Imaging for Thoracic Aortic Dissections and Other Acute Aortic Syndromes

Fenton H. McCarthy, MD, MS[a,b,*], Christopher R. Burke, MD[c]

KEYWORDS

• Aortic dissection • Aortic imaging • Cardiovascular imaging

KEY POINTS

- Computed tomography scans are the mainstay for diagnosis of acute aortic syndromes, including dissections.
- Patient with aortic dissection should be management by a multidisciplinary aortic team that includes an imaging specialist.
- Patients with aortic dissection will require long-term, at least 5 years and possibly lifelong, imaging surveillance. Each patient should have an individualized aortic surveillance plan created by a multidisciplinary aortic team. This plan should be specifically designed for the patient's individual benefit and cognizant of their lifetime radiation exposure.
- MRI and echocardiography can offer additional and valuable information in certain settings, such as long-term surveillance using MRI and for intraprocedural echocardiographic imaging.
- There is rapid development of new imaging techniques across all aortic imaging modalities with exciting future uses and capabilities.

INTRODUCTION

Patients with aortic dissections present with varied and complex pathologies. Appropriate, accurate, and timely imaging is the cornerstone of aortic dissection diagnosis, operative planning, and surveillance. Computed tomography (CT) scans are the most widely utilized dissection imaging modality and will be the focus of most of the discussion here. Echocardiography, MRI, and other imaging modalities are also used and can provide additional valuable imaging and information in certain settings. There is ongoing evolution in all these modalities with important potential future developments for enhanced imaging capabilities such as 3-dimensional (D) echo and 4D CT scans.

The type and timing of aortic imaging varies with different presentations and management plans. For acute dissection, the greatest consideration is given to rapidly achieve a complete and accurate diagnosis, most commonly with a CT scan. Ideally, this is an electrocardiogram (ECG)-gated CT scan of the chest, abdomen, and pelvis with aortic timed intravenous (IV) contrast. For the management of chronic dissections or prolonged aortic surveillance, other considerations such as lifetime radiation exposure, likelihood of future interventions, and patient age should be included into the patient's individualized lifelong imaging plan. Multidisciplinary aortic teams, which include an imaging specialist can provide the patient the best access and outcomes through appropriate

[a] Providence Sacred Heart Medical Center, Spokane, WA, USA; [b] Spokane Heart Institute, 67 West 7th Avenue, Spokane, WA 99204, USA; [c] UW Medicine, Heart Institute at UW Medical Center – Montlake, Seattle, WA, USA
* Corresponding author.
E-mail address: Fenton.McCarthy@providence.org

Cardiol Clin 43 (2025) 219–227
https://doi.org/10.1016/j.ccl.2024.10.001

cardiology.theclinics.com

imaging combined with a comprehensive aortic dissection management plan.

COMPUTED TOMOGRAPHY IMAGING FOR ACUTE AORTIC DISSECTION

Acute Aortic Dissection Definition and Classification

An aortic dissection is a tear in the intima, which disrupts the media of the aortic wall and creates a false lumen between the adventitia and the intima (**Fig. 1**). There are several acute aortic dissection classification systems (**Fig. 2**). The Stanford classification system uses Type A for intimal tears involving the ascending aorta and Type B for intimal tears beyond the left subclavian artery. The DeBakey classification system also includes the distal propagation of the dissection.

Fundamentally, each dissection has 4 distinct elements of a dissection: (1) proximal intimal tear, (2) distal propagation of the false lumen, (3) re-entry tears/fenestrations and (4) potential malperfusion. The most recent Society for Vascular Surgery and Society for Thoracic Surgery classification system incorporate the first 3 elements: location of the intimal tear, the extent of the dissection's false lumen propagation, and re-entry tears (**Fig. 3**). All of these classification systems are image-based, with the most common modality being CT scans. The fourth element of malperfusion is captured in the Penn clinical classification system of local and/or global ischemia in the setting of acute aortic dissection.[1,2]

Computed Tomography Scan Protocols and Analysis of Acute Aortic Dissection

The diagnosis of acute aortic dissection is most commonly made in the CT scanner of the emergency department. The type of CT scan performed is important for ascertaining the most diagnostic information about the aortic dissection. The most valuable CT scan is ECG gated with arterial timing of iodine-based, IV contrast. A spatial resolution of the CT scan of 1 mm is ideal for planning both open and endovascular therapies. Dual-source, photon-counting CT scanners provide improved isotropic spatial resolution of 0.2 mm and temporal resolution of 66 milliseconds along with reduced radiation. Within a single dataset, the imaging should be of the chest, abdomen, and pelvis, inclusive of the common carotid arteries superiorly to common femoral arteries inferiorly.[3,4]

Fig. 1. Stanford type A aortic dissection.

The standard evaluation of the aorta and particularly for aortic dissections includes 8 measurements at specified anatomic locations (**Fig. 4**). Measurements should also include dimensions at the largest portion of the aorta, as well as at any abnormalities. In the setting of a dissection, an evaluation should also include the initial intimal tear, any re-entry tears, the propagation of the intimal dissection, involvement of any arterial branch involvement, and the origins of branch vessels off of true or false lumens. Root measurements should be performed orthogonally and can be from commissure to opposite sinus of Valsalva or from sinus to sinus.[3]

Additional information beyond the dissection classification can also be gathered from the CT scan. It is important to evaluate for signs of rupture or contained rupture including pericardial effusion, pleural effusion, extravasation of contrast, or radiographic malperfusion. The anatomy of the aorta should also be evaluated, at least including the presence of a bovine arch, a 4-vessel arch, aberrant subclavian arteries, and arch sidedness. It is also worth looking for evidence of prior cardiac surgery as judged by the presence of surgical grafts, clips, or sternal wires.

Ungated CT scans or those with contrast timed for the pulmonary vasculature are less informative for diagnosing and assessing aortic dissection. Given the overlap in symptoms and presentation of acute pulmonary embolism (PE) and aortic dissection, the relatively high frequencies of PE protocol CT scans that show aortic dissections are understandable in real world clinical practice. Depending on the information gained and the clinical status of the patient, the PE protocol scan may provide enough information. An additional, dedicated aortic CT scan may be required. This decision, or frankly any decision that delays acute aortic dissection therapy, should be made in consultation with a cardiothoracic surgeon.

Special Consideration for Type B Dissections and Thoracic Endovascular Repair

The clinical management and radiographic evaluation of Type B aortic dissections are distinct and

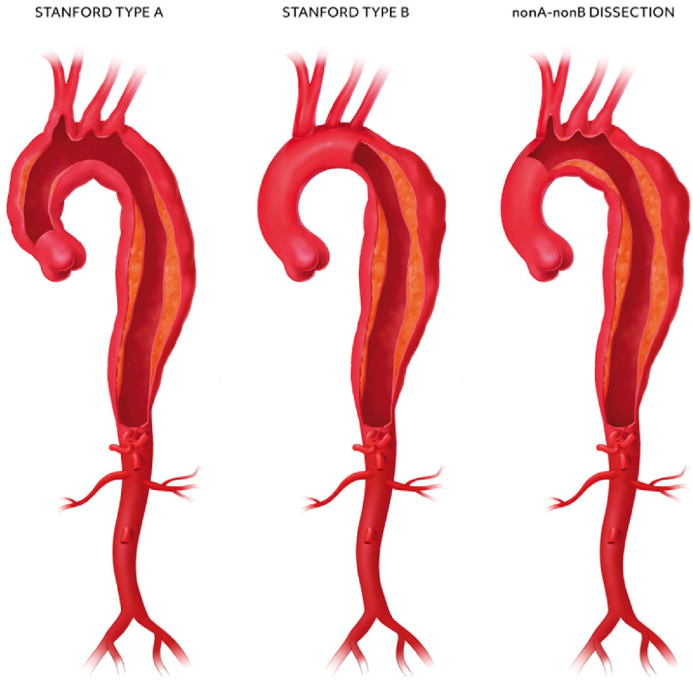


Fig. 2. Stanford aortic dissection classification. (*From*: Authors/Task Force Members; Czerny M, Grabenwöger M, Berger T, Aboyans V, Della Corte A, et al. EACTS/STS Guidelines for Diagnosing and Treating Acute and Chronic Syndromes of the Aortic Organ. Ann Thorac Surg. 2024 Jul;118(1):5-115. https://doi.org/10.1016/j.athoracsur.2024.01.021. Epub 2024 Feb 26. PMID: 38416090.)

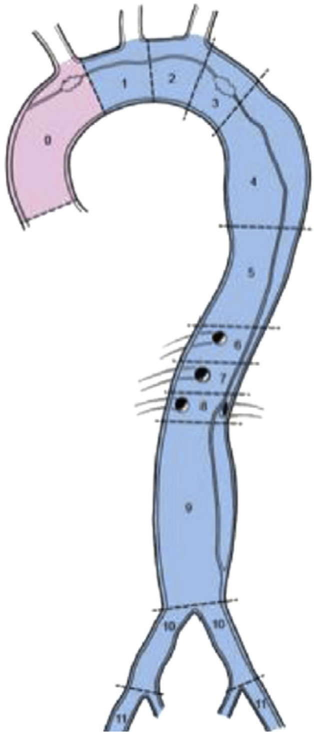
arguably more nuanced than Type A dissections. The management recommendations for Type B dissections are based on a classification scheme of uncomplicated—uncomplicated with high-risk features—and complicated Type B dissections.[5] While clinical presentation is a significant part of the designation of a complicated Type B dissection, the high-risk features of an uncomplicated Type B dissection are primarily based on the radiographic evaluation of the dissection. High risk radiographic features of uncomplicated Type B dissections include aortic size greater than 40 mm, false-lumen diameter greater than 20 to 22 mm, entry tear greater than 10 mm, entry tear on the lesser curvature, increase in total aortic diameter of greater than 5 mm between serial imaging, and bloody pleural effusion or image-only evidence of malperfusion. Acute Type B dissections can also be classified as complicated if they have increasing aortic dimensions.[6]

Surgical intervention, primarily Type B dissections and thoracic endovascular repair (TEVAR), is indicated in uncomplicated Type B dissections with high-risk features and complicated Type B dissections. TEVAR intervention planning in the setting of Type B dissections relies on radiographic information such as branch vessel involvement of the dissection, center line measurements, femoral access size, and proximal and distal landing zones.

Patients with Type B dissections may receive multiple CT scans prior to any intervention during the index hospitalizations, as well as in the subacute and chronic phases. Since Type B dissections are rarely treated as emergencies and instead are more commonly intervened upon in the subacute phase, these early CT scans are primarily to evaluate changes in the dissection and plan surgical therapies. When consideration is given to the likely future CT scans required for continued aortic surveillance and additional potential radiation exposure from CT scans for other medical conditions, ordering providers should be mindful of the lifetime radiation exposure in these patients. In order to minimize radiation exposure, coordinate care, and achieve optimal clinical outcomes, the clinical care and radiographic analysis of patients with Type B dissections should be done by a multidisciplinary aortic team at an aortic center of excellence.

Intramural Hematoma and Penetrating Atherosclerotic Ulcer

Intramural hematoma (IMH) and penetrating atherosclerotic ulcer (PAU) can present with similar symptoms as acute aortic dissection and be diagnosed by CT scans. IMH is defined as bleeding into the aortic wall creating a circumferential increase in the wall thickness in the absence



Type	Proximal Extent	Distal Extent
	0	0
A_D	1	1
Entry tear: **Zone 0**	2	2
	3	3
	4	4
B_{PD}	5	5
	6	6
Entry tear: **≥Zone 1**	7	7
	8	8
	9	9
I_D	10	10
Unidentified entry tear involving **Zone 0**	11	11
	12	12

Fig. 3. Society for vascular surgery/society of thoracic surgeons aortic dissection classification system. (*From* Lombardi JV, Hughes GC, Appoo JJ, et al. Society for Vascular Surgery (SVS) and Society of Thoracic Surgeons (STS) reporting standards for type B aortic dissections. J Vasc Surg. 2020 Mar;71(3):723-747. https://doi.org/10.1016/j.jvs.2019.11.013. Epub 2020 Jan 27. PMID: 32001058.)

of a false lumen. A complete radiographic analysis of IMH includes wall thickness, overall aortic diameter, involvement of aortic arch vessels, and proximal and distal extent of the IMH. The ability to detect a specific or likely source of the intimal injury in IMH varies. A non-contrast CT scan prior to a contrast scan can provide additional information in diagnosing IMH.

The radiographic analysis of IMH is part of the classification scheme of both complicated IMH and high-risk features of IMH. For complicated IMH, these include periaortic hematoma, pericardial effusion with tamponade, and rupture. The high-risk features for Type A IMH are maximum aortic diameter greater than 45 to 50 mm, hematoma thickness greater than or equal to 10 mm, focal intimal disruption with ulcer-like projecting involving the ascending aorta or arch, pericardial effusion. The high-risk features for Type B IMH maximum aortic diameter greater than 47 to 50 mm, hematoma thickness greater than or equal to 13 mm, increasing or recurrent pleural effusion, and focal intimal disruption with ulcer-like projection involving the descending thoracic aorta developing in the acute phase. The high-risk features for both Type A and Type B IMH are progression to aortic dissection, increasing aortic diameter, and increasing hematoma thickness.[6]

PAU is defined as an atherosclerotic ulceration in the intima with progression in the media of the aortic wall. PAUs may or may not produce a focal saccular aneurysm but also lacks the characteristics of the thickened wall of an IMH or flap of a dissection. IMH and PAU are not completely exclusive and patients can present with components of both pathologies. An accurate diagnosis is best made off of the same aortic CT scan for dissection, meaning ECG gated with arterial timed IV contrast and appropriate spatial resolution. There are fewer consensuses on the management of IMH and PAU. Once the diagnosis has been made off of a CT scan, consultation with a cardiothoracic surgeon and ideally, a multidisciplinary aortic team should be performed emergently.

Additional Acute Aortic Pathologies: Inflammatory Aortic Pathologies and Blunt Aortic Trauma

Making the diagnosis and performing the evaluation of patients with inflammatory aortic conditions, otherwise referred to as large vessel

Fig. 4. Standard anatomic locations for CT scan based aortic measurements. (*From* Authors/Task Force Members; Czerny M, Grabenwöger M, Berger T, Aboyans V, Della Corte A, et al. EACTS/STS Guidelines for Diagnosing and Treating Acute and Chronic Syndromes of the Aortic Organ. Ann Thorac Surg. 2024 Jul;118(1):5-115. https://doi.org/10.1016/j.athoracsur.2024.01.021. Epub 2024 Feb 26. PMID: 38416090.)

vasculitis is a clinical and radiographic challenge. Takayasu and Giant Cell Aortitis are the 2 most common forms of large vessel vasculitis. The CT scans for inflammatory aortic conditions can be particularly difficult to distinguish from IMH. The use of fluorodeoxyglucose PET scan is recommended when large vessel vasculitis is suspected[7] The management of inflammatory aortic conditions ideally begins with medical therapy of the inflammatory aortic condition, but this can be confounded if a patient presents with acute symptoms of chest or back pain or significant, concomitant aneurysmal disease. There can be some distinguishing features between IMH and aortitis with the latter having no intimal disruption and some anatomic distribution patterns with involvement of branch vessels. However, since biopsies of the aorta can only be performed intraoperatively, occasionally the final pathologic diagnosis can only be performed after open aortic surgery.

Blunt aortic trauma differs from other aortic pathologies, because clinically patients are suffering from polytrauma as opposed to isolated aortic pathology and its sequela. Blunt aortic trauma is the second most common cause of death in trauma patients.[8] The treatment of blunt aortic trauma relies heavily on the radiographic classification into Grades 1 to 4, as well as other high-risk features (**Fig. 5**). Grade 1 is an isolated intimal tear; Grade 2, intramural hematoma; Grade 3 is aortic pseuodoaneurysm; and Grade 4 is a free rupture. High-risk imaging features include posterior mediastinal hematoma greater than 10 mm, lesion to normal aortic diameter ratio greater than 1.4, pseudocoarctation of the aorta, large left hemothorax, aortic arch hematoma, or involvement of the ascending aorta, aortic arch or great vessels. Intervention, primarily endovascular therapy, is recommended for blunt aortic injuries classified as Grade 3, Grade 4, and Grade 2 with high-risk features.[6]

COMPUTED TOMOGRAPHY IMAGING FOR CHRONIC AORTIC DISSECTIONS AND PROLONGED AORTIC SURVEILLANCE

The most recent dissection guidelines recommend aortic surveillance at 1 mo, 6 mo, 1 y, and annually thereafter[6] for up to 5 y.[3] While this is a good, broad framework for aortic dissection surveillance, there is significant heterogeneity in the patient population, presentations, pathologies, and aortic dissection interventions to necessitate individualized surveillance plan. Patients may have a significant genetic or family history or demonstrate

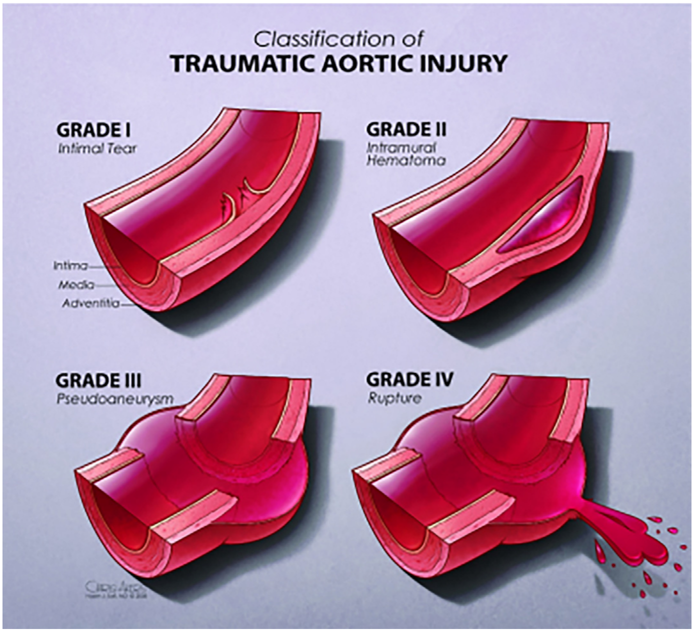


Fig. 5. Blunt traumatic aortic injury grades. (Ali Azizzadeh et al., Blunt traumatic aortic injury: Initial experience with endovascular repair, Journal of Vascular Surgery, 49 (6), 2009, 1403-1408, https://doi.org/10.1016/j.jvs.2009.02.234.)

growth on successive scans where a prolonged time interval between subsequent scans could be hazardous. Similarly, patients may have demonstrated prolonged radiographic and clinical stability mitigating the value for annual CT scans or suggesting progressively lengthening in the aortic surveillance window.

Lifetime exposure to radiation must also be considered and placed into an individualized context as opposed to a purely algorithmic approach. There is evidence of increased cancer risk with radiation exposure from 2 to 3 CT scans based on studies of the Japanese survivors of the atomic blast.[9,10] Overall, the risk is low with an estimate that 0.4% of all cancers in the United States (US) are attributable to CT scans radiation exposure.[11–13] The risk and benefit of each scan is related to both patient age and potential future therapy.

While older patients are less likely to suffer harm from radiation exposure compared to younger patients and particularly children, older patients may also be less likely to undergo reintervention based on radiographic changes. Younger patients are the opposite in that they face increased lifetime risk from higher radiation exposure, but they may also experience greater benefit from these scans in terms of early future interventions or therapies. Current guidelines recommend a multidisciplinary aortic team, which includes an imaging specialist to manage patients with previously repaired Type A dissections, Type B dissections with TEVAR repair, or medically managed dissections.[3,6] Highlighted here is the utility and expertise the aortic team can provide in not just creating an individualized aortic surveillance plan, but interpreting and potentially acting on the radiographic findings.

ECHOCARDIOGRAPHY, MRI, AND OTHER IMAGING MODALITIES

In the clinical setting of aortic dissection, particularly acute aortic dissections, other cardiovascular imaging modalities play a role, albeit somewhat limited compared to CT scans. It is also important to keep in mind that any comparison at different time points should be between the same imaging modality using the same protocol. CT scans using an aortic protocol should ideally be compared to other aortic protocol CT scans for the same patient as opposed to comparing measurements and findings between CT and MRI, echocardiography, or even CT scans using a different protocol.

Echocardiography can rapidly, and in real time, evaluate biventricular and valvular function without radiation exposure. Transesophageal echocardiography (TEE) should be performed in the operating room in the setting of any open or endovascular dissection repair. TEE can also provide information regarding true and false lumen, as well as wire and device location in these lumens as part of planned TEVAR and/or frozen elephant trunk repairs. Transthoracic echocardiography (TTE) has the advantage of bedside accessibility and should be included as part of a comprehensive cardiovascular evaluation in the setting of chronic aortic dissection. In the setting of acute dissection, operative therapy should not be delayed obtaining a TTE, particularly if there is an imminent intraoperative TEE.

MRI as a dissection imaging modality is primarily reserved for chronic dissection management and prolonged aortic surveillance, particularly in younger patients mindful of radiation exposure. MRI can also quantify biventricular and valvular function. Intravascular ultrasound is used primarily in the setting endovascular interventions, either TEVAR or frozen elephant trunk. It has a somewhat limited institutional availability and is dependent on real-time, intraoperative interpretation, further supporting the differential capabilities of multidisciplinary teams and aortic centers of excellence.

MULTIDISCIPLINARY AORTIC TEAMS AND AORTIC CENTERS OF EXCELLENCE

The implementation of multidisciplinary aortic teams has been associated with improved outcomes in emergent aortic surgeries.[14,15] Both of the most recent guidelines in aortic surgery recommend a multidisciplinary team approach to determine the optimal intervention. Along with cardiac surgeons and vascular surgeons, imaging specialists are explicitly included as part of the multidisciplinary team.[3,6] Within the US, there are a somewhat limited number of multidisciplinary aortic teams working at high-volume aortic surgery institutions, with 116 centers performing greater than 20 to 25 aortic cases and only 24 centers performing greater than 50 aortic cases annually.[16] The limited number of high-volume aortic centers is particularly striking in comparison to the number of imaging centers, clinics, urgent care facilities, and hospitals. These centers are important for patients with acute aortic conditions in terms of accessing the healthcare system and forming part of the chain of care for aortic dissections and other acute conditions.

AREAS OF CONTROVERSY IN AORTIC IMAGING

There are a few areas of aortic imaging controversy, both in the acute and chronic settings. The evaluation of coronary anatomy and determination of potential obstructive coronary lesions by CT is an area of active inquiry[17] There is a logical push to extend CT based coronary evaluation into the area of aortic surgery. Dissection patients have usually already received or are planning to receive a CT scan, so perhaps the same scan could be used to simply offer additional coronary information. Using the gold-standard modality of a coronary catheterization would require sending patients to the catheterization laboratory instead of directly to the operating room, delaying surgical therapy in the acute setting. Additionally, even in the chronic setting, there can be some resistance from interventional cardiologists to perform a catheterization in the presence of a dissected aorta out of concern for iatrogenically propagating the dissection or other possible complication.

Current CT technology would generally require an additional cardiac CT scan for coronary anatomy that is distinct from the original CT scan, ideally but not always captured as an aortic protocol CT scan. The additional cardiac CT scan would require more time, radiation, and contrast exposure. Considering that elective coronary artery bypass surgery still preferentially relies on an invasive coronary catheterization study to plan these surgeries over the non-invasive Cardiac CT, using cardiac CT scan to perform planned or prophylactic bypasses at the time of an emergent, high-risk aortic surgery operation is not recommended.

Bypass surgery is occasionally performed at the time of aortic surgery due to either dissected coronary buttons or concern for coronary blood flow status post-aortic surgery reconstruction as usually judged by ventricular performance, ECG and hemodynamics. It is possible that future imaging technology and changes in the standard-of-care for elective coronary bypass surgery increase the utility of the cardiac CT scan for planned or likely coronary bypasses performed at the time of emergent acute or elective chronic aortic reconstructions.

FUTURE AORTIC IMAGING DEVELOPMENTS

Across all imaging platforms discussed here, there are exciting future developments that are currently being incorporated, while additional developments remain under active investigation. Amongst the most salient in terms of valuable additional information and ease of implementation for aortic imaging evaluation is 4D CT scan, 3D echocardiography, and enhanced MRI capabilities.

4D CT scans offer the ability to image certain aspects of either the heart or the aorta over time. The value of these scans are similar to enhanced MRI capabilities and include flow analysis into both true and false lumens, intimal tears, and strain, which in turn could be used to plan interventions and/or predict future adverse aortic events.[18,19] Improved 3D echocardiography both in terms of image fidelity and image processing speed could also potentially offer similar information, but its intraoperative use is more foreseeable in terms of wire and catheter locations and evaluation of flow or change in flow of the true and false lumens.

There are future developments in aortic interventions occurring in parallel to the imaging developments. The ability of current and future imaging modalities to facilitate current and future aortic interventions is paramount, which includes an understanding of the best way to synergistically combine imaging modalities during therapeutic interventions. The introduction of stenting into the ascending aorta and the aortic root highlights this intersection of emerging aortic interventions with combined imaging modalities. Aortic dimensions and center line measurements are taken from the preoperative CT scan while intraoperative delivery of the device is under fluoroscopy and TEE.

Lastly, as artificial intelligence (AI) is rapidly incorporated into more aspects of our personal and professional lives, there are several easily anticipated areas of AI in aortic imaging. It is not immediately foreseeable that AI could replace the value of an aortic imaging specialist. However, rapid and automated report generation of aortic dimensions and center line measurements off of a CT scan is easy to anticipate and could offer significant value and quality checks, particularly at centers without aortic imaging specialists. We should also anticipate the incorporation of AI in ways that are not immediately foreseeable.

SUMMARY

Imaging for aortic dissections and other acute aortic syndromes primarily uses CT scans due to their widespread availability, easily interpreted images, and capability of performing a comprehensive radiographic evaluation. There is a continued need to educate providers and imaging specialists regarding the different protocols for CT scans and the heightened value of aortic protocol scans for acute aortic syndromes.

Current dissection guidelines recommend the treatment for patients with acute aortic syndromes be performed at a high-volume center by a multidisciplinary team that includes an imaging specialist.

Other imaging modalities such as MRI, echocardiography, and intravascular ultrasound at PET can provide additional information and possibly at lower risk from radiation exposure compared to CT scans. All imaging modalities are rapidly evolving with new and future uses and capabilities. Amongst these developments is the incorporation of AI. It is important for the community of providers taking care of patients with aortic disease to expect, prepare, and become educated on anticipated and unanticipated uses of AI in thoracic aortic imaging.

CLINICS CARE POINTS

- Acute Aortic Syndromes, including Aortic Dissections, are clinical emergencies that may require emergent, life-saving surgeries.
- Accurate and prompt diagnosis of Acute Aortic Syndromes depends on approriate imaging modalities and techniques, predominantly CT scans with contract timed for the systemic arterial circulation.
- A program of surveillance imaging post acute aortic syndromes is recommended, ideally coordinated at an Aortic Center.

DISCLOSURES

Drs F.H. McCarthy and C.R. Burke have no financial disclosures.

REFERENCES

1. Augoustides JGT, Geirsson A, Szeto WY, et al. Observational study of mortality risk stratification by ischemic presentation in patients with acute type A aortic dissection: the Penn classification. Nat Clin Pract Cardiovasc Med 2009;6(2):140–6.
2. Patrick WL, Yarlagadda S, Bavaria JE, et al. The Penn classification system for malperfusion in acute type A dissection: a 25-year experience. Ann Thorac Surg 2023;115(5):1109–17.
3. Czerny M, Grabenwöger M, Berger T, et al, Authors/Task Force Members. EACTS/STS guidelines for diagnosing and treating acute and chronic syndromes of the aortic organ. Ann Thorac Surg 2024;118(1):5–115.
4. Schlett CL, Hendel T, Hirsch J, et al. Quantitative, organ-specific interscanner and intrascanner variability for 3 T whole-body magnetic resonance imaging in a multicenter, multivendor study. Invest Radiol 2016;51(4):255–65.
5. Lombardi JV, Hughes GC, Appoo JJ, et al. Society for vascular surgery (SVS) and society of thoracic surgeons (STS) reporting standards for type B aortic dissections. Ann Thorac Surg 2020;109(3):959–81.
6. Isselbacher EM, Preventza O, Hamilton Black J, et al. 2022 ACC/AHA guideline for the diagnosis and management of aortic disease: a report of the American heart association/American college of cardiology joint committee on clinical practice guidelines. Circulation 2022;146(24):e334–482.
7. Lariviere D, Benali K, Coustet B, et al. Positron emission tomography and computed tomography angiography for the diagnosis of giant cell arteritis: a

real-life prospective study. Medicine (Baltim) 2016; 95(30):e4146.
8. Scalea TM, Feliciano DV, DuBose JJ, et al. Blunt thoracic aortic injury: endovascular repair is now the standard. J Am Coll Surg 2019;228(4):605–10.
9. Ge CB, Kim J, Labrèche F, et al. Estimating the burden of lung cancer in Canada attributed to occupational radon exposure using a novel exposure assessment method. Int Arch Occup Environ Health 2020;93(7):871–6.
10. Preston DL, Pierce DA, Shimizu Y, et al. Effect of recent changes in atomic bomb survivor dosimetry on cancer mortality risk estimates. Radiat Res 2004;162(4):377–89.
11. Brenner DJ, Elliston CD, Hall EJ, et al. Estimates of the cancer risks from pediatric CT radiation are not merely theoretical: comment on "point/counterpoint: in x-ray computed tomography, technique factors should be selected appropriate to patient size. against the proposition.". Med Phys 2001;28(11):2387–8.
12. Brenner DJ, Hall EJ. Computed tomography–an increasing source of radiation exposure. N Engl J Med 2007;357(22):2277–84.
13. Ngachin M, Garavaglia M, Giovani C, et al. Radioactivity level and soil radon measurement of a volcanic area in Cameroon. J Environ Radioact 2008;99(7): 1056–60.
14. Andersen ND, Ganapathi AM, Hanna JM, et al. Outcomes of acute type a dissection repair before and after implementation of a multidisciplinary thoracic aortic surgery program. J Am Coll Cardiol 2014; 63(17):1796–803.
15. Khan H, Hussain A, Chaubey S, et al. Acute aortic dissection type A: impact of aortic specialists on short and long term outcomes. J Card Surg 2021; 36(3):952–8.
16. Mori M, Shioda K, Wang X, et al. Perioperative risk profiles and volume-outcome relationships in proximal thoracic aortic surgery. Ann Thorac Surg 2018;106(4):1095–104.
17. Serruys PW, Kageyama S, Pompilio G, et al. Coronary bypass surgery guided by computed tomography in a low-risk population. Eur Heart J 2024;45(20):1804–15.
18. Zimmermann J, Bäumler K, Loecher M, et al. Hemodynamic effects of entry and exit tear size in aortic dissection evaluated with in vitro magnetic resonance imaging and fluid-structure interaction simulation. Sci Rep 2023;13(1):22557.
19. Omidi A, Weiss E, Wilson JS, et al. Quantitative assessment of intra- and inter-modality deformable image registration of the heart, left ventricle, and thoracic aorta on longitudinal 4D-CT and MR images. J Appl Clin Med Phys 2022;23(2): e13500.