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Characterization of Aortic Dissection: What the Radiologist Needs to Know

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Abstract Evaluation of acute aortic dissection by computed tomography angiography provides detailed characterization of this disease beyond the Stanford classification. Recent publications based on large patient registries and other sources have identified morphological characteristics that impact patient prognosis, and advanced understanding of both the incidence and demographics of this disease. This article reviews the recent literature and discusses the importance of imaging findings, such as aortic/false lumen diameter, signs of organ malperfusion, false lumen thrombosis, and characterization of intimal tears. The associated entity acute intramural hematoma is discussed, as well as imaging features that predict adverse outcomes. Familiarity with these imaging characteristics maximizes the utility of radiographic evaluation in this disease.

Keywords Dissection · Acute aortic syndrome · Intramural hematoma · CT angiography

Introduction

Acute aortic dissection is a life-threatening diagnosis, with in-hospital mortality of 32.5 % in Stanford type A dissection and 13 % in Stanford type B dissection [1, 2]. Although a relatively uncommon cause of acute chest pain with an incidence of 6 per 100,000 people per year (in comparison to 440 myocardial infarctions per 100,000 people per year) [3••, 4], aortic dissection has been reported as the most common acute aortic condition requiring immediate intervention [5, 6]. Figure 1 shows the pathophysiology of aortic dissection.

Evaluation with CT angiography (CTA) is established as the standard imaging modality for diagnosis and characterization of aortic dissection [7]. Advantages of this modality include widespread availability, excellent spatial resolution, and the ability to completely evaluate the anatomy the thoracoabdominal aorta and major branch vessels in one rapid examination [8]. Advances in multidetector CT imaging have enabled detailed characterization of aortic dissection beyond the Stanford classification. The importance of additional morphological characteristics, such as aortic and false lumen diameter, false lumen thrombosis, and intimal tears in the dissection flap, has been evaluated in recent studies.

The International Registry of Acute Aortic Dissection (IRAD), including 21 tertiary referral centers in 11 countries with consecutively enrolled patients presenting with aortic dissection, is the largest registry of patients with this disease [4]. The registry includes both clinical information on in-hospital clinical outcomes and follow-up as well as imaging data, predominantly utilizing CTA. We review recent IRAD reports and other studies with the aim of empowering the radiologist who encounters aortic dissection to identify features that warrant intervention or close follow-up.

Incidence and Demographics

Aortic dissection is more common and associated with increased morbidity/mortality in men and in individuals more than 65 years old. However, some studies have suggested that older individuals have less rapid expansion or extension of aortic disease than younger patients.

The incidence of acute aortic dissection has been difficult to estimate, with only a few hospital-based studies forming the

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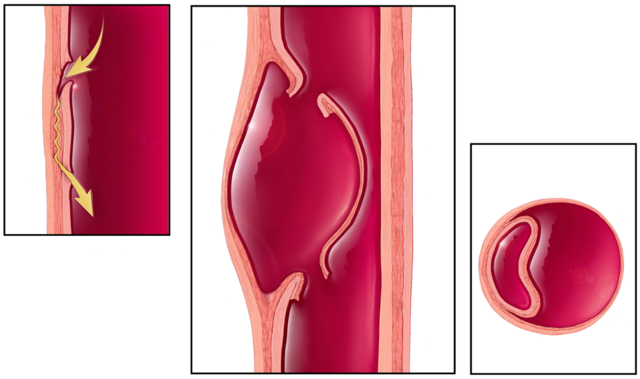

Fig. 1 Pathophysiology of aortic dissection. Blood under arterial pressure enters at a site of intimal weakening/injury and extends along the media, dissecting the layers of the aortic wall (*left* longitudinal image). The resulting false lumen consists of a channel of blood within the aortic wall, primarily surrounded by the media of the vessel. Proximal and distal entry sites (or intimal tears) may be seen, and the false lumen may compress the adjacent true lumen (*center* longitudinal image, *right* cross-sectional image). Used with permission from Macura et al. [57]

basis for most prevalence data since 1980 (Clouse et al. reported an incidence of 3.5 per 100,000 for the period 1980 – 1994 in Olmsted County, Minnesota [9]). The accuracy of these estimates was limited by exclusion of deaths before hospital admission, and lower availability of cardiovascular imaging such as CTA compared to the present day. Howard et al. recently reported a population-based study of the incidence of aortic dissection (including out-of-hospital cases) in Oxfordshire, UK, from 2002 to 2012 [3••]. Interestingly, the incidence of dissection was greater than previous estimates, at 6 per 100,000 people per year, and among individuals aged 65 years or older the incidence was 27 – 35 per 100,000. Men are afflicted slightly more often than women (2:1) [3••, 10], and several recent studies have shown that men have a greater aortic growth rate and long-term mortality from this condition [1, 11•, 12, 13].

Not surprisingly, several studies have shown increasing morbidity and mortality from both type A and type B acute aortic dissection with increasing age. Likely due to comorbid conditions, older patients are less likely to undergo surgery or endovascular procedures in management of type A [14] or type B [12] dissections, and have increased operative mortality. However, a 2010 report from IRAD demonstrated that surgical management of type A dissection was associated with significantly lower in-hospital mortality than medical management, even up to the age of 80 years [14]. Piccardo et al. in 2013 reported that octogenarians with type A dissection may also benefit from emergency operation when presenting without complications such as neurological deficit, mesenteric ischemia, or need for cardiopulmonary resuscitation [15•].

There is some recent evidence that older patients with aortic dissection have a more stable disease course. Tolenaar et al. found that increasing age is associated with decreased aortic growth rate in uncomplicated type B dissection [11•]. A study by Ryliski et al. among patients enrolled in the multicenter German Registry for Acute Aortic Dissection Type A (GERAADA) found that patients presenting at age 70 years or older were less likely to have extension of dissection to the supraaortic vessels or the abdominal aorta [16]. Though not seen in all studies [12], these findings are hypothesized to be secondary to decreased elasticity of the aortic wall in older individuals.

Dissection Classification

The most critical distinction the radiologist can make when evaluating a dissection is whether or not it involves the ascending aorta (Stanford type A), as these patients will be referred for surgical repair [17]. Figure 2 shows CT imaging in several patients with Stanford type A dissection. CT evaluation of the ascending aorta is improved with ECG gating, as artifacts related to cardiac motion may mimic the appearance of dissection. ECG gating has been shown to decrease motion artifacts and increase diagnostic certainty when evaluating the proximal aorta [18].

Stanford type B dissections involve only the descending aorta (Fig. 3). In a recent population-based study 71 % of dissections were Stanford type A while 29 % were Stanford type B [3••]. However, approximately 50 % of people with type A dissections died before hospital admission, which may account for more equal proportions between the groups seen in hospital-based studies [10].

In the US and Europe, surgical therapy is considered standard for all Stanford type A dissections and endovascular therapy is often performed in patients with Stanford type B dissections presenting with complications such as aneurysmal dilatation or organ/limb ischemia. Treatment for Stanford type B dissection without associated complications is less well established, and there is debate in the literature over whether these patients should receive endovascular therapy or medical management. For this reason many recent studies have focused on imaging or clinical factors that may predict progressive aortic disease in patients initially diagnosed with "uncomplicated" Stanford type B aortic dissection.

Malperfusion Complications

Malperfusion of the visceral organs identifies patients with type B dissection who may need intervention and those with type A dissection at higher risk of mortality. Multiplanar reformations with CTA allow exact characterization of branch vessel involvement, may determine whether malperfusion is dynamic or static, and guide the choice of percutaneous intervention.

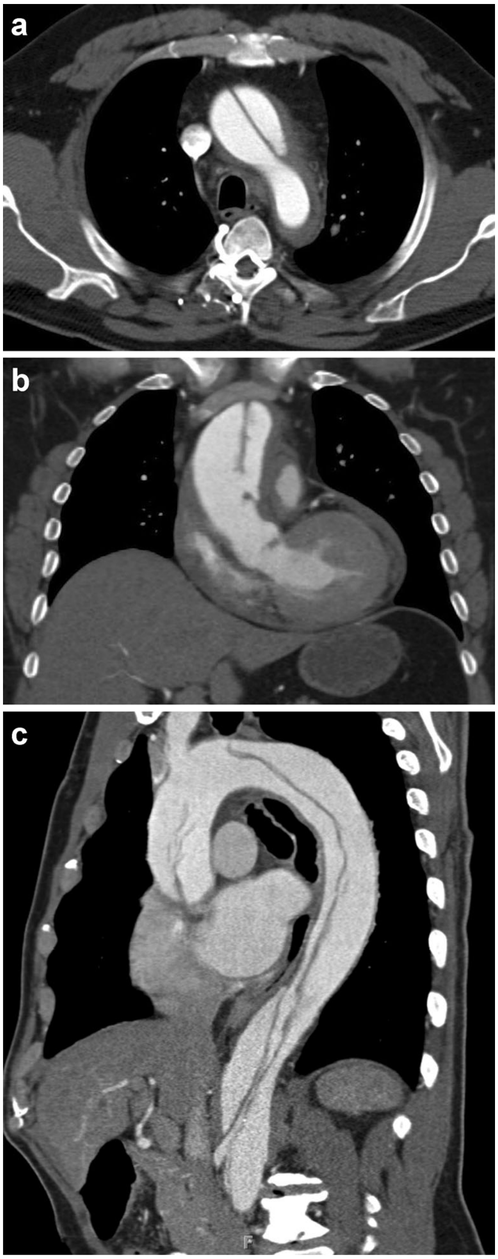

Fig. 2 Stanford type A dissection. **a**, **b** Axial (**a**) and coronal (**b**) CTA images in a 41-year-old man presenting with sudden onset chest pain associated with dyspnea and diaphoresis show dissection of the ascending aorta extending to the arch. **c** Oblique CTA image in another patient presenting with abdominal pain shows extensive type A dissection involving both the ascending and descending aorta

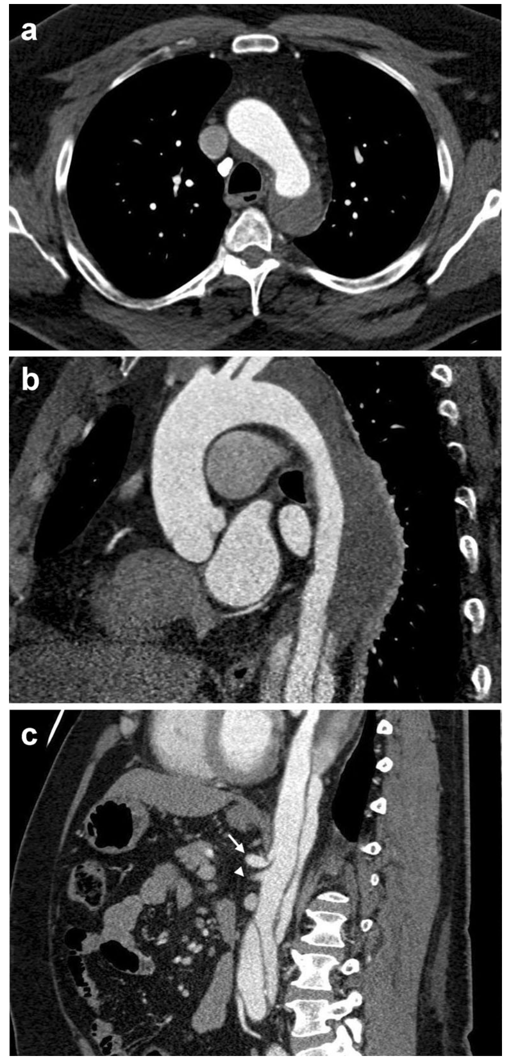

Fig. 3 Stanford type B dissection. CTA images in a 47-year-old man with hypertension, dyslipidemia, and coronary artery disease presenting with chest discomfort. Axial (**a**) and oblique (**b**) images show type B aortic dissection with thrombus in the proximal false lumen. Note that the ascending aorta is uninvolved. Oblique image (**c**) shows extension to the abdominal aorta, with the celiac artery (*arrow*) and superior mesenteric artery (*arrowhead*) arising from the true lumen

Acute malperfusion syndromes are suggested by the patient's clinical presentation. Mesenteric ischemia is indicated by abdominal pain or gastrointestinal bleeding. Renal artery involvement may result in oliguria or elevated serum creatinine. Lower extremity malperfusion is manifested by pain, pulse deficit, and cold extremity. However, the attentive radiologist may identify malperfusion of visceral or lower extremity branches in patients with equivocal clinical signs.

Renal impairment may be assessed by measuring the kidney size and evaluating enhancement of the renal cortex after intravenous injection of contrast material. Figure 4 shows renal hypoenhancement in a patient with type B dissection. Ischemia of the bowel and other organs can also be assessed by enhancement, as can associated wall thickening and edema. Hypoenhancement of abdominal organs at initial presentation has been associated with postoperative mortality in both type A and B dissection [19]. Figure 5 shows type A dissection complicated by ischemia of the small bowel. Identification of involvement of this branch artery may be an indication for endovascular therapy in type B dissection ("complicated" type B aortic dissection). Mesenteric

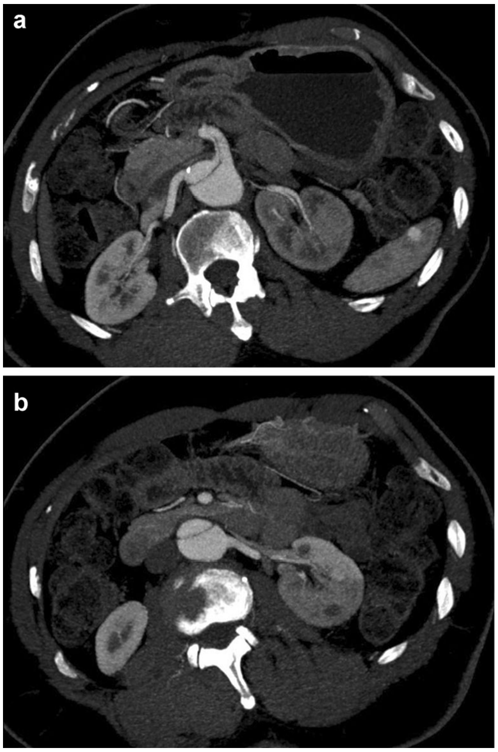

Fig. 4 Renal ischemia. CTA images in a 66-year-old man with a history of hypertension presenting with chest and abdominal pain, followed by numbness and paralysis of the right leg. On laboratory evaluation he was found to be in acute renal failure. Imaging demonstrated Stanford type B aortic dissection. Thick-section maximum intensity projection images demonstrate the left renal artery originating from the false lumen, and hypoenhancement of the majority of the left renal parenchyma

malperfusion in type A dissection is associated with nearly three times greater in-hospital mortality (63.2 % vs. 23.8 %) among patients enrolled in IRAD [20].

Multiplanar reformations of CT images allow characterization of the dissection flap involvement at branch vessel origins. Gaxotte et al. in 2003 proposed a classification system for branch vessel involvement including three broad categories [21]: type 1 involves a branch vessel arising from the true lumen (which may cause "dynamic" malperfusion by extrinsic compression from the false lumen), type 2 involves extension of the false lumen into the branch vessel narrowing the vessel origin (cause of "static" dissection on angiography and intravascular ultrasound evaluation [22]), and type 3 involves avulsion of the branch artery ostium (which may induce stenosis if incomplete). These types of branch artery involvement are shown in Fig. 6. Recommended percutaneous interventions are fenestration for type 1 lesions, and branch vessel stenting for type 2 and 3 lesions [21, 23]. The type 3 configuration includes branch vessels that arise from the false lumen on CTA evaluation (as in Fig. 3), and malperfusion in this situation may also result from reduced perfusion to the false lumen.

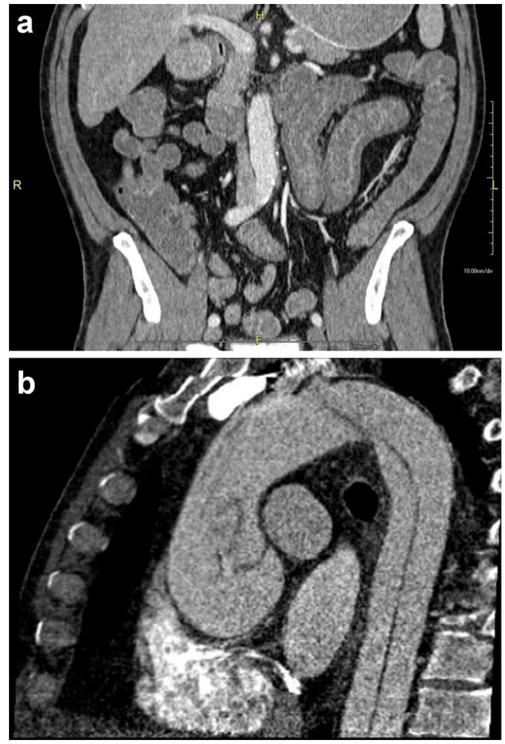

Fig. 5 Bowel ischemia. CTA images in a patient with Stanford type A dissection. Coronal image of the abdomen (**a**) shows edema and hypoenhancement of the small bowel, consistent with bowel ischemia. Oblique image (B) shows a dissection flap involving both the ascending and descending aorta

Aortic and False Lumen Diameter

Accurate measurement of aortic diameter is an important aspect of CTA evaluation of dissection. Several studies from Japan have shown that among patients with uncomplicated type B dissection, a maximum aortic diameter of >40 mm in the acute phase is associated with aortic enlargement and need for intervention in the chronic phase [24, 25]. Similarly Kudo et al. found that a maximum aortic diameter of >40 mm in acute type B dissection is associated with a greater risk of malperfusion, aortic enlargement, or rupture [26]. However, these results have not been replicated in all studies [11•], and surprisingly a 2012 report from IRAD identifies an association between a maximum diameter of >40 mm and *decreased* growth rate [27••]. These findings suggest that aortic diameter may have variable importance depending on ethnicity. However, once the diameter increases to become aneurysmal, the patient is at increased risk of rupture, and intervention is considered (Fig. 7).

Morphological evaluation of the false lumen in type B dissection may also have prognostic significance. Ueki et al. found that among patients with uncomplicated type B dissection, an initial false lumen thickness of >15 mm is associated with increased dissection-related

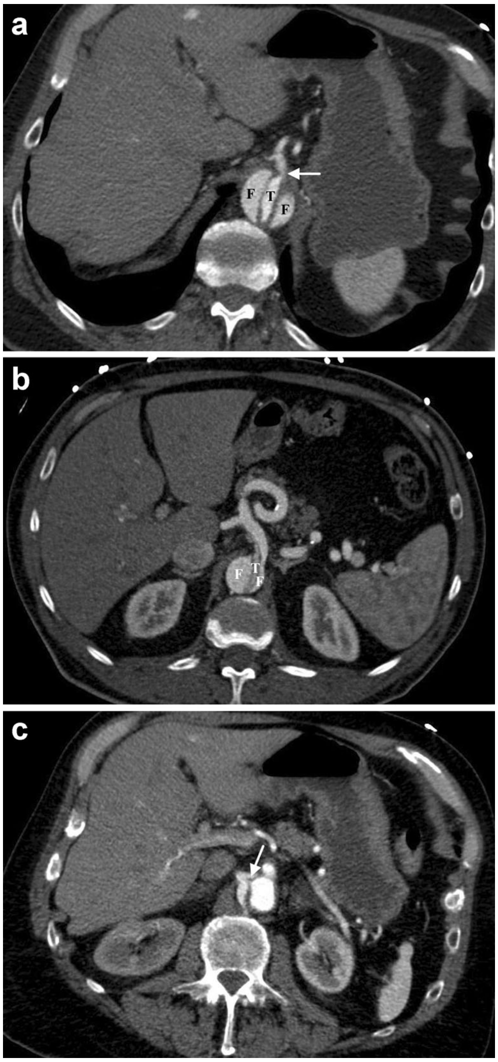

Fig. 6 Branch vessel involvement by aortic dissection. The relationship between the dissection flap and aortic branch vessels can be characterized using the classification of Gaxotte et al. [21]. **a** Branch vessels arising from the true lumen (*T*) may be narrowed (*arrow*) by compression from the adjacent false lumen (*F*), seen in the celiac axis in this patient (type 1). **b** The dissection flap may extend into the branch vessel (type 2), as seen with extension of the false lumen (*F*) into the celiac axis in this patient. **c** The false lumen may cause avulsion of the branch artery ostium (type 3, *arrow*), which may induce stenosis if incomplete. This is seen in the involvement of the right renal artery in this patient with slight hypoenhancement of the renal parenchyma

mortality [28]. Tolenaar et al. found that a circular configuration of the false lumen (as opposed to a crescent shape) is associated with increased aortic growth rate in type B dissection [11•]. Different appearances of the false lumen are shown in Fig. 8.

As Stanford type A dissections are typically managed surgically regardless of aortic diameter, the maximum diameter of the ascending aorta has shown no association with patient mortality among patients enrolled in IRAD [29]. Studies from Japan and Korea have shown that among medically treated

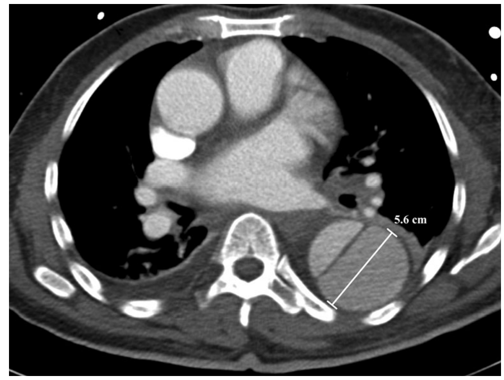

Fig. 7 Aortic diameter. A 60-year-old man presenting with acute chest pain was found to have type B aortic dissection with the axial CT image showing dilatation of the aorta to 5.6 cm (short axis on axial section), indicating a high risk of complications such as rupture

patients with thrombosed type A dissection (type A intramural hematoma, IMH) maximum aortic diameters >48 – 55 mm and maximum hematoma thicknesses of >11 – 16 mm are predictive of adverse events such as need for surgery, rupture, and death [30–32], though these results have not been universally observed [33]. For greatest accuracy, aortic aneurysm measurements should be measured in cross-section perpendicular to the long axis of the vessel using a postprocessing workstation either with manual creation of double oblique images or

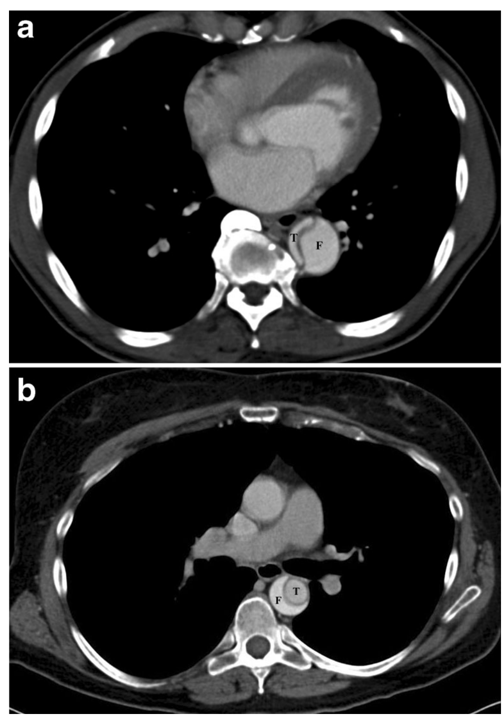

Fig. 8 False lumen morphology. On CTA evaluation a circular configuration of the false lumen in axial section (**a**), rather than an elliptical shape (**b**), has been associated with an increased aortic growth rate [11•]. This is hypothesized to represent compression of the true lumen (*T*) by a false lumen (*F*) with higher perfusion pressure

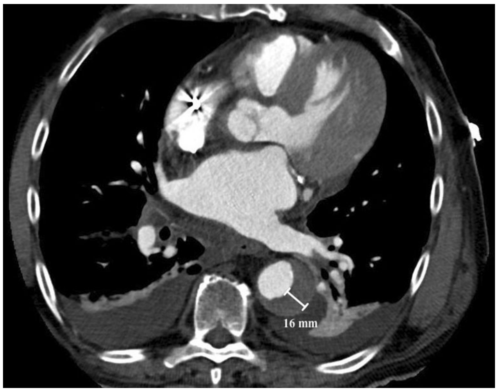

Fig. 9 Intramural hematoma thickness. CTA image in an 84-year-old man with a history of coronary artery disease presenting with new onset of increasing chest pain radiating to his back and shortness of breath shows type B intramural hematoma. A thick hematoma (>11 – 16 mm) has been found to be predictive of adverse events in many studies

automatically generated short-axis images perpendicular to the aortic centerline [34, 35]. An example of high risk IMH is shown in Fig. 9.

Partial False Lumen Thrombosis

Interestingly, evidence from IRAD suggests that in patients with type B dissection a partially thrombosed false lumen may be associated with even greater risk of aortic enlargement and mortality compared to a patent false lumen. This may be especially true in the case of distal thrombus, which may result in a blind-ending sac with pulsatile inflow. A study analyzing partially thrombosed false lumen in type B aortic dissection in patients enrolled in the IRAD showed that a partially thrombosed false lumen is a significant predictor of postdischarge mortality compared to a patent false lumen [36]. The authors' proposed mechanism for this observation was that partial thrombus occludes distal intimal tears, which "decompress" the false lumen in patients without thrombus, and thus results in higher arterial and mean blood pressure within the false lumen. In extreme cases this results in a blind-ending sac, with pulsatile blood inflow and no outflow. An example of this morphology is shown in Fig. 10. Support for this observation comes from a recent follow-up study of patients with medically treated type B acute aortic dissection showing that aortic segments with a partially thrombosed false lumen have a significantly higher annual aortic growth rate than those with either complete thrombosis or a patent false lumen [37•].

However, these findings differ from recently published results showing that patients with a patent false lumen have a significantly higher rate of operative intervention than those with complete thrombosis, without a difference in mortality [13]. Partial thrombosis of the false lumen was intermediate in risk, and not significantly different from either completely

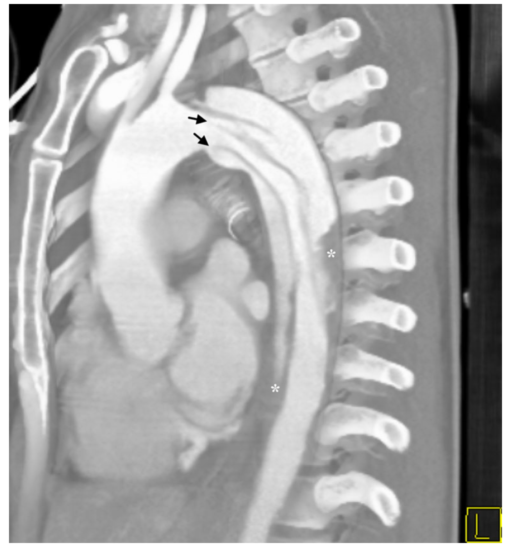

Fig. 10 Distal false lumen thrombus. CTA image with 3-D reconstruction in a 60-year-old man presenting with chest pain radiating to his back, diaphoresis, and lightheadedness shows type B aortic dissection with several large intimal tears (*arrows*) and thrombus in the distal aspect of the false lumen (*asterisks*). According to recent literature, this morphology is associated with a higher aortic growth rate and postdischarge mortality among patients with type B dissection

patent or thrombosed false lumen. Other studies have also failed to confirm the observed increase in growth rate of partially thrombosed false lumen compared to patent lumen [38], although partial thrombosis in the *distal* false lumen (formation of the blind-ended sac) may identify those at risk of aortic enlargement [13, 38].

Intimal Tears

Description of all visualized intimal tears on CTA is important in the interpretation of type B aortic dissection, for prognostic significance and planning of stent graft placement. There is evidence that more than one intimal tear is associated with decreased aortic growth rate, possibly because of decompression of the false lumen. Patients with distal intimal tears receiving endovascular therapy may benefit from uncovered stent placement in the distal aorta to induce false lumen thrombosis and favorable aortic remodeling.

The morphology of intimal tears, or entry sites, in the dissection flap is closely related to the perfusion of the false lumen. Chung et al. demonstrated using phantom studies of type B aortic dissection that increased size of the entry sites to the false lumen can induce collapse of the true lumen, which has also been demonstrated as a mechanism for aortic branch malperfusion [39]. The same group showed that exclusion of the entry site is the most effective method of relieving true lumen collapse [40].

The number of intimal tears may have prognostic significance. An ex-vivo model of aortic dissection demonstrated that diastolic false lumen pressure is highest in the presence of only a single entry tear, whereas pressure is lower when both proximal and distal tears are present [41]. Tolenaar et al. found a decreased aortic growth rate in patients with an increased number of intimal tears [42], supporting the hypothesis of additional intimal tears decompressing the false lumen.

Among patients with complicated type B dissection, the majority of intimal tears have been reported to occur in the thoracic aorta proximal to the celiac axis origin [43]. Data are mixed regarding whether a proximal intimal tear (closer to the left subclavian artery) predicts aortic enlargement in type B dissection [28, 38, 42]. A recent study by Loewe et al. found that primary intimal tears located at the concavity or lower circumference (inferior 180°) of the distal aortic arch are associated with the development of complicated type B dissection by predisposing to rupture, retrograde extension to the ascending aorta, hemothorax, or hemopericardium [44]. Examples of the different locations of primary intimal tear are provided in Fig. 11.

Endovascular therapy for type B aortic dissection involves exclusion of all possible intimal tears with a covered stent graft, while maintaining perfusion to the aortic branch vessels. Patients with large distal intimal tears not excluded by the stent graft may be at higher risk of incomplete distal aortic remodeling (i.e. lack of decrease in false lumen size) and persistent patency of the false lumen [45, 46], which results in a higher incidence of true lumen collapse and branch vessel malperfusion. These patients may benefit from placement of uncovered stents at the distal aspect of the dissection to induce thrombosis and decrease the size of the false lumen [45, 47].

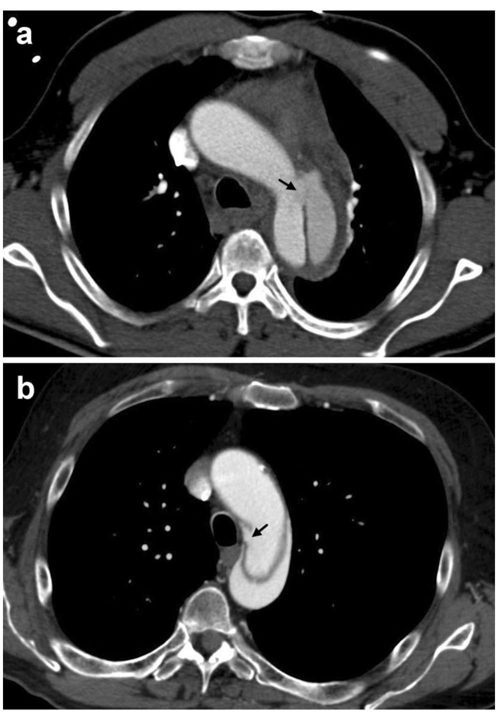

Fig. 11 Location of proximal intimal tears (entry site). In type B aortic dissection it has been found [44] that a proximal intimal tear located on the concavity or lower circumference of the distal arch (**a** *arrow*) is associated with a higher risk of complications than a tear on the convexity of the distal arch (**b** *arrow*)

Intramural Hematoma

Thrombus within the aortic wall with the absence of intimal tears establishes the diagnosis of IMH. Among patients enrolled in IRAD, type B IMH appears to have a more benign clinical course than type B dissection, but type A IMH has similar mortality to dissection. Identification of ulcer-like projections from the lumen into the aortic wall may identify patients with a worse prognosis.

IMH is defined as the development of an intramural thrombus in the absence of an intimal tear, secondary to the rupture of the vasa vasorum. This condition may not be discernible from aortic dissection with a thrombosed false lumen using current imaging methods, as the latter may have very small or secondarily healed intimal tears. Data from the IRAD demonstrates that type B IMH is associated with a decreased aortic growth rate when compared to type B dissection [27••, 48]. This is in agreement with reports of favorable prognosis in type B aortic dissection with a thrombosed false lumen at onset (an appearance that may be indistinguishable from IMH) [25, 49]. In contrast, a 2012 IRAD report found that type A IMH does not differ from type A dissection with regard to in-hospital mortality. Compared to dissection, type A IMH is less likely to present with aortic regurgitation or pulse deficits and more likely to have associated periaortic hematoma and pericardial effusion [50••]. At centers included in the IRAD (the majority of which are in North America and Europe), type A IMH is primarily managed surgically, whereas studies from Japan and Korea demonstrate adequate results with medical treatment [30–32]. Figure 12 shows type A IMH (or dissection with a thrombosed false lumen).

Sueyoshi et al. have described ulcer-like projections in IMH as localized blood-filled pouches that protrude from the lumen into the thrombus-containing aortic wall which enhance similar to the aortic lumen after administration of contrast material [51]. These defects are thought to represent small tears of the intima that are secondary to shear stress. Intimal abnormalities such as ulcer-like projections have been associated with increased risk of progression to dissection, rupture, need

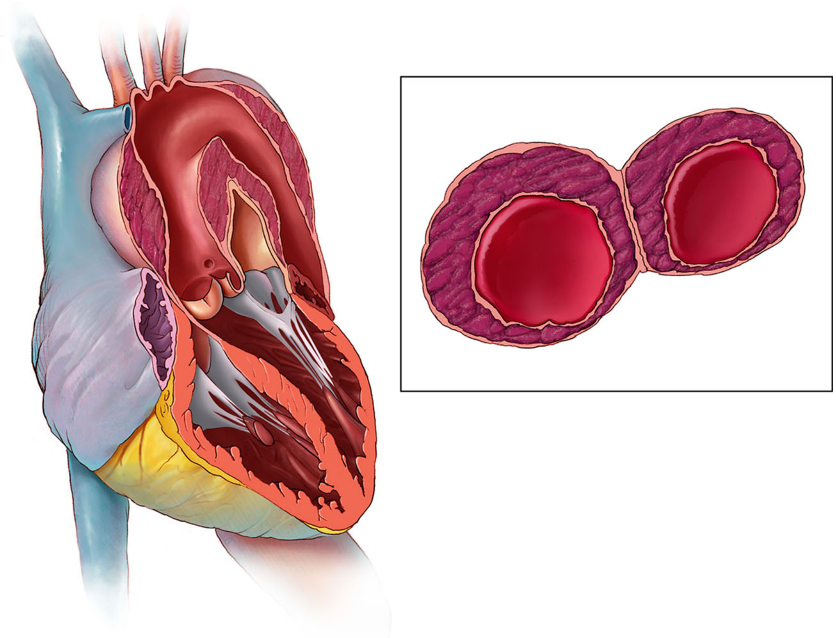

Fig. 12 Type A intramural hematoma. Oblique (*left*) and axial cross-sectional (*right*) images show thrombus in the aortic wall involving both the ascending and descending aorta. Used with permission from Johnson et al. [58].

for surgery, and mortality among patients with IMH [52, 53, 54•]. The typical appearance of ulcer-like projections is shown in Fig. 13. Patients with thrombosed dissection (or IMH) associated with ulcer-like projections have a similar prognosis to those with a patent false lumen, and a significantly greater risk of late aortic events (aortic expansion, malperfusion, or need for intervention) than patients with a thrombosed false lumen and no intimal abnormalities [55].

Ulcer-like projections should be distinguished from intramural blood pools, an alternative cause for the presence of contrast within the wall of an IMH. Intramural blood pools are created when expansion of the aortic wall with hemorrhage results in shearing of the ostia of the intercostal arteries from the aortic lumen [56]. This creates small pseudoaneurysms in the aortic wall that manifest as localized areas of contrast enhancement on CTA (Fig. 14) that have either a narrow or absent communication to the aortic lumen. In a study of type B IMH, Schlatter et al. found that all of 22 subjects with aortic branch lesions (i.e. intramural blood pools) demonstrated regression on follow-up, in contrast to 20 of 26 subjects with ulcer-like projections who had increased aortic diameter or complications [54•].

Fig. 13 Intramural hematoma and ulcer-like projection. CTA image in a 67-year-old woman presenting with chest pain radiating to the back and upper abdomen shows type B intramural hematoma with an ulcer-like projection in the medial aspect of the descending aorta (*arrow*). Patients with IMH and this finding have been shown to be at increased risk of progression to complications and higher mortality

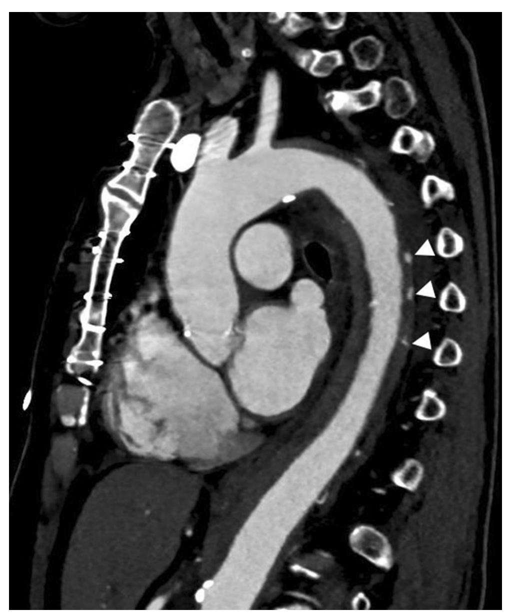

Fig. 14 Intramural hematoma and intramural blood pools. Oblique CTA image in an 81-year-old woman presenting with sudden onset chest and epigastric pain shows type B intramural hematoma with multiple intramural blood pools (*arrowheads*), likely resulting from pseudoaneurysm at the ostia of the intercostal arteries

Conclusion

In summary, clinical investigations conducted among patients enrolled in IRAD and other aortic dissection populations have identified morphological details of aortic dissection that have important implications for therapy and prognosis. Knowledge of these features enables recognition of essential information that can be gained with CTA evaluation of aortic dissection, and maximizes the value of the imager's interpretation in clinical practice.

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Compliance with Ethics Guidelines

Conflict of Interest Matthew J. Kruse, Elliot K. Fishman, and Stefan L. Zimmerman declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- • Of importance
- •• Of major importance

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