Management of Acute Type A Aortic Dissection

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KEYWORDS

• Type A aortic dissection • Emergent • Surgical repair • Intimal tear • Perfusion

KEY POINTS

- Acute type A aortic dissection (ATAAD) is an emergent surgical problem for which the mainstay of treatment is immediate surgical intervention.
- Blood pressure control, anti-impulse therapy, resuscitation, and potential transfer to an aortic center are primary principles of management until surgical treatment can occur.
- The degree of surgical aortic resection and replacement depends primarily on the location and extent of the intimal tears and the aneurysmal dilation of the aorta.
- At a minimum, resection and replacement of the ascending aorta with an open distal anastomosis ("aortic hemiarch" operation) should be achieved for ATAAD, with examination of the distal extent of the tear under direct visualization.
- Other acute type A aortic syndromes are treated similarly to ATAAD.

INTRODUCTION

Acute Type A aortic dissection (ATAAD) is an emergent surgical problem for which the mainstay of treatment is immediate surgical intervention, necessitating early cardiothoracic surgical consultation. For centers not equipped for surgical treatment of Type A aortic dissection, immediate referral and transfer to a designated aortic center should be made, with the understanding that if transfer to an aortic center is not possible in a timely fashion, the patient should be sent to any available institution that has the surgical capability for ATAAD repair. In this article, we discuss the various factors in management and treatment of ATAAD, from initial medical therapy to the various implications and techniques for surgical repair, which depend primarily on the location and extent of the intimal tears and any aneurysmal dilation of the aorta. We furthermore review other acute aortic syndromes and developing treatment techniques.

INITIAL TREATMENT AND MEDICAL THERAPY

Medical therapy in ATAAD is temporizing and supplemental to surgical intervention, and while it may occur in parallel, it should not replace or delay surgery. Several critically important measures may be taken to stabilize and temporize a patient who is waiting for operative intervention or transfer to an equipped aortic center.

"Anti-impulse" therapy is recommended to control heart rate and blood pressure.[1] Such therapy provides benefits of lowering aortic wall stress (shear stress on dissected layers), and hence rupture risk, as well as false lumen propagation in the preoperative period. Decreased afterload also allows for decreased cardiac work and improved myocardial perfusion during this time.[1] The systolic blood pressure goal should be 100 mm Hg to 120 mm Hg, and the heart rate goal should be less than 60 beats per minute. Invasive monitoring[2] including an arterial line should be utilized. Fast-acting IV beta blockers are recommended unless

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Abbreviations	
ACP	antegrade cerebral perfusion
ATAAD	Acute type A aortic dissection
AV	aortic valve
CABG	coronary arterial bypass grafting
COR	class of recommendation
CPB	Cardiopulmonary bypass
FET	Frozen Elephant Trunk
HCA	hypothermic circulatory arrest
IMH	Intramural Hematoma
PAU	Penetrating Atherosclerotic Ulcer
RCP	retrograde cerebral perfusion
STJ	sinotubular junction
TAR	Total Arch Replacement
TEE	transesophageal echocardiography
TEVAR	thoracic endovascular aortic repair

the patient has severe aortic regurgitation (AR).[1,3,4] If further blood pressure control is needed, or if the patient does not tolerate beta-blockade due to bradycardia, secondary agents may be necessary. For example, calcium channel blockers may also be used, which additionally decrease wall stress on the adventitia.[2] Vasodilators may be used to control hypertension if needed after initial rate control measures.[3,4] Of important note, anti-impulse therapy is contraindicated in hypotension or if there is concern for cardiac tamponade. Hypotension should warrant resuscitation with blood products and fluids, and typically indicates worsening clinical status with potentially poor outcomes in absence of immediate surgical intervention.

Pain control may be particularly important in this group of patients, as pain increases blood pressure and heart rate via the release of catecholamines and can undermine anti-impulse therapy.[5,6] Intravenous opioids are generally preferred given their effective delivery and rapid onset.

Above all, rapid interhospital transfer to a comprehensive aortic center is critical as medical management is a temporizing measure only.[1,3] Mounting evidence suggests that increased hospital and surgeon experience with Acute Type A dissection is associated with decreased operative morbidity and mortality.[7–9]

The treatment recommendations throughout this article are based on established Class of Recommendations for repair based on the International Guideline Harmonization Group grading system.[10]

GENERAL INDICATIONS FOR REPAIR

Open surgical repair is the standard of care in the management of acute ascending aortic pathologies, which include type A acute dissection. The goal of repair is to prevent rupture, as well as treat or prevent the onset of aortic insufficiency, cardiac tamponade, antegrade propagation of the dissection (causing stroke and malperfusion syndromes of the various vascular beds), and retrograde propagation of the dissection (causing coronary artery malperfusion and resulting myocardial ischemia).

Emergency surgery is a COR (class of recommendation) level 1 recommendation for ATAAD, and also a recommendation in those with brain malperfusion[1] (**Table 1**).

CANDIDATES FOR SURGICAL REPAIR

The overwhelming majority of patients are candidates for repair of acute type A dissection.

- Relative contraindications: Advanced age, significant comorbidities, hemorrhagic stroke (due to intraoperative heparinization), profound shock, or multiorgan failure.
- Absolute contraindications: Patient refusal.

There is not a sanctioned nonoperative approach for treatment of ATAAD. Significantly worse mortality and complications have been shown with the nonoperative route across many studies, and nonoperative patients should be only those who are pursuing comfort care. Patients and families might decide to pursue comfort care in cases where poor outcomes are highly likely even with surgical intervention, but it is critical for the patients and their decision makers to be fully informed and understand that ATAAD is not considered survivable in the absence of surgical repair. While this is somewhat unique compared to many other cardiac surgical scenarios, neurologic deficits are not typically a contraindication to ATAAD repair, as these symptoms are often known to improve after surgical repair.[11] This is due to the fact that they are typically caused by the brain malperfusion sequalae of the aortic dissection itself and can therefore resolve after surgical repair.

KNOWN PREOPERATIVE COMPLICATIONS

Acute type A dissection has many well-established complications in the preoperative period, making timely open surgical repair of paramount importance.[2] Several common complications are discussed below:

Cerebral malperfusion, discussed in more detail in article *Cerebral Perfusion and Protection During Repair of Type A Dissection*, remains an ongoing challenge in the management of ATAAD. The preoperative rate of brain malperfusion is 15%

Table 1
Recommendations for surgical triage in acute type A aortic dissection

Recommendations	COR	LOE	References
Surgical Triage			
1. Emergency surgery recommended in acute type A aortic dissection	I	B	—
2. Surgery recommended in type A IMH w 1+ high-risk features	I	C	—
3. Expectant management reasonable for type A IMH if significant comorbidities in absence of high-risk features	IIb	C	—
4. Surgery effective in ATAAD and brain malperfusion	IIa	B	—
5. In catheter induced ATAAD, nonoperative management reasonable if limited to aortic root	IIa	B	—
6. In retrograde ATTAD, descending TEVAR reasonable	IIb	C	

Abbreviations: IMH, intramural hematoma; LOE, level of evidence; TEVAR, thoracic endovascular aortic repair.
From Malaisrie SC, Szeto WY, Halas M, et al. 2021 The American Association for Thoracic Surgery expert consensus document: Surgical treatment of acute type A aortic dissection. J Thorac Cardiovasc Surg 2021;162(3):735-758.e2, https://doi.org/10.1016/j.jtcvs.2021.04.053

according to the International Registry for Aortic Dissection (IRAD Registry).[12] Stroke may occur by several different mechanisms in this setting, including propagation of the dissection into the arch vessels, embolic debris from the dissection flap, and profound hypotension and resulting brain ischemia in the perioperative period. Despite the reasonable possibility of a poor outcome, operative treatment is still favored[13–15] (COR IIa).

Malperfusion syndrome, defined as inadequate perfusion of the aortic branch vessels causing end-organ ischemia,[16] is likewise an ongoing challenge. Mesenteric or limb ischemia, in particular, may require revascularization and immediate collaboration with vascular surgery colleagues for an open or endovascular approach.[17,18] While a minority of centers are using endovascular techniques and stenting *prior* to Type A dissection repair in severely malperfused patients,[19] this is not the current standard of care and is not formally recommended.

Myocardial ischemia typically occurs when a coronary orifice is involved by retrograde propagation of the dissection. There are several possible mechanisms by which myocardial infarction (MI) may occur, including an intimal tear of the coronary ostium, coronary detachment, or complete avulsion, as well as potential embolization of thrombus or debris from the dissected aorta into the coronary arterial tree. This complication is addressed in some of the operative techniques discussed in this article and may, in some cases, warrant emergent coronary arterial bypass grafting (CABG).[20] Other well-established cardiac complications include aortic regurgitation due to the dilation of the aortic root or avulsion of the aortic valve (AV) leaflets/commisures, cardiac tamponade caused by blood extravasation from false lumen into pericardial space, and intrapericardial rupture, another mechanism of tamponade by which a very proximal intimal tear causes tamponade itself.

Surgical Repair

Cardiopulmonary bypass strategy

Cardiopulmonary bypass (CPB) cannulation strategy should provide true-lumen perfusion to critical organs, while taking into account the extent of the aortic pathology, required distal extent of the operation, and peripheral arterial involvement. The most common cannulation sites are the central aorta itself, the right axillary artery, and the femoral arteries.

Central cannulation The ascending aorta and/or aortic arch offer cannulation that is convenient, expeditious, requires no additional incision, and provides antegrade true lumen perfusion when performed correctly. A bypass cannula may typically be inserted by the Seldinger technique or, less commonly, using the direct open true lumen cannulation (*Samurai* cannulation).

An important consideration of the Seldinger technique includes identifying the location of the true lumen, as cannulation of the false lumen could be catastrophic. This necessitates the use of epiaortic ultrasonography, often in combination with transesophageal echocardiography (TEE), to identify the true lumen, which may be categorized as anterior, posterior, or free-floating. Notably, posterior and free-floating true lumens are thought to be more difficult for cannula placement. Upon true lumen identification, it is accessed using a needle under direct visualization, and a wire is passed into the true lumen with epiaortic ultrasound and TEE

confirmation. Aorta is then dilated and a cannula inserted over the wire into the true lumen in the usual fashion.

The direct open true lumen (*Samurai*) cannulation, the far less common of the 2 central cannulation techniques, involves aortic transection and may offer an advantage in the setting of aortic rupture when there is an extremely rapid need for cannulation and establishment of CPB. In *Samurai* cannulation, the adventitial and intimomedial walls of dissected ascending aorta incised simultaneously with large scissors and a perfusion cannula is directly and gently cannulated into true lumen. The aorta is then snared down around the cannula for initiation of CPB.[21] An important consideration of this approach is that it, by definition, results in loss of perfusion to coronary arteries and therefore requires immediate cardioplegic protection of the heart.

Right axillary artery The right axillary artery tends to provide safe and convenient antegrade perfusion. This vessel typically has less atherosclerotic disease and is often spared from the dissection process, and is a cannulation site favored by many aortic surgeons. It also provides a convenient method of continuing antegrade cerebral perfusion via the innominate and right common carotid arteries during circulatory arrest portion of the case. Care should be taken to ensure the innominate artery is not involved in the dissection at the site of cannulation, as preferential false lumen flow could occur. Cannulation typically involves a separate right axillary incision with isolation and control of the axillary artery, followed either by direct cannula insertion, or by end-to-side graft anastomosis, which is then used for connection to the CPB circuit. Notably, the latter approach tends to preserve right arm perfusion for the duration of the case.

Femoral arteries Cardiothoracic surgeons are generally well-versed in femoral cannulation. Drawbacks to cannulation here include retrograde perfusion and increased risk of emboli in an atheromatous and/or dissected thoracic or abdominal aorta. Importantly, consideration must be given to the fact that complicated dissection flaps or multiple reentry points in the descending aorta may result in inconsistent true lumen perfusion in this approach (**Fig. 1**A-C).

Cerebral protection

All cases of acute type A dissection warranting a hemiarch or more extensive resection should be performed under hypothermic circulatory arrest (HCA) with antegrade cerebral perfusion (ACP) or retrograde cerebral perfusion (RCP).[1] Please refer Claire M. Faltermeier & Christopher R. Burke's article, "Cerebral Perfusion and Protection During Repair of Type A Dissection," in this issue, for a comprehensive review of the topic.

Briefly, HCA constitutes lowering of the body temperature to decrease metabolic tissue demands.[22] Blood flow is suspended when cross-clamping is not possible (due to the need to examine the lumen of the aorta for tears, and/or there being no room to place the clamp distal to the intimal tear), such as in the case of a hemiarch or total arch replacement, or in some specific scenarios when cross clamping is not safe. HCA is not only neuroprotective, but additionally provides optimal exposure of the anastomosis and more complete visualization of the arch to rule out additional tears.[1]

There are different established levels of body target temperature range during this period. Moderate hypothermia (20.1 C–28.0 C) is considered safe and similar to deep hypothermia (14.1 C–20.0 C) across many studies.[1,23,24] A study employing the ARCH international database found that patients who underwent moderate hypothermia also had significantly shorter CPB, cross-clamp, and cerebral perfusion times than those undergoing deep hypothermia.[25] This becomes increasingly important as ATAAD patients often present with neurologic symptoms. Cerebral perfusion during ATAAD repair (with either ACP or RCP) is associated with reduced risk of death and reduced risk of stroke[8]

Antegrade cerebral perfusion ACP describes cold, oxygenated blood routed to cerebral circulation by way of the unilateral or bilateral carotid arteries. Bilateral ACP, which includes antegrade perfusion via both the left and the right common carotid arteries is preferable over unilateral ACP if the completeness of the circle of Willis (COW) is unknown.[26] While unilateral ACP is usually adequate (depending on COW anatomic variations), it is estimated that unilateral ACP is safely possible in only 72% of patients, and the use of bilateral brain oximetry is recommended.[26] Please refer Claire M. Faltermeier & Christopher R. Burke's article, "Cerebral Perfusion and Protection During Repair of Type A Dissection," in this issue.

Retrograde cerebral perfusion RCP describes cooled, oxygenated blood routed to cerebral venous circulation typically via the superior vena cava. In addition to delivering bilateral perfusion, this approach also provides an advantage in that any embolic debris is potentially flushed out of cerebral circulation. However, due its retrograde nature and anatomic considerations of the venous vascular beds involved, it is considered inferior to ACP. Please refer Claire M. Faltermeier &

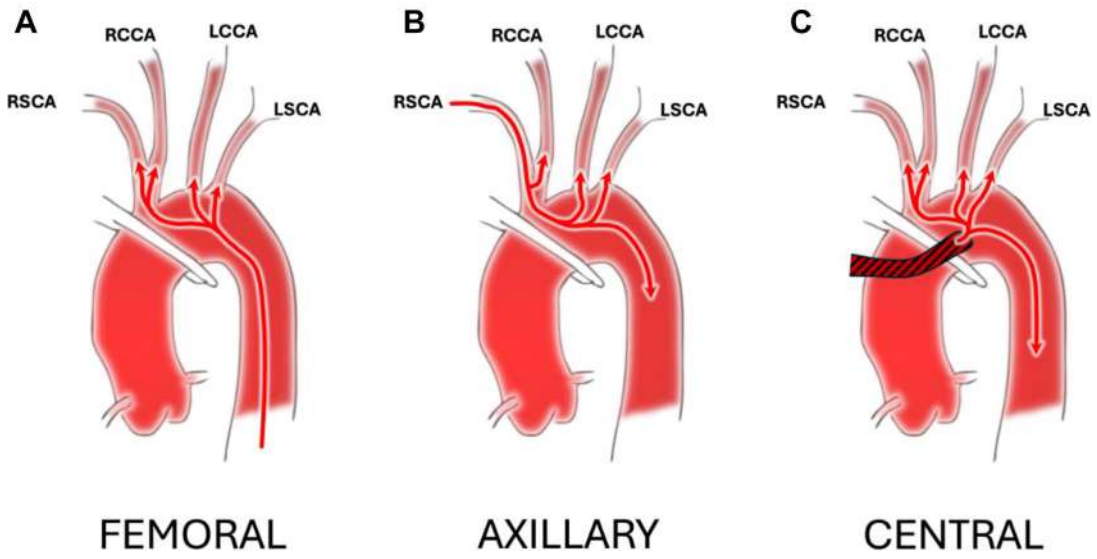

Fig. 1. (*A-C*) Direction of flow associated with the common cannulation techniques.

Christopher R. Burke's article, "Cerebral Perfusion and Protection During Repair of Type A Dissection," in this issue,

Repair options and considerations

All patients with ATAAD benefit from *emergent* open surgical repair.[2] Repairs may range from minimal to extensive, with the primary goal being the survival of the patient with as little morbidity as possible, especially in community settings where extensive aortic operative expertise is not available. With that in mind, broad open surgical principles include:[2,27]

- Excision of the intimal tear
- Proximal obliteration of flow into false lumen
- Aortic reconstruction with graft
- Repair or replacement of the AV (if indicated)

As with any operation, preoperative planning is of paramount importance, and some surgical considerations are typically identifiable and should be assessed on preoperative imaging (**Table 2**):

- Location and extent of intimal flap/dissection
- Location of primary intimal and reentry tears
- Involvement of arch vessels (implications for cannulation techniques and cerebral protection)
- Characteristics of femoral and axillary arteries (for CPB considerations)
- Presence of aneurysmal dilation, especially of the aortic root and transverse arch, as this may affect the extent of repair required
- Evidence of malperfusion (cerebral, visceral, renal, extremities, etc)
- Pericardial or pleural effusions
- Degree of aortic calcification or intramural hematoma (may affect safe cross-clamping)
- Presence of aberrant anatomy
- Size and anatomic considerations of vertebral arteries and Circle of Willis, when available

Once in the operating room, the patient is typically placed in the supine position, in preparation for a standard median sternotomy. Of note, the period of anesthesia induction, intubation and central line placement may be critical, especially in hypotensive patients presenting with suspected or confirmed rupture and pericardial or large pleural effusions. The operation classically begins with sternotomy, establishment of CPB, and assessment of the aorta, with modifications as necessary in case of peripheral (axillary or femoral) cannulation.[28]

Proximal Extent and Aortic Root Involvement

Once cardiopulmonary bypass is initiated and the patient begins cooling to the desired temperature, the ascending aorta, arch, and head vessel takeoffs should be well exposed and freed from surrounding structures. Left ventricular vent via the right superior pulmonary vein and retrograde cardioplegia catheter are useful adjuncts that are commonly placed. Typically, the ascending aorta is clamped, cardioplegia initiated, and the ascending aorta incised transversely.[28] Notably, standard antegrade cardioplegia via a root catheter is often unsafe in the setting of dissected ascending aorta and antegrade cardioplegia should be delivered to the coronary ostia under direct visualization once the aorta is opened, taking great care not to injure or dissect the coronary arteries. Of note, if aortic cross-

Table 2
Recommendations for aortic root management in acute type A aortic dissection

Recommendations	COR	LOE
Aortic Root Management		
1. Aortic valve resuspension is recommended for most patients with ATAAD.	I	B
2. Aortic root replacement is recommeded in ATAAD with root aneurysm or primary entry tear in the root.	I	B
3. Aortic root replacement is reasonable in patients with ATAAD and Marfan syndrome or other hereditary thoracic aortic disorders.	IIa	C
4. Valve-sparing aortic root replacement may be reasonable in selected patients with ATAAD	IIb	C
5. Expeditious coronary artery bypass grafting should be performed in patients with ATAAD and persistent coronary malperfusion after repair	I	C

Abbreviations: LOE, level of evidence.

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clamping is deemed not to be safe, the patient should be cooled to the target temperature and hypothermic circulatory arrest commenced before opening the aorta. Opening the aorta at or above the level of the sino-tubular junction to avoid injury to the right coronary ostium or the AV is good practice. The location of the most proximal extension of the intimal tear is determined by direct visual inspection.

The aortic root is the interface between the left ventricle and the ascending aorta, more specifically it bulges outward to form the 3 sinuses of Valsalva, 2 of which give rise to the coronary arteries (in addition to one noncoronary sinus).[29] This region lies between the AV leaflets and the sinotubular junction (**Fig. 2**).

During repair, the AV leaflets are inspected and the integrity of the coronary artery ostia and the aortic wall of the Sinuses of Valsalva are assessed. Generally, if the intimal tear extends below the sinotubular junction (STJ), or the root is aneurysmal, the aortic root should be replaced. In expert hands, prophylactic root replacement is also reasonable in patients with connective tissue disorders, though this recommendation is beyond the scope of this review. Aortic root replacement by definition necessitates coronary reimplantation and either reimplantation (*valve sparing*) or replacement of the AV. Because aortic regurgitation is often caused by the dissection flap extending down and causing detachment and prolapse of one or more commissures, AV replacement may not always be required. There are several approaches by which the aortic root and proximal ascending aorta may be treated, and the choice depends on the underlying pathology, the stability of the patient, and the experience/expertise of the surgeon.

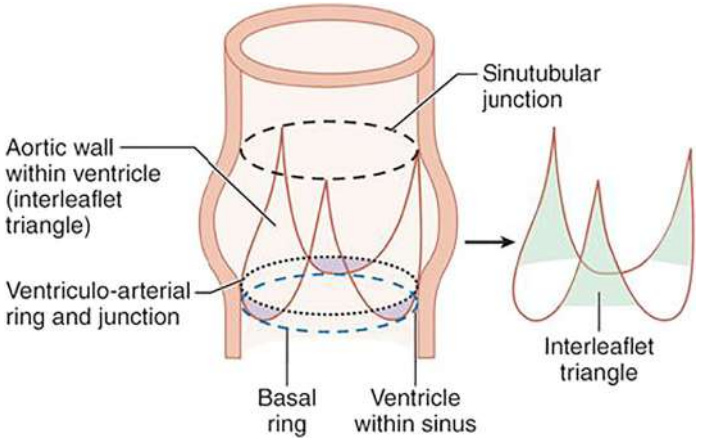

Fig. 2. Aortic root anatomy. (*Source* Cohn LH, Adams DH. Cardiac Surgery in the adults, 5e. McGraw- Hill Education.)

Aortic valve resuspension

This intervention occurs at the level of the STJ and the coronaries *do not* require reimplantation. By definition, AV resuspension does not replace the aortic root/Sinuses of Valsalva, and is therefore indicated in cases in which the aortic root does not need to be replaced. Of note, this should not be confused with a valve sparing aortic root replacement which involves AV reimplantation (as well as coronary button reimplantation).

In AV resuspension, all 3 valve commissures are resuspended using transmural suture to reattach each commissure to the aortic wall[1] and reapproximate the STJ. The false lumen in the aortic root may be obliterated with neomedia (felt, bovine pericardium, less commonly, surgical adhesive) or simple suture repair.[1] This procedure occurs concurrently with replacement of the ascending aorta with a tubular graft starting at the level of the STJ. It should extend distally at least to the proximal transverse arch (*open distal anastomosis* or the *hemiarch* operation is a Level 1B recommendation (Malaisrie and colleagues, 2021)) (**Fig. 3**).

Indications for aortic root replacement include intimal tear of the root, aneurysmal dilation of the Sinuses of Valsalva, hereditary thoracic aortic disease, and coronary orifice involvement.[1] Techniques can broadly be divided into valve-sparing and valve-replacing (or *valve-sacrificing*) approaches:

Valve-Sparing Techniques are indicated for an intrinsically normal valve with good quality cusps or for a correctable lesion (such as incomplete leaflet closure or prolapse or dissection flap prolapse).[1] Drawbacks of this approach include possible late aortic regurgitation or root dilation, increased risk of proximal aortic reoperation, greater technical difficulty, and longer cardiac arrest and operating times.[1]

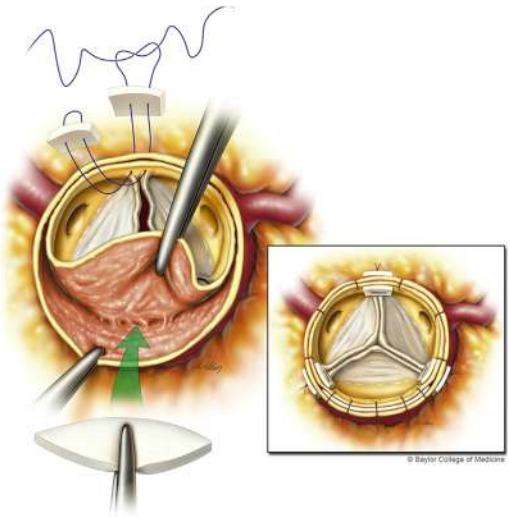

Fig. 3. Aortic valve resuspension. (*Source* Malaisrie SC, Szeto WY, Halas M, et al. 2021 The American Association for Thoracic Surgery expert consensus document: Surgical treatment of acute type A aortic dissection. J Thorac Cardiovasc Surg 2021;162(3):735–758.e2, https://doi.org/10.1016/j.jtcvs.2021.04.053)

In the David procedure (valve reimplantation), the aorta is transected just above the origin of the coronary arteries, the coronary ostia are preserved as small buttons, and the remainder of the ascending aorta is removed except for the valve tissue, leaving a small rim around the plane of leaflet and commissural attachment to the aortic wall. The native valve is then positioned and sewn into a new aortic graft and the coronaries are reimplanted, with the graft providing external support to the level of the annulus, below the nadir of the AV cusps.[30]

In the Yacoub procedure (root remodeling), a similar approach to the David procedure is taken, but an additional 2 mm–3 mm of tissue is preserved above the level of the annulus, and the aortic graft is anastomosed the native aortic tissue at this level in an attempt to create full artificial sinuses of Valsalva.[30] Aortic tissue is not supported by the graft down to the level of the aortic annulus (**Fig. 4**).

Other, emerging valve-sparing techniques such as the Robicsek wrap, the *Florida sleeve* and the PEARS (Personalized External Aortic Root Support) technique are not commonly used and are beyond the scope of this review.

Valve-Replacing Techniques are indicated in cases where the aortic root needs to be replaced but the valve cannot or should not be preserved. Absolute indications include acquired or preexisting AV pathology (heavily calcified or stenotic valves, injury to the commissures or leaflets themselves), tears or aortic tissue quality that would compromise the ability to achieve a secure and hemostatic anastomosis between the native tissue and the graft, whereas relative indications include connective tissue disorders, bicuspid valve, lack of surgeon experience or expertise and patient instability or comorbidities requiring more expeditious surgery with shorter cardiac arrest and bypass times.[1]

A modified button Bentall procedure involves complete replacement of the aortic root, ascending aorta and the AV using aortic graft sutured to mechanical valve (a *valved conduit*, which can be created or obtained premade commercially), where the coronary arteries are sewn into openings in the graft[31] as *buttons* with some aortic tissue around the coronary ostia. Similarly, a *bio-Bentall* procedure is performed when a tissue instead of a mechanical AV prosthesis is used (**Fig. 5**A, B).

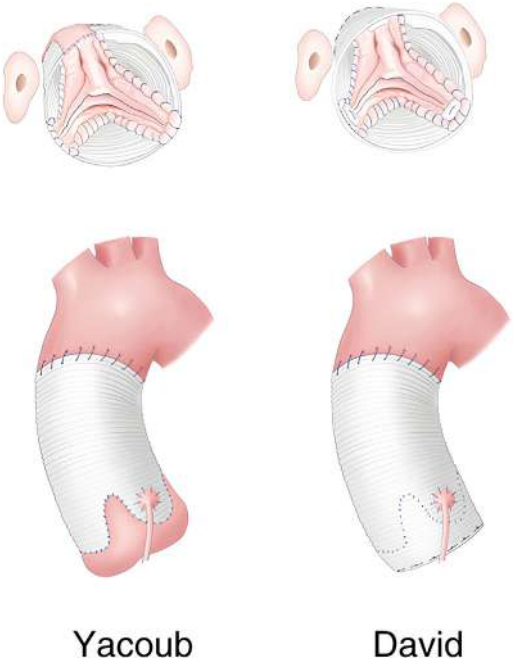

Fig. 4. Valve-Sparing Techniques–in both approaches the native valve is left in place and is attached to a graft. In Yacoub procedure, this is achieved by "root remodeling," while in David procedure, the valve is reimplanted into the graft itself. Like other root replacement approaches, they also require reimplantation of coronary arteries. (Christian D. Etz et al., Surgical management of the aorta in BAV patients, Progress in Cardiovascular Diseases, 63 (4), 2020, 475-481, https://doi.org/10.1016/j.pcad.2020.06.013.)

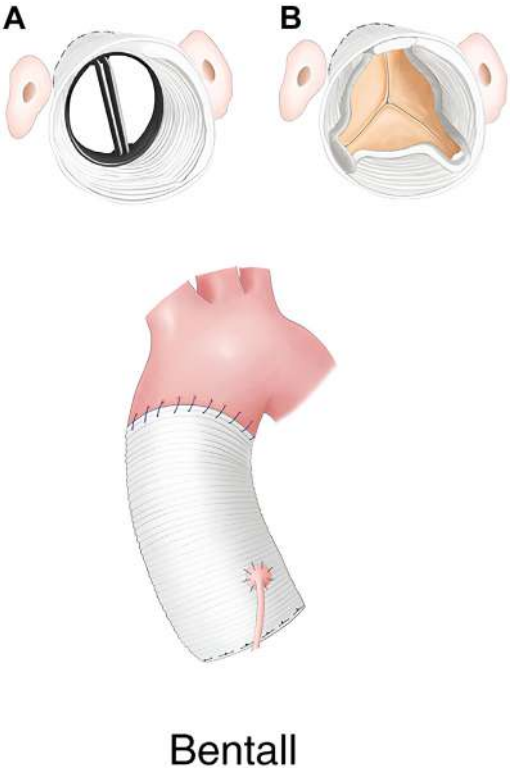

Fig. 5. Root replacement procedure with valve replacement–(*A*) Bentall with a mechanical valve and (*B*) *bio-Bentall* with a bioprosthetic valve. Like other root replacement approaches, it also requires reimplantation of coronary arteries. (Christian D. Etz et al., Surgical management of the aorta in BAV patients, Progress in Cardiovascular Diseases, 63 (4), 2020, 475-481, https://doi.org/10.1016/j.pcad.2020.06.013.)

Ascending Aorta

The ascending aorta is the most likely location of aortic rupture and under considerable pressure during ventricular systole.[1] It is anatomically defined as extending from the AV annulus to the origin of the innominate artery, inclusive of the aortic root, although in surgeons tend to differentiate procedures involving the aortic root and those involving only the ascending aorta roughly above the level of the STJ. By definition, a type A aortic dissection involves a dissection in the ascending aorta (zone 0, **Fig. 6**), and requires ascending aortic replacement.[32]

Classically, in a strictly ascending aortic replacement, a portion of the ascending aorta is resected and replaced with a tubular graft with the aortic cross clamp in place at the level of the origin of the innominate artery, which allows for continued perfusion of the brain and the body with ongoing cardiopulmonary bypass. Therefore, cerebral perfusion is *not* required and there typically is no circulatory arrest because the aorta is cross clamped. Body temperature is typically maintained at 32°C to 34°C, standard for CPB. However, a classic *clamp on* ascending aortic replacement is not recommended in ATAAD because it precludes the ability to examine the arch for tears intraoperatively. Instead, *open distal anastomosis* equating to the *hemiarch* operation is a Level 1B recommendation[1] (**Table 3**).

In a hemiarch replacement, the aorta is replaced right up to the level of the innominate artery takeoff. Hypothermic circulatory arrest with either ACP or RCP is required because the aortic cross clamp is removed to assess the arch for tears and trim the aortic tissue all the way to the underside of the innominate artery takeoff, resulting in an open distal anastomosis. Open distal anastomosis to the proximal arch graft results in complete resection of ascending aorta. There is additionally the option of utilizing a beveled anastomosis for a borderline intimal tear on the lesser curve of the arch.[1]

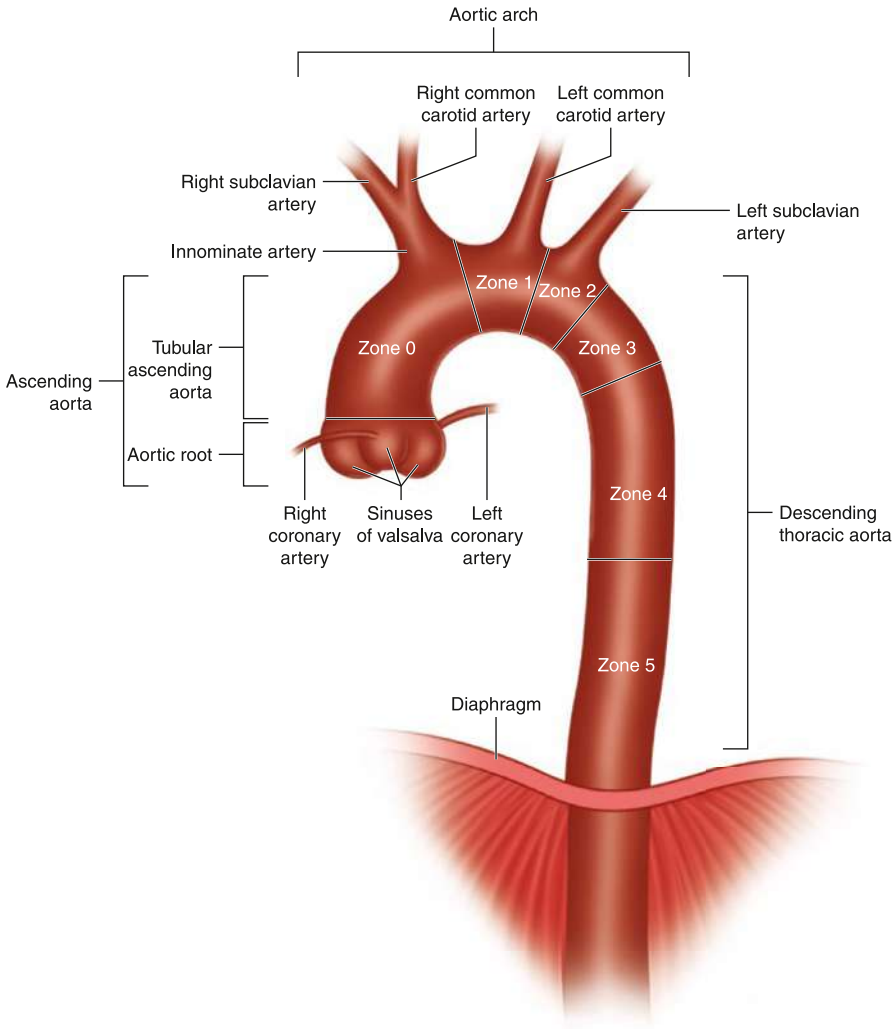

Fig. 6. Zones of the thoracic aorta. (Huckaby, L.V., Gleason, T.G. (2021). Aortic Anatomy and the Pathophysiology of Acute Aortic Syndromes. In: Sellke, F.W., Coselli, J.S., Sundt, T.M., Bavaria, J.E., Sodha, N.R. (eds) Aortic Dissection and Acute Aortic Syndromes. Springer, Cham. https://doi.org/10.1007/978-3-030-66668-2_2.)

Aortic Arch Involvement

The aortic arch, defined as the segment between the ascending and descending aorta[33] extending from the origin of the innominate artery to the left subclavian artery, contains 3 major arch branches that supply the head and upper extremities. The repair of a dissection involving the aortic arch requires interruption of native cerebral blood flow and requires hypothermic circulatory arrest with ACP or RCP (**Table 4**).

There are various modern methods of aortic arch replacement. Arguably, indications for a total arch replacement in the setting of an ATAAD are relative, as the recognized priority is the immediate survival of these critically ill patients. The relative indications for total arch replacement in acute dissections include primary entry tear is in the arch or proximal descending thoracic aorta, especially when there is cerebral or peripheral malperfusion (clinical or radiologic), or when there is rupture or aneurysm involving the arch. It may also be considered in Marfan's syndrome or other connective tissue disorders in younger patients.[1] Finally, it should be recognized that this extensive operation requires surgical experience and expertise that may not be readily available in an emergent setting.

Zone 2 Total Arch Replacement (TAR) is a commonly used approach to total arch replacement in ATAAD. There are several techniques and modifications in use.

Table 3
Recommendations for ascending aortic management in acute type A aortic dissection

Recommendations	COR	LOE	References
Ascending Aorta Management			
1. Circulatory arrest with open distal anastomosis is preferred.	I	B	—
2. Surgical resection should include the entire ascending aorta and primary intimal tear.	I	C	—

Abbreviations: LOE, level of evidence.

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In a *standard/classic approach*, the innominate and left common carotid arteries are debranched and reimplanted on the new aortic graft. Aorta is replaced up to the level of the left subclavian artery (**Fig. 7**A). In addition to addressing the tears or aneurysmal dilation of the aortic arch, the main advantage of the Zone 2 TAR is that it enables future endovascular interventions on the descending aorta as it creates a robust thoracic endovascular aortic repair (TEVAR) landing zone. In many cases, patients who require further management of thoracic aortic disease and have an aneurysmal or dissected arch that was not repaired during the ATAAD procedure (such as a hemiarch) will require reoperative replacement of their arch, although there are now emerging endovascular approaches to management of arch disease.

Historically, prior to emergence of endovascular therapies, patients with descending thoracic pathology required open repair in the form of descending thoracic or thoracoabdominal aortic replacement via left thoracotomy at a later date. Because a left thoracotomy approach cannot routinely provide access to the mid- or proximal aortic arch, an operation termed total arch with an *elephant trunk* was developed to facilitate future descending thoracic aortic replacement.

TAR with traditional Elephant Trunk involves debranching and reimplantation of the innominate and left common carotid arteries (zone 2) and sometimes the left subclavian artery (zone 3), at which time an extension graft cuff is left free-floating in the descending aorta – resembling an *elephant trunk* (**Fig. 7**B). This elephant trunk has no rigid structure and is not a self-expanding stent. The elephant trunk cuff is left behind to serve as the site of proximal anastomosis in a second operation (descending thoracic or thoracoabdominal aortic replacement) at a later time, when it can be easily accessed from the left chest. Finally, with the advances and increased use of endovascular stenting, a modification of this concept has been developed.

In a *TAR with Frozen Elephant Trunk (FET),* a self-expanding covered endovascular stent is used as the descending *elephant trunk* (and is

Table 4
Recommendations for aortic arch management in acute type A aortic dissection

Recommendations	COR	LOE	References
Aortic Arch Management			
1. Arch replacement is reasonable in those with a primary intimal tear in the arch or proximal descending thoracic aorta, brain or peripheral malperfusion, or arch/descending thoracic rupture or aneurysm.	IIa	B	—
2. Frozen elephant trunk technique may reasonable to promote aortic remodeling.	IIb	B	—
3. Arch replacement may be considered in young patients with Marfan's or thoracic aortic disorders.	IIb	C	—

Abbreviations: LOE, level of evidence.

From Malaisrie SC, Szeto WY, Halas M, et al. 2021 The American Association for Thoracic Surgery expert consensus document: Surgical treatment of acute type A aortic dissection. J Thorac Cardiovasc Surg 2021;162(3):735-758.e2, https://doi.org/10.1016/j.jtcvs.2021.04.053

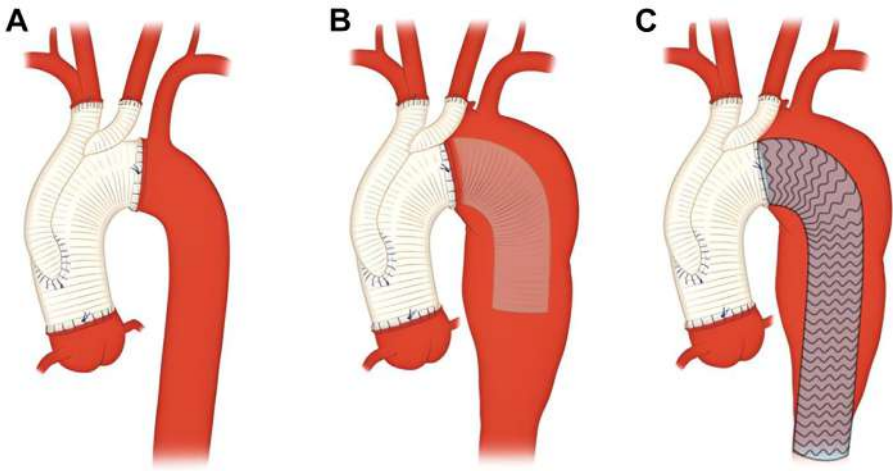

Fig. 7. Techniques for zone 2 total arch replacement – (*A*) Standard or classic Zone 2 arch, (*B*) Zone 2 arch with *elephant trunk*, and (*C*) Zone 2 arch with "frozen elephant trunk."

therefore termed *frozen* given its rigid nature) (Fig. 7C). There are several techniques for FET stent deployment after completion of the graft to native aortic arch anastomosis:

- Arch replacement followed by retrograde covered endovascular stent deployment (TEVAR), in which a covered endovascular stent is inserted though the femoral artery over a wire and landed in the distal portion of the open repair
- Arch replacement followed by antegrade covered endovascular stent deployment under direct vision in the operating field, in which a covered endovascular stent is inserted by the surgeon with or without a wire down into the true lumen of the descending thoracic aorta
- Hybrid frozen elephant trunk device (Thoraflex, Terumo Aortic (US), Bolton Medical Inc., Sunrise, FL) combines a traditional aortic graft bonded to a self-expanding endovascular stent (Fig. 8), which is deployed and positioned in the open surgical field. This potentially offers an easier implantation technique by eliminating several steps (Fig. 9A-D)

There are several advantages to a FET approach, which include positive aortic remodeling and false lumen thrombosis,[1] and decreased rates of arch and descending aneurysmal degeneration.[34] Additionally, the presence of a self-expanding covered stent in the descending aorta can serve to cover additional tears present, and may lead to more robust reexpansion of the true lumen. For the Thoraflex device in particular, an additional advantage is avoidance of Type 1a endoleak (Fig. 10) and stent migration. Notably, a feared risk of the FET approach is the increased risk of spinal cord ischemia as the stent graft covers intercostal artery take-offs that supply the spinal cord.[35] Preoperative spinal drain placement and staged-procedures may decrease these risks, though they are uncommon in the urgent setting of ATAAD.

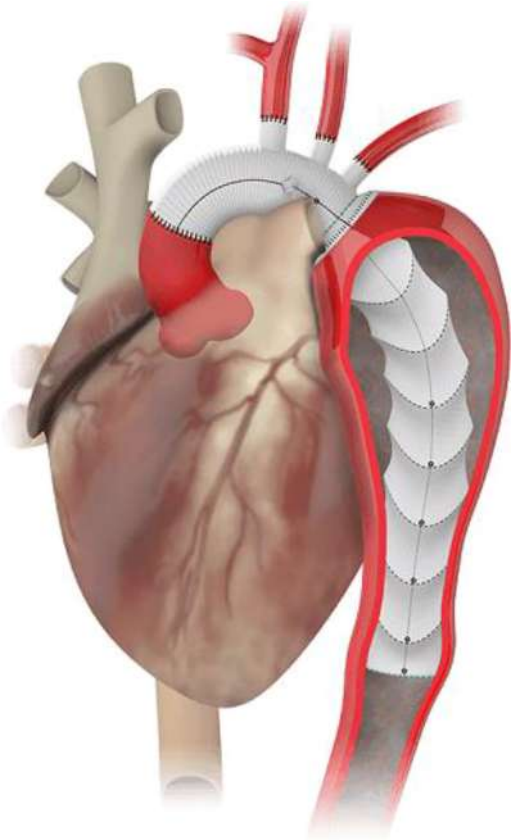

Fig. 8. Thoraflex hybrid endoprosthesis. (© 2022 Vascutek Limited trading as Terumo Aortic. All rights reserved. Reprinted with permission of Vascutek Limited trading as Terumo Aortic.)

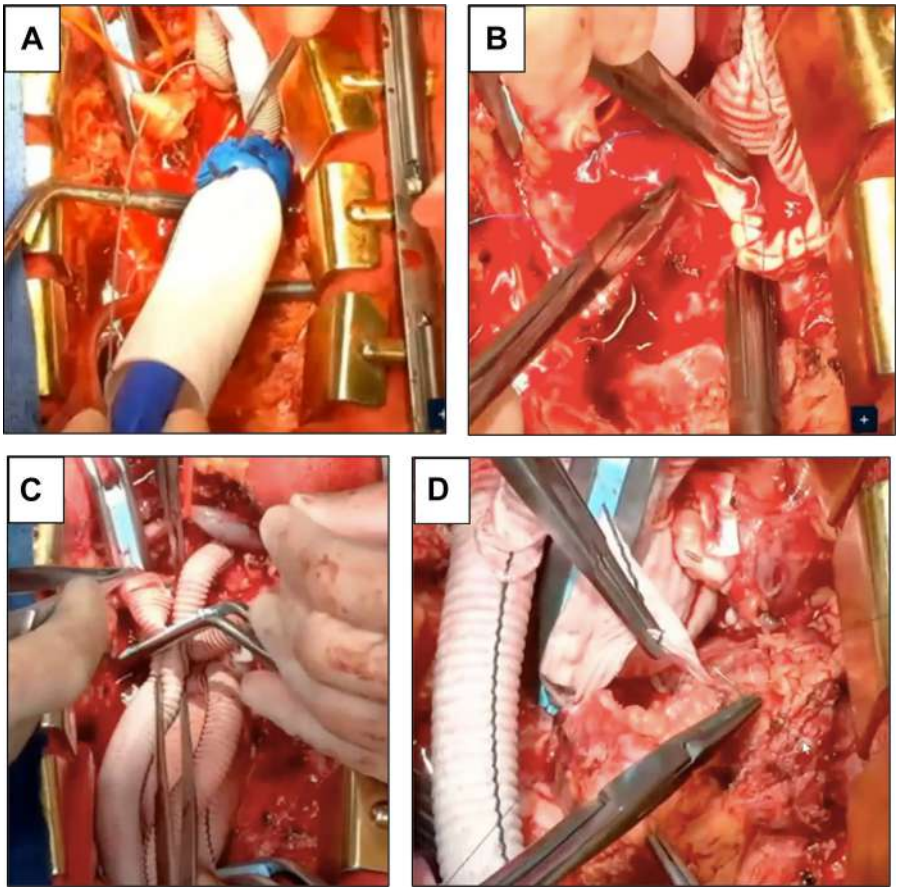

Fig. 9. Intraoperative photos of thoraflex reconstruction. (*A*) Thoraflex preloaded on a stiff wire placed into the true lumen under direct visualization and passed antegrade down thoracic aorta to be deployed (*B*) Sewing collar to facilitate distal anastomosis (*C*) Innominate artery anastomosed end-to-end with trifurcated graft (*D*) Proximal Thoraflex anastomosed to ascending aorta. (*Courtesy of* Keck Medicine of USC.)

Management of Left Subclavian Artery in Zone 2 Arch Replacement

In a Zone 2 aortic arch replacement, the left subclavian artery is not replaced or debranched off the native aorta. In a standard or classic Zone 2 TAR the left subclavian therefore remains intact with its original route of perfusion taking off of the aorta. In a Zone 2 TAR with a traditional elephant trunk, the left subclavian will continue to be perfused around the cuff as the cuff is not rigid in structure. In both of these cases, the left subclavian artery remains to be managed at the time of subsequent procedures (TEVAR or open descending replacement), though the details are beyond the scope of this review.

Conversely, however, in a Zone 2 TAR with a frozen elephant trunk, the blood supply to the left subclavian artery is occluded to varying degrees at the time of the initial operation, as its opening is covered by a self-expanding covered stent graft. This may result in a number of scenarios, ranging from complete lack of symptoms due to collateral flow, minimal left arm symptoms in the postoperative period (some patients will complain of nonacute tingling or weakness), all the way to *steal* syndrome in which the blocked origin of the subclavian artery results in *stealing* reverse blood flow the left vertebral artery to supply the left arm, resulting in differing degrees of vertebrobasilar insufficiency, which may be minimally symptomatic or have severe neurologic consequences. Additionally, a Type 2 endoleak (see **Fig. 10**) from the left subclavian artery often occurs around the FET covered stent, which may lead to continued perfusion and pressurization of the false lumen. While there is no standard for management of the left subclavian artery in Zone 2 TAR with FET during ATAAD repair, in some situations surgeons may opt to ligate the left subclavian artery origin during the initial operation, with a plan for potential left arm

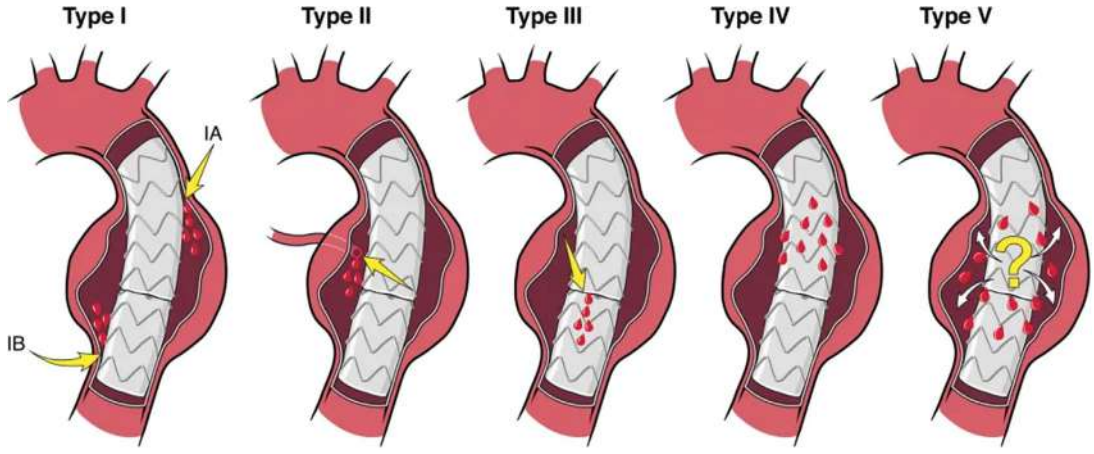

Fig. 10. Various types of endoleaks. (Maciej L. Dryjski, Dimitrios Koudoumas, Brendon Reilly, 19 - TAA Endoleaks, Editor(s): Maciej L. Dryjski, Linda M. Harris, Complications in Endovascular Surgery, Elsevier, 2022.)

revascularization if needed postoperatively with a left subclavian transposition or a left carotid to subclavian bypass.

Other Notable Approaches

Another approach to arch replacement in ATAAD is a Zone 3 TAR, which involves complete debranching and replacement of the aorta and all of its branches including the left subclavian artery. Other emerging techniques are being developed but remain investigational or nonstandard and should be considered for high-risk patients only. One example is complete arch debranching followed by TEVAR,[36] which involves an ascending graft replacement during open repair with head vessel debranching, which then acts as a proximal landing zone in TEVAR (Zone 0 requiring complete arch debranching or Zone 1 requiring carotid-carotid bypass). Additionally, total endovascular arch repair with or without aortic root repair (*endo-Bentall*, which combines endovascular aortic stenting with a transcatheter aortic valve replacement and main coronary artery stenting) has been described.[37] Finally, ascending-only aortic stents such as the Ascyrus Medical Dissection Stent (AMDS) Hybrid Prosthesis (Artivion, Inc., Kennesaw, GA) for open repairs (**Fig. 11**), and the GORE Ascending Stent Graft (currently in the ARISEII trial) for endovascular approaches are being evaluated.[38]

Operative decision making in acute type A aortic dissection

The underlying concept governing the extent of repair is adequate exposure to identify the distal extent of the dissection and entry tear(s), which is critical to ensure complete treatment. A conceptual approach for basic decision making in ATAAD has been proposed by Czerny and colleagues in the 2024 EACTS/STS Guidelines and relies on the identified location of the entry tear (**Fig. 12**). Briefly, if the tear is not visible or is isolated to ascending aorta, ascending and hemiarch replacement may be appropriate. Similarly, ascending and hemiarch replacement are acceptable in cases where the entry tear is in the arch or the descending aorta, except in cases where the tear is at the outer curvature of the arch or within 10 cm distal to the left subclavian origin, in which case emergent TAR

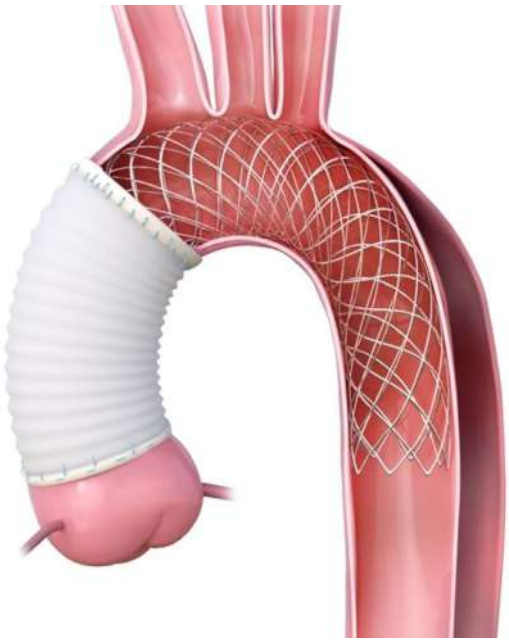

Fig. 11. Ascyrus medical dissection stent hybrid prosthesis (Artivion, Inc., Kennesaw, GA) a bare-metal stent used in open repairs. (*Used with the Permission of* Artivion, Inc.)

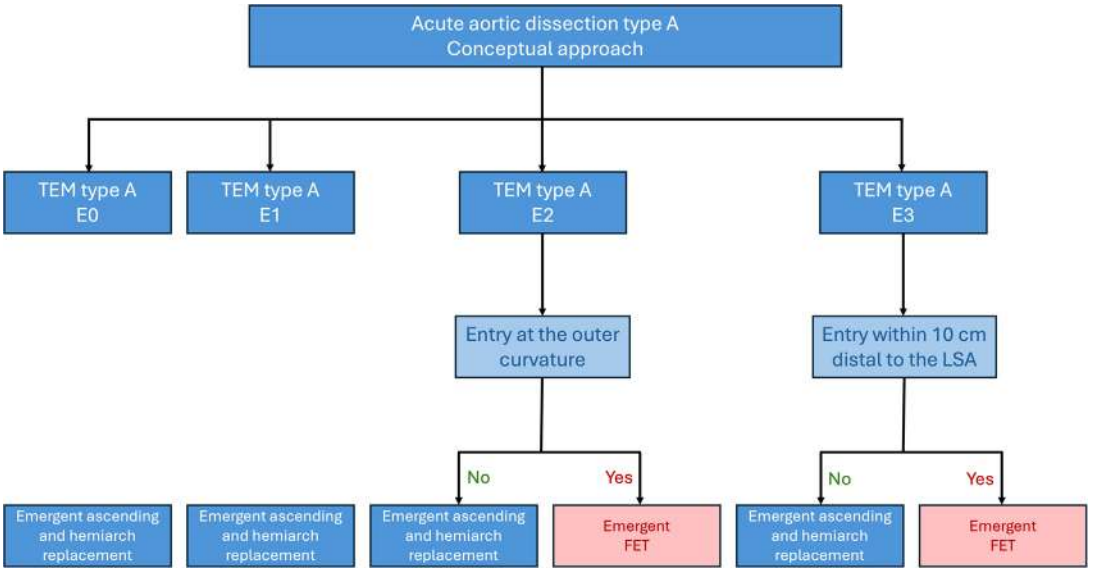

Fig. 12. Flow diagram to conceptualize extent of aortic resection. E0, no entry visible; E1, ascending entry; E2, arch entry; E3, descending entry; LSA, Left subclavian artery; TEM, type, entry, malperfusion. (*From* Czerny M, Grabenwöger M, Berger T, et al. EACTS/STS Guidelines for Diagnosing and Treating Acute and Chronic Syndromes of the Aortic Organ. Ann Thorac Surg 2024;118(1):5–115, https://doi.org/10.1016/j.athoracsur.2024.01.021)

with FET should be performed. As discussed previously, in expert hands, other factors should be considered.

Other Intraoperative Considerations

Finally, other concurrent surgical issues may arise and need to potentially be addressed while the patient is in the operating room:

- Emergent CABG is indicated if there is persistent coronary malperfusion after aortic repair, or if there is obvious dissection or lack of integrity of the coronary arteries.
- Visceral revascularization and/or exploratory laparotomy may be required in cases of bowel ischemia.
- Fasciotomies may be indicated in cases of extremity ischemia, especially in setting of reperfusion injury.
- Hemothorax evacuation and chest tube placement is indicated after control and appropriate seal/repair of aorta is completed.

MANAGEMENT OF OTHER ACUTE TYPE A AORTIC SYNDROMES

Retrograde Type A Dissection

In a retrograde Type A dissection, the primary intimal tear is distal to left subclavian artery, with the false lumen propagating retrograde into arch and the ascending aorta.[1] In De Novo dissections, an endovascular covered stent graft may be used.[39] In the case of iatrogenic retrograde dissections (most likely occurring from TEVAR) an immediate proximal open repair versus TEVAR extension may be warranted.[40,41]

Non-A, Non-B Dissections

Non-A, Non-B dissection is defined as an entry tear distal to the left subclavian with retrograde dissection *or* an entry tear between the innominate artery and the left subclavian with a dissection flap with or without distal extension.[42] Management is complex and may require open versus endovascular approaches depending on individual patient anatomy, characteristics, and center capabilities.

Intramural Hematoma

Intramural Hematoma (IMH) is the presence of blood in the medial layer of the aortic wall in the *absence* of an overt intimal tear or patent false lumen.[11] IMH is thought to be caused by rupture of the vasa vasorum or small intimal tears that are not seen on standard imaging.[43] IMH should be repaired as it may progress to aortic rupture.[44] Studies show that survival is better with immediate surgery as opposed to expectant management.[45,46]

Penetrating Atherosclerotic Ulcer

Penetrating Atherosclerotic Ulcer (PAU) occurs when an atherosclerotic plaque ulcerates leading to focal disruption in the aortic intima, allowing blood into medial layer.[11] PAUs may progress to IMH formation, dissection, or rupture[15] and are

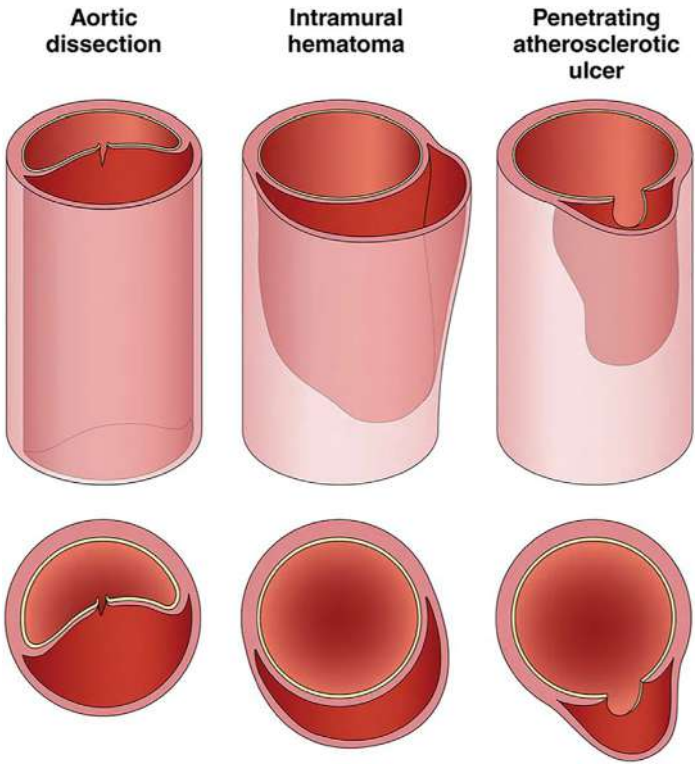

Fig. 13. Depiction of aortic dissection versus intramural hematoma versus penetrating atherosclerotic ulcer. (Eric M. Isselbacher et L., 2022 ACC/AHA Guideline for the Diagnosis and Management of Aortic Disease: A Report of the American Heart Association/American College of Cardiology Joint Committee on Clinical Practice Guidelines, Journal of the American College of Cardiology, 80 (24), 2022, e223-e393, https://doi.org/10.1016/j.jacc.2022.08.004.)

Table 5
Recommendations for aortic arch management in acute type A aortic dissection

Recommendations	COR	LOE	References
Aortic arch management			
1. Urgent repair is recommended in patients with PAU and rupture.	I	B	—
2. Urgent repair is recommended in PAU of ascending aorta with associated IMH.	I	B	—
3. Urgent repair reasonable in PAU patients of the arch or thoracic aorta if associated IMH present	IIa	C	—

Abbreviations: LOE, level of evidence.

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associated with high mortality if not treated (**Fig. 13**, **Table 5**).[44]

Summary

ATAAD is an emergent surgical problem for which the mainstay of treatment is immediate surgical intervention. Until such surgical treatment can occur, blood pressure control, anti-impulse therapy, resuscitation, and potential transfer to an aortic center are paramount. The degree of surgical aortic resection and replacement depends primarily on the location and extent of the intimal tears and the aneurysmal dilation of the aorta. In most cases, resection and replacement of the ascending aorta with an open distal anastomosis (*aortic hemiarch* operation) should be achieved for ATAAD. There are many acceptable approaches for aortic resection and reconstruction, governed by aortic pathology and surgical experience and expertise. Other acute type A aortic syndromes, such as ascending aortic penetrating ulcers and intramural hematomas, should be treated similarly to ATAAD.

CLINICS CARE POINTS

- AATD is a surgical emergency, and medical management focused on blood pressure and anti-impulse control via pain control and beta-blocade should be utilized as a

temporizing measure until surgical intervention can occur.

- Identification of the distal and proximal extents of the dissection tear is critical and will determine the extent of surgical resection, in addition to the size of the aorta. At a minimum, the repair should include an open distal anastomosis (ascending aortic and hemiarch operation).
- There are several techniques for total arch repacement, which typically involve debranching of the innominate and left common carotid to be reimplanted onto a graft.
- Zone 2 TAR with FET will occlude the take off of the left subclavian artery, which is acceptable in this emergent setting, but may need subsequent revascularization.
- Other surgical issues should potentially be addressed before leaving the operating room (visceral revascularization, fasciotomies, etc).

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