Anesthetic Management in Open Descending Thoracic Aorta Surgery

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Main Messages

1. Open repair of the descending aorta is performed to repair a spectrum of aortic diseases including aneurysms, penetrating atherosclerotic ulcers, intramural hematomas and aortic dissections
2. Techniques used for descending aorta repair include 'clamp-and-sew,' left heart bypass, partial or complete cardiopulmonary bypass and deep hypothermic circulatory arrest
3. Anesthetic management during open descending aortic repair includes improving surgical exposure, optimizing end-organ perfusion, maintaining hemodynamic stability, monitoring extra-corporeal circulation and correcting coagulopathy
4. Trans-esophageal echocardiography is helpful in confirming the pre-operative diagnosis, evaluating for progression of the known aortic disease and optimizing cardiac preload, afterload and contractility
5. Descending aorta repair is associated with range of complications including stroke, paraplegia, myocardial ischemia, lung injury and renal failure. The incidence of each complication is dependent on the location and extent of the aortic pathology as well as the surgical technique utilized
6. Perioperative strategies to decrease the incidence of paraplegia include the use of lumbar spinal drains to optimize spinal cord perfusion pressure by increasing mean arterial pressure and draining cerebrospinal fluid

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Aneurysmal disease of the thoracic aorta has an incidence of approximately six per 100,000 person-years and contributes disproportionately to morbidity, mortality and cost of healthcare in the United States [1, 2]. About 40% of thoracic aortic aneurysms affect the descending thoracic aorta [1]. The complexity of the descending thoracic aortic pathologies that warrant open surgical

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repairs in combination with major presenting comorbidities that patients who have thoracic aortic disease frequently have means that this surgical population is at particularly high risk for developing significant postoperative neurologic, pulmonary and cardiovascular complications. These surgeries therefore present unique challenges for the anesthesiologist and the rest of the perioperative care team with regards to mitigating risks and preventing complications.

The descending thoracic aorta is anatomically defined as beginning immediately distal to the origin of the left subclavian artery. These aneurysms can further be localized within the descending thoracic and abdominal aorta and are often characterized using the Crawford classification scheme (Fig. 10.1).

The etiology of aneurysmal disease is thought to begin with the degeneration of connective tissue in the aortic tunica media due to aging, hypertension, or connective tissue disorders or a combination of these. The relationship between atherosclerosis and development of thoracic aortic aneurysms (TAAs) has not been conclusively determined, but the two are frequently known to coexist and share several risk factors [2].

Aortic dissection involves an intimal tear that results in blood flow through the medial layer of the aorta, resulting in separation of the medial layer to create a true and a false lumen within the aorta. A comprehensive natural history study conducted at Yale University revealed that descending TAAs grow more than twice as fast as ascending aortic aneurysms and are significantly more likely to dissect or rupture once they reach a critical dimension [3]. Based on this and other population studies, recent guidelines recommend repairing descending TAAs electively when they measure 5.5–6.0 cm in diameter and to repair at even smaller diameters in patients who have known genetic connective tissue disorders [4, 5]. Intramural hematomas (IMH) and penetrating atherosclerotic ulcers (PAU) are distinct from aneurysmal disease but can also progress to aortic dissection or aortic rupture. IMH results from bleeding from the vasa vasorum into the tunica media without intimal disruption. PAU results from an atherosclerotic plaque that erodes through the layers of the aorta, leading to hematoma formation and rupture.

Open surgical repair of descending TAAs began in the 1950s when Drs. Gross, Swan, Lam

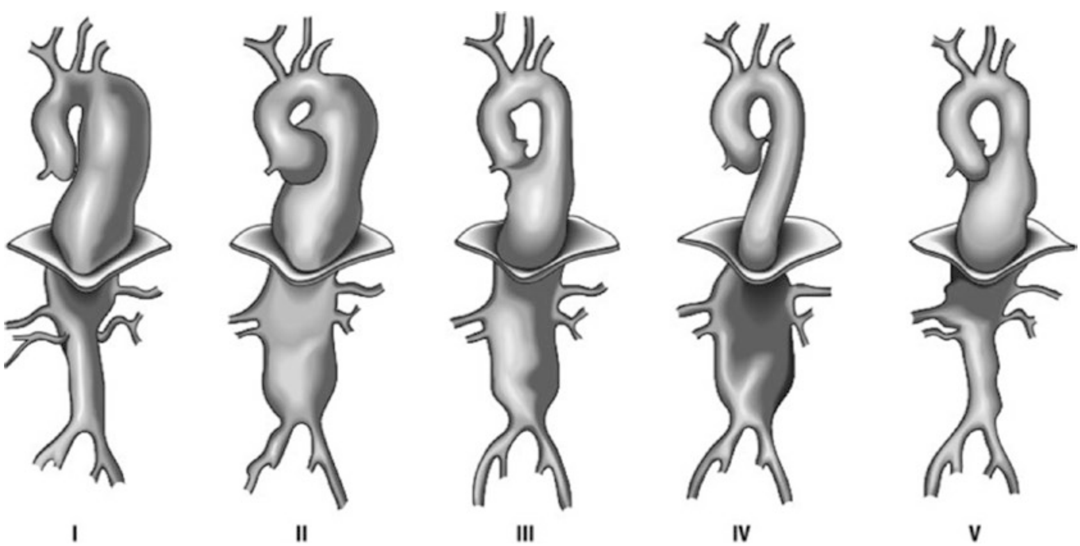

Fig. 10.1 Crawford classification of thoracoabdominal aneurysms, modified by Safi. Black S.A., Brooks M.J., Wolfe J.H.N. (2007) Thoracoabdominal Aneurysms. In: Liapis C.D., Balzer K., Benedetti-Valentini F., Fernandes e Fernandes J. (eds) Vascular Surgery. European Manual of Medicine. Springer, Berlin, Heidelberg. With Permission of Springer

and Debakey pioneered the techniques of resecting diseased portions of the descending aorta and replacing them with synthetic grafts [6]. Over the next four decades, a variety of techniques were developed to improve upon this general procedure in order to reduce associated complications. These enhancements included utilizing left atrial cannulation with perfusion to the distal aorta, partial cardiopulmonary bypass (CPB) through bifemoral cannulation, and complete cardiopulmonary bypass (CPB) combined with hypothermic circulatory arrest (HCA). The development of endovascular stent-grafts in the 1990s has further decreased the complications associated with descending TAA repair and the 2014 European Society of Cardiology guidelines recommend this as the primary approach in suitable candidates [5]. In patients with familial connective tissue disorders and those with anatomy precluding endovascular repair, open surgical repair can provide a durable therapeutic option.

Perioperative Management

The Preoperative Evaluation

A detailed assessment of preoperative physical condition and associated anesthetic risk is an essential part of perioperative planning for patients presenting for open descending TAA repair. Appropriate surgical candidates require a versatile anesthetic plan that addresses their presenting aortic disease process, coexisting medical conditions and the implications of surgical approach. A thorough history and physical examination should take place before surgery with a focus on cardiovascular, neurologic, pulmonary and renal conditions.

Cardiovascular

Given many overlapping risk factors for coronary artery disease and for development of TAAs, it is not surprising that most patients representing for repair of descending TAAs have a history of hypertension [7] and one-third have concurrent coronary artery disease [7, 8]. A comprehensive evaluation of cardiac function and risk for postoperative adverse cardiovascular events is therefore necessary. An electrocardiogram can provide information about the patient's baseline heart rhythm, new EKG changes, and any pre-existing arrhythmias. Transthoracic echocardiography is useful to evaluate for cardiac ventricular dysfunction and valvular pathology, both of which may influence the perioperative selection of pre-induction monitors and induction agents. Patients who are at increased risk for coronary artery disease may have poor functional capacity and may require pharmacologic stress testing and coronary angiography to evaluate and treat flow limiting coronary artery lesions prior to elective surgery [9].

Pulmonary

A history and physical exam can offer significant insight into the pulmonary status of most patients. For example, wheezing or a persistent cough may signify tracheal compression by the aneurysm, while hemoptysis can indicate communication between the aneurysm and the lungs. Patients with suspected pulmonary disease should undergo pulmonary function testing (PFTs) for risk stratification and to guide post-operative rehabilitation. Poor PFT results can indicate intolerance of one lung ventilation (OLV) and may necessitate cardiopulmonary bypass. Smokers should be counseled to stop at least 4 weeks before the date of surgery and should be referred to smoking cessation resources [10]. Computerized tomography (CT) or magnetic resonance imaging (MRI) is always performed for diagnosis and surgical planning, and the astute anesthesiologist should also evaluate these studies for potential impingement of the aneurysm on airway, esophagus and vascular structures. Impingement on the esophagus may be a relative contraindication to intraoperative monitoring with transesophageal echocardiography (TEE), and in this situation TEE monitoring should be a risk benefit balance weighed by the anesthesiologist—i.e. consider risk for aortic rupture secondary to TEE probe placement and manipulation.

Neurologic

Paraplegia and stroke are recognized as significant complications of descending TAA repair. The possibility of postoperative neurologic injury in the context of patient-specific risk factors should be discussed with the patient and family members. The preoperative exam should focus on establishing a neurologic baseline so that subtle postoperative changes indicative of spinal cord ischemia can be recognized readily. Recurrent laryngeal nerve (RLN) palsy is another complication of either the existence of a large descending TAA or as a consequence of injury during descending TAA repair [11]. Hoarseness or stridor should alert the perioperative physician to consider the possibility of this neurologic complication.

Renal

Preoperative renal insufficiency is an independent predictor of postoperative major morbid events and operative mortality after open surgical descending TAA repair [12]. Preoperative optimization of renal function includes intravenous hydration, minimizing the use of nephrotoxic contrast agents and correction of electrolyte abnormalities. All patients scheduled for open surgical descending TAA repair should undergo a serum chemistry evaluation. In patients with significantly impaired kidney function (e.g. GFR < 30 ml/min), renally cleared medications should be dosed appropriately and nephrotoxic medications should be substituted for alternative agents. The intraoperative mean arterial pressure (MAP) should be maintained above 65 mm Hg and perhaps higher in hypertensive patients to ensure kidney perfusion [13].

Intraoperative Monitors

Selection of hemodynamic monitors placed for intraoperative and postoperative management is influenced by individualized patient and procedural concerns, but hemodynamic monitoring should generally aim to track cardiac function, end organ perfusion and central neurologic function.

Blood Pressure Monitoring

Hemodynamic monitoring is an essential component of goal-directed intraoperative management. Both the aneurysm itself and the introduction of the aortic cross clamp can create zones of differential perfusion pressure along the aorta. Invasive arterial catheters ideally should be placed to measure the blood pressure in each zone (i.e. proximal and distal to the aneurysm and then proximal and distal to the aortic cross-clamp) to best optimize tissue perfusion. The right radial artery is ideally suited to measure blood pressure proximal to the more proximal aortic cross-clamp. Alternatively, a right radial arterial line can also be used to monitor anterograde cerebral blood flow administered via the right axillary artery if this technique is employed in conjunction with deep hypothermic circulatory arrest (DHCA). A second arterial line can be placed in the left radial artery if right axillary cannulation is employed so as to get accurate blood pressure monitoring on cardiopulmonary bypass. A femoral arterial line can be used to measure blood pressure distal to the aortic cross-clamp. It is particularly helpful to employ arterial blood pressure monitoring in both a radial and femoral artery if left heart bypass is utilized, as this will guide degree of bypass in balancing cerebral perfusion with perfusion distal to the aneurysm. The left radial artery is susceptible to inaccurate or redundant blood pressure readings if the aneurysm involves the left subclavian artery.

Cardiac Output Monitoring

A central venous line is necessary both to provide large-bore, central access and to monitor central venous pressure (CVP). CVP assessment can be used as a continuous monitor of right ventricular preload. Both a pulmonary artery catheter (PAC) and trans-esophageal echocardiography (TEE) may be used to monitor cardiac function. In contrast to the PAC which may not provide accurate measurements of pulmonary artery (PA) pressures during OLV and lateral positioning, TEE often can provide adequate direct visualization of right and left heart function. Doppler interrogation of a tricuspid regurgitation jet can be used to assess PA pressures. TEE can be used to confirm preoperative cardiac and aortic pathologies, but can also be used to evaluate for any intraoperative progression of aortic pathology or changes in right and left ventricular function, volume status, or changes in estimated pulmonary arterial systolic pressures. It can also be used as a continuous monitor to evaluate for left ventricular volume changes as well as for new regional wall motion abnormalities. The PAC is arguably more useful for postoperative monitoring than intraoperative monitoring if intraoperative TEE is concurrently used, but postoperatively a PAC may be useful for guiding fluid management, particularly in patients with reduced ejection fraction and/or marginal renal function.

Neurologic Monitoring

Intraoperative somatosensory evoked potentials (SSEP) and motor evoked potentials (MEP) are often used to monitor function in the sensory and motor spinal columns, respectively. MEP monitoring directly measures motor column function and potential poor perfusion but requires use of a balanced low dose volatile-intravenous anesthetic technique with sparing use of neuromuscular blockers. Both SSEP and MEP signal attenuation that remains abnormal after removal of the aortic clamp strongly correlates with postoperative paraplegia [14].

Stroke detected after descending TAA repair typically results from embolic phenomena during CPB or aortic cross-clamping and/or cerebral hemorrhage secondary to higher cerebral perfusion pressures occurring proximal to the aortic cross clamp. Cerebral oximetry, which uses infrared spectroscopy to determine the oxygen saturation of cerebral blood is often used during aortic surgery. Because measurements are limited to a small sampling region on the forehead, the cerebral oximeter is an unreliable monitor for focal ischemia but may be a relatively sensitive indicator of global hemispheric perfusion.

Induction of Anesthesia

At least one intra-arterial catheter should be placed prior to induction of general anesthesia for hemodynamic monitoring to avoid excessively high pressures during intubation and for overall hemodynamic monitoring in patients with reduced ejection fraction. Induction is generally performed using a combination of sedative hypnotics and opioids to accomplish two competing goals: the avoidance of myocardial depression and hypotension—which can result in tissue ischemia—and the prevention of tachycardia and hypertension—which can contribute to aortic wall stress and precipitate aneurysm rupture or propagate dissection. Esmolol, a short acting beta blocker, can also be administered immediately prior to periods of anticipated adrenergic stimulation, such as those that may occur with direct laryngoscopy.

Airway considerations in patients with large, proximal descending TAAs differs from those for patients with other aortic aneurysms due to the need for lung isolation for surgical exposure and because they may involve and distort the trachea, left main bronchus and pulmonary parenchyma. For this reason, radiologic studies delineating the anatomy of the aneurysm should be reviewed prior to surgery. Both compression and distortion of the left bronchial tree and rightward deviation of tracheobronchial structures by large aneurysms can occur. A left sided double lumen tube (DLT) is most commonly used for lung isolation to facilitate OLV, but a right sided DLT can be used when the aneurysm impinges upon the left main stem bronchus. A single lumen tube with a bronchial blocker or Univent (Teleflex Medical, Morrisville, NC) tube may be preferable when airway deviation complicates DLT placement [1]. However, bronchial blockers may be easily displaced throughout the case when the surgeons manipulate the left lung and the anesthesiologist may have to frequently reposition the bronchial blocker. Fiber-optic bronchoscopy should be performed after endotracheal intubation to confirm correct placement of the double lumen tube or bronchial blocker and to evaluate for airway deviation and aortobronchial fistulae.

Intraoperative Management

The anesthetic management during descending TAA repair focuses on allowing optimal surgical exposure, monitoring and optimizing end-organ perfusion, maintaining hemodynamic stability, replacing blood loss, correcting coagulopathy and generally mitigating risk for developing adverse postoperative outcomes. Common to all currently utilized surgical techniques for open repair of descending TAAs is a left posterolateral thoracotomy incision that requires right lateral decubitus positioning. An axillary roll should be used to protect the right brachial plexus, and pressure points must be covered with soft padding. The main surgical approaches to open descending thoracic aortic repair are outlined below with emphasis on their implications for anesthetic management.

"Clamp-and-sew"

Clamping the aorta proximal and distal to the aneurysm and repairing it without establishing distal perfusion is the earliest developed surgical approach to repairing descending TAAs (Fig. 10.2a). Because of the large hemodynamic swings typically associated with clamping and unclamping the aorta as well as distal ischemia, this technique is mostly reserved for expedient repairs of small, focal aneurysms [15]. The anesthesiologist should anticipate that the application of the aortic cross clamp can result in proximal hypertension, an increase in cardiac afterload and distal hypotension [16]. The placement of a Gott shunt, a small heparinized piece of tubing which allows passive aorto-aortic flow across the cross-clamp can be used to provide distal perfusion. Using blood pressure measurements from both a radial and femoral arterial line—i.e. proximal and distal to the aneurysm—and assessing TEE-measured indices of cardiac filling and contractility will allow vasoactive infusions to be titrated to optimize perfusion pressure on both sides of the aortic cross clamp.

With the clamp-and-sew approach, aortic cross clamp times are planned to be short—i.e. less than 30 min—to mitigate effects of distal ischemia. Thus, the anesthesiologist should be ready for quick release of the clamp and the consequent hypotension that can occur from redistribution of blood flow, possible bleeding and vasodilation that can occur from metabolites from ischemia-reperfusion. Goal-directed replacement of fluid loss with crystalloids, colloids and blood products should be undertaken so that the patient is euvolemic prior to release of the clamp. After the clamp is released, the patient's blood pressure should be supported with short acting vasopressors and inotropes as needed. A brief period of hyperventilation and infusion of sodium bicarbonate may be necessary to counteract the acidemia generated from anaerobic metabolism.

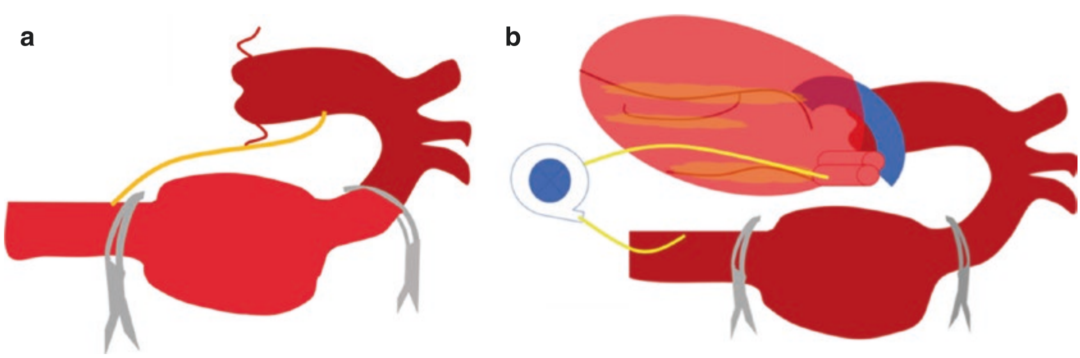

Fig. 10.2 Illustration of 'clamp-and-sew' and left heart bypass surgical techniques. (**a**) (left): The clamp-and-sew technique involves the application of proximal and distal clamps. A Gott shunt, which is a small length heparinized polyvinylchloride tube, can be used to provide passive flow distal to the clamp. (**b**) (right): Left heart bypass involves active direction of oxygenated blood from the left atrium or one of its pulmonary veins into the distal aorto-iliac system by means of a centrifugal pump

Left Heart Bypass

Complications associated with distal ischemia occurring with the clamp-and-sew technique led to the development of left heart bypass, during which blood from one of the pulmonary veins is directed to the distal aortoiliac system by an extracorporeal centrifugal pump (Fig. 10.2b). A moderate dose of heparin (typically 100 U/kg) targeting an activated clotting time (ACT) of 180–200 is necessary to facilitate left heart bypass. Because the distal organs and lower extremities receive oxygenated blood, they do not transition to anaerobic metabolism and the metabolic acidemia frequently seen with the clamp-and-sew technique is largely avoided. The perfusionists should work together with the anesthesiologist to adjust left heart bypass flows to prioritize proximal perfusion to the brain while also ensuring as much distal perfusion as possible. Proximal perfusion of the brain is favored preferentially to distal perfusion, and in the setting of hypovolemia the flow rates of left heart bypass may need to be slowed while the patient is volume resuscitated. The volume status of the heart should be monitored on TEE and pump flows can be adjusted depending on cardiac preload, and left heart bypass flows may be increased in the setting of cardiac volume overload or proximal hypertension. The left heart bypass approach is most beneficial in patients with Extent I and II aneurysms, those with impaired cardiac function and those at a higher risk of renal failure or paraplegia [17].

Partial CPB

In patients with impaired cardiac function or in extensive, complex or reoperative descending aneurysm repairs, partial CPB can be used to reduce cardiac stress and end organ ischemia even further. To facilitate partial bypass, the venous cannula is generally placed in either the right atrium or a femoral vein and the arterial cannula is placed in the distal aorta or femoral artery. After the proximal aorta is clamped, CPB is initiated and pump flow is titrated to produce adequate perfusion as measured in both an upper extremity and femoral arterial lines. Partial CPB requires full systemic heparinization (typically ~300 U/kg) and is associated with more bleeding and coagulopathy when compared to left heart bypass. Because the heart continues to eject blood into the pulmonary circulation with partial flow CPB, ventilation of the right lung must continue. Partial CPB can be increased to full CPB as needed during aortic repair.

Full CPB with DHCA

In cases where there is not an adequate location for placement of a proximal aortic clamp—e.g. aortic pathology involves the left subclavian take-off or there is significant complex aortic disease that does not allow aortic clamp placement distal to the left subclavian—CPB with DHCA allows aneurysm repair in a bloodless field with cerebral and other end-organ protection. By reducing oxygen demand in the brain, spinal cord, kidneys and gut, DHCA has an organ protective effect and has been shown to reduce the incidence of postoperative paraplegia and renal failure [18]. However, DHCA is associated with significant coagulopathy due to platelet dysfunction and consumption of clotting factors. When aneurysm repair under DHCA is expected to take longer than 30 min, anterograde cerebral perfusion (ACP) should be considered [19]. If ACP is utilized, cerebral oximetry monitoring can be used to help assess if both sides of the brain are being perfused or if additional efforts need to be introduced to perfuse the left brain—this likely occurs in patients without an intact Circle of Willis [20].

Transesophageal Echocardiography

Most patients presenting for open descending TAA repair have extensive preoperative imaging by CT or MRI. Contrast-enhanced MRI provides excellent delineation of aneurysm and other aortic pathologic anatomy while MR angiography (MRA) can be used to map branch vessels arising from the aorta. Because the esophagus runs parallel to the aorta, trans-esophageal echocardiography can usually be used to image the entire length of the descending thoracic aorta. Transthoracic echocardiography imaging is frequently done in the preoperative setting to define cardiac function. While TEE is generally not needed for preoperative assessment, if there are no contraindications to placing a TEE probe, the intraoperative use of TEE can be very useful during open descending TAA surgery. Before placing the TEE probe in patients with large descending TAAs, preoperative imaging studies should be reviewed to determine esophageal proximity to avoid potential aortic rupture.

Intraoperative TEE Imaging

After induction of general anesthesia and endotracheal intubation, TEE should be used to confirm the preoperative diagnosis and to evaluate for any progression of the aneurysm, significant atheroma within the aneurysm, or propagation of an aortic dissection flap. From the mid-esophageal four chamber view, the TEE probe should be rotated leftward until the descending aorta appears in short axis. The probe should then be withdrawn until the takeoff of the left subclavian artery appears on the screen (Fig. 10.3a). The imaging depth should be reduced to exclude the area beneath the aorta and the probe should be gradually advanced, while carefully evaluating the imaged cross section of the aorta for pathology. Simultaneous bi-plane can be used to display the orthogonal view of each cross section (Fig. 10.3b). Color Doppler should also be used to evaluate for abnormalities of flow. The presence of an intimal flap in the aorta can signify aortic dissection and should be confirmed using bi-plane and color Doppler in multiple views in order to distinguish it from artifact (Fig. 10.3c). TEE should also be used to assess for a left pleural effusion, which will appear as an anechoic space below the aorta and curve to the left, as this may signify aneurysmal rupture (Fig. 10.3d).

The TEE probe can also be withdrawn up the esophagus to visualize some of the distal aortic arch proximal to the takeoff of the left subclavian. The bulk of the aortic arch cannot be well visualized on TEE examination because of interposition of the tracheal and left main bronchus between the esophagus and the heart. The ascending aorta should also be viewed, as concurrent involvement of the ascending aorta can sometimes occur. After performing a comprehensive examination of the aorta, the TEE exam should continue to evaluate cardiac structures and valve and ventricular function. Ventricular and valvular function can dictate choice of vasopressors and inotropes used during critical portions of the case and may influence choice of surgical technique.

It is generally helpful to use TEE throughout surgery for continuous monitoring of cardiac function—i.e. when not on full CPB or DHCA. When the clamp-and-sew technique or left heart bypass is utilized for descending TAA repair, TEE can be a useful monitor of left and right ventricular filling and function. Left ventricular end-diastolic volume is best assessed in the transgastric mid-papillary short axis view. Volume overload can result from translocation of venous capacitance from the lower extremities and may necessitate the use of venodilators to reduce cardiac preload. When left heart bypass or partial CPB is used to offload the volume proximal to the aortic cross-clamp and to provide perfusion distal to the aortic cross-clamp, TEE is helpful in guiding bypass pump flow rate. Left ventricular distension on TEE should prompt increasing bypass flow rates, while decreased ventricular volume should prompt decreasing pump output or administering intravascular volume. When complete CPB is used, TEE is helpful for assessing ventricular function while separating from CPB. Prior to separation from CPB, the long axis views of the aortic valve and left ventricle are valuable for assessing for intracardiac air. Along with available hemodynamic monitors, TEE should be used to ensure that cardiac preload, afterload and contractility are optimal.

Postoperative Outcomes

Improving postoperative outcomes after open descending TAA surgery requires the perioperative team—i.e. the surgeon, anesthesiologist and

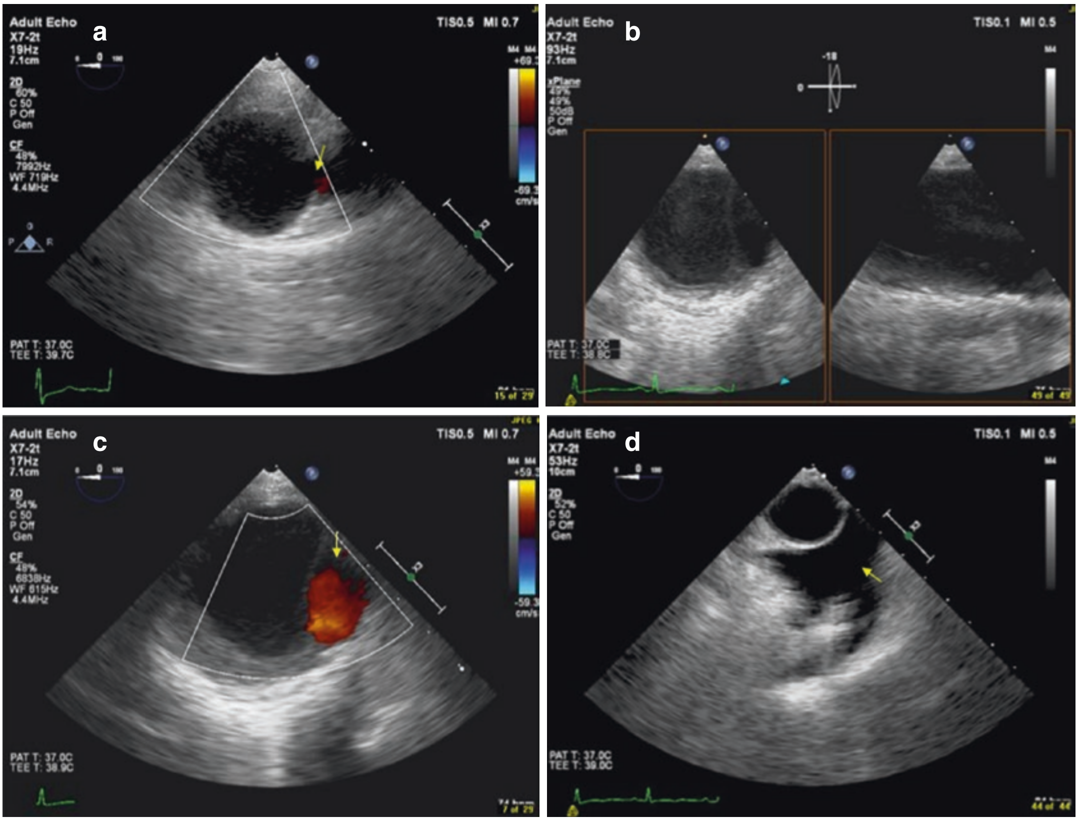

Fig. 10.3 Transesophageal echocardiography for evaluation of the thoracic aorta. (**a**) Color flow Doppler demonstrating flow to the left subclavian artery from the aortic arch. (**b**) 2D Biplane used to evaluate orthogonal aspects of descending thoracic aorta. (**c**) Color Doppler used to evaluate flow within the true lumen of an aortic dissection. (**d**) Left-sided pleural effusion from ruptured aortic aneurysm

intensivist—to recognize patients who are at risk for complications and to initiate appropriate perioperative measures to prevent or mitigate them.

Paraplegia

Paraplegia can be a devastating complication after descending TAA repair, with a reported incidence of 3–10% [21, 22]. The mechanism of spinal cord injury is thought to result from a combination of hypoperfusion distal to the aortic clamp, elevated cerebrospinal fluid (CSF) pressure and individual variability in collateral arterial flow. The spinal cord receives its blood supply from a single anterior spinal artery and paired posterior spinal arteries. The artery of Adamkiewicz, which originates from an intercostal artery between T9-T12 in most individuals, makes an important contribution to the blood supply of the thoracolumbar spinal cord. Injury to this vessel can result in ischemia of the anterior spinal cord and consequent motor deficits. Additionally, in patients with atherosclerotic disease, the smaller segmental arteries may not be patent, resulting to ischemia during aortic clamping [23].

Surgical strategies to decrease the incidence of paraplegia include the use of passive or active aorto-femoral bypass, re-implantation of arterial spinal segmental vessels and the induction of hypothermia during the clamping period. The anesthesiologist can contribute to this strategy by optimizing spinal cord perfusion pressure (SCPP).

$$\text{SCPP} = \text{Mean Arterial Pressure}\left(\text{MAP}\right) - \text{Cerebrospinal Fluid}\left(\text{CSF}\right)\text{ Pressure}$$

Increasing SCPP can be done using two mechanisms: raising MAP with use of vasopressor drugs and volume resuscitation and reducing CSF pressure by draining CSF via a lumbar spinal drain. Placement of a lumbar spinal drain allows the measurement of SCPP as well as the drainage of CSF. In patients without contraindications, a large bore Touhy needle is inserted into a lumbar interspace below the termination of the spinal cord (i.e. L1/L2) and is used to access the intrathecal space. A catheter is then threaded through the Touhy needle into the intrathecal space. This intrathecal catheter can now be connected to a manometer to allow transduction of CSF pressure. While the utilization of lumbar spinal drains in open descending TAA surgery has resulted in better outcomes in some studies, they are also associated with a host of complications including neuraxial and subdural hematomas, persistent CSF leak, infection and retained catheter. Patients at greatest risk for postoperative paraplegia include those with ruptured aneurysms, those with extensive aneurysms, previous aneurysm repair and those with numerous medical comorbidities [24]. In lower risk patients, an alternative strategy may be postoperative drain placement in patients who develop concerning intraoperative motor evoked potential (MEP) signals, those who emerge from anesthesia with paraplegia or those who develop delayed postoperative paraplegia.

Renal Failure

Acute kidney injury (AKI) after descending TAA repair occurs as frequently as 29% and is associated with increased incidence of need for long-term dialysis as well as higher mortality [25]. Multiple studies have found that a history of chronic kidney disease and prolonged aortic clamping are the strongest predictors of postoperative AKI [12, 25]. The etiology of postoperative AKI after TAA repair likely involves renal hypoperfusion due to aortic clamping, systemic hypotension and embolization of cellular debris. Prospective data suggests surgical techniques that may prevent AKI include extracorporeal circulation that allows perfusion of the kidneys below the aortic cross- clamp; local or systemic hypothermia; and selective renal perfusion with cold crystalloid solution [26, 27]. Additional anesthetic management strategies to reduce AKI require goal-directed intravenous hydration, limiting intra-operative hypotension and avoidance of nephrotoxic medications. There is some suggestion from the cardiac surgical literature that goal-oriented management of CPB and other parameters can help to mitigate AKI, but this has not been studied to date for descending aortic surgery [28].

Coagulopathy

Coagulopathy after descending TAA repair is related to blood loss and transfusion of packed red blood cells and cell saver, inflammatory responses to surgery, and extent and duration of extracorporeal circulation of DHCA. The clamp-and-sew technique, which does not rely on active bypass flow, is associated with decreased clotting factor activity and an increase in fibrinolysis [29]. The use of left heart bypass requires a smaller dose of heparin than is required for full CPB and may avoid some of the associated coagulopathy. CPB with DHCA is often associated with the most coagulopathy resulting from platelet dysfunction, thrombocytopenia, consumption of clotting factors and hypofibrinogenemia. Antifibrinolytics such as the lysine analog, ε-aminocaproic acid can be used prophylactically in all patients in whom bypass flow is established. Thrombo-elastography assessment can be used throughout the intraoperative period to evaluate for etiologies of bleeding. The transfusion of blood products should be guided not only by laboratory results, but also by vigilantly observing the surgical field and communicating with the surgical team regarding concerns related to potential ongoing surgical bleeding. A massive transfusion involves the replacement of one or more of a patient's blood volume and is associated with a unique set of complications. These include lung injury, hypocalcemia, hyperkalemia, hypothermia and dilutional coagulopathy. To mitigate these complications, we recommend a goal directed transfusion strategy guided by thrombo-elastography, platelet count, INR measurement and frequent measurement of electrolytes.

Postoperative Care

After open surgical repair of descending thoracic aortic disease patients should be transferred to the postoperative intensive care unit (ICU) for continued hemodynamic and neurologic monitoring, and for respiratory monitoring. In the absence of significant head and neck edema—which could cause concern regarding successful endotracheal tube exchange—the DLT should be exchanged for a single lumen endotracheal tube at the end of surgery. Both the use of an airway exchange catheter and a videolaryngoscope may be helpful in enhancing the safety of exchanging the endotracheal tube. Frequently there is enough hemodynamic instability or pulmonary edema that patients are left intubated after surgery and weaned from the ventilator and extubated after a few hours in the postoperative intensive care unit.

Aggressive postoperative pulmonary and physical rehabilitation is very useful for avoiding common postoperative complications such as atelectasis, pneumonia, deep venous thromboses and pulmonary thromboemboli. Common enhanced rehabilitation approaches in the ICU include early extubation, mobilization from the ICU bed and frequent ambulation as tolerated by the patient. As renal failure occurs in approximately one-third of these patients, acid-base and electrolyte laboratory tests should be monitored frequently. Renal replacement therapy may be necessary to correct severe metabolic abnormalities.

Patients undergoing open descending TAA repair have an increased risk of perioperative stroke, owing to patient and procedural factors. Thus, these patients should be extubated as soon as possible in the ICU to allow for optimal neurologic monitoring and early detection of perioperative stroke. If they cannot be extubated early, then periodically reducing sedation to perform neurologic checks can be helpful. Hourly examination by the ICU nursing staff for detection of spinal cord ischemia is necessary to detect neurologic changes early and institute acute interventions. Because paraplegia can occur hours or days after surgery, the spinal drain should be left in and CSF pressure should be monitored postoperatively. In the setting of paraplegia MAP should be increased using vasoactive drugs and CSF should be drained from the spinal drain. If the patient does not have a lumbar spinal drain and develops postoperative paraplegia, strong consideration should be given to placing a lumbar spinal drain and draining CSF to enhance arterial spinal cord perfusion. The CSF drainage strategy employed in the majority of published studies includes the drainage for a CSF pressure between 10–15 mm Hg [24]. To avoid the excessive drainage of CSF, we advocate the drainage of no more than 10–15 mL of CSF hourly for an institutionally designated maximum CSF pressure. CSF drainage should be performed in accordance with strict institutional guidelines by nursing staff who are familiar with the drain and potential complications associated with its management. In patients without paraplegia, the drain should be removed within 72 h of placement to avoid infectious complications.

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