non-comatose patients, and long-term mortality was 60.3% at 5 years and 48.3% at 10 years [45]. Furthermore, Di Eusanio and colleagues published IRAD data showing that medical management alone was performed in 33.3% of coma and 24.1% of cerebrovascular accident (CVA) patients, and higher in-hospital mortality was observed in both groups compared to patients without ND. However, in those patients with ND who underwent surgical management, mortality was significantly less than in the medical management group. CVA patients had 76.2% mortality in the medical vs. 27% in the surgical group, while the coma patients strikingly had 100% mortality in the medical group vs. 44.4% in the surgical group [48]. Therefore, recent trends in management of severe neurological injury patients may begin to favor aggressive management.

Surgical Approach

Surgical repair is the mainstay of acute type A aortic dissection treatment, yet the optimal approach to surgery remains unknown. Diverse options include the extent of repair to be attempted, use of hybrid endovascular modalities, cannulation site, and cerebral perfusion strategy (Fig. 9.7).

Survival in type A aortic dissection is improved when performed by specialized aortic surgeons, rather than general cardiac surgeons. In a German study of 162 consecutive patients who underwent ATAAD surgery with a dedicated aortic team compared to a general cardiac surgery team, in-hospital mortality was 4% versus 21.8%, though surgical techniques were variable among the groups [49]. Other environmental factors which may improve outcomes include the development of an aortic dissection protocol [50] and performance of surgery at a teaching hospital [51] or a high volume center [51].

Extent of Repair and Risk of Reoperation

The over riding goal of aortic repair during type A dissection is to leave the operating room with a living patient. Repair typically involves excision of the primary entry tear in order to avoid extension of the dissection, prevent aortic rupture, and restore flow to the true lumen while obliterating the false lumen [41, 52]. As surgical techniques and outcomes have improved, the extent of repair has become open to debate, with the hope of not simply stabilizing the patient but also reducing the need for downstream intervention. Surgery may involve replacement of ascending aorta with a synthetic vascular graft and proximal arch repair only, versus extensive repair including the total arch, descending aorta, and/or root.

While proximal reoperations are most related to the degree of postoperative aortic insufficiency [53], distal reoperations are most often due to distal aneurysmal disease. At the Cleveland Clinic, 305 type A patients required 429 distal interventions during 3.8 years follow-up. The study's authors argued for more extensive repair in appropriate patients at the time of initial intervention [54]. Others have found that the descending aorta diameter grows at a rate of 1 mm/year after repair, with a risk of reoperation of 16% at 10 years [55]. In addition to distal aortic diameter, residual patency of the false lumen is predictive of late outcomes [55, 56].

Total Arch Replacement

Total arch replacement (TAR), as compared to hemiarch repair, is indicated in aneurysmal disease greater than 5 cm, arch rupture, and complex arch tear [57]. In studies comparing TAR outcomes to limited proximal repair, there was similar earlier mortality [57, 58], stroke [57], and reintervention rate [59, 60]. In most [61, 62] but not all [60, 63] studies, TAR led to increased thrombosis of the false lumen compared to hemiarch repair. In GERAADA, immediate postoperative complications such as bleeding were higher in TAR, but 30-day outcomes showed no difference compared to conservative arch repair [64]. However, one group of 188 patients, 44 with TAR, found greater risk of death and permanent neurologic injury with TAR [60].

Arch tears are uncommon and have not been extensively studied. In one center's study of 106 patients with ATAAD, 16 had arch tears and preoperative tamponade was a predictor of mortality. The rate of stroke was 6.6% and that of temporary neurologic dysfunction was 20% [65]. In another group of patients with 88 arch tears, in-hospital mortality was significantly higher for those undergoing TAR, and the authors recommended performing hemiarch repair only if the tear was limited to the lesser curvature [66].

Frozen Elephant Trunk Technique

Attempts to treat and prevent future distal aneurysmal disease at the time of ATAAD surgery has led to the increasing prevalence of graft placement in the thoracic aorta. The classic elephant trunk technique was first described by Borst in 1983 in which the arch replacement prosthesis is connected to an "elephant-trunk" piece which reaches into the distal aorta and allows a landing site for future repairs [67]. The frozen elephant trunk technique is a newer method that uses

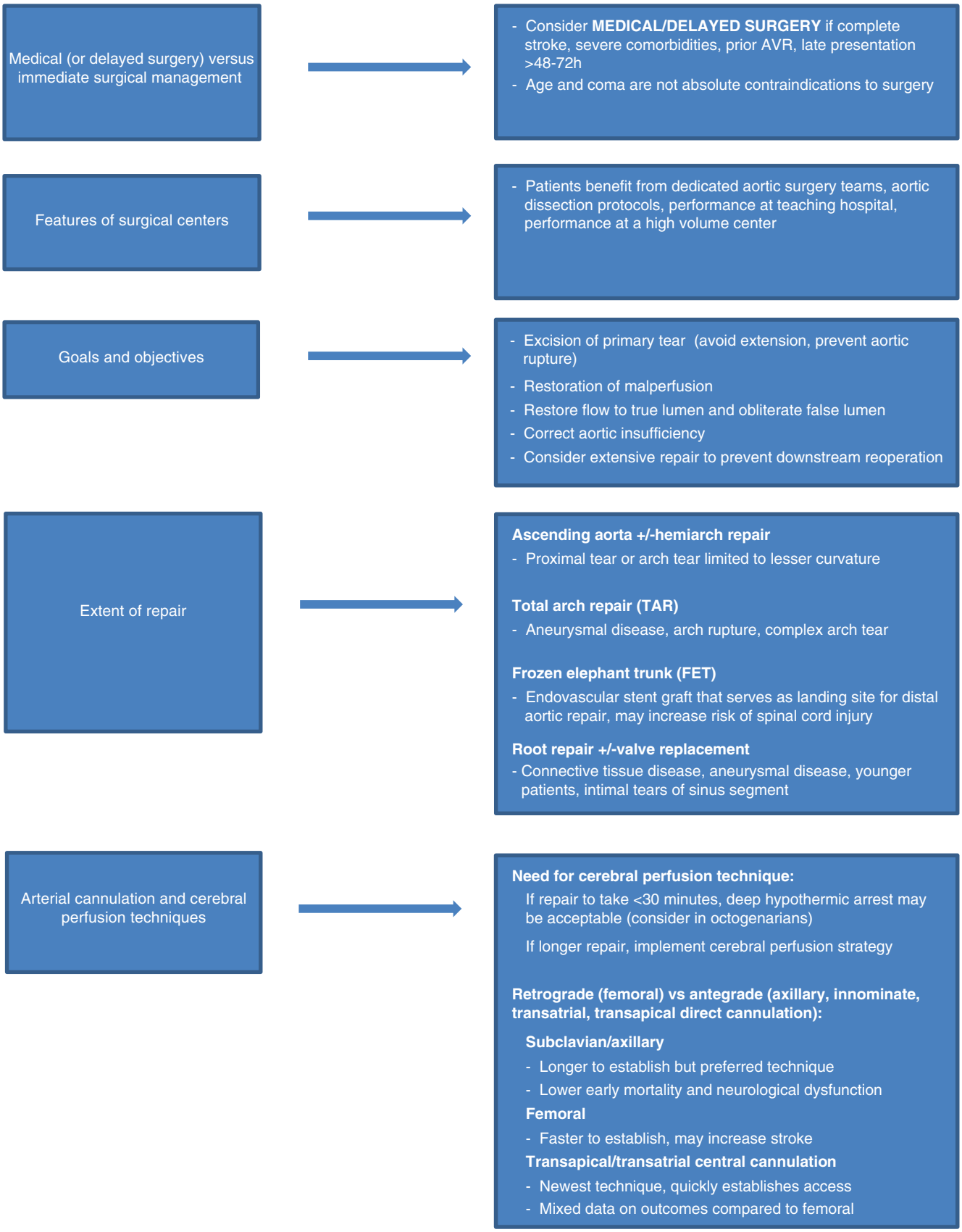

Fig. 9.7 Management algorithm for ATAAD. (Data from Dougenis [218])

an endovascular stent-graft connected to the arch graft, allowing a single-stage distal aortic repair [41, 67].

FET has enjoyed mainly positive findings, leading to a surge in its popularity. It is often described as the "new standard" for ATAAD surgery [68]. Numerous centers have found that FET either decreases or has low rates of reintervention on the distal aorta [62, 69–71]. In one analysis of 197 patients, thrombosis of the false lumen was found in all of the patients in the TAR + FET group and only 24.6% of the limited repair group ($p < 0.001$) [62].

Two meta-analyses have assessed FET outcomes. An analysis of eleven observational studies including 881 patients found acceptable in-hospital mortality at 8%, neurological outcomes of stroke 4%, and spinal cord injury (SCI) of 3% [72]. While some centers have found that FET decreases mortality [73], others have found similar in-hospital mortality to the classic ET [62, 74]. In another analysis of nine studies looking at 1872 patients comparing proximal aortic repair (ascending aorta repair +/− hemiarch) and extensive aortic repair (replacement of ascending aorta and aortic arch + elephant trunk implantation in descending aorta), hemiarch replacement had a lower early mortality than TAR. Proximal repair, however, was associated with a higher incidence of long-term aortic events such as reoperation. The long-term mortality was similar in both approaches [75].

Concerns about FET revolve around feared neurological complications, including SCI. FET requires longer bypass and surgical times, and the placement of endovascular stents increases the risk of SCI. While conventional elephant trunk surgery has a low rate of SCI, FET has ranged from 4% to 22% in patients undergoing acute repair [74, 76–78]. Additionally, a comparison of hemiarch + FET compared to TAR + FET showed similar mortality but fewer transient neurologic deficits in the hemiarch group [79].

Root

Root repair and valve replacement are another source of debate in the extent of surgery performed for acute dissection. Options for repair include a Bentall procedure with biological or mechanical aortic root replacement (ARR), or valve-sparing surgery such as the David procedure. In patients for whom the root is involved, a root-sparing technique had lower mortality compared to valve replacement (1.9 vs. 12.5%) in a group of 86 patients [80] but was similar in numerous other studies [81–87]. The greatest benefit for ARR is in patients with connective tissue disease [82, 87–89], aneurysmal disease [88, 90], younger age [89], and intimal tears of the sinus segment [88, 91].

Bicuspid and Marfan Patients

Acute type A aortic dissection occurs approximately 20 years earlier in patients with Marfan Syndrome than without, and repair for ATAAD accounts for 16–35% of aortic procedures performed in this population. Though in-hospital mortality for these patients was low in a retrospective study of repair for AATAD in Marfan Syndrome at tertiary care centers in the United States and Europe, they recommend root replacement in these patients [92].

Bicuspid aortic valve (BAV) patients who present with type A dissection are younger, have more aortic insufficiency, and have larger ascending aortic diameters than do tricuspid valve patients. Root repair is required six times more often in BAV patients [93].

Temperature and Cerebral Perfusion Technique

The German Registry for Acute Aortic Dissection Type A found that hypothermic circulatory arrest alone was appropriate if the repair could take less than 30 minutes, but once it exceeded this time limit, mortality increased three-fold. This suggests that a cerebral perfusion strategy should be implemented during more complex procedures [94].

Retrograde cerebral perfusion was one of the first adjunctive techniques introduced [95], which utilized perfusion via the SVC but could result in cerebral edema [96]. The more common adjunct now used is selective antegrade cerebral perfusion (SACP), which can be unilateral or bilateral, and involves cannulation of the head and neck vessels [94]. Antegrade technique has shown similar [97, 98] or more favorable [99, 100] outcomes compared to retrograde perfusion.

Recently, moderate levels of hypothermia >24C have been used successfully along with antegrade or retrograde cerebral perfusion methods [101]. One study of patients who underwent repair at Emory from 2004 to 2014 found similar outcomes in patients who underwent deep and moderate hypothermic circulatory arrest, with no significant difference in stroke or dialysis-dependent renal failure [102]. Moderate hypothermia may allow for a decrease in bypass time as compared to that with deep hypothermia protocols [103]. Another recent study of ATAAD repair found that there was no additional benefit of using deep hypothermic cardiac arrest (DHCA) compared to moderate hypothermic cardiac arrest (MHCA) when SACP was used [102].

Cannulation Strategy

Arterial cannulation is necessary for cardiopulmonary bypass during ATAAD surgery and can be performed in a retrograde (femoral) or antegrade (axillary, innominate, transatrial, and transapical direct cannulation of the aorta) fashion [104]. In two meta-analyses, axillary cannulation showed lower early mortality and neurological dysfunction than did femoral cannulation [105, 106]. Similarly, a best evidence topic found that femoral artery cannulation mortality and stroke occurred at rates of 6.5–40% and 3–17%, com-

pared to axillary rates of 3–8.6% and 1.75–4% [107]. The main downside to femoral access is that retrograde flow is thought to cause reverse embolization through pressure in an atheromatous descending aorta [105].

While axillary cannulation takes longer than femoral access to establish [105], central cannulation can be quickly achieved in order to establish circulatory arrest [108–110]. Some groups have found that stroke and overall mortality were lower in transatrial cannulation compared to femoral [104]. Others found no mortality or stroke reduction when comparing central cannulation to femoral cannulation [108, 109, 111]. Outcomes such as respiratory failure have mixed data, with some showing more respiratory failure with central cannulation [112], while others show shorter intubation times [113].

Outcomes

Mortality

In-hospital and long-term mortality for ATAAD remain elevated but have been improving over the last few decades [114, 115]. In type A patients who underwent surgical repair in the National Inpatient Sample, mortality decreased from 20.5% in 2003 to 14.8% in 2012 [115]. Others have found early mortality rates of 16.9–25.7% [116, 117], with predictors of in-hospital mortality including comatose state, number of malperfused organs, older age, and need for cardiopulmonary resuscitation [117, 118].

Prior cardiac surgery is also associated with significantly higher in-hospital mortality compared to patients without prior cardiac surgery, with rates varying from one third [119], to double [120], or almost triple [121] those without prior cardiac surgery.

In a multicenter Italian study spanning 33 years of follow-up, survival was 95.3% at 5 years, 92.8% at 10 years, and 52.8 at 20 years [116].

Malperfusion: Complicated and Uncomplicated Dissection

Malperfusion is a dreaded complication that can occur preoperatively, intraoperatively, or postoperatively and is associated with both perioperative and long-term mortality. Perfusion defects result when aortic side branches are compromised and can be classified as static or dynamic. Dynamic refers to malperfusion that occurs from the intimal flap decreasing blood flow to vital organ systems; restoring blood flow via the true lumen will therefore reinstate perfusion [122]. Static malperfusion syndromes (MPS) are the result of stenosis, thrombosis, or dissected artery [52]. Approximately one third of patients with ATAAD present with a malperfusion syndrome [123–126].

In a study of GERAADA patients ($n = 2137$), there was a linear correlation between the number of malperfused organs and increase of mortality of 10% [127]. Given this dramatic worsening of outcome with malperfusion, the authors argued for classifying dissection as either complicated or uncomplicated based on the presence of malperfusion. In the postoperative period, cerebral malperfusion was seen in 6.8% of patients, renal 6.8%, visceral 6.8%, peripheral 3.3%, coronary in 1.9%, and spinal 1.1%.

Complicated dissection is associated with worse survival, with patients at the University of Michigan showing median survival of 54 months if complicated versus 96 months if uncomplicated [122]. Similarly, Olsson et al. found that Penn class at presentation corresponds to mortality [128]. Other poor outcomes of complicated dissection include coma, MI, sepsis, delirium, renal failure [129], and prolonged ICU stay [124]. One look at quality of life in patients who presented with MPS found no difference from non-MPS patients, except in the case of CNS malperfusion [130].

Mesenteric ischemia has high morbidity and mortality, with 3.7% of IRAD patients showing mesenteric malperfusion on presentation. These patients showed significantly greater mortality than those without mesenteric malperfusion (62.3% vs. 23.8%) and were more likely to show malperfusion in additional organ systems including coma and renal failure [131]. Others have shown mortality that is as high as 75% [124]. Some case reports argue for addressing the mesenteric ischemia first during repair [132, 133].

In 502 patients from the Emilia-Romagna Regional Registry, 20.5% of patients presented with malperfusion, and had higher in-hospital mortality than did the non-malperfusion group (43.7% vs. 15%, $p = 0.001$). Like in the GERAADA data, multiple organ systems were associated with worse survival – single-organ malperfusion had a mortality rate of 34.7%, two systems 61.9%, and more than two 85.7% [123].

Patel et al. looked at delaying aortic repair in patients who have MPS, given a lower likelihood of surviving aortic repair. They found that patients who did survive to the aortic repair had similar mortality to those with uncomplicated dissection [125]. In a study that combined both type A and B dissections, patients with MPS had triple the operative mortality compared to uncomplicated patients [134].

Shiya et al. proposed techniques for addressing complicated dissection by system – CABG for coronary malperfusion, SCP for cerebral malperfusion, CA and SMA bypass in visceral malperfusion, and fem-fem bypass in unilateral lower extremity malperfusion [135]. Coronary malperfusion is found in 6–15% [41, 136, 137] of patients and most often compromises the right coronary artery [41].

Independent predictors for both neurologic injury and postoperative renal failure include age, prolonged cross-clamping time, and longer cerebral perfusion times. Renal failure is also predicted by preexisting renal impairment [138].

Age

Whether or not to perform surgery in older patients, who frequently have more comorbidities than younger counterparts, has been the source of debate. In patients of all ages, hemodynamic instability is predictive of poor outcomes [139].

While greater extent of repair has overall become the trend in ATAAD surgery, many centers have focused on limited repair to just the ascending aorta or hemiarch to allow for shorter surgical times in octogenarians [140–143]. Extension of the dissection into the supraaortic vessels and down to the abdominal aorta actually decreases with age [144], however if arch surgery is needed, it may be a predictor of mortality [145]. The elderly may have a non-significant trend toward more tamponade and intubation at the time of surgery [146]. A "less invasive quick replacement" technique involving no cerebral protection strategy and rapid rewarming shortened surgical times [147] and decreased mortality [148].

GERAADA found that septuagenarians had an early mortality rate of 15.8%, which was similar to the entire registry's 30-day mortality of 16.9%. Octogenarians, however, had more than double the early mortality at 34.9% [149]. Most others have found similar high perioperative mortality [142, 145, 150–152] though a few reports have found comparable in-hospital mortality to younger patients [153–155]. In IRAD, patients from 70 up to 80 had significantly decreased in-hospital mortality with surgical compared to medical management, whereas 80–90 year olds had decreased mortality with surgery (37.9% vs. 55.2%), but it failed to reach significance [156].

Discrepancies in mortality are also seen in longer term outcomes in the elderly. One year survival is 53.3–82% compared to generally more than 90% in younger patients, and five-year mortality 42.6–76% [140, 142, 157, 158]. Successful ATAAD surgery has been performed in a nonagenarian [159].

Generally, surgical treatment in the elderly is recommended given higher but acceptable perioperative mortality compared to medical management only [160]. One study found higher rates of neurological complications in the elderly which trended down with SACP [161] and others have found no significant difference in temporary neurologic dysfunction when SACP was used [162]. However, further study is needed to determine long-term outcomes, with some centers finding a decreased ability to live independently [158] while others found higher emotional well-being scores compared to younger patients [154].

On a study of root replacement in octogenarians, only some of whom had type A dissection, in-hospital mortality was similar to that in younger patients but there was greater postoperative atrial fibrillation [163].

Young patients between ages twenty and forty have lower mortality, ranging from 11% to 14% at 30 days, with mortality rising with age [144, 164]. Etiology of dissection in the young includes bicuspid aortic valve, connective tissue disease, cocaine use, and severe hypertension [164] and reoperations at the root were needed in 40% of patients [164]. These patients typically have larger aortic diameters than older patients [165]. Neurological outcomes in GERAADA did not differ among age groups [144].

Race

Little data is available on outcomes by race in acute aortic dissection. IRAD compared black and white patients, and found that the black cohort had significantly more HTN, DM, and cocaine use. They more often presented with abdominal pain and LVH on echocardiogram. Despite differences in presentation and risk factors, in-hospital and 3-year mortality between groups were similar [166].

Sex

Presenting characteristics for men and women differ in ATAAD, but whether there is a true difference in outcomes is unknown. Women experience type A dissection less frequently than do men, and therefore, fewer women are represented in registries and trial data. In 2004, IRAD included 32.1% women and showed that women presented for ATAAD at an older age than did men [167], with additional studies showing the age range for men 58–59.7 and women 67–71.5 [168, 169]. Women were more likely to present with coma, altered mental status, hypotension, and tamponade [167].

Early data showed that women had higher in-hospital mortality even after adjusting for age [167], however more recent data showed similar early and late mortality between sexes [168, 169]. One trial showed different findings, with more neurologic deficits in men and greater mortality in women [170]. Interestingly, surgeons' approaches to women may differ than approaches to men in surgical technique. In an analysis where women were an average age of 71.5 compared to 59.7 in men, women had less extensive surgery (less TAR and root surgery) and shorter surgical times. The difference in approach may be attributed to the older age at presentation of women, a finding that warrants further investigation [171].

Women are also less likely to be discharged on beta blockers than men, though not significantly [168].

The pathophysiology that explains sex-based differences is unclear. A study of aortic geometry throughout life in

patients without aortic pathology showed that women have smaller aortic dimensions at younger ages, but their aortic dimensions increase at a faster rate than men's rates [172]. When indexed by body-surface area (BSA), women's ascending aortic length increased by 2.9% per decade compared to 2.5% in men, and aortic diameter increased 3.4% in women compared to 2.6% in men. At older ages, women had higher BSA-adjusted aortic diameters than men [172].

Pregnancy

Type A dissection is rare in pregnancy but accounts for more than three-quarters of dissections that occurs in pregnant patients and has a maternal mortality of 21% [173]. The pathophysiology of pregnancy, including increased estrogen binding to aortic wall estrogen receptors and increase in cardiac output, elevates wall stress and can bring about dissection in those already at risk [173]. The third trimester, when intravascular volume has increased and hemodynamic effects of pregnancy are greatest, is when most dissections occur [174]. Marfan syndrome is associated with more than half the associated cases in the literature [173]. In a review of 75 cases of dissection in pregnancy, fetal mortality was reduced if C-section was performed concomitantly with aortic repair [173]. Current recommendations for dissection follow general guidance of cardiac surgery in pregnancy, suggesting maintaining a MAP > 70 mmHg and avoiding deep hypothermic arrest [174].

LV Function

While mortality is the major outcome of concern after type A dissection repair, long-term outcomes such as LV function have been studied. In a study of 97 patients who underwent valve-sparing aorta replacement (VSAR), supracoronary ascending aorta replacement (SCAR), and aortic valve and aorta replacement (AVAR), aortic regurgitation was greater in those who underwent only partial repairs compared to AVAR. Although immediate postoperative LV function was similar among surgical techniques, the SCAR group showed late adverse LV remodeling [175].

Iatrogenic Dissection

Iatrogenic aortic dissection is an uncommon but real complication during coronary procedures and cardiac surgery. It occurs in <0.1% of patients who undergo coronary angiography(176–178), most often when trying to engage a coronary artery, and generally has favorable outcomes despite the use of antithrombotics and antiplatelet agents [176]. Retrograde dissections typically self-sealed, while anterograde with an entry point at a coronary artery could be sealed with a stent [176]. The incidence of dissection during cardiac surgery is more common, ranging from 0.06% to 0.29% of cases [177–179] with mortality as high as 40% [179]. One group suggested that intraoperative TEE may be responsible for their observed decrease in iatrogenic dissection over time [179].

Follow-Up

In patients who survive ATAAD, serial imaging is recommended at 1 month, 3 months, 6 months, 12 months, and annually if no concerning features are found [5].

Hypertension control is the main parameter monitored in the follow-up period, with lower blood pressure and beta-blocker use associated with freedom from reoperation [180]. In one analysis of ATAAD patients, freedom from reoperation was 99%, 82%, and 79% at 1, 5, and 10 years respectively [181]. Proximal risk factors for reoperation included the use of glue and root preservation, while distal reoperation was more likely with a patent false lumen [181]. Others found that a patent false lumen was associated with significantly greater growth rate of the aorta, but this growth did not translate into higher distal reoperation rate [182]. Another group found that late reoperation wad predicted by a non-resected primary tear, Marfan syndrome, lack of beta-blocker use, and persistent hypertension [183].

Limited data is available on quality of life and changes in lifestyle after dissection. One study of survivors, which acknowledges recall bias, surveyed 82 out of 197 patients, over half of whom had ATAAD, a median of 7 years after discharge [184]. More patients said that they exercised than pre-dissection, which corresponded to lower blood pressures than those who did not exercise. While before dissection 38% of patients lifted for their occupation, only 3% (one patient) lifted afterwards [184]. Seventy-six percent of patients felt that dissection had negatively impacted their lives, due to burden of doctor visits, number of medications, activity limitations, fear, and impact on sex life. About one third self-reported depression and one third anxiety [184].

Intramural Hematoma (IMH)

Epidemiology and Presentation

IMH is an acute aortic syndrome that occurs when blood from the vasa vasorum infiltrates the medial layer [185], but there is no intimal tear and the hemorrhage does not communicate with the lumen (Fig. 9.8) [5]. Blood pools close to the adventitial layer [186] which increases the risk of tamponade [187]. IMH is classified into type A and type B like dissection, with type A having greater mortality [4] but type B comprising the majority (50–85%) of cases [187, 188].

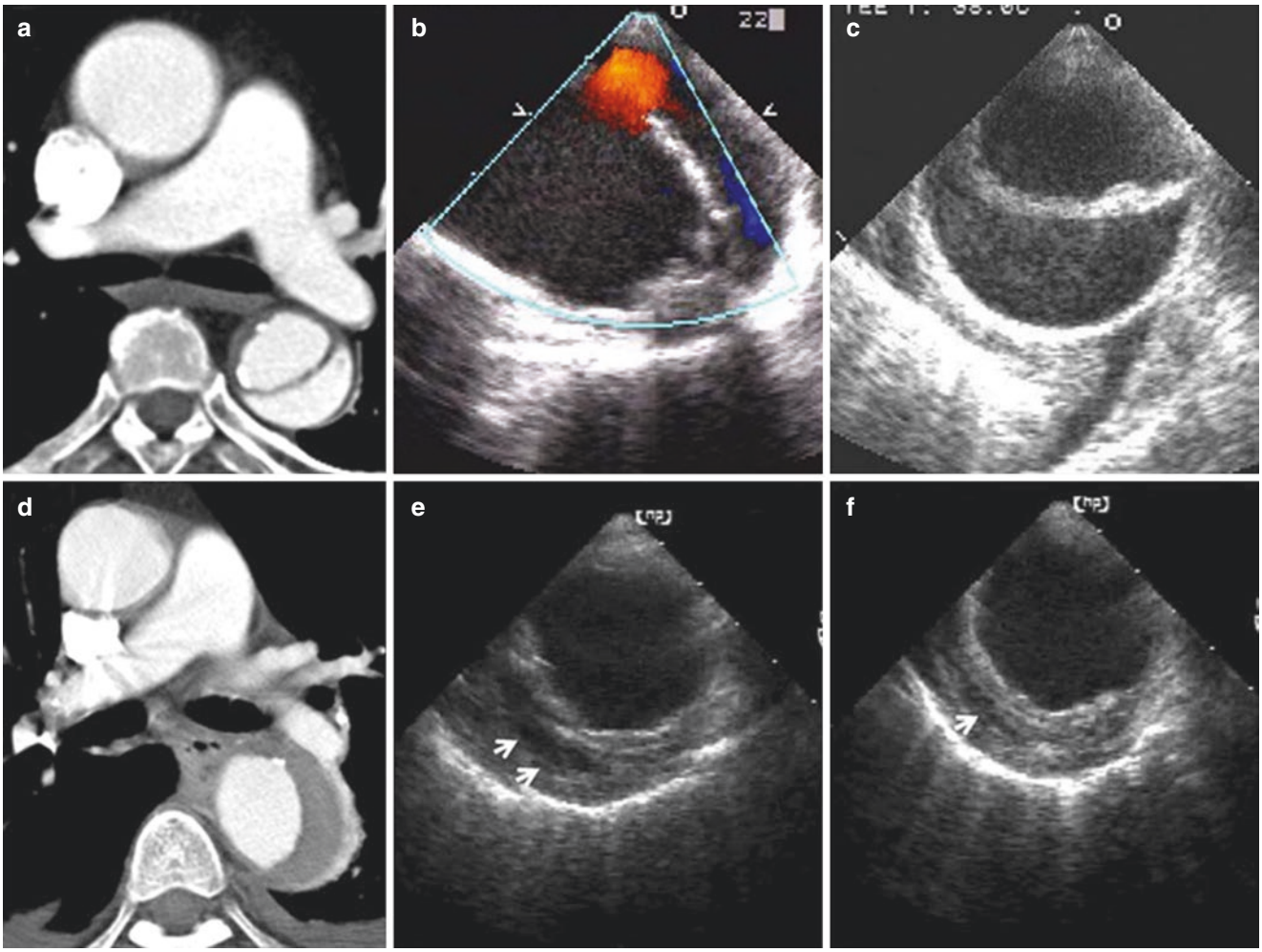

Fig. 9.8 Comparison of aortic dissection on CT and TEE (**a**–**c**) and intramural hematoma (**d**–**f**). (Reprinted from Song et al. [194] with permission from Springer)

Approximately 16–47% of patients with IMH progress to full dissection [4]. IMH patients tend to be older [189, 190], have more hypertension [191, 192], and have more pericardial effusion [190] and tamponade [191] than do classic dissection patients but are less likely to present with malperfusion [191–193], aortic insufficiency [189, 191, 193], or have Marfan syndrome [194]. Like dissection patients, IMH patients typically present with chest pain, but they are more likely to have a normal EKG [189].

Interestingly, IMH is more common in Asia where one third to one fourth of all type A dissections are the result of IMH [188].

Diagnosis, Treatment, and Outcomes

CT, MRI, and TEE are all used to diagnose IMH [195]. On noncontrast CT, IMH appears as an area of high attenuation, but it can be easily missed on first imaging due to appearing like a thrombosed false lumen [31]. IMH should result in wall thickness > 7 mm and appear crescent-shaped [187]. MRI is particularly sensitive in assessing abnormalities of the vascular wall [187].

Medical versus surgical management is controversial in type A IMH, with Western countries favoring surgical management. There are mixed outcomes looking at medical management in Asia. In a Korean registry of 165 patients, there was no significant difference in in-hospital or two-year mortality between medically and surgically managed patients [196]. A review of 328 cases of type A IMH in twelve studies also concluded that there was no significant difference in early mortality between medical and surgical approaches, however up to 40% of patients progressed to dissection or aneurysm downstream [197]. A best evidence topic, though, found that there was lower mortality in type A IMH with a surgical approach [198]. In a group of 179 patients, the medical management group had higher mortality including more emergent surgery for pericardial tamponade [199]. Others

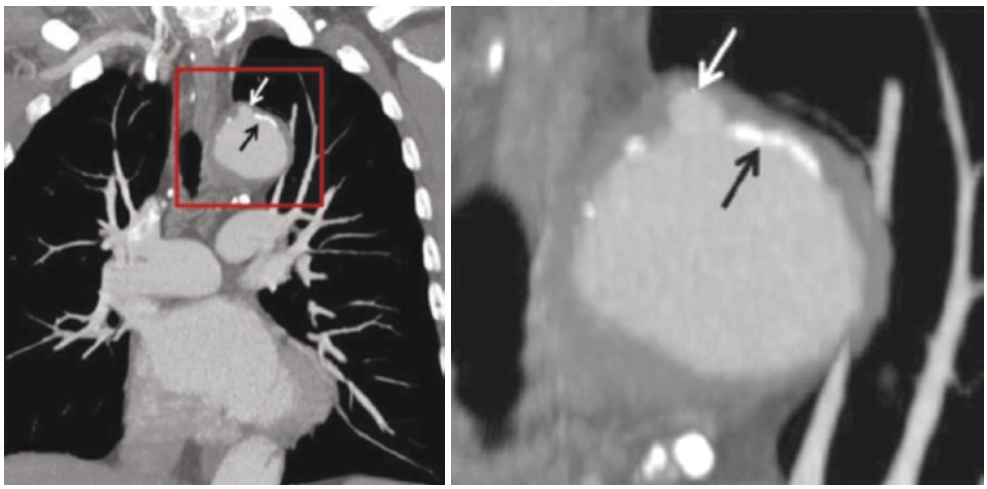

Fig. 9.9 Penetrating atherosclerotic ulcer (PAU) with outpouching (white arrow) visible through calcification (black arrow). (Reprinted from Nathan et al. [205] with permission from Elsevier)

found that up to 30% of patients progressed to true dissection when managed medically [200]. When patients are medically managed, conversion to true dissection is not always immediate, and may actually be more common after 8 days [201].

Aortic diameter > 50 mm [200, 202] or 55 mm [203] and hematoma thickness > 16 mm are predictive of adverse aortic events [203]. In a group of patients with both type A IMH and dissection, a ratio of false lumen thickness/aortic diameter > 0.98 was predictive of adverse aortic outcomes [204].

Penetrating Atherosclerotic Ulcer (PAU)

PAU is the least common acute aortic syndrome, comprising less than 10% of cases [26, 205]. PAU occurs when an atherosclerotic plaque erodes through the internal elastic lamina into the media (Fig. 9.9) [8]. It was first described as a separate entity from dissection by Stanson et al. in 1986 [206]. On pathologic examination, plaque erosion leads to medial hemorrhage and pseudoaneurysm of the aortic wall, which is distinct from cystic medial necrosis seen in dissection [207]. PAU is more likely than type A dissection to rupture the aorta, with 32–42% resulting in rupture [5, 208]. PAU may also progress to dissection [209]. The ulcers vary in depth from 4 to 30 mm and in diameter from 2 to 25 mm [209].

PAU is generally a disease of the descending thoracic aorta, occasionally the arch, and exceedingly rare to find in the ascending aorta though case reports are available [210–213]. The entity is described in more detail in the chapter on descending aortic diseases. In one study of 328 PAU detected on CTA, 27 occurred in the arch and none in the ascending aorta [205]. In another series, 2 out of 15 ulcers were in the ascending aorta [214]. Risk factors for PAU include comorbidities that contribute to atherosclerosis, including older age [214, 215], male sex [202], and hypertension [202].

Type A PAU are generally repaired surgically [215], though there is debate about how best to manage these ulcers in the descending aorta when their symptomatology varies from incidental finding to aortic rupture [202]. Increasingly, endovascular repair is being used for these lesions in the descending thoracic aorta [209].

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