Facing the Challenges of Endovascular Repair of the Aorta

Albert R. Robinson III, MD
Assistant Professor
Anesthesiology
University of Florida College of Medicine
Gainesville, Florida

John G. T. Augoustides MD, FASE, FAHA
Associate Professor
Anesthesiology and Critical Care
Perelman School of Medicine
University of Pennsylvania
Philadelphia, Pennsylvania

Learning Objectives

At the conclusion of the discussion, the participants will be able to:

1. Review the anesthetic plan for endovascular repair of the descending thoracic aorta
2. Understand the endovascular approaches to hybrid repair of the aortic arch
3. Discuss the current progress in hybrid repair of the ascending aorta and aortic root

Stem Case and Key Questions

A 75 year old man with multiple significant co-morbidities presents with an extensive atherosclerotic aortic aneurysm involving the aortic arch and descending thoracic aorta (DTA). He is referred to your institution for possible hybrid repair.

(1) What is a hybrid aortic arch repair? How would you classify this procedure?

(2) How is the operative risk for these procedures assessed?

What are the typical mortality and stroke rates associated with these procedures?

During clinical evaluation, his aortic arch pathology is more fully defined. He has a 7 cm saccular aneurysm involving the entire aortic arch with proximal extension into the ascending aorta down to the sinotubular junction and distal extension into the distal half of the DTA proximal to the celiac artery (landing zone 5).

(3) What are the aortic landing zones? What is the classification of these zones?
(4) Does the proximal extent of the aortic aneurysm matter? How does the proximal extent affect the conduct of the planned operation? What are the consequences for anesthetic management?

(5) Does the distal extent of the aneurysm matter? How does the distal extent affect the conduct of the planned operation? What are the anesthetic management consequences?

The decision is reached to proceed with a type III hybrid aortic arch repair, given that there is no suitable proximal landing zone in the ascending aorta or distal landing zone in the proximal DTA.

(6) What clinically significant comorbidities are typical in this patient population?

(7) What are some of the major anesthetic consequences of these conditions?

(8) What roles does transesophageal echocardiography (TEE) have in this procedure, a type III hybrid aortic arch repair?

The decision is made to conduct the procedure in a hybrid operating room.

(9) What is a hybrid operating room? Why does this procedure require this specialized environment?

(10) What monitoring will you plan to use in this case?

(11) What types of neurologic monitoring should be utilized for the proposed type III hybrid aortic arch repair?

The patient undergoes uneventful anesthetic induction. The case proceeds to sternotomy and cannulation for cardiopulmonary bypass (CPB).

(12) Why is CPB required in this case? Is CPB always required for a hybrid aortic arch repair?

(13) Is there a difference in heparin dosing for this type III hybrid arch repair compared to heparin dosing for a zone 5 endovascular stenting?

(14) Is there a role for deep hypothermic circulatory arrest (DHCA) in this case?

The surgeon cannulates the right axillary artery for cardiopulmonary bypass.

(15) What advantages does this arterial cannulation site offer in this clinical scenario? Does TEE have a role in guiding the choice of arterial cannulation site? Is there a role for epiaortic scanning?
During aortic arch debranching, the left frontal cerebral oximetry values decrease acutely by 50% - the new values are well below 80% of their baseline values. There is also left cerebral slowing on the electroencephalogram.

(16) Is this important? What is the likely diagnosis? What interventions would you suggest to correct this problem?

The aortic arch debranching procedure and ascending aortic replacement are completed. Separation from CPB is uneventful. The patient experiences a smooth recovery in the intensive care unit.

(17) What is the next step? Should this next step be completed in the same hospitalization?

The decision is reached to proceed with endovascular stenting of the DTA in the same hospitalization.

(18) What is your anesthetic plan for this patient? What are the advantages and disadvantages of the various anesthetic options?

(19) What anesthetic monitoring would you choose? Is any neuromonitoring required? What are the potential benefits of spinal cord monitoring?

While doing a retrograde delivery of the stent-graft system (a 22F sheath) into the iliac artery, the patient’s blood pressure increased from 140/80 to 225/115 mmHg.

(20) What do you suspect is occurring?

(21) Given the hypertension with the introduction of the stent-graft system, how would you manage this situation?

(22) Why is it important to drop the blood pressure before deployment of the stent graft to MAP < 80 mmHg (in a majority of stent-graft system) especially for endovascular thoracic aortic aneurysm (TAA) repair?

(23) What are effective ways for rapid reduction of the systemic blood pressure prior to stent deployment?

(24) After stent deployment, the lower extremity cortical somatosensory evoked potentials attenuate significantly bilaterally. What has happened? What are the management options for this complication?

(25) Once the stent is deployed, what is the “optimal” systolic blood pressure the patient should be kept? Why?

The somatosensory evoked potentials are restored to their baseline.
Transesophageal echocardiography detects using color Doppler detects flow into the aneurysm cavity from the distal DTA. This is also confirmed with aortography.

(26) How would you classify this endoleak? What are the management options? Is conservative management realistic?

After interventional management, the endoleak is closed.

The case is completed and the patient is transported to the surgical intensive care unit. The following day after tracheal extubation, the patient complains of lower extremity weakness.

(27) What is the most likely cause of this neurological deficit? What can be done to manage this neurological presentation?

The patient regains full muscle power in his lower extremities, and is discharged home after an uneventful hospital stay.

The patient develops progressive aneurysm enlargement below the DTA endovascular stent with extension down the abdominal aorta below the renal bifurcation.

(28) Is endovascular repair of this thoracoabdominal aneurysm possible? What are the types of endovascular technologies available for addressing this type of aneurysm?

(29) Is there a risk of spinal cord ischemia in this scenario?

Discussion
The following outline serves as a starting point for the discussion in the live PBLD session. Further details are also available in the provided references.

**Question (1):** The hybrid aortic arch repair (HAAR) combines an open aortic procedure to secure a proximal landing zone with subsequent endovascular stent graft deployment in the aortic arch. These procedures are classified into 3 types.  

- **Type I HAAR** has a stent landing zone both in the ascending and proximal DTA: the aortic arch branches are anastomosed to the ascending aorta and the stent is then deployed across the aortic arch. Type I HAAR’s can be performed off-pump (Type IA) or on-pump (Type IB).  
- **Type II HAAR**’s have a distal landing zone in the proximal DTA but no suitable proximal landing zone in the ascending aorta: after prosthetic ascending aorta replacement, the aortic arch branches are anastomosed to the ascending aorta and the stent is then deployed across the aortic arch to complete the repair. Type II repairs require CPB with deep hypothermic circulatory arrest (DHCA).  
- **Type III HAAR**’s have no proximal or distal landing zones for endovascular stenting of the aortic arch: the ascending aorta and aortic arch are replaced with prosthetic graft left as an elephant trunk in the proximal DTA. This elephant trunk serves as the new proximal landing zone for the subsequent endovascular repair of the DTA. The DTA stenting can be completed during the same
hospitalization (Type IIIA) or during a second hospitalization (Type IIIB). Type III repairs require CPB with DHCA to facilitate total the initial aortic arch replacement.

**Question (2):** HAAR’s are still evolving.\(^1\)\(^-\)\(^2\) The current literature consists of small case series and limited retrospective studies with significant variation in outcomes.\(^2\)\(^-\)\(^4\) Recent systematic review has documented pooled outcomes rates as follows: mortality 10.8% (95% confidence interval 9.3%-12.5%); stroke 6.9% (95% confidence interval 5.7% - 8.4%); and spinal cord ischemia 6.8% (95% confidence interval 5.6% - 8.2%).\(^2\)\(^-\)\(^3\) The evidence thus far does not support any outcome superiority of hybrid aortic arch repair over conventional open techniques.

**Question (3):** The landing zones in the aorta for endovascular stenting are defined as follows\(^5\)\(^-\)\(^6\): (1) **Zone 0** – the proximal edge of the stent lies proximal to the distal end of the innominate artery, (2) **Zone 1** – from distal end of the innominate artery to the distal end of the left common carotid artery (3) **Zone 2** – from the distal end of the left common carotid artery to the distal end of the left subclavian artery (4) **Zone 3** – from the distal end of the left subclavian artery to the end of the aortic arch curvature (5) **Zone 4** – from the end of the aortic arch curvature to within the proximal half of the DTA (approximately T6) (6) **Zone 5** – from the distal half of the DTA (beyond T6) but proximal to the celiac artery.

**Question (4):** The proximal extent of the aneurysm matters because it determines the type of hybrid aortic arch repair. If there is an adequate proximal landing zone in the ascending aorta, a type I repair is possible. If there is inadequate native ascending aorta to allow proximal stent deployment, then prosthetic replacement of the ascending aorta is indicated to create the proximal landing zone, as defined in a type II or type III repair. If the aortic disease process involves the aortic root complex, surgical intervention may be required to address aortic valve dysfunction and aortic root integrity.

**Question (5):** The distal extent of the aortic aneurysm determines the site of the distal landing zone and hence the type of hybrid arch repair. In this case, given the distal extent of the aneurysm in the DTA and consequent absent landing zone in the proximal DTA, a type III hybrid arch repair is indicated. A second consequence of distal extent is the risk of spinal cord ischemia which increases with the extent of repaired DTA due to progressive loss of collateral spinal perfusion from the intercostal arterial network.\(^7\)\(^-\)\(^9\)

**Questions (6) and (7):** The typical co-morbidities in this high-risk population include advanced age, extensive aortic atheroma, hypertension, and chronic smoking.\(^1\)\(^-\)\(^2\) These factors often result in clinical organ dysfunction which can be classified by system: neurological – cerebrovascular disease which presents as transient ischemic attacks and stroke; advanced coronary artery disease which presents as prior myocardial infarction and angina; significant chronic obstructive pulmonary disease which may require home oxygen therapy; and renal dysfunction.\(^1\)\(^-\)\(^4\) The anesthetic plan must take these issues into account.
**Question (8):** The baseline TEE exam can confirm the aortic pathology and rule out any concomitant significant conditions. Significant aortic root dilation and/or aortic valve disease may require surgical correction. TEE can also assist in the conduct of CPB and the endovascular component for the hybrid repair. Furthermore, TEE can interrogate the heart and aorta after the procedure to assess the interventions and also cardiac function.

**Question (9):** A hybrid operating suite is ideal for HAAR as it combines a conventional operating room with high-quality multi-plane radiographic imaging which is essential for aortic endovascular stenting. This environment has all the advantages of an operating room for complex aortic surgery but also allows expert conduct of endovascular stenting.

**Question (10) and (11):** Besides ASA routine monitors, full invasive monitoring is typically indicated (arterial line; central venous pressure, and/or pulmonary artery pressure). Given its multiple roles in HAAR, TEE is also indicated. Since total arch replacement is planned, it is likely that antegrade cerebral perfusion will be utilized during hypothermic circulatory arrest. It is useful to plan with the surgical team the site of the arterial line(s) for monitoring both systemic and brain perfusion. Given the risk of neurological injury, neuromonitoring is typically implemented. The tracings of the electroencephalogram can guide the conduct of hypothermia by providing an endpoint to systemic cooling for circulatory arrest, namely an isoelectric pattern. Cerebral oximetry is helpful to monitor cerebral perfusion during aortic arch reconstruction with antegrade cerebral perfusion. Spinal cord function can be tracked with monitoring of somatosensory evoked potentials and/or motor evoked potentials. In a type III hybrid repair, the endovascular repair of the DTA is typically deferred until later, as outlined earlier.

**Question (12) and (13):** The indications for CPB in hybrid aortic arch repair depend not only on the type of hybrid repair, but also on concomitant procedures and institutional experience. Typically, CPB is indicated when prosthetic aortic replacement is required (e.g. type II and type III repairs) or when aortic side-clamping is deemed impossible e.g. type IB repair. Concomitant procedures can include coronary artery bypass grafting (CABG) and valve procedures (e.g. mitral valve repair; aortic valve replacement). While heparin dosing for CPB is typically 300-400 U/kg, it is substantially lower for endovascular DTA stenting e.g. 100 U/kg.

**Question (14):** Deep hypothermic circulatory arrest (DHCA) facilitates neuroprotection and a bloodless field for aortic arch repair. There are institutional variations in the conduct of DHCA with adjunct cerebral perfusion adjuncts such as retrograde cerebral perfusion (RCP) and antegrade cerebral perfusion (ACP). For example, at the University of Pennsylvania (arch first technique), DHCA is initiated with brief RCP until ACP is established through balloon-tipped cannulae in the aortic arch vessels. After completion of the distal arch anastomosis, antegrade systemic circulation is reestablished. The aortic arch branches are then sequentially anastomosed end-to-end to the branched graft. Alternatively, at the University of Florida (branch first technique), DHCA is commenced
to allow immediate anastomosis of the branched graft to the aortic arch vessels with subsequent ACP established through a side arm of this branched vascular graft. This approach allows for cerebral perfusion, protection, and rewarming while the concomitant ascending aortic and arch replacement is undertaken. In selected situations, antegrade deployment of a stent graft for DTA is an option prior to proximal closure of the ascending and arch aorta graft and termination of CPB. This frozen-elephant technique requires a distal landing zone in the DTA and is emerging as a viable treatment option for DeBakey type I acute aortic dissections.\textsuperscript{17} In our case of a type III HAAR, this technique is not applicable due to the absence of a suitable landing zone in the proximal DTA.

**Question (15):** Right axillary cannulation has emerged as a popular technique for arterial cannulation for complex aortic arch surgery.\textsuperscript{18} It avoids the risks of cerebral embolism from cannulation of a diseased ascending aorta to decrease perioperative stroke risk. It also allows unilateral ACP for complex aortic arch surgery.\textsuperscript{18} It is important to monitor cerebral perfusion in this setting. TEE is helpful in this setting to assess the extent and severity of atheroma and thrombus in the thoracic aorta but is limited by the blind-spot in the ascending aorta.\textsuperscript{11-12} Epiaortic scanning can further the accuracy of this assessment in the ascending aorta to guide ascending aortic cannulation to minimize the risks of cerebral embolism as outlined in the SCA guidelines.\textsuperscript{11-12}

**Question (16):** Left frontal desaturation suggests left cerebral ischemia in the setting of right-sided unilateral ACP. It is important to ensure adequate delivery of unilateral ACP with respect to pressure and volume.\textsuperscript{19} If left-sided desaturation persists despite adequate right-sided unilateral ACP (flow and pressure), adding left-sided ACP typically restores left cerebral perfusion and returns the cerebral oximetry to baseline.

**Question (17):** The next step in this scenario of a type III HAAR is completion of the elephant trunk procedure with endovascular stenting of the DTA to complete exclusion of the aortic aneurysm. This procedure can be completed within the same hospitalization (Type IIIA) or a subsequent one (type IIIB). Since patients are often lost to follow-up (non-compliance; aortic rupture), it is advantageous to complete the procedure within the same hospitalization. The typical approach is to allow adequate clinical recovery from the open aortic arch procedure. Then, the patient is returned to the OR for endovascular stenting of the DTA in a retrograde fashion (via ileofemoral arterial access).

**Question (18):** General or neuraxial anesthesia are anesthetic options for endovascular stenting of the DTA.\textsuperscript{20} General anesthesia is typically utilized for TEVAR given the benefits of limited patient movement during fluoroscopy, ensured patient comfort for long cases, controlled ventilation, and the ability to utilize TEE. On the other hand, regional anesthesia has advantages such as postoperative pain relief and the avoidance of tracheal intubation. Furthermore, an awake patient facilitates the detection of neurological deficits. The associated sympathectomy from neuraxial blockade can induce spinal cord ischemia due to systemic hypotension.
**Question (19):** In addition to standard ASA routine monitors, an arterial line for continuous arterial blood pressure monitoring facilitates preservation of adequate spinal cord perfusion pressure. Large bore intravenous access is required for rapid volume expansion that may be required in the event of arterial rupture. Central venous access is helpful for rapid drug administration and vasopressor infusion. Monitoring of the spinal cord function with somatosensory and/or motor evoked potentials allows early detection of ischemia and facilitates immediate interventions such as arterial blood pressure augmentation and lumbar spinal CSF drainage to improve spinal cord perfusion.\textsuperscript{9-10, 20-21} Patients at high risk for spinal cord ischemia from the procedure should ideally have a lumbar cerebrospinal fluid drain placed at the start of the procedure. Established risk factors for spinal cord ischemia in this setting include extensive DTA coverage and prior aortic procedures.\textsuperscript{9-10} It is also reasonable to monitor the electroencephalogram, given the stroke risk in this type of procedure.\textsuperscript{22-23} Given the administration of considerable radiographic contrast agents during the stenting procedure, it is reasonable to consider measures to reduce the risk of contrast agent nephropathy such as volume expansion, sodium bicarbonate and N–acetylcysteine.\textsuperscript{24}

**Question (20):** Hypertension can be due to hypoxia and hypercarbia due to sympathethic simulation. Anxiety, hypervolemia, discontinuation of a vasodilator, and bladder distention are other causes of hypertension. The most likely cause of this acute increase in blood pressure is pain due to the stretching of the arterial system during introduction of the stent graft. Serial dilation of the arterial tree (e.g. iliac, femoral) should be undertaken to reduce dramatic increases in blood pressure.

**Question (21):** Increases in blood pressure can be treated with vasodilators such as nitroglycerin, nitroprusside, nicardipine and clevidipine. Additional pharmacological interventions for consideration include additional opioid and/or increasing the dose of volatile anesthetic (keep in mind the neuromonitoring effects). Aggressive treatment of severe hypertension will enhance perioperative outcome. It is also important to avoid tachycardia in this patient population, given the essentially universal incidence of coronary artery disease.

**Question (22):** The endovascular graft is competing with the antegrade blood flow. Induced hypotension before deployment facilitates precise landing of the endovascular graft (ideally MAP 60-80 mmHg). Hypotension may be induced pharmacologically, by continuous positive airway pressure and/or by balloon occlusion of the inferior vena cava (IVC).

**Question (23):** There are at least four ways to prevent/decrease the chance of the “windsock effect” on the endograft before it is affixed to the aortic wall: (1) pharmacologically controlled hypotension (2) controlled transient hypotension by balloon occlusion e.g. IVC (3) rapid ventricular pacing and (4) adenosine-induced transient cardiac arrest.\textsuperscript{25} Intravenous infusions of vasodilators are safe and effective ways to quickly lower the blood pressure prior to stent deployment. The anesthesiologist can also encourage the surgeon to place a balloon in to IVC so that the surgeon can acutely reduce preload prior to stent graft deployment.
A recent report has demonstrated the feasibility of rapid ventricular pacing in this setting utilizing a pacing pulmonary arterial catheter. These hemodynamic strategies must take into account concomitant cardiac disease so as to ensure immediate and complete hemodynamic recovery.

**Question (24):** Bilateral loss of the somatosensory evoked potentials after stent deployment is indicative of acute spinal cord ischemia. The acute measures that typically relieve this ischemia include (1) augmentation of systemic blood pressure with vasopressor administration (goal MAP of 100mmHg -120 mmHg); and/or (2) CSF drainage. Furthermore, optimization of adequate oxygenation and hemoglobin will also augment spinal cord delivery of oxygen for relief of ischemia via pressurized spinal collateral arterial network. Avoidance of subsequent hypotension is also important to optimize recovery from spinal cord ischemia in this setting.

**Question (25):** In the absence of spinal cord ischemia, a systolic BP of (140-160) mm Hg is optimal after deployment of the stent graft. This is in order to keep the stent graft open and assist with spinal cord perfusion. These blood pressure goals will have to be augmented in the event of spinal cord ischemia, as explained in question 24. Furthermore, perioperative blood pressure management will also have to consider end-organ function besides the aorta and the spinal cord. For example, myocardial ischemia may require a lowering of the blood pressure target to reduce myocardial oxygen demand.

**Question (26):** Endoleaks are defined as extravasation of contrast material out of the graft into the aneurysm sac and are defined as follows: (1) **Type Ia** - a leak noted at the graft attachment proximal site; (2) **Type Ib** – a leak detected at the graft attachment distal site; (3) **Type II** - contrast is noted coming back into the aneurysm (retrograde flow) from branch arteries such as the intercostals or lumbars; (4) **Type IIIa** – a leak that is detected in a modular disconnect; (5) **Type IIIb** – a leak that occurs due to a tear in the stent graft fabric; and (6) **Type IV** – a leak that occurs where there is flow detected through penetrated/porous fabric of the graft. The endoleak described in this PBLD is consistent with a type Ib. Type I endoleaks are regarded as treatment failures that require intervention. In this case, the distal endoleak was sealed after reballooning coupled with deployment of a second stent in the distal DTA.

**Question (27):** This presentation is most consistent with delayed spinal cord ischemia. The management approach is similar to the algorithm described in question 24. It is important to note that CSF drains placed preoperatively are typically left in situ for 48 hours postoperatively due to the incidence of delayed spinal cord ischemia. As with all neuraxial catheters, adequate coagulation status is essential prior to removal to decrease the risk of neuraxial hematoma.

**Question (28):** There are several endovascular repair options in this setting. The first option is debranching of the visceral segment of the abdominal aorta combined with subsequent endovascular stenting, based on the principles of aortic arch debranching in HAAR. The second option is endovascular stenting of the aneurysmal segment with branch vessel stenting via snorkel or chimney stents to preserve visceral segment
perfusion. The third option is endovascular stenting of the aneurysm with a stent designed to preserve branch vessel perfusion either via fenestrations or branched stents. The advantages and disadvantages of these techniques will be discussed during the PBLD.

**Question (29):** There is a chance of spinal cord ischemia during the repair of this distal aneurysmal aortic segment, given the already compromised spinal collateral vascular network and the extensive endovascular pavement. Neither of the endovascular techniques will preserve lumbar arterial perfusion of the spinal cord. The anesthetic options for management of this risk will be outlined during the PBLD.

**References**


