

AHA SCIENTIFIC STATEMENT

Multidisciplinary Collaboration in the Performance of Aortic Surgery: A Scientific Statement From the American Heart Association

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ABSTRACT: Intraoperative management of a patient undergoing cardiac surgery requires continuous and independent interventions by multiple healthcare professionals, including surgeons, anesthesiologists, and perfusionists, among others. Although each clinician performs tasks based on their training and accepted techniques, guidelines, and protocols, an action by one member of the team can have immediate consequences for other team members. Aortic surgery adds a level of complexity, with the need for interventions such as single-lung ventilation, systemic cooling (and subsequent rewarming), and myocardial, cerebral, and visceral protection. Much has been made of the utility of the multidisciplinary team. This scientific statement is intended to approach the patient undergoing aortic surgery from 3 different viewpoints: that of the surgeon, the anesthesiologist, and the perfusionist. This scientific statement is not intended to provide an exhaustive summary of approaches to aortic surgery but rather to illustrate the specific concerns that each member of the team may have.

Key Words: AHA Scientific Statements ■ anesthesiologists ■ aortic aneurysm ■ one-lung ventilation ■ patient care team ■ surgeons

Cardiac surgery, by its nature, is a multidisciplinary process requiring a collaborative approach to patient care. In the operating room, this collaboration includes surgeons, cardiac anesthesiologists, perfusionists, nurses, physician assistants, and surgical technicians. Each member of the team brings unique experience and training and shares in the commitment to patient safety. In open procedures on the thoracic and thoracoabdominal aorta, real-time collaboration among the surgeon, perfusionist, and anesthesiologist is essential (Figure 1). This is reflected in the 2022 American College of Cardiology/American Heart Association (AHA) guideline for the diagnosis and management of aortic disease, which emphasizes the importance of Centers of Excellence, with elements including hospital and surgeon volume and the presence of a multidisciplinary team.¹ Recommendations for intraoperative collaboration, however, were not defined.

This scientific statement is intended to complement existing recommendations¹ and outline the considerations of the core specialties involved in the operating room. No cardiac operation is performed in isolation; communication among members of the multidisciplinary aortic team (MAT) is paramount because of the potential or plan for disruption of normal circulation. This is especially important, for example, when circulatory arrest is necessary during the procedure or during surgery on the descending thoracic aorta, which requires lung isolation. Moreover, because no two aortic procedures are alike, flexibility in adapting to the operative plan in real time is required.

In this scientific statement, we focus on 2 scenarios commonly encountered by a MAT: acute type A aortic dissection (ATAAD) and surgery of the thoracic and thoracoabdominal aorta. There are overlapping considerations between these procedures (eg, preoperative evaluation,

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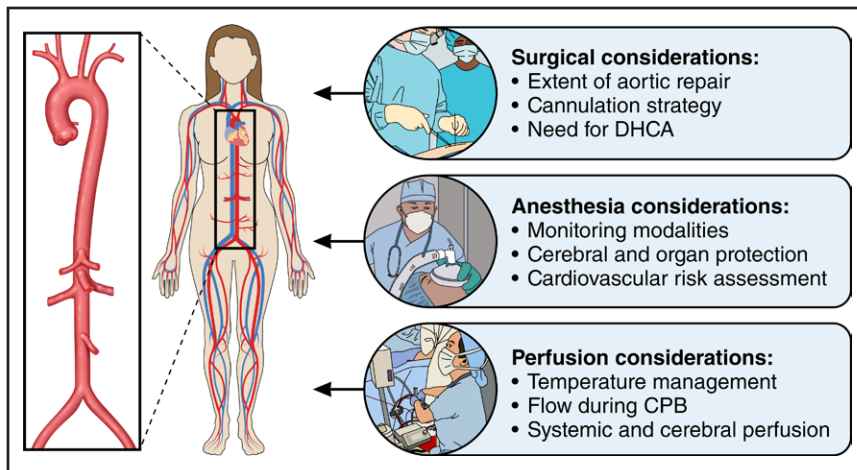


Figure 1. Collaboration among the surgeon, anesthesiologist, and perfusionist is essential to the overall success of the operation.

CPB indicates cardiopulmonary bypass; and DHCA, deep hypothermic circulatory arrest.

anemia management, monitoring); to avoid redundancy, these are addressed as needed.

SURGICAL ATAAD REPAIR INVOLVING THE ASCENDING AORTA AND THE AORTIC ARCH

ATAAD is a life-threatening cardiovascular emergency, with prehospital mortality rates of up to 40% and perioperative mortality rates ranging from 10% to 25%.^{2–4} Early surgical intervention is required to avoid or treat complications of ATAAD, such as cardiac tamponade, severe aortic regurgitation with heart failure and shock, coronary dissection with myocardial ischemia, end-organ malperfusion, and vessel rupture.¹ Malperfusion syndromes can greatly influence mortality and morbidity, and the decision to manage malperfusion first (with fenestration or endovascular stenting) depends on the surgeon and institution and is beyond the scope of this scientific statement.

Extent of Surgery

A tear-oriented management strategy for ATAAD is a Class 1 recommendation, with the primary goal of resecting or excluding the entry tear.⁵ Extent of the repair proximally into the root is individualized based on the extent of root destruction, root aneurysm, or known genetic aortic disorder.^{1,5} If the primary entry tear does not involve the root and there is only a partially dissected root without clinically significant valve pathology, aortic valve resuspension is recommended over valve replacement.^{4,5} However, when the primary entry tear involves the root or there is extensive root destruction, root aneurysm, or genetic aortic disease, a mechanical or biologic valve conduit is warranted.^{4,5} Select patients who are hemodynamically stable with appropriate anatomy may undergo valve-sparing root replacement using a MAT.^{1,5}

Surgical repair of the ascending aorta with an open distal anastomosis under hypothermic circulatory arrest

(HCA), which allows extension into the aortic arch, is a Class 1 recommendation according to the American College of Cardiology/AHA guidelines.¹ The extent of distal repair (ie, hemiarch versus arch repair with or without the frozen elephant trunk technique) depends on the location of the proximal entry and distal reentry tears, the extent of the tear (eg, involvement of the arch or descending thoracic aorta), and the presence of malperfusion.^{1,5} A hemiarch repair is recommended over more extensive arch replacement when the entry tear does not involve the arch, or when the entry tear is within the arch but not at the outer curvature, and if there is no clinically significant arch aneurysm.^{1,5} Extended arch repair with antegrade stenting of the proximal descending thoracic aorta may be considered for entry tears within the outer curvature of the arch or descending thoracic aorta within 10 cm of the left subclavian artery, or for dissection flaps extending through the arch into the descending thoracic aorta, to treat malperfusion or reduce late distal aortic complications.^{1,5}

Hemiarch replacement is efficient, effective, and safe, and therefore is the most common approach for emergent ATAAD repair.⁶ Nonetheless, more extensive arch replacement into zones 1 through 3 (Figure 2), with or without the frozen elephant trunk procedure, is increasingly used at academic centers for patients with arch dissection, distal entry tears, arch dilation, or concerns for progression risk, with acceptable outcomes.^{7–10} To date, comparison studies of extended or total arch versus hemiarch have mixed results regarding early and late mortality and need for reoperation, suggesting that a selective individualized approach is warranted.^{7,10–15}

Cannulation Strategies

To safely establish cardiopulmonary bypass (CPB) in the setting of ATAAD, careful consideration must be given to several key factors, such as the location of the primary intimal tear, the degree of hemodynamic instability, the urgency of the intervention, the technical ease and safety of cannulation, and the need for cerebral protection.

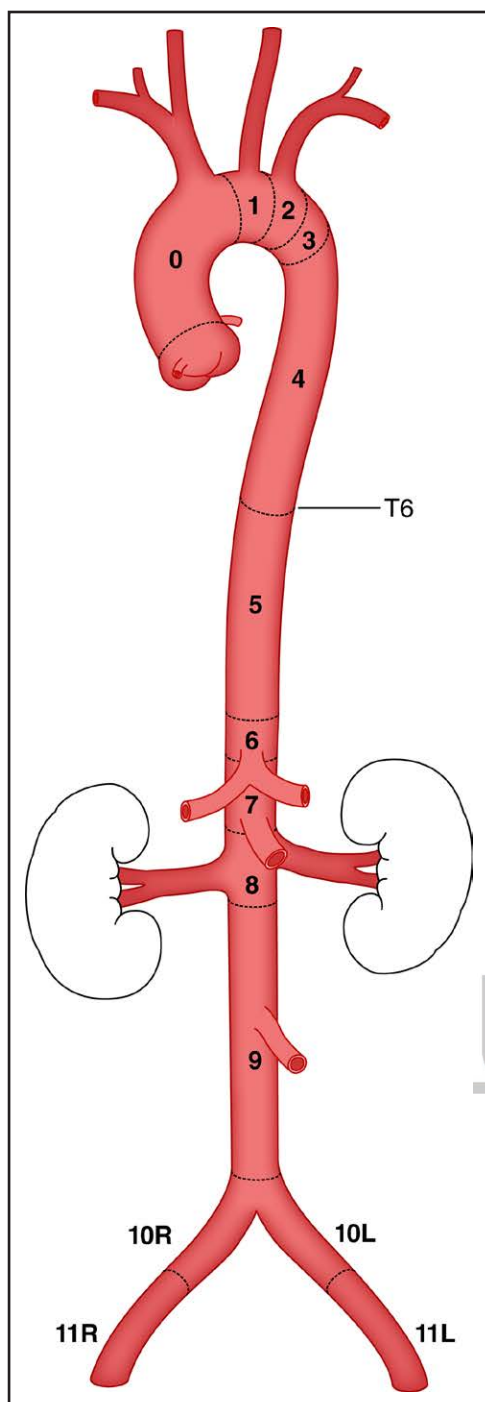


Figure 2. Aortic zones.

The choice of cannulation site may have a considerable effect on perfusion dynamics and surgical outcomes, as well as on the sites available for patient monitoring by the anesthesiologist. The femoral site is the traditional choice for cannulation, but the American College of Cardiology/AHA guidelines¹ consider axillary artery cannulation a reasonable alternative to femoral artery cannulation, when feasible, to reduce the risks of retrograde malperfusion or stroke.^{16–18} Innominate artery cannulation is also a reasonable alternative to femoral or

axillary cannulation.¹ Both axillary and innominate artery cannulation enable antegrade cerebral perfusion (ACP) during circulatory arrest to improve neurologic protection and reduce stroke risk.^{16–22} This is accomplished in the majority of cases by sewing a Dacron graft onto the artery as a conduit rather than using direct cannulation, thereby allowing antegrade blood flow to the brain that more closely mimics physiologic circulation.

An alternative to femoral and axillary cannulation is direct aortic cannulation. Direct aortic cannulation using the Seldinger technique is an effective and safe strategy if the true lumen is easily accessible.^{23–25} Intraoperative transesophageal echocardiography or epiaortic ultrasound is commonly used to ensure correct placement of the wire and cannula within the true lumen of the aorta. This approach allows for quick entry and implementation of CPB and does not require manipulation of additional vessels. Like axillary cannulation, direct aortic cannulation is a safe approach that may reduce in-hospital mortality and reduce stroke compared with femoral cannulation.^{26,27} Combinations of these approaches may also be considered; for example, when unreasonably high line pressures are noted with axillary or innominate artery cannulation, inflow can be split between the femoral site and the upper-body site. Likewise, in the setting of arch work, a side arm off the arch graft may be used to provide systemic (lower-body) flow while the proximal portion of the procedure is completed.

Along with these cannulation strategies, femoral artery cannulation is an expedient and accessible option for ATAAD, especially in patients with a previous sternotomy or hemodynamic instability, when rapid institution of CPB is paramount.^{19,28} Although logistically simple, femoral cannulation delivers retrograde aortic perfusion, which has been associated with a heightened risk of malperfusion, extension of the dissection flap, and retrograde embolization of atherosclerotic plaque.^{16–22} These complications may compromise cerebral and visceral perfusion.

Hypothermic Circulatory Arrest

HCA is used during surgical repair of ATAAD to facilitate adequate visualization of the surgical field during open distal anastomosis at the time of proximal aortic replacement. Several cerebral protection strategies may be used during HCA, including deep hypothermia. These strategies may be used in conjunction with cerebral perfusion strategies, such as ACP or retrograde cerebral perfusion (RCP), and pharmacologic interventions that reduce the cerebral metabolic rate (CMR_{O_2}).

Hypothermia is the primary cerebral protection strategy when the cessation of blood flow is required for surgical intervention. Benefits of hypothermia stem from its ability to reduce CMR_{O_2} , reduce free radical generation and inflammation, and inhibit excitotoxicity and

apoptosis.^{29,30} Every 1 °C reduction in brain temperature confers a reduction in CMRO₂ of 6% to 7%.²⁹ Profound and deep hypothermic temperatures (<14 °C and 14 °C to 20 °C, respectively) have been used for cerebral protection for decades.³¹ In general, the degree of hypothermia has not been shown to affect neurologic outcome in the Society of Thoracic Surgeons database, the International Registry of Acute Aortic Dissection, or the German Registry for Acute Aortic Dissection Type A.^{16,32,33} However, levels of deep hypothermia have been found to have deleterious systemic effects, such as coagulopathy, arrhythmias, vasoconstriction, impaired wound healing, and electrolyte disorders.³⁴ In addition, deep to profound hypothermia alone may adequately protect the brain from profound neurologic sequelae when used for ≈30 minutes, but this may not allow adequate time for complex surgical repairs.³⁵

Using moderate or mild levels of hypothermia (20.1 °C–28 °C or 28.1 °C–34 °C, respectively) with protective cerebral perfusion strategies is increasingly applied, with findings illustrating safety, improved outcomes, and acceptable neurologic and visceral organ protection.^{36–39} Moderate hypothermia was associated with shorter CPB times, lower mortality, and fewer neurologic sequelae.^{34,40} However, more high-quality prospective research is needed in this area.

Conductive brain cooling can be accomplished with topical application of ice packs directly to the patient's head. This technique is used to reduce passive rewarming of the brain by the surrounding intraoperative environment and to provide direct reductions in brain temperature.⁴¹ Widely used techniques such as ACP or RCP to maintain brain perfusion have demonstrated definitive improvement in patient outcomes, whereas conductive brain cooling has not consistently demonstrated the same degree of protection.⁴¹ In addition, there is a risk of injury to surrounding tissues, and the application and removal of ice packs pose a risk of interrupting cerebral monitors, such as cerebral oximetry sensors.

Cerebral Perfusion

Due to the limitations of hypothermia alone for adequate cerebral protection, RCP and ACP are used to protect against neurologic injury during HCA. RCP and ACP provide continued cerebral perfusion during HCA, but each of these methodologies has unique limitations.

During RCP, blood flow is delivered through a catheter positioned within the snared superior vena cava. Recommended flow rates are typically maintained between 300 and 500 mL/min, with corresponding central venous pressures in the range of 25 to 30 mm Hg.⁴² RCP is most often used in conjunction with deep HCA, generally at core body temperatures of 12 °C to 20 °C, while delivering blood cooled to ≈10 °C to the cerebral vessels. This technique is typically

restricted to relatively brief HCA periods, ideally ≤30 minutes, because the risk of neurologic complications increases significantly when perfusion exceeds 40 minutes.⁵ RCP has demonstrated neuroprotective benefits through maintenance of cerebral hypothermia and by flushing air and particulate emboli retrograde from the cerebral circulation.

ACP may be administered unilaterally by clamping the base of the innominate artery while perfusing through the axillary or innominate artery cannula or bilaterally through catheters inserted into the left and right common carotid arteries. Blood flow is generally targeted at ≈10 mL/kg per minute, with perfusion pressures measured at the radial artery maintained between 40 and 60 mm Hg, and perfusate temperatures ranging between 10 °C and 18 °C.⁴³ ACP has gained momentum as the preferred strategy for cerebral protection in ATAAD when axillary or innominate cannulation is used.⁴⁴ Advantages of ACP are that it maintains physiologic blood flow, is compatible with moderate hypothermia (20 °C–28 °C) during HCA, and provides reliable cerebral protection during HCA periods that exceed 40 minutes, making it the superior choice for complex or prolonged repairs.⁴³ Both RCP and ACP have been shown to improve cerebral protection in ATAAD surgical repair.

Nonetheless, the optimal cerebral perfusion strategy for ATAAD remains debated, and the choice varies by institution. Studies using the Society of Thoracic Surgeons database found that RCP was associated with a reduced risk of stroke in ATAAD; for arch repair in ATAAD, both ACP and RCP were recommended to reduce stroke and mortality.^{16,44} The American College of Cardiology/AHA guidelines¹ recommend ACP and RCP as reasonable adjuncts to reduce neurologic injury during ATAAD repair. With respect to unilateral versus bilateral ACP, no clinically significant advantages were found for implementing bilateral ACP even in the setting of total arch repair in ATAAD.^{45–48}

Monitoring Strategies

Arterial Access

Arterial monitoring ideally provides continuous and accurate measurements of cerebral and systemic perfusion pressures. However, the optimal anesthetic monitoring technique for the different cerebral perfusion strategies has not been identified in any major study; therefore, institutional differences exist, and each cannulation approach has distinct advantages.^{34,49} Arterial cannulation in the left upper extremity provides uninterrupted blood pressure measurements if the right axillary artery or innominate artery must be clamped during CPB cannulation. Arterial monitoring of the right upper extremity provides an accurate measurement of cerebral perfusion pressures during HCA with ACP⁵⁰; however, right upper extremity pressures may be interrupted or inaccurate if

the right axillary artery is cannulated for ACP. Femoral arterial pressure monitoring provides accurate measurements of central aortic pressures when compared with radial arterial pressures.⁵¹ Hence, a combination of these arterial pressure monitoring techniques can be used depending on the planned surgical repair approach of ATAAD.³⁴ Ideally, both femoral and right upper extremity arterial pressures are monitored to allow for central and cerebral pressure monitoring during planned HCA with ACP, with a target blood pressure of 40 to 60 mmHg for ACP. In addition, RCP requires monitoring of central venous pressure, with 25 to 30 mmHg considered adequate for retrograde flow to the brain.

Cerebral Monitoring

Various methods for monitoring the adequacy of HCA and cerebral perfusion have been used over the years, with the most common monitoring tools being near-infrared spectroscopy (NIRS), electroencephalography (EEG), and transcranial Doppler. Transcranial Doppler has specific advantages and disadvantages in cerebral monitoring and is mainly used in research applications. The most commonly used methods for cerebral monitoring in clinical practice are NIRS and processed EEG.⁵⁰

In NIRS, a probe placed on the forehead transmits near-infrared wavelengths of light into the cranium and, using known absorption spectra of oxygenated and deoxygenated hemoglobin, provides noninvasive, continuous monitoring of regional cerebral oxygen saturation ($r\text{ScO}_2$) in the anterior areas of the brain. Oxygen saturation of the anterior and (less reliably) the middle cerebral arteries are monitored by NIRS.⁵² The tissue being sampled includes a mixture of venous and arterial blood. Because 70% to 80% of cerebral blood is venous, $r\text{ScO}_2$ readings indicate the balance between regional cerebral oxygen supply and demand.⁵³ In general, a $\approx 20\%$ reduction from the preinduction/preoxygenation baseline or a saturation $< 50\%$ is considered clinically significant because desaturations in NIRS have been linked to postoperative neurologic injury; these changes warrant investigation for inadequate cerebral perfusion.^{53,54} Changes in $r\text{ScO}_2$ can provide warning of inadequate cerebral perfusion due to arterial or venous cannula malposition and information on the adequacy of cerebral perfusion during selective ACP or RCP.⁵³ Patient factors, including low cardiac output, cerebrovascular disease, anemia, or pulmonary disease, may reduce cerebral arterial oxygen supply, resulting in low $r\text{ScO}_2$; in addition, confounders that may affect accurate interpretation include hypothermia, alkalosis, and hypocapnia, making NIRS less reliable for definitive identification of postoperative neurologic sequelae.⁵³ Because the exact cause or causes of a decrease in $r\text{ScO}_2$ are not always immediately evident, interventions can be performed to address patient and pump issues, often simultaneously.

Examples include repositioning the head, verifying the cannula position, increasing pump flow, increasing mean arterial pressure, normalizing arterial carbon dioxide tension, deepening anesthesia, increasing FiO_2 , increasing hematocrit, and providing pulsatile perfusion (Figure 3), highlighting the importance of the anesthesiologist and perfusionist working together on the multidisciplinary team.

Traditional EEG has been performed in the operating room, but processed EEG indices are more commonly used.⁵⁵ A processed EEG can be used to determine anesthetic depths.⁵⁶ For example, spectral edge frequency, a quantitative EEG metric that identifies the specific frequency below which a certain percentage (usually 90% or 95%) of the total EEG power is concentrated, can provide valuable information regarding anesthetic depth. An isoelectric processed EEG or EEG waveform before HCA indicates a reduced CMRO_2 ,⁵⁵ which is protective against cerebral injury; however, the clinical benefits with regard to reducing delirium and cognitive dysfunction remain unclear.

Protective Strategies During HCA: Pharmacology

Protective strategies during circulation arrest are centered around optimizing cerebral metabolic and perfusion needs. Pharmacologic agents are used to reduce the CMRO_2 , promote electrocortical suppression, improve cerebral blood flow, and reduce intracerebral pressure during HCA; however, there is little evidence to support that these modalities provide clinical benefit.^{34,57}

Barbiturates have historically been used to reduce CMRO_2 , produce electrocortical suppression, and reduce apoptosis in laboratory studies; however, clinical efficacy has not provided reproducible outcomes.⁵⁷ Similarly, propofol reliably produces electrocortical suppression and lowers CMRO_2 , without clear clinical benefit. Intracerebral pressure-reducing agents include barbiturates, mannitol, and etomidate. Corticosteroids have been used to reduce cerebral edema because of their anti-inflammatory capabilities. A lidocaine dosage of 4 mg/kg before HCA and 2 mg/kg during reperfusion reduced CMRO_2 in clinical studies by blocking sodium channels³⁴; clinical studies of neurologic outcome effects are mixed, with one study showing improved short-term outcomes,⁵⁸ whereas another study found worsened outcomes in patients with diabetes.⁵⁹ No clear method for pharmacologic cerebral perfusion has been identified, and more research is needed.

There are myriad approaches to repair of an ATAAD, including differences in the extent of repair, cannulation, perfusion, and cerebral protection. This is a dynamic process, with preoperative, perioperative, and intraoperative inflection points requiring real-time discussion among team members (Figure 4).

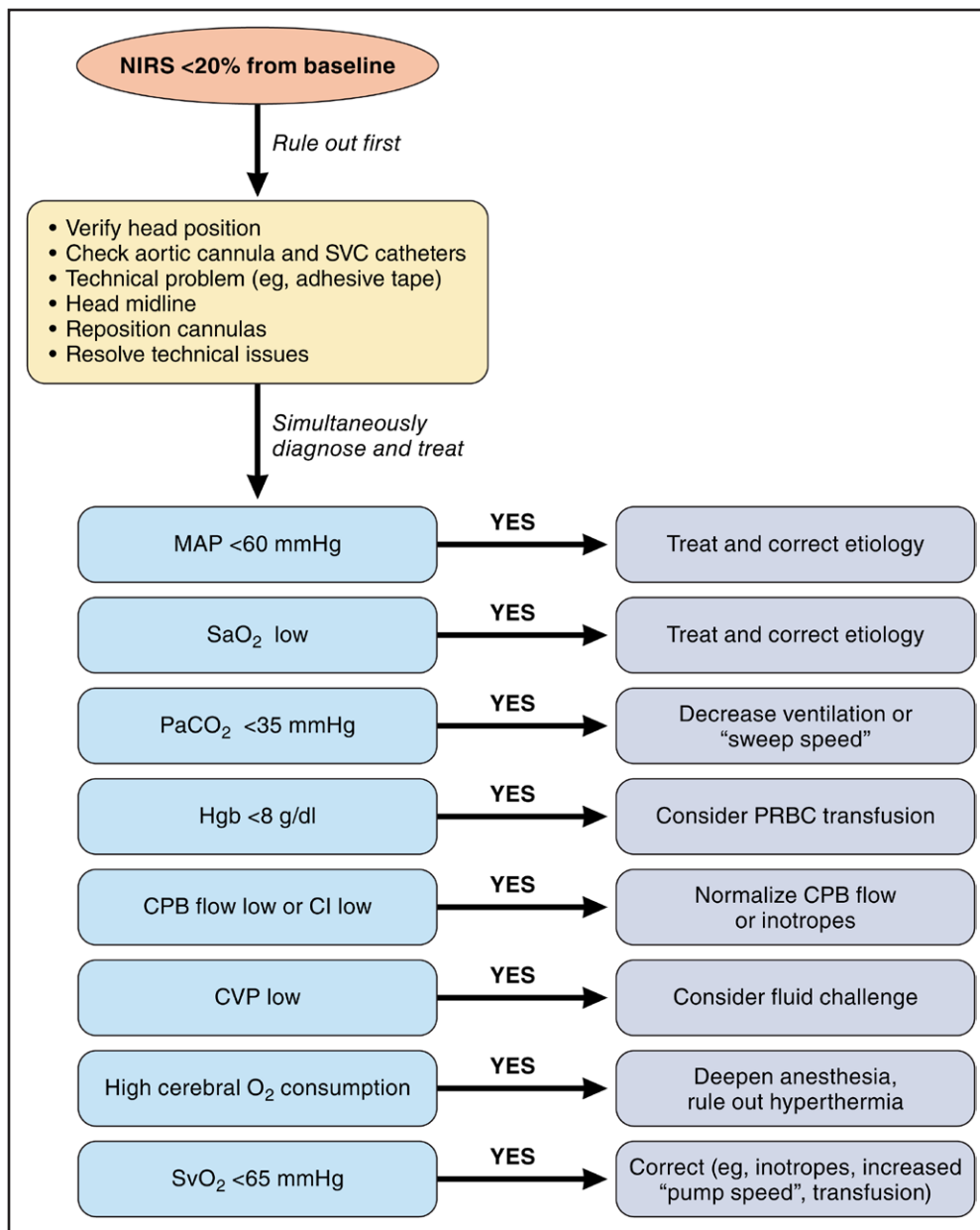


Figure 3. Near-infrared spectroscopy algorithm.

CI indicates cardiac index; CPB, cardiopulmonary bypass; CVP, central venous pressure; Hgb, hemoglobin; MAP, mean arterial pressure; NIRS, near infrared spectroscopy; PaCO₂, arterial partial pressure of carbon dioxide; PRBC, packed red blood cell; SaO₂, arterial oxygen saturation; SVC, superior vena cava; and SvO₂, mixed venous oxygen saturation.

SURGICAL REPAIR OF THORACIC AND THORACOABDOMINAL AORTIC PATHOLOGY

Risk Assessment, Perioperative Testing, and Patient Optimization

Risk assessment for thoracoabdominal aortic repair must account for the procedure's high perioperative risk profile, with major complications including cardiac events, pulmonary compromise, renal injury, and neurologic deficits, such as spinal cord ischemia.^{60–63} The

risk of persistent paraplegia is particularly notable, and is associated with diabetes, previous percutaneous coronary intervention, chronic kidney disease, tobacco use, symptomatic aortic disease, and the extent of aortic repair (especially Crawford extent II).⁶⁴ Comorbidities such as coronary artery disease, congestive heart failure, and chronic lung disease are frequently present, underscoring the importance of thorough evaluation and risk stratification.^{1,62,65} Scoring systems and nomograms, including those derived from multivariable models, can facilitate personalized risk prediction and guide perioperative planning.^{62,64}

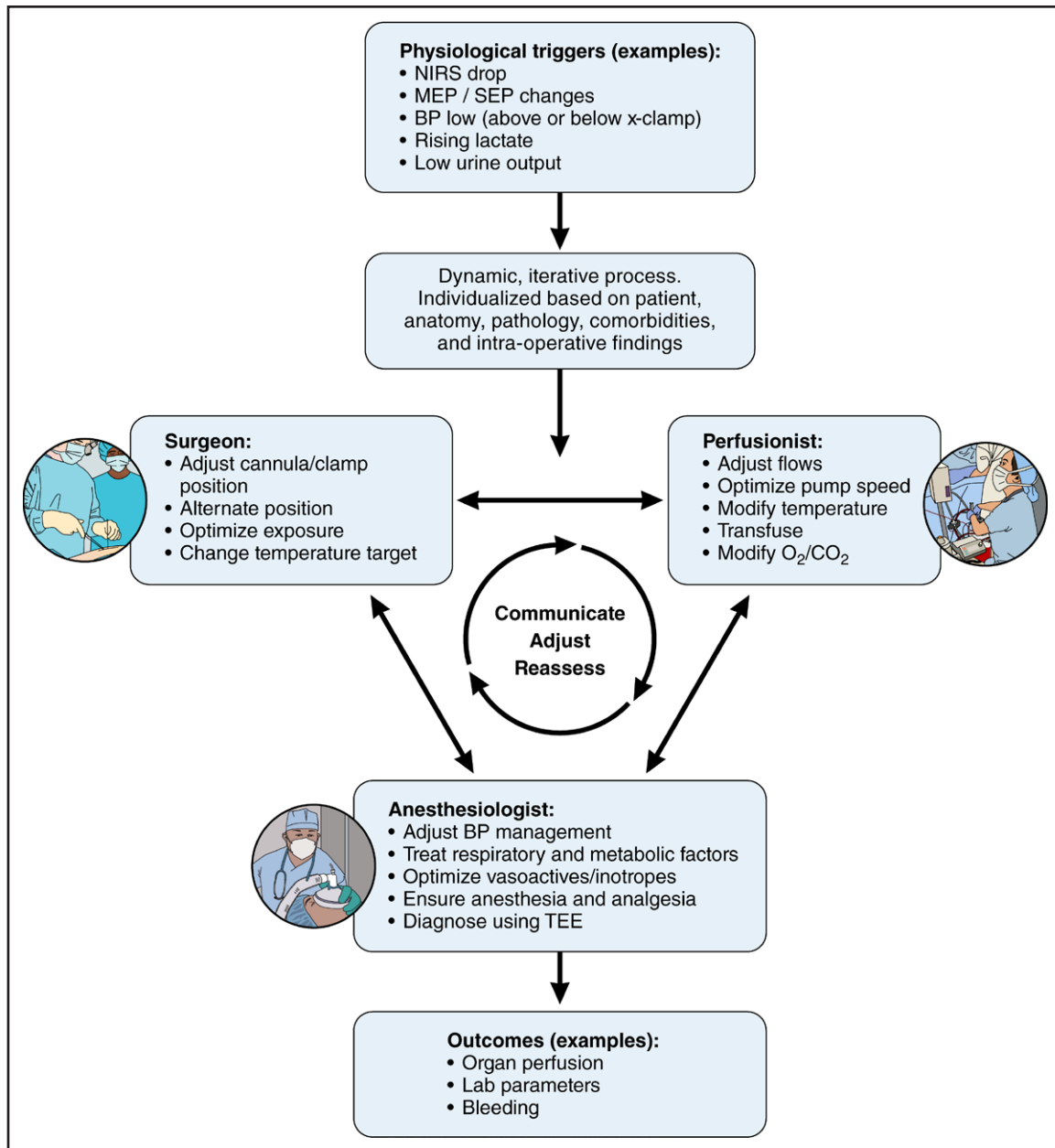


Figure 4. Hypothetical illustrative case.

Surgeon's plan for ascending aortic and arch (zone 2) repair with deep hypothermic circulatory arrest in a patient with acute type A aortic dissection. BP indicates blood pressure; DHCA, deep hypothermic circulatory arrest; MEP, motor evoked potential; NIRS, near infrared spectroscopy; SEP, sensory evoked potential; and TEE, transesophageal echocardiography.

Comprehensive preoperative testing, ideally in the elective setting, is tailored to the patient's risk profile. Computed tomography angiography, ideally with 3-dimensional reconstruction, is used to evaluate the aortic disease, and also provides valuable information regarding atherosclerotic burden in various vascular beds. Cardiac evaluation includes ECG, echocardiography to evaluate cardiac and valvular function, and either noninvasive stress testing or coronary angiography. Angiography is preferred in individuals with poor functional capacity or clinically significant risk factors, such as known coronary artery disease, heart failure,

cerebrovascular disease, diabetes, or chronic renal insufficiency.^{1,62,65} Cardiology consultation and presurgical treatment intervention when appropriate is indicated for active cardiac conditions (eg, unstable angina, decompensated heart failure, severe valvular disease, clinically significant arrhythmia). Pulmonary assessment may include pulmonary function tests and arterial blood gases, especially in patients with chronic lung disease or a history of smoking, because these are strong predictors of postoperative respiratory complications.^{1,62,65} Renal function can also be evaluated preoperatively with a baseline creatinine and estimated glomerular filtration rate.^{1,65}

Additional individualized testing may be warranted, such as Holter monitoring, carotid duplex, or neurocognitive studies in select cases.⁶⁵

Patient optimization strategies are essential to reduce perioperative morbidity and mortality. Optimization strategies to consider include initiation of statin therapy and uptitration of β -blockers in at-risk patients.⁶² Preoperative testing may reveal evidence of anemia, and in the elective setting, early intervention such as iron therapy with or without the administration of erythropoietin may be helpful in decreasing the need for intraoperative or postoperative transfusion. Smoking cessation is strongly advised and prehabilitation considered (including pulmonary rehabilitation and exercise programs) for patients with pulmonary risk factors, advanced age, or heart failure.^{62,66}

Monitoring Strategies

Monitoring choices are heavily dependent on the locations of aortic pathology, expected surgical approach and extent, and perfusion approaches, and therefore require close communication between the surgical and anesthetic teams. Standard anesthetic monitors, including a 5-lead ECG and temperature monitors at sites most pertinent to the perfusion approach, are used.⁶⁷ Large-bore intravenous access (peripheral and central) is needed for open aortic surgery.

Multiple-site invasive arterial pressure monitoring, which may vary depending on the surgical approach and at different stages of a procedure, has been given a Class 1, Level of Evidence C recommendation.⁵ Central (femoral)-to-radial pressure gradients are common in patients undergoing cardiac surgery, and femoral arterial pressure monitoring is preferred in the early postoperative phase. Therefore, it is also reasonable to preferentially use femoral arterial pressure during any phase of the procedure in which it is expected to reflect central pressure. Continuous cardiac output monitoring by pulmonary artery catheterization or arterial waveform analysis could be considered intraoperatively, in anticipation of postoperative need, in patients for whom preoperative evaluation, intraoperative plans, or intraoperative events suggest a risk of low intraoperative or postoperative cardiac output.

As was described for surgery on the ascending aorta, intraoperative transesophageal echocardiography remains an essential tool in interventions of the thoracic and thoracoabdominal aorta, including identification of the true and false lumens as well as real-time assessment of cardiac function.^{5,68}

The extent of aortic disease and surgical approach affect the risk of spinal cord injury due to hypoperfusion. Cerebrospinal fluid drainage has been given a Class 1, Level of Evidence B recommendation for open thoracoabdominal aortic aneurysm (TAAA) replacement.¹ Cerebrospinal fluid drainage directly reduces intrathecal pressure and increases spinal cord perfusion pressure

(spinal cord perfusion pressure=mean arterial pressure—spinal cord fluid pressure). Cerebrospinal fluid is typically drained at a rate of 5 to 10 mL/h to maintain an intraspinal pressure <10 mm Hg. There is no standard method for monitoring spinal cord hypoperfusion, but motor evoked potential or somatosensory evoked potential neuromonitoring allows continuous, real-time assessment of spinal cord functional integrity and is “encouraged” in European guidelines without a formal recommendation.⁵ Intraoperative changes in either motor evoked potential or somatosensory evoked potential could be used to modify the number of segmental vessels (ie, intercostal or lumbar arteries) reimplanted during the procedure. In a 2023 survey by the Aortic Association,⁶⁹ 60.4% of responding centers used either motor evoked potential or somatosensory evoked potential monitoring, with use varying by Crawford classification ([Supplemental Materials](#)). NIRS was used in 70.8% of centers, and 97.9% used cerebrospinal fluid drainage.⁶⁹ Motor evoked potential and somatosensory evoked potential neuromonitoring can be affected by some anesthetic and paralytic agents, and therefore require close multidisciplinary communication for successful use.

Intraoperative and immediate postoperative monitoring can also include laboratory or point-of-care testing of coagulation status to aid in decision-making regarding transfusion as well as other adjuncts to address potential postoperative bleeding.

Special Considerations for Lung Isolation

Lung isolation (selective right-lung ventilation) is frequently needed, particularly for thoracotomy approaches to the thoracic aorta and thoracoabdominal aorta. Right-lung ventilation facilitates surgical exposure while maintaining oxygenation and ventilation during stages of the operation without full-flow CPB.

Right-lung ventilation is typically achieved using a left-sided double-lumen endotracheal tube (DLT) or a left bronchial blocker due to ease of placement and avoidance of obstruction of the right upper lobe; placement of either device can be difficult in patients with aortic airway compression secondary to aneurysmal disease. In this setting, a right-sided DLT may be used. These methods have not been compared prospectively in TAAA surgeries, but meta-analyses in patients undergoing thoracic surgery reveal advantages in lung collapse and displacement during isolation using DLT and less incidence of hoarseness, sore throat, and tracheal injury when using a bronchial blocker.^{70,71} Additional advantages of using a bronchial blocker include avoiding potential exacerbation of dysphagia aortica or postsurgical recurrent laryngeal nerve injury by a DLT. In addition, when postoperative ventilation is needed, removal of the patient's airway to exchange the DLT for a single-lumen endotracheal tube can risk periods of apnea. In support of using DLT,

suctioning blood or secretions from the isolated lung is more effective with a DLT than a bronchial blocker.

Technical pros and cons of lung isolation methods aside, the mode of ventilation and use of lung-protective ventilation strategies play an important role in mitigating the risk of postoperative pulmonary dysfunction,⁷² which has a high incidence among patients undergoing thoracoabdominal aortic surgery.⁷³ During stages of surgery when full or partial oxygenation and ventilation support can be provided, close communication among the surgeon, anesthesiologist, and perfusionist can further optimize patient care pathways.

Choice of Perfusion Approach

A major source of morbidity in open TAAA repair is cross-clamping of the thoracoabdominal aorta, which induces proximal hypertension and distal ischemia. Distal perfusion methods during TAAA repair have been developed to reduce lower-body ischemia and subsequent complications, particularly paraplegia.^{74–77} Perfusion strategies for open TAAA repair can vary substantially and depend on the extent of the repair, the conduct of the operation, and institutional and surgeon preferences. Distal perfusion strategies include no perfusion (clamp and sew), passive shunts, left heart bypass, CPB, and, more recently, extracorporeal membrane oxygenation (ECMO).^{60,63,74,77–80}

Clamp and sew, a strategy without lower-body perfusion cannulae, can be considered when the procedure can be performed expeditiously for extent I, III, or IV aneurysms, as well as in emergent scenarios, such as acute dissection and rupture.⁶³ Passive Gott shunts, which are rarely used, involve a heparin-bonded cannula, most commonly placed in the ascending and descending aorta⁸¹; these shunts do not allow for flow measurement. A left heart bypass circuit uses a pump to deliver oxygenated blood drained from the left atrium into either the femoral artery or distal aorta, providing native cardiac output above the clamp and maintaining distal perfusion during proximal aortic repair.⁷⁷ In contrast, CPB and ECMO drain deoxygenated blood from the central venous circulation and return extracorporeally oxygenated blood to the arterial circulation.⁷⁸ This is frequently achieved through cannulation of the femoral artery and vein, although various other cannulation strategies are feasible.

Left heart bypass, CPB, and ECMO typically rely on partial drainage of either the left atrium or the central venous system while maintaining sufficient left ventricular filling to adequately perfuse the upper body, including the coronary arteries and the brain. This can be monitored in real time by the cardiac anesthesiologist using transesophageal echocardiography, which allows simultaneous monitoring of efficient drainage while maintaining adequate left ventricular preload. Balancing efficient drainage in the face of optimizing preload highlights the needed close communication between

anesthesia and perfusion. Temperature control can be performed through the circuit, allowing for active cooling and rewarming. Left heart bypass and ECMO can be used with lower anticoagulation targets (activated clotting time >250) and have a closed circuit that does not allow for cardiectomy suction cannulas. CPB requires full anticoagulation (activated clotting time >400) with the availability of cardiectomy suction cannula return for blood salvage.⁷⁸ CPB use is mandatory when proximal control with a clamp is not feasible and HCA is used.⁸²

CONCLUSION, KNOWLEDGE GAPS, AND FUTURE DIRECTIONS

Optimal outcomes in open thoracic and thoracoabdominal aortic surgery depend on precise coordination among surgeons, anesthesiologists, and perfusionists. This coordination and teamwork have previously been examined in the broader context of cardiac surgery in a 2013 scientific statement from the AHA.⁸³ In that review, Wahr et al⁸³ examined teamwork skills, with a focus on communication, pointing out the contribution of communication issues to teamwork failures, and the effects of these failures on patient outcomes. Each discipline in the operating room contributes essential expertise. The preoperative phase requires comprehensive risk assessment, optimization of comorbidities, and anticipation of procedure-specific challenges. Intraoperatively, integration of case-specific appropriate multimodal monitoring (eg, transesophageal echocardiography, NIRS, spinal cord neuromonitoring) enables dynamic assessment of perfusion and neurologic integrity. Cannulation strategy, perfusion method, temperature management, and cerebral protection must be tailored to the anatomy, dissection pattern, and hemodynamic stability of each patient. Communication is key during transitions among circulatory arrest, cerebral perfusion, and rewarming phases. The multidisciplinary aortic team model provides the organizational framework for this collaboration, emphasizing real-time decision-making and flexibility in response to evolving intraoperative conditions. Such team-based execution transforms individual technical excellence into integrated, system-level performance.

Hybrid and endovascular techniques are redefining the scope of aortic repair by expanding treatment to high-risk and anatomically complex patients. Hybrid procedures that combine open debranching with thoracic endovascular aortic repair illustrate the merging of open and minimally invasive paradigms. These operations require meticulous planning, coordination of perfusion strategies, and anesthetic management capable of adapting to alternating open and endovascular stages. Adjuncts such as left-heart bypass, ECMO, and ACP are increasingly used to maintain end-organ perfusion during hybrid procedures. As branched and fenestrated stent graft technologies evolve, the boundaries between traditional cardiac and vascular surgery will continue to blur. This progression reinforces

the need for hybrid Centers of Excellence where interdisciplinary communication, advanced imaging, and real-time perfusion management converge.

Future investigations should prioritize multicenter prospective studies to define best practices in cerebral and spinal cord protection, perfusion management, and perioperative monitoring. Incorporating data from translational research, such as biomarkers of ischemia–reperfusion injury and neurologic risk, may allow for earlier detection of end-organ compromise. Equally important is the development of multidisciplinary training programs and simulation-based curricula to improve intraoperative communication and crisis management. As the field progresses toward increasingly complex hybrid procedures as well as the increasing incidence of reoperative procedures, the shared goal remains unchanged: to deliver patient-centered, evidence-based, and team-driven care that reduces mortality and enhances long-term outcomes in aortic surgery.

ARTICLE INFORMATION

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Disclosures

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*Modest.

†Significant.

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*Modest.
†Significant.

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